

MATERIALS

experience

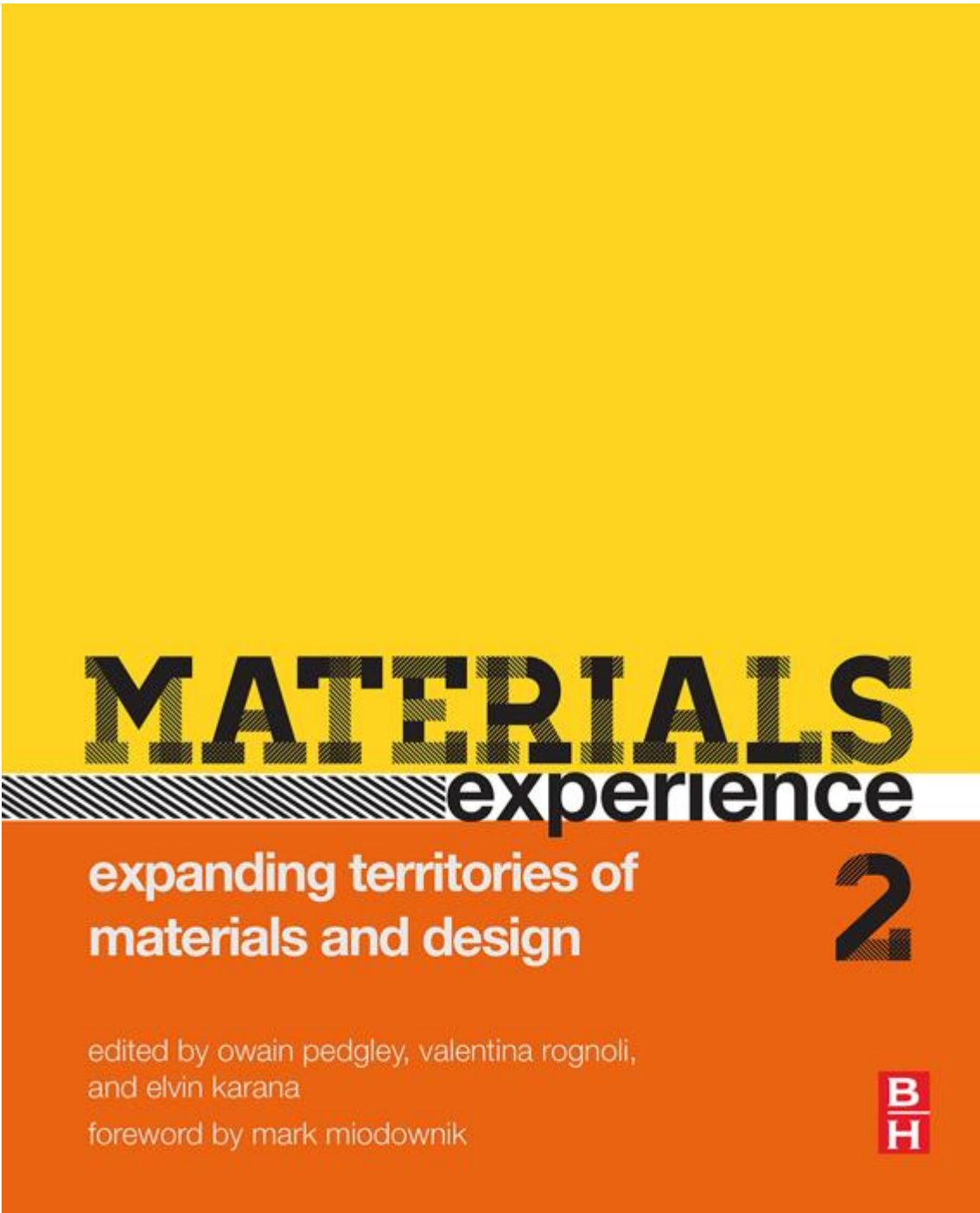
expanding territories of
materials and design

2

edited by owain pedgley, valentina rognoli,
and elvin karana

foreword by mark miodownik





Materials Experience 2

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Materials Experience 2

Expanding Territories of Materials and Design

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Butterworth-Heinemann is an imprint of Elsevier

The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United
Kingdom

50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

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British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-819244-3

For Information on all Butterworth-Heinemann publications

visit our website at <https://www.elsevier.com/books-and-journals>

Publisher: Matthew Deans

Acquisitions Editor: Christina Gifford

Editorial Project Manager: Marina L. Kuhl

Production Project Manager: Sojan P. Pazhayattil

Cover Designer: Matthew Limbert

Typeset by MPS Limited, Chennai, India

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Owain Pedgley is Professor of Industrial Design at Middle East Technical University, Ankara. His expertise is in design for interaction and user experiences, with specialization in two areas of application: materials and material-

ization, and musical instrument design and innovation. He has published widely in these areas and coordinates projects as a researcher, thesis supervisor, and instructor. Owain is a strong advocate of research through design (RtD), having championed this approach to academic studies for over 20 years through publications and supervisions, traced back to early adoption of RtD in his own PhD (1999). He is a member of the Editorial Board of Design Studies and an Associate Editor of She Ji: The Journal of Design, Economics and Innovation. He is also an Honorary Research Fellow in the School of Engineering at the University of Liverpool, having served as a founding member of its Industrial Design BEng/MEng programs (2014-17). Prior to commencing his academic career, Owain worked as a product designer in the sports equipment and musical instrument sectors, co-founding the polymer acoustic guitar innovation venture “Cool Acoustics.”

(Image Credit: Bahar Sener-Pedgley)



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Biographies

Valentina Rognoli is Associate Professor in the Design Department at Politecnico di Milano. She is a pioneer in the field of materials experience, starting almost 20 years ago and has established internationally recognized expertise on the topic in both research and education. Her mission is raising sensibility and making professional designers and future designers conscious of

the
infinite
potential
of
materials
and
processes.

The
investigations of her research group focus on pioneering and challenging
topics including DIY-Materials for social innovation and sustainability; bio
and circular materials; urban materials and materials from waste and food
waste; materials for interactions and IoT (ICS Materials); speculative mate-
rials; tinkering with materials; materials-driven design method; CMF
design; emerging materials' experiences; and material education in the field
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Europe Program of The European Union, which aimed to boost talents
toward circular economies across Europe. Valentina is the author of over
50 publications. She has organized international workshops and events

and has contributed as an invited speaker and reviewer for relevant journals and international conferences.

(Image Credit: Lab Image Design Polimi)



Biographies

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Elvin Karana is Professor of Materials Innovation and Design in the Faculty of Industrial Design Engineering at Delft University of Technology. Giving emphasis to materials' role in design as experiential and yet deeply rooted in

their inherent properties, Elvin explores and navigates the productive shifts between materials science and design for materials and product development in synergy. In 2015, she founded the cross-country research group Materials Experience Lab, which she leads jointly with Valentina Rognoli. Elvin has over

70 scientific publications in peer-reviewed journals and conferences. Her recent book *Still Alive* (2020) brings to the attention a new and exciting design space, where she proposes that by discovering ways to maintain an organism's aliveness as a tangible manifestation of a biodesign process, livingness will become a persistent material quality in design. In 2019, she founded the biodesign research lab Material Incubator ([MI] Lab) that invites designers to harness the potential of living organisms for unique functionalities, interactions, and expressions in the everyday. Material Incubator brings together researchers and practitioners from Avans University of Applied Sciences and Delft University of Technology.

(Image Credit: Elvin Karana)

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Foreword

I am writing this Foreword in the middle of the COVID-19 global pandemic. My family and I are locked down in our flat in London. The schools are shut, and I spend my time swapping between helping my kids interact with

their teachers online, to interacting with my own university students, again through a screen. Over many months of doing this, I have realized that although online teaching has been a lifeline, it is no way a substitute for real face-to-face teaching. This is not because the medium is deficient for communicating ideas and information. What gets lost is meaning. This seems odd because other screen-based activities such as TV programs and films are able to communicate meaning very well. But somehow an online lecture, or workshop, seems to be a simulation of real meaningful interaction. The physical classroom, with its sounds, smells, and sensations, all contribute to something very different—it is a material experience. For this and many other reasons, most people accept the experience of face-to-face education is fundamentally different from online learning and think no more. But designers and materials researchers find it impossible to resist exploring the origin of such differences. If you are one of these people, then this book and its predecessor, *Materials Experience*, are for you.

That the COVID-19 coronavirus is transmitted through material interaction, either through touch or through the air we all breathe, is the reason why schools are closed. The virus itself is invisible but its presence or potential presence has made us hyper-aware of the physicality of interacting with each other in schools, offices, or shops. Clasp the handle of a door now has an

element of jeopardy that it lacked before. On the way into a cafe, we wonder how many infected people touched the door handle before us. We know the risk of infection is real not just because other people have told us that small droplets of liquid can pass between people that touch the same things. We know it is real because of the millions of times we ourselves have touched a surface and left a smudge on it. I have to clean my spectacles several times a day for this reason, and the screen of my phone too. Our materials experience of surfaces and their other affordances such as their ability to attract, extract, and collect oils and essences from our hands (viruses and all) is

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Foreword

learnt this way. It is this experience that gives credence to the danger of viruses being transmitted via touch. And yet this same touch is also how we transmit our affection and feelings for each other. They literally go hand-in-hand, communication, and contamination. And so the pandemic has not only closed schools but emotionally sealed us off from each other. It is one of the many tragedies of the COVID-19 pandemic that millions have died in hospital without anyone hugging them goodbye as they slipped out of this world.

When we reach in our bag for a small bottle of cool alcohol gel and squirt it onto our hands, we experience a feeling of protection that is emphasized by the coolness of gel. This is due to the evaporation of the alcohol on our hands, removing energy from our hands through the flow of latent heat. To design a materials experience like that needs not only the scientific knowledge of how to make a liquid that will destroy the virus and then vanish, but also an understanding of how humans react to coolness, stickiness, and slipperiness. The pandemic has been a lesson for me on the good, the bad, and the ugly of alcohol sanitizers. Some are too runny and gush out leaving me soaked and annoyed. Others stick to my hands but then do not evaporate fast enough and leave my hands wet for an annoying amount of time. Others evaporate fast but leave my hands sticky and uncomfortable. I have had so many bad experiences that when I find a hand sanitizer that cleans, cools, and then disappears in seconds, I feel the need to shake the hand of the person who designed such a great material experience. That person, or more likely team of people, understands the complexity of material experience and how to design products using that knowledge. It is one of my hopes that more people will read this book and understand the mix of art, science, engineering, and cultural understanding required to design better products.

The daily wearing of a mask is another materials experience that is new to me with the pandemic. Through experimentation I have found the combination of materials and mask design that suits me, my beard, and my glasses that steam up. But the biggest discovery for me has been the relaxing nature of mask-wearing. No longer do I feel the need to smile out of politeness at every public interaction. Nor do I feel that my irritation with a particular situ-

ation will be written clearly on my face. To be muted like this does not feel like oppression. It is restful, serene even. It is a freedom, a privacy, and a pro-

tection. No doubt I would feel different if my mask-wearing became permanent, which it is of course to many in the world. The materials experience of mask-wearing has made me much more interested in the cultural wearing of masks, as well as those in the medical profession for whom it is part of a daily uniform worn 8 10 hours a day. It is my hope too that the designers of the masks of the future will read this book.

Foreword

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My purpose for recounting my impressions of lockdown life in a pandemic is to emphasize first that our lives are always changing, and this brings us new materials experiences. But also, to show that the role of product

designers and materials researchers is so fundamental. We need communities of researchers well versed in understanding materials experiences, spanning their cultural, social, scientific, and engineered aspects. The physical world is

an almost infinite realm of experience and we need people able to navigate it to design the products and materials of the future. This necessitates understanding different disciplinary approaches to materials properties and making, as well as the interfaces between them and the living world. There is no better guide out there to this approach than the Materials Experience books, and I am very happy to see this second book continuing to provide a guide for future designers and materials researchers.

Mark Miodownik,

Director, UCL Institute of Making

February 2021

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Preface

Seven years have passed since the publication of the first volume of Materials

Experience, subtitled Fundamentals of Materials and Design. We had in mind that the book would bring together a wide range of views from an equally wide range of contributors—spanning design, engineering, architecture, user

experience, materials science, and education—all focused on opening a discussion on what the “experiential side” of materials is and what it involves. Gathering the views and experiences of practicing designers as well as scholars was a major motivation for the book. As a result, the book struck a chord among academic and professional design communities for whom materials are much more than a substance that serves to give physical form to an idea. We started out with no timetable to put together a successor to *Materials Experience*. Our view was that it needed to be “out there” for some time before we could properly gauge its influence and understand which of the various concepts and streams of work embedded within would take root and deliver new research. As it happens, all Editors converged on the idea in 2018 that a new book was merited. We felt that a substantial body of knowledge had developed in the intervening years and that a new book was warranted to catch it into a single location. Serendipitously, we were invited by Elsevier to prepare a follow-up book. So, spurred on through a combination of circumstances, we put together plans for this companion volume to *Materials Experience*—envisioned as a new set of original works—which would continue the lineage started with the first volume.

Materials Experience 2: Expanding Territories of Materials and Design is organized

as a “sandwich” of three sections. The first and last sections comprise peer-

reviewed chapters from invited authors on a variety of contemporary topics in materials experience, especially those that we identified as emergent or significantly developed since the first volume of the book.

The middle section, titled “Around the Corner,” presents a shortlist of peer-reviewed projects following an open call to doctoral students and early career

researchers to disseminate their work through the book. We are especially pleased with the results: an energetic collection spanning current or recently

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Preface

completed research in materials and design, collectively providing an interna-

tional view not only of contemporary subjects but also hints for where subjects will emerge or expand in the future. The project contributors represent institutions from around the globe: Belgium, Canada, China, Finland, Hungary, Italy, the Netherlands, North Macedonia, Sweden, the United Kingdom, and the United States.

As academics, we grow through nurturing discussions and interactions with our colleagues and our students. We would like to thank our institutions for

the opportunity to develop intellectually through our research and educational activities: the Department of Industrial Design at Middle East Technical University, Turkey; the Department of Design at Politecnico di Milano, Italy; and the Department of Sustainable Design Engineering at Delft University of Technology, the Netherlands. We would like to thank all contributors to this volume of Materials Experience for their support, dedication, and patience during the process—especially when having to work under the exceptional demands that the COVID-19 pandemic has brought. We would also like to highlight special gratitude to Mark Miodownik for picking through the book draft to prepare his Foreword.

Our thanks extend to the core team at Elsevier, to whom we often made special requests, which were gracefully granted: Christina Gifford, Mariana Kühl

Leme, and Indhumathi Mani. We thank you for your patience, and for having to deal with the pickiness of “designer” Editors.

As always, our final words of thanks must be reserved for our immediate family members who have encouraged and tolerated us during the process of turning the idea of a second volume into reality: Bahar ,Sener-Pedgley (along-side Jessica and Lucas), Yunier Virelles (alongside Ernesto and Camilo), and Jaap Rutten (alongside Elis and Eren).

Editors

January 2021

CHAPTER 1

Expanding territories of materials and
design

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Introduction

People's experience of materials, regarding their here-and-now and possible futures, is largely bound into complex accounts of how materials are mobilized

in the design of artifacts. The first volume of Materials Experience, subtitled

Fundamentals of Materials and Design ([Karana et al., 2014](#)), focused on describing people material relationships, with the central premise that materials experience can be viewed from the perspective of the designer who creates artifacts

and from the perspective of people who own and interact with those artifacts.

In this second volume, we have drawn upon our observations of how materials

experience as a concept has evolved and been mobilized to incorporate new ways of thinking and doing in design. We have subtitled the book *Expanding Territories of Materials and Design*, encompassing a critical perspective on the

changing role of design/designers, the increased prevalence of material-driven

design (MDD) practices, and the increasing attention among design scholars to

the role of materials themselves as active and influential agents within and out-

side design processes. *Materials Experience 2* is therefore a companion to the first

volume. In this introductory chapter, to benefit readers venturing into the field

of materials experience, we first provide a concise account of where materials

experience originated from, alongside its main concepts.

1.1.1

Lineage of materials experience

Materials experience as a topic of discussion can be traced to two landmark

books, published in different decades: [Manzini \(1986\)](#) and [Ashby & Johnson](#)

[\(2002\)](#); [Manzini \(1986\)](#) was the first author, and for a long time also the only author, to present convincing arguments and examples on the interrelationships between materials, inventions, and people's experiences.

His work

1

Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00028-4>

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2

CHAPTER 1 :

Expanding territories of materials and design

emphasizes the role of materials, which, when combined with design, can invent new solutions and meaningful experiences. The book stands as a milestone in this area of research. It confirmed the importance of materials in the design process, in addition to their autonomy: that is, the fact that materials can be considered design objects in themselves.

In 2002 Ashby and Johnson provided the first textbook on materials and design that purposefully adopted a “designerly” view of the materials world, in which product esthetics were discussed alongside technical possibilities and engineering material properties. Their work was particularly significant because of its heritage and interdisciplinarity—born from Ashby’s world-renowned expertise in the Engineering Department of Cambridge University and Granta Design Ltd—but reaching out into product design through Johnson’s doctoral studies and connections with the innovation consultancy IDEO. This book, which has been revised through multiple editions, remains

crucial because it highlights very strongly how materials and design benefit from interdisciplinary approaches.

Around the time of Ashby and Johnson's publication, design research on the subjects of user experience, materials selection, materials information, and material sensory qualities started to expand significantly. In 2004 Rognoli's doctoral thesis ([Rognoli, 2004](#)) contributed to this field providing a vocabulary and a tool for designers to understand the sensorial qualities of materi-

als. [Karana et al. \(2008\)](#) coined the term "materials experience" to describe the experiences that people have with, and through, the materials of a product. Subsequently, in her thesis, entitled Meanings of Materials, [Karana \(2009\)](#)

conducted a series of studies providing empirical evidence on the multifaceted system that underpins our material experiences. Materials experience is therefore firmly rooted within the practices and research activities of product design. Its fundamentals formed through a fusion of the aforementioned materials and design studies. The subsequent years saw a sharp increase in research and general interest in materials experience, across a variety of design specialties and professions, beyond its origins in product design. The aim of Materials Experience: Fundamentals of Materials and Design ([Karana et al., 2014](#)) was to bring together these various scientific developments and practical insights into a single location, to construct a comprehensive view on the concept of materials experience.

Readers are recommended to refer to earlier publications for a lengthier discussion on the drivers and origins of materials experience: to the article On Materials Experience in the journal Design Issues ([Karana et al., 2015a](#)), which itself was a development of the Introduction in the original volume of Materials Experience; and to the Editorial of the special issue on Emerging Material Experiences in the journal Materials and Design ([Karana et al., 2016](#)),

1.1 Introduction

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in which it was argued that designing with new materials through the lens of “materials experience” can be a powerful strategy to introduce those materials to societies. In the context of design education, a number of tools and techniques have been developed to make materials experience thinking more actionable in design thinking ([Pedgley et al., 2016](#)). [Veelaert et al. \(2020\)](#) published an extensive analysis of 64 experiential material characterization studies in the journal Materials and Design, which clearly indicates how materials experience research has become prominent among design scholars over the past few years. We anticipate the trend to continue, especially given the emergence of new kinds of materials into everyday experiences.

1.1.2

Materials experience framework

In its original description, materials experience consists of three experiential levels: esthetic (sensorial) experience (e.g., we find materials cold, smooth, and shiny), experience of meaning (e.g., we think materials are modern, sexy, and cozy), and emotional experience (e.g., materials make us feel amazed, surprised, and bored). We used these levels to ground the first volume of *Materials Experience*. In 2015 the performative level was added as a fourth level of materials experience, inviting scholars to explore how new and emerging materials in the everyday may elicit novel actions and, ultimately, practices ([Giaccardi & Karana, 2015](#)). Accordingly, the expanded four-level framework emphasizes that a comprehensive definition of materials experience should acknowledge the active role of materials not only in shaping our

internal dialogs with artifacts, but also in shaping our ways of doing.

The addition of the performative level has been a springboard for many fruitful and diverse research studies. It has opened up possibilities to design for and with novel materials through an interactional lens. For example, one study has looked at the use of mycelium-based composites that offer a new practice for unpacking (wine) bottles ([Fig. 1.1](#)), by inviting people to pluck and pick the material to reveal its contents ([Karana et al., 2018](#)). The qualities of the material are fine-tuned to guide this response.

The performative level is also explicit in the domain of Interactive Connected

Smart (ICS) Materials, which are hybrid material systems that exhibit adaptive and responsive qualities triggered by environmental inputs or through interaction with people ([Ferrara et al., 2018](#)). These materials imply and enable novel material experiences relying on dynamism, surprise, and, among others, performativity ([Parisi & Rognoli, 2021](#); [Rognoli, 2020](#)). For example, one project developed under the umbrella of ICS Materials investigation has aimed to create do-it-yourself (DIY) conductive ink to understand its properties, opportunities, and limitations ([Fig. 1.2](#)).



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FIGURE 1.1

An innovative packaging for (wine) bottles, designed with mycelium-based materials ([Karana et al., 2018](#)), by Davine Blauwhoff, 2017/18 Master's Graduation Project, Industrial Design Engineering, Delft University of Technology. Reproduced with permission from Davine Blauwhoff.

Metamaterials are another class of material for which the performative level of materials experience is highly relevant. These materials are designed with complex internal geometric microstructures and typically realized through high-resolution 3D printing ([Ion & Baudisch, 2020](#); [Ion et al., 2018](#)). The materials deform and reshape in a controllable way when exposed to an input such as a force. Such dynamic qualities of the material can be mobilized to evoke certain actions from people, for example, through changes in surface texture ([Fig. 1.3](#)).

1.2

Expanding territories

If we scan across the contributions to this second volume of *Materials Experience*, some noticeable themes become evident that were either absent in the first volume or less prominent. We have defined the themes as the expanding territories of materials and design: the changing role of design and designers as well as the changing role of materials in design.

Unsurprisingly, material implications in achieving sustainability goals continue to be a connective theme among many of the contributions, with a detectable sense of urgency in tone.

1.2.1

Changing role of design and designers

Material skills are (re)gaining importance in design. Hands-on material manipulation and evaluation has a long history with design. Crafts practices

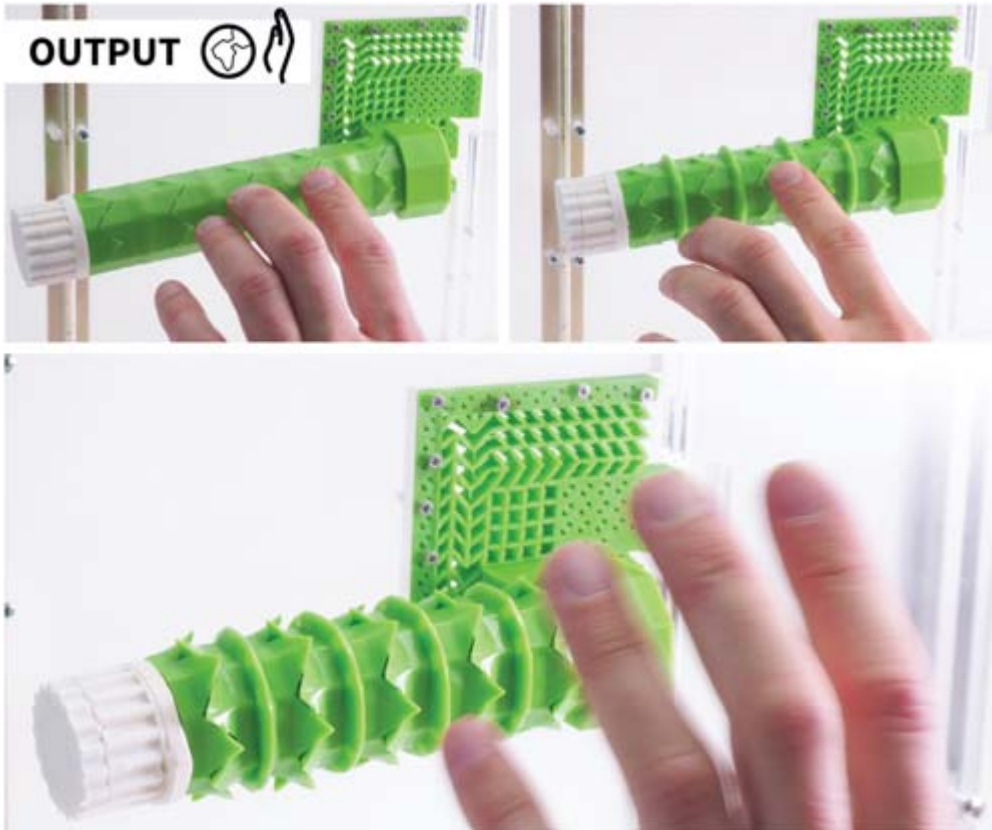


1.2 Expanding territories

FIGURE 1.2

L-INK project—“test, learn, hack” project by Gaia Bianco, 2017/18 Master’s Graduation Project, Product Design for Innovation, Politecnico di Milano, supervised by Valentina Rognoli and Stefano Parisi. Reproduced with permission from Gaia Bianco.

are built on such relations, with craftspeople shaping materials into often unique artifacts. With the arrival of industrial design came a separation between intent (design) and making (production). The separation did not remove the designer’s involvement with materials, but it did bring about changes. Propositional knowledge on material properties, material processing, and material applications became dominant because designers were no longer also the makers. Instead, designers were required to hand-over designs that were materially feasible and producible by someone else, somewhere else. In product design education, particularly at technical universities,



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FIGURE 1.3

Door handle from metamaterial, resulting in dynamic surface texture changes and tactile communication. Reproduced with permission from Alexandra Ion/Hasso Plattner Institute.

it became normal to be informed about materials, rather than have experience with or through materials. It was (and still is) convenient to teach and learn in

this manner since the requirements for workshops, technicians, and access to

materials are minimized. In this respect, educational institutions in the art and design tradition have been much more resilient in maintaining material skills and direct material contact, placing them at the core of the student experience.

In recent years, the rise of maker spaces and hacker/repair hubs has contributed to a renewed emphasis on material skills and first-hand physical material experiences. Material libraries, today's ubiquitous and organized realities

intended to be catalysts of reflection on design materials, have turned out to be insufficient for the needs of designers who have shown willingness not only to select a material but also to create and transform it directly. We now see the emergence of designers who are no longer satisfied with choosing or selecting materials, but now create materials independently, with a spirit of innovation in the language and the choice of resources and raw materials (see, e.g., the work of renowned designers Diana Scherer, Maurizio Montalti, and Natsai Audrey Chieza, among others).

From this standpoint, material explorations and material tinkering ([Karana et al., 2015b](#); [Parisi et al., 2017](#); [Rognoli & Parisi, 2021](#)) are talked about as no less important than materials selection. In the contemporary material



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atelier, designers and designers-in-training become acquainted with materials

in highly practical ways. They tinker with the existing materials and engage in DIY material creation, namely, DIY Materials ([Ayala-Garcia et al., 2017](#); [Rognoli et al., 2015](#)) (Fig. 1.4).

When the principles of personal materials tinkering and DIY material-making are scaled up to become professional practices in and of themselves, designers become the creators of new materials as much as creators of new products embodying those materials. In this journey, designers are increasingly cooperating with materials scientists, engineers, and biologists—traditionally separated communities—for the common purpose of designing new

materials. It is not that design communities in the past have failed to engage with other disciplines to develop materials—there are successful examples (e.g., [Franinović & Franzke, 2015](#); [Miodownik & Tempelman, 2013](#)). The difference in recent times is that these cooperations are giving rise to a new fig-

ure, the materials designer, with distinctive new forms of design practice.

In fact, the figure of the material designer had already been theorized in Italy as early as the 1980s and realized in the 1990s ([Manzini & Petrillo, 1991](#); [Trini Castelli & Petrillo, 1985](#); [Manzini, 1996](#)). The focus then was on material expressions, whereas today “materials design” is emerging as a new trans-

discipline, with material designers as transdisciplinary practitioners who can design materials with unique functionalities and experiential qualities.

FIGURE 1.4

A DIY-Material example from cigarette butt materials. “Butts Bunny” by Carolina Giorgiani, Jinan Jezzini, Davide Mosito, Designing Materials Experience Course 2016/17, School of Design, Politecnico di Milano. Reproduced with permission from Carolina Giorgiani.

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A major difference compared with the 1990s is that it is now far easier to take this path, thanks to the democratization of technologies, easier access to

tools and above all access to information (courtesy of the Internet and social networks). Hence, boundaries between the “design of materials” and the “materials of design” fade, to become united under the common endeavor of exploring novel form, function and experience potentials of materials and their process-abilities ([Barati & Karana, 2019](#)).

1.2.2

Changing role of materials

Materials for design have traditionally been sourced and selected from among natural inert, once-living, or synthetic matter. In recent years, living materials have come to the fore of research and development. Emerging bio-design and biofabrication practices centered on growing materials ([Camere & Karana, 2018](#); [Ginsberg & Chieza, 2018](#); [Collet, 2013](#); [Myers, 2012](#)), or facilitating the growth of living artifacts ([Karana, 2020](#); [Karana et al., 2020](#)), present a shift in our understanding of what a material can be and the processes by which a product becomes materialized. In these practices, the designer assumes the role of co-creator of artifacts with living organisms. The designer still exerts intent, but also steps back to delegate responsibility to the material itself to grow into a design-relevant entity. A shift takes place: from being a materials designer to a facilitator of the grown, as if she or he was a breeder.

In such practices, among many others, materials are given a purposefully special standing: they can form the launch pad for ideation and be the “raison d'être” for a project. When the material is the star, designers engage in a process that is the antithesis of a reductionist, selection-based approach to materials. In other words materials become a fruitful starting point for conceptual product design. However, the utilitarian and expressive potential of new, unusual, and emerging materials can be challenging to envision and to design for, especially when compared to familiar materials commonly found in products. To this end [Karana et al. \(2015b\)](#) introduced the MDD Method—suggesting techniques to understand and integrate both the technical properties of a material and its experiential qualities in unveiling the design potential of the material. Motivating a return to making and material tinkering in design, the MDD Method was designed with the aim to give the designer guidelines for creating meaningful materials experiences.

1.2.3

Materials experience and sustainability goals

Environmental problems are increasingly evident in the world. Societal inter-

est and comprehension of sustainability are probably higher than ever. The responsibility of designers is to transition toward sustainability goals by

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proposing solutions that include environmental reflection on materials. The role of materials experience in the context of sustainability has already been investigated using the concept of “Materially Yours” ([Karana et al., 2017](#)), in which strategies are indicated to suggest ways of using materials at different experiential levels to assist in the design of longer-lasting products. By expanding the territories of materials experience, we hope that the ability for designers to address environmental considerations will be widened. The growing impact of our objects (and waste) and the ever-increasing pressure on material resources requires a change in our relationship with the objects themselves and the materials they are made of.

The circular economy, low carbon footprints, reduced consumption, and local sourcing are terms and concepts that have been clearly explained and promoted for some considerable time as ways to reach sustainability goals and keep material usage in check. Yet, the responsibility and accountability of the individual designer has been difficult to tie down. What is clear is that there are currently renewed efforts, initiatives, and impetus to deliver impact-

ful change in this regard, against a backdrop of severe consequences of inaction. Sustainability goals are integral to many of the contributions to this volume of Materials Experience. For example, through the lens of materials

experience, a thorough understanding of people's acceptance of new and alternative materials can be gained, as well as people's willingness to engage

as product and material (resource) custodians rather than owners of products or consumers of material ([Karana, 2020](#)).

In the context of design, much research has been carried out aimed at studying alternative materials. As well as being driven by innovation, DIY materials have as motivation for their development the designer's will to propose resources deriving either from the biological context or from the world of waste ([DIY Materials, 2020](#)). Designers are autonomously suggesting ideas for more sustainable and circular materials trying to motivate industrial production to invest in this area. Ideas are not lacking; what is lacking is more

to do with the feasibility and economic convenience to encourage companies. It would seem that environmental problems alone and catastrophic predictions concerning life on Earth are not enough.

Research at a European level, on the other hand, has been active in this area, for example, in financing the recently concluded project, [MaDe \(2020\)](#). The project aimed at boosting talents toward circular economies across Europe, by partnering with design and cultural institutions. It focused on the figure of the material designer as an agent of change: designing, redesigning, reforming, reusing, and redefining materials to give them an entirely new

purpose. Increasing the potential of materials, material designers can go on to research, advise, educate, and communicate what materials are and can be

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in the immediate, near, and far future, implementing positive social, economic, political, and environmental change across all sectors toward a responsibly designed future.

1.3

Where next?

Materials experience has helped designers and researchers transform materials

and design from a narrow-focused technically oriented selection process into a vibrant, investigative, and inspirational practice. It provides a lens through which human material relations may be examined at multiple levels of experience. While the expanding territories define the current state-of-the-art, an inevitable question remains: where next for materials experience? We offer

some reflections on areas that we have started to make progress in, and which are likely to gain prominence.

New forums and means of sharing DIY-Materials and their experiences

will be established.

G MDD will be explicitly integrated with circular thinking, likely requiring renewed models, frameworks, and practices.

G MDD will be provided with extensions to support scaling-up of novel materials, mainstream adoption, and increased impact.

G Design education will embrace a hybrid approach of learning materials through community-generated information and by practical, experiential investigation and material creation.

What we are certain of is that materials experience will continue to feed the conscientious mind on the topic of materials and design: from a catalyst for new practices, through to an influencer of thoughtful choices of materials for design, as well as thoughtful decisions in new materials development, which will take into account our experiences with and through materials in tailoring material qualities. We foresee more intense blurring of the boundaries between material and product.

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CHAPTER 2

How new materials speak: analyzing the

language of emerging materials in

architecture

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2.1

Introduction

In the middle of crowded Hong Kong Island lies the former Central Police Station (CPS), Victoria Prison, and Central Magistracy complex. Once a prominent feature on the central Hong Kong hillside, the CPS is now dwarfed by high-rise towers on all sides. In recent years, the complex has been transformed into the Tai Kwun Centre for Heritage and Arts, a cultural destination and urban oasis ([Tai Kwun Centre, 2018](#)).

Upon first visiting the site, a visitor will notice a couple of unusual additions situated among the original 19th-century colonial buildings. Designed by

Swiss architects [Herzog & de Meuron \(2018\)](#), the new structures—called the Old Bailey Wing and Arbuthnot Wing—stand in stark contrast with their historic surroundings ([Fig. 2.1](#)). Unlike the planar, masonry walls of stone and brick, the new wings are clad in a unique system of cast aluminum modules.

According to the architects, “The unit system references existing masonry block elements on site in terms of scale and proportion,” such as the existing granite retaining wall ([Herzog & de Meuron, 2018](#)).

Yet the layperson may not recognize this visual connection at all. Despite the proportional allusion, the new system appears completely alien: lozenge-shaped

ellipsoids protrude at various depths and angles, their horizontal slits pointing

outwards and at the streetscape below ([Fig. 2.2](#)). This thick aluminum screen partially obscures glazing that sits behind the primary surface, revealing hints of

activity from within the building. Rather than turning the corner, the modules are cut at acute angles, revealing their intricate sectional profiles in a way that

appears intentionally unfinished. Thus despite the architect’s claims, the new system is wholly unlike brick or stone. It is hung rather than stacked, porous rather than opaque, and formally complex rather than simple. Furthermore, it is

composed of a material and a set of details not seen in masonry walls.

Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00009-0>

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How new materials speak: analyzing the language of emerging materials

FIGURE 2.1

Herzog and de Meuron, Old Bailey and Arbuthnot Wings, Tai Kwun Centre for Heritage and Arts. View showing historic context.

FIGURE 2.2

Herzog and de Meuron, Old Bailey and Arbuthnot Wings, Tai Kwun Centre for Heritage and Arts. Detail of building modules turning the corner.

One's initial confrontation with the curious facades of the Old Bailey and Arbuthnot Wings is representative of initial encounters with emergent materials and systems in general. When a visual distinction is made apparent, as is the case with many emergent materials, the human observer experiences several perceptual shifts. Responses may include confusion, intrigue, fascination, surprise, and delight. Architects like Herzog and de Meuron anticipate and plan for these reactions. In fact, the intent to shift public perception—and with it, visual culture—is a primary driver of their work.

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But why is this case? What motivates architects and designers to transform users' attitudes via emerging materials and applications? How do they accomplish this objective, and what knowledge of material interpretation do

they employ in the design process? Why are emerging materials of particular interest for architects and designers, as opposed to conventional materials? How might a broader understanding of emerging materials' perceptual potency, a fundamental type of material agency, enhance design praxis in general? This chapter will attempt to address these and other questions, focusing primarily on new materials and applications in building construction.

2.2

Emerging materials

First, what constitutes an emerging material? According to the Oxford English Dictionary, "emerging" or "emergent" is defined as "to come forth into view" and "to rise into notice, to come forth from obscurity." Another

definition considers “the production of a type by such a process as evolution” ([Oxford English Dictionary, 2020](#)). Of note is a now obsolete connection between “emergent” and “emergency,” “an unforeseen occurrence, a

contingency not specially provided for” ([Oxford English Dictionary, 2020](#)).

Yet another connotation is “an effect produced by a combination of several causes, but not capable of being regarded as the sum of their individual effects”—a scientific use that contrasts with “resultant,” in which the outcome is predictable ([Oxford English Dictionary, 2020](#)). Thus for our purposes, the general meaning of “emerging/ent” connotes something in the process of becoming in a way that cannot be predicted.

At the time of this writing, there is no universally accepted definition of emerging materials. In the science and engineering fields, where the term is commonly used, the phrase refers to advanced materials. According to South Africa’s [Department of Trade and Industry \(2019\)](#), “advanced materials refer to all new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the applica-

tion under consideration.” The Versailles Project on Advanced Materials and Standards, established at the 1982 G7 Economic Summit, sought to address “the growing need for pre-standards research necessary to provide the techni-

cal basis for drafting specifications and codes of practice for advanced materi-

als” ([Early & Rook, 1996](#)). The motivation concerned the “special properties”

and “advanced processing procedures” that distinguish such materials and

thus merit further scrutiny ([Early & Rook, 1996](#)). Today, advanced materials appear in journals such as [Emergent Materials \(2018\)](#), which claims to publish articles related to material research “at the forefront of physics, chemis-

try, biology, and engineering.” Advanced materials are also the subject of

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programs such as the [Argonne National Laboratory’s Emerging Materials](#)

[\(2020\)](#), “a physics-based materials discovery program, emphasizing design, synthesis, and understanding of new materials. . .”

For the architecture and design fields, the term emerging materials is more inclusive, referring to both scientific and artistic and other forms of advance-

ment. For example, the Emerging Materials program at [T.U. Delft \(2020\)](#)

considers “novel, superior materials as better alternatives to convention.” In

design, emerging denotes one or more kinds of innovation, such as techno-

logical, functional, environmental, or esthetic. The implicit message is one of

promise or potential: emerging materials represent not only individual

achievements but also possible broader trends. The economist Clayton M.

Christensen coined the phrase “disruptive technology” to describe this phenomenon from a business perspective. Simply put, a disruptive technology is a novel product or technique capable of displacing established technologies based on competitive functionality, price, or other characteristics ([Christensen](#)

[et al., 2004](#)). Due to the nature of architecture and design as visually oriented fields, disruptive technologies may satisfy esthetic as well as functional and economic criteria.

For the purposes of this chapter, the term “emerging materials” will be used broadly—including references to advanced materials and disruptive technologies—but with an emphasis on esthetic and application novelty. Because the fundamental concern here is human experience, the examples to be discussed are commonly exposed to the human eye and other sensory organs, at a comprehensible scale. These materials’ emerging qualities should be readily recognizable even if they are not themselves identifiable. Furthermore, in the spirit of the open-ended and multiscale meaning of materials in design, the term “emerging materials” will be used inclusive of materials, products, systems, and assemblies.

2.3

The language of materials

Material language bears similarities with written and spoken language.

According to novelist Victor [Hugo \(1964\)](#), “Architecture began like writing. It was first an alphabet. A stone was planted upright to be a letter and each letter became a hieroglyph. And on every hieroglyph there rested a group of ideas, like the capital of a column. Thus primitive races of the same period ‘wrote’ all over the world” (p. 175).

Throughout architectural history, materials have been used to represent significant ideas. Particularly before the invention of the printing press in the middle ages, architecture was expected to convey substantial moral and spiritual information to the public. With the birth of the Industrial

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Revolution—after print media had become the predominant vehicle for information—architecture began to emphasize the intrinsic character, structure, and process of materials. In the early 20th century, the concept of authenticity gained importance in an architectural community obsessed with the establishment of a new, modern material language. “Let us be led by this enthusiasm which animates us,” wrote [Le Corbusier et al. \(2007\)](#), p. 45 in “The Expression of the Materials and Methods of our Times . . .

Industrialization, standardization, mass production, all are magnificent implements; let us use these implements.”

However, the material language of architecture has never entirely rid itself of the

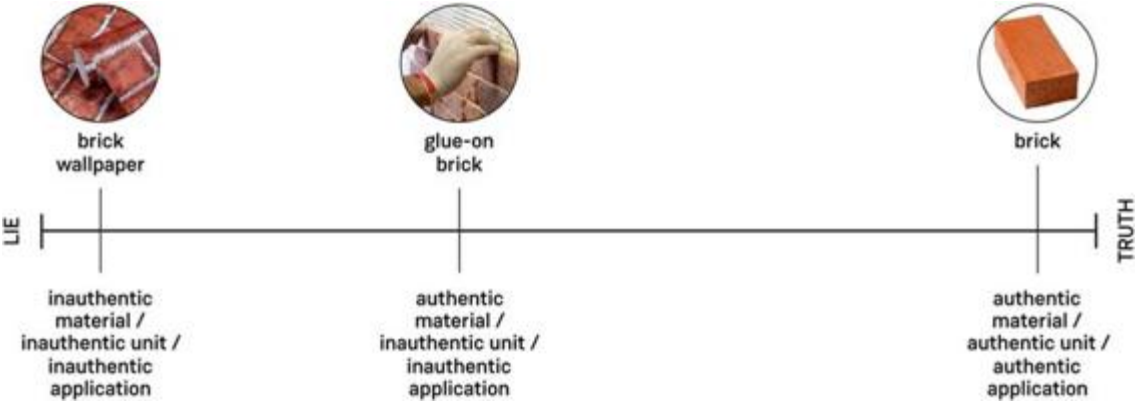
past. As architectural phenomenologist David Leatherbarrow and architect Mohsen Mostafavi argue in their seminal book *Surface Architecture* (2002), “Production and representation are in conflict in contemporary architectural practice.” Buildings that prioritize the adoption of new technologies without thought to their expression abandon the project of representation, whereas pro-

jects that emphasize historical symbolism at the expense of contemporary build-

ing methods neglect the project of production ([Leatherbarrow & Mostafavi, 2002](#), p. 1). When one considers the array of building products available today, one can see this phenomenon clearly evident at the material scale.

Based on this chapter’s opening reference to masonry, it is pertinent to start with the common brick. The architect Louis Kahn advocated a “highest and best use” approach to building materials, and the brick is no exception. His support for construction appropriateness is evident in his imagined dialog with brick, given in a lecture in 1973: “You say to brick, ‘What do you want, brick?’ And brick says to you, ‘I like an arch.’ And you say to brick, ‘Look, I want one too, but arches are expensive and I can use a concrete lintel over you, over an opening.’ And then you say, ‘What do you think of that, brick?’ Brick says, ‘I like an arch.’” (quoted in [Twombly, 2003](#), p. 271).

The public has largely subscribed to Kahn’s view of how brick should be used: to form load-bearing, compression-based structures composed of individual (and presumably handlaid) units. This widespread consensus is apparent in the way that brick is commonly represented. However, the reality is that brick—or “brickness” is typically a cosmetic treatment today, particularly in multistory and commercial structures. Thin brick-faced precast, glue-on brick, foam disguised as brick, wallpaper brick, and other such perversions maintain the pretense of brick without its material reality. To construct a direct link to written or verbal language: if one imagines a linear gradient of truth, one can begin to rate brick products on their authenticity concerning material ingredients, units, and uses (Fig. 2.3). Traditional brick would score high, brick wallpaper low, and glue-on brick somewhere in-between (based on its use of faithful ingredients).



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FIGURE 2.3

Gradient of truth: from brick to brick wallpaper.

2.4

Establishing a dialog

These aspects of materials—ingredients, units, and uses—describe physical details but not affects. As architects Farshid Moussavi and Michael Kubo con-

tend, architects often experiment with the communicating potential of materials

to influence perception. “These affects may start with found imagery or iconog-

raphy as raw cultural material,” they explain in *The Function of Ornament*

([Moussavi & Kubo, 2008](#), pp. 7 8). “However, they do not remain as pure acts of consumption, but rather are disassembled and reassembled to produce new

sensations that remain open to new forms of experience. It is in this way that

they are contemporary and committed to progress.” ([Moussavi & Kubo, 2008](#),

pp. 7 8) The creation of “new sensations” and “new forms of experience”

require establishing an intentional dialog with the user. The many inauthentic

materials available today—such as foam brick, fiberglass columns, or vinyl

siding—are not intended to generate a dialog; they are meant to be ignored. If

they are ever scrutinized, these materials are effectively camouflaged by fictive

representations. In contrast, the affects described by Moussavi and Kubo are meant to be recognized by users, regardless of their authenticity.

A good example is Jun Aoki's Aomori Museum of Art in Aomori, Japan. Aoki con-

ceived this project as a dialog between two primary material identities, one relat-

ing to excavated earth and the other to the snow-covered landscape aboveground.

The courtyards and tunnels recessed below grade are composed of earthen walls

and floors; the aboveground surfaces are clad primarily in white brick. From a dis-

tance, this brick resembles a standard running bond surface. Seen closer, however,

it reveals a strange affect. The brick wraps the upper volumes comprehensively,

including vast expanses of flat, cantilevered soffit ([Fig. 2.4](#)).



2.4 Establishing a dialog

FIGURE 2.4

Jun Aoki, Aomori Museum of Art. View of brick soffit.



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FIGURE 2.5

Jun Aoki, Aomori Museum of Art. Detail of brick turning corner.

One seldom sees brick applied in this way as it adds a large amount of unnecessary weight (the closest approximation of “appropriate” brick use would be in a shallow vault; otherwise, a lighter material would be used).

Viewed more closely, the details of the building become even odder. With brick masonry walls, one expects to see the depth of the brick as it turns a horizontal or vertical corner. However, this is not the case in the Aomori Museum, where the corner details reveal the brick to be seeming without depth ([Fig. 2.5](#)). The architect has obviously specified an ultrathin brick for use as a veneer. This application resembles the everyday use described above,

but with a notable exception: Aoki is intentionally showing us the thinness of the brick, not trying to disguise it. The interpretation is that he is expressing “the materials and methods of our times,” as Le Corbusier described it, in an ironic way. He is revealing the fact that brick today is a decorative element.

Aoki’s brick at Aomori clearly contrasts with Herzog and de Meuron’s “new masonry.” The materials, uses, and affects are obviously quite different. What

unites them, however, is their shared aspiration toward affect—to shape the user’s conscious experience of the material world. There are perhaps limitless

ways to manifest such an affect in building materials, but a starting point is to propose three general strategies as a way to clarify preliminary design conceptualization. The first concerns the use of a common material or



2.5 Common materials, uncommon applications

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material language in an uncommon way. In its subversive details, Aomori fits this description. The second regards the application of an uncommon material to fulfill or represent a common application language. The Tai Kwun Centre corresponds with this approach. The third pertains to the use of an uncommon material in an uncommon application. Although relatively rare, such examples of holistic novelty do exist, and they convey their own particular affects.

2.5

Common materials, uncommon applications

When architects and designers consider the unconventional use of a standard material, they begin by pushing the conceptual boundaries of that material's expected function and performance. [Karana et al. \(2018\)](#) discuss the fine balance that exists between typicality and novelty in design and argue that the process of material acceptance involves more than considerations of utility.

Studio Gang pursued this approach in the Marble Curtain project installed at the National Building Museum ([Fig. 2.6](#)). Designed for a 2003 exhibition entitled "Masonry Variations," the firm created an installation that questioned a seemingly irrefutable assumption: the fact that masonry may only

be relied upon to handle loads under compression, not tension. Studio Gang worked with engineers to devise a tension-only application for marble. The design team developed modular, interlocking jigsaw pieces that were cut sufficiently thin by water-jet to transmit light. They then suspended these marble pieces from the ceiling with steel cables, adding more modules until the

FIGURE 2.6

Studio Gang Architects, Marble Curtain, National Building Museum, Washington, DC. Studio Gang Architects.



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“curtain” reached the floor. Aside from a fiber-resin backing attached as a safety precaution, the stone operated entirely in tension without additional supports. From a distance, the installation conveyed the appearance of taut fabric; but up-close, observers were surprised to realize that the primary material was stone.

Another example installation is Vermilion Sands by Matthew Soules

Architecture ([Fig. 2.7](#)). In this case, the shift involved thinking upside-down.

Soules considered unexpected uses for geotextile fabric, which is intended to secure and improve soil structure, particularly along sloped or retaining surfaces. Rather than applying the fabric to the ground plane, however, Soules

chose to elevate it. He created pyramid-shaped modules by wrapping the geotextile fabric around lightweight wire, then sprayed the modules with a slurry of ryegrass seeds and mulch—a process called hydroseeding. After allowing the grass to grow on the units in a nursery for 1 month, Soules inverted and suspended the modules from a steel frame, creating an expansive grass canopy overhead. The large structure incorporated water spray nozzles to mist the grass regularly and provide cooling for visitors on hot summer days. The result was an upside-down garden: a grass pergola that invited visitors seeking shade.

Another example, in this case a permanent construction is Swing Time by Höweler and Yoon Architecture ([Fig. 2.8](#)). The transformation here pertains to manipulating expected functionality. The primary material language in consideration is lighting [in this case, light-emitting diodes (LEDs)], which typically assumes the single function of illumination. In the spirit of multifunctionality, the architects combined lighting with the application of a playground swing set. With the charge to create a nocturnal playscape in a

FIGURE 2.7

Matthew Soules Architecture, Vermilion Sands. Sandy Wang.



2.6 Uncommon materials, common applications

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FIGURE 2.8

Höweler and Yoon Architecture, Swing Time. Höweler and Yoon Architecture, LLP.

dark and relatively unoccupied urban area, Höweler and Yoon set out to create an interactive, self-illuminating playground. They designed 20 custom swings made from welded polypropylene tubes, inside of which they placed LED lights, microcontrollers, and accelerometers. The color and intensity of the light vary based on how users interact with the swings. Slow activity prompts a soft white light, whereas fast swinging results in

bright purple illumination. Not only does Swing Time demonstrate a novel use of lighting, but it minimizes the number of products required to create an illuminated play area.

2.6

Uncommon materials, common applications

Innovative material strategies can also emerge when the primary ingredients in everyday products, structures, or assemblies are transformed in significant ways. Returning to the brick theme, a notable example of this approach is

BioBrick by North Carolina startup bioMASON ([Fig. 2.9](#)). As previously discussed, brick masonry is a nearly ubiquitous form of construction, which is

used for a wide variety of residential and commercial applications.

Traditional brick is made from formed, dried, and fired clay. The firing process lasts between 10 and 40 h, depending on the kiln, with temperatures up to 1300C or higher ([Brick Industry Association, 2006](#)). Brick contributes about 0.2 kg CO₂ per kg of material produced—approximately double that



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FIGURE 2.9

bioMASON, BioBrick. bioMASON.

of concrete ([Ashby, 2013](#)). bioMASON founder Ginger Dosier developed an alternative process, however, that employs bacteria instead of kilns.

Channeling

natural

biomineralization

processes,

Dosier

introduces

Sporosarcina pasteurii to a mixture of yeast extract, urea, and calcium chloride

in brick-shaped molds. After 5 days, the BioBrick—which resembles sandstone—is ready for use, with a strength equivalent to traditional brick.

Another common application that invites scrutiny is building insulation.

Many of the various insulation products available today are derived from petroleum. Rigid polymer foams, such as polystyrene, contribute 3.7–4.1 kg

CO₂ per kg of material. Some insulating foams, like extruded polystyrene,

are made with hydrofluorocarbon blowing agents, which exhibit significant

global warming potential ([Ashby, 2013](#)). Scientists at the Fraunhofer Institute for Chemical Technology identified an alternative material for building insulation: *Posidonia oceanica*, a seaweed known as Neptune grass.

Mediterranean beaches are often lined with clumps of the so-called Neptune

balls formed by washed-up seaweed, which local beautification crews often

move to landfills. Recognizing Neptune grass' advantageous qualities, including

moisture tolerance and rot resistance, the Fraunhofer researchers devised

a way to dry the clumps and cut the material into collections of short fibers.

These fibers require minimal processing and no chemical additives and may

be treated as effective loose-fill insulation, to be blown into roof or wall

cavities.

Another omnipresent application in need of rethinking is the highway barrier: specifically, the sound barrier wall erected to stop the noise and light

2.7 Uncommon materials, uncommon applications

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pollution generated by vehicular traffic from spilling into adjacent residential neighborhoods. According to architecture firm Fieldoffice, there are over lin-

ear 75,000 km of highways lined with sound barrier walls in the United

States alone ([Hutchins, 2008](#)). The firm's Superabsorber is designed as a replacement barrier system, composed of porous, titanium dioxide (TiO₂)-

rich concrete. Emulating the form of a sea sponge to maximize surface area,

the photocatalytic concrete reduces local air pollutants when activated by

sunlight. Based on cement manufacturer Italcementi's demonstration that

15% of TiO₂-based cement coverage results in a 50% reduction in airborne

pollution, the new barrier wall functions to reduce air pollution—as well as

noise and light pollution—while representing a significant esthetic upgrade

from typical sound barrier walls ([Schelmetic, 2012](#)).

2.7

Uncommon materials, uncommon applications

This strategy is the most novel of approaches, given the unconventionality of both the material and its application. The term “uncommon material”

here refers to the product, unit, or module more than actual chemical ingredients—although these too can be novel in some cases. For example, the Pneumatic Biomaterials Deposition project by the Mediated Matter Group at the Massachusetts Institute of Technology (MIT) employs both a material and a procedure rarely used in building construction. Most building materials are rigid elements, and those that are soft, pliable, or fluid are typically contained by, within, or between rigid components. However, the MIT research demonstrates a significant departure from this norm. Looking at the living tissues of biological organisms, the researchers devised a method to print hydrogels via pneumatic deposition. They connected a custom-designed apparatus of various syringes and nozzles to a robotic arm, which enables liquid-based additive manufacturing with precise control. The

machine can print fluids ranging in viscosity between 500 and 50,000 cPs, which transform into elastic solids after printing. Initial applications include experimental wearable prosthetics, tissue scaffolds, and soft architectural skins.

In the case of the Air Flow(er) project by Lift Architects, the uncommon material is shape memory alloy (SMA), which is utilized to impressive collec-

tive effect ([Fig. 2.10](#)). Air Flow(er) is a smart, responsive ventilating surface composed of individual modules resembling flowers. The system was

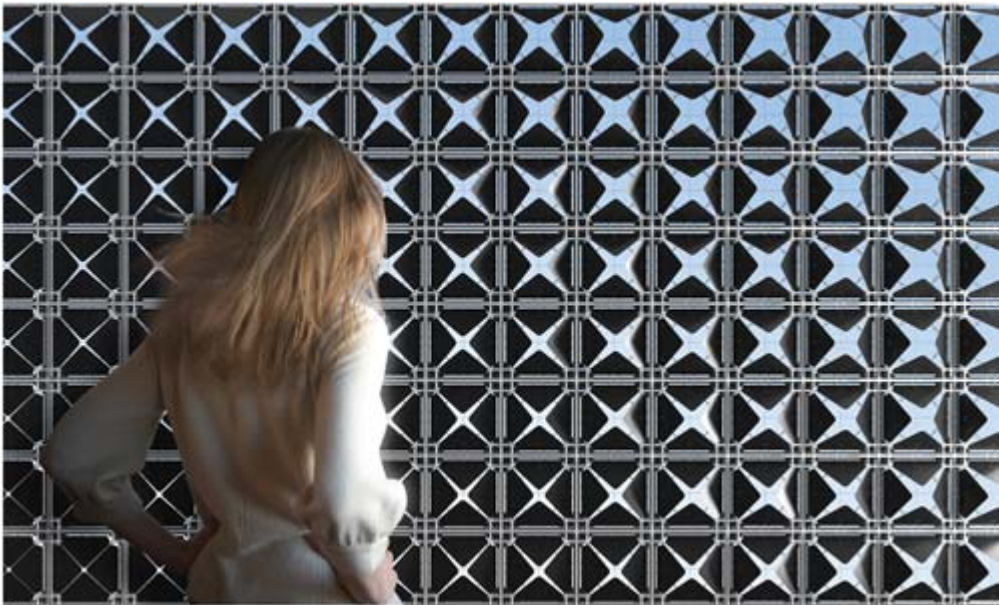
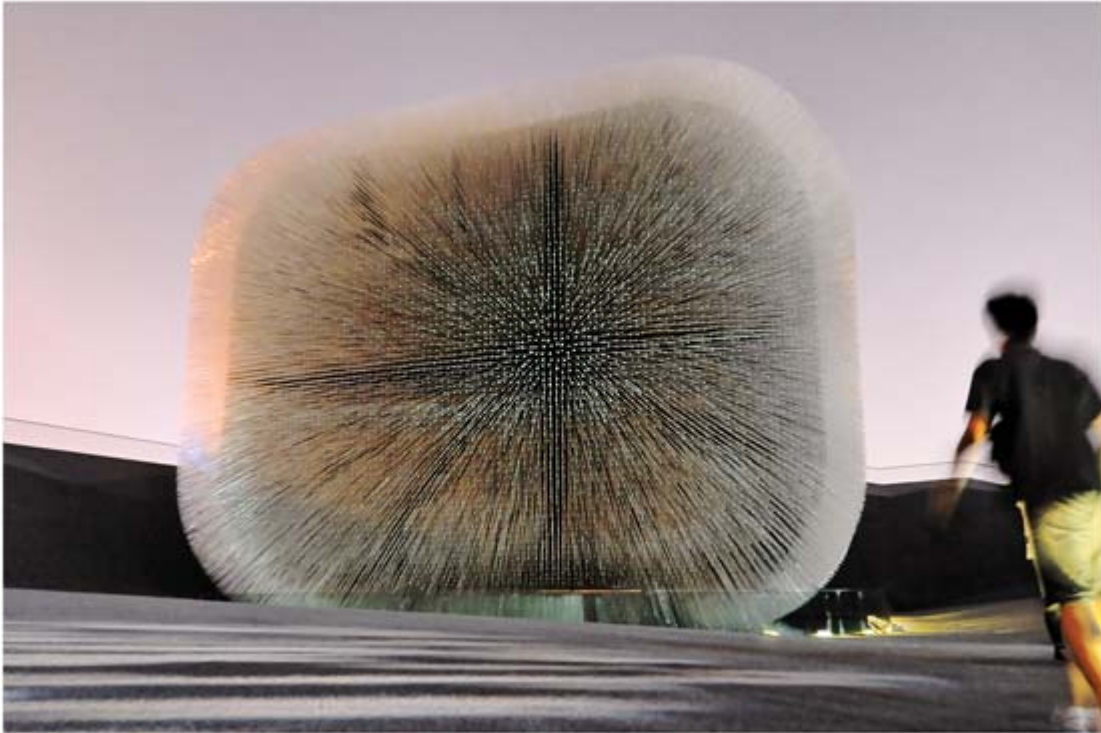
inspired by the natural principle of thermonasty, as seen in the crocus flower,

which enables plants to move when ambient temperatures change. Each

module consists of four thin gusset plates attached to a frame by nickel- and

titanium-based SMA cables. The SMA material automatically responds to trig-

ger temperatures around 16C and 27C: when the air heats up to the higher



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FIGURE 2.10

LIFT Architects, Air Flow(er). Andrew O. Payne, LIFT Architects.

FIGURE 2.11

Heatherwick Studio, Seed Cathedral, Shanghai, China. View at night showing illuminated rods.

temperature, the panels open; when it falls below the lower set point, the panels close. In this way, the system dynamically responds to the local climate by increasing porosity and ventilation when needed, all without electricity.

Another example of holistic innovation is the Seed Cathedral created by Heatherwick Studio ([Fig. 2.11](#)). Designed as the UK Pavilion for the 2010

2.8 Advancing material linguistics

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World Expo in Shanghai, the temporary structure was sufficiently novel when built that it was difficult to describe. Composed of over 60,000 acrylic rods that projected at all angles, the pavilion appeared to be more of a cloud than a solid structure. When seen in person, the wind-responsive rods bobbed almost imperceptibly, conveying the effect of a continuously blurred image—a soft, thickened surface always in motion. Each 7.5-m-long acrylic element extended into the interior of the pavilion, resulting in a similarly delineated interior cavity. Heatherwick Studio embedded a different type of seed from the Kew Gardens Millennium Seed Bank Project at

the end of each optical strand. Driving ambient light deep inside the Seed Cathedral, the tubes outlined the seeds in sharp silhouettes, thereby conceptually transforming an atmospheric construction into an earthbound seed bank.

2.8

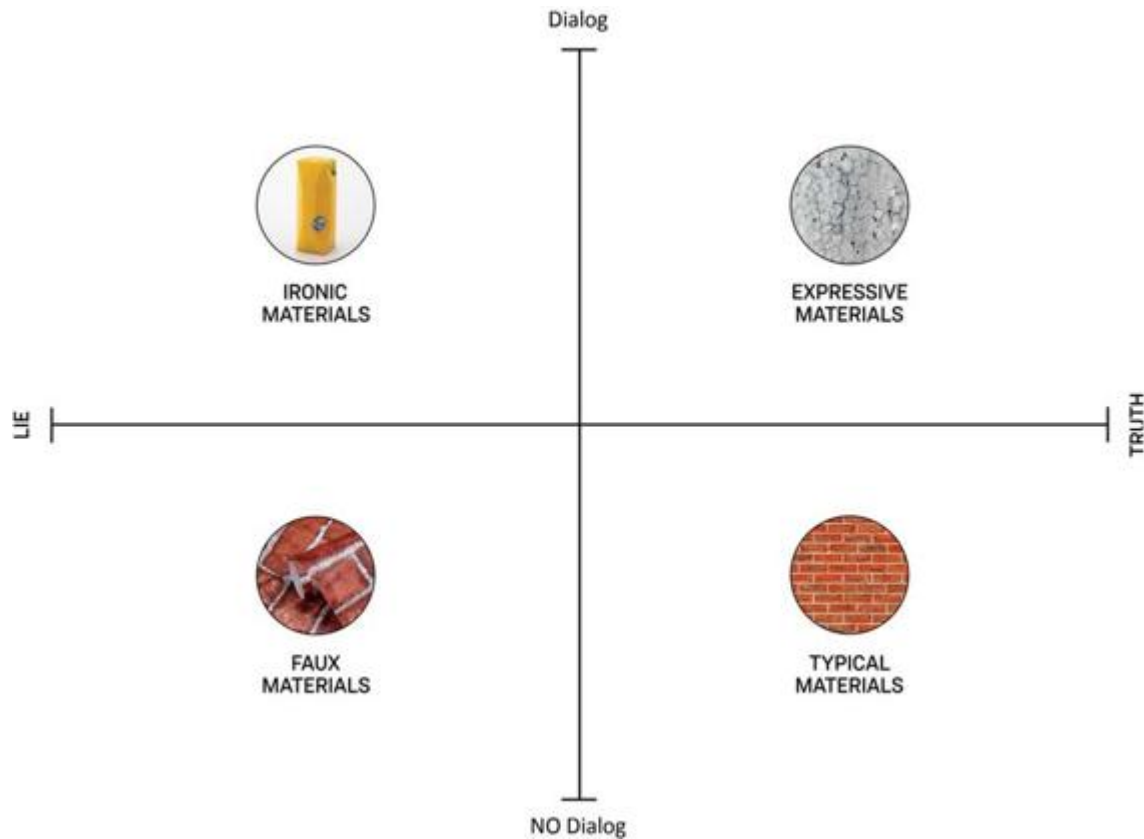
Advancing material linguistics

The three material strategies outlined in [Sections 2.5](#) through [2.7](#) are not static, but vary with context. The first two approaches depend on the conceptual starting point of the designer and may be interchangeable when the

emphasis shifts between a material and its application. For example, the Marble Curtain project was initiated with a material question about the properties of stone. However, given the result, the designer could conceivably have started with the notion of a curtain as an application and asked what uncommon material could be used to realize such an application. In this case, the example would shift to the category of Uncommon Material, Common Application. Furthermore, the third method (Uncommon Material, Uncommon Application) is dependent upon an audience's perspective on its degree of novelty. For example, when LEDs were first introduced as a disruptive lighting technology, a project like Swing Time would have been classified in the third category. However, in time, LEDs have

become a familiar technology with widespread commercial availability—thus landing the project in the first classification. In other words, the third strategy of Uncommon Material, Uncommon Application is highly subjective, based on the anticipated users’ familiarity with both aspects of material language.

In all of these cases, the fundamental question concerns the frame of reference. The attributes that determine whether a material or an application is common or uncommon relate to the general concept of baseline. According to Merriam-Webster, baseline is “a usually initial set of critical observations or data used for comparison or a control” and “a starting point” ([Merriam-Webster, 2020](#)). For our purposes, the notion applies to commonality in availability and practice. Baseline knowledge is accumulated through



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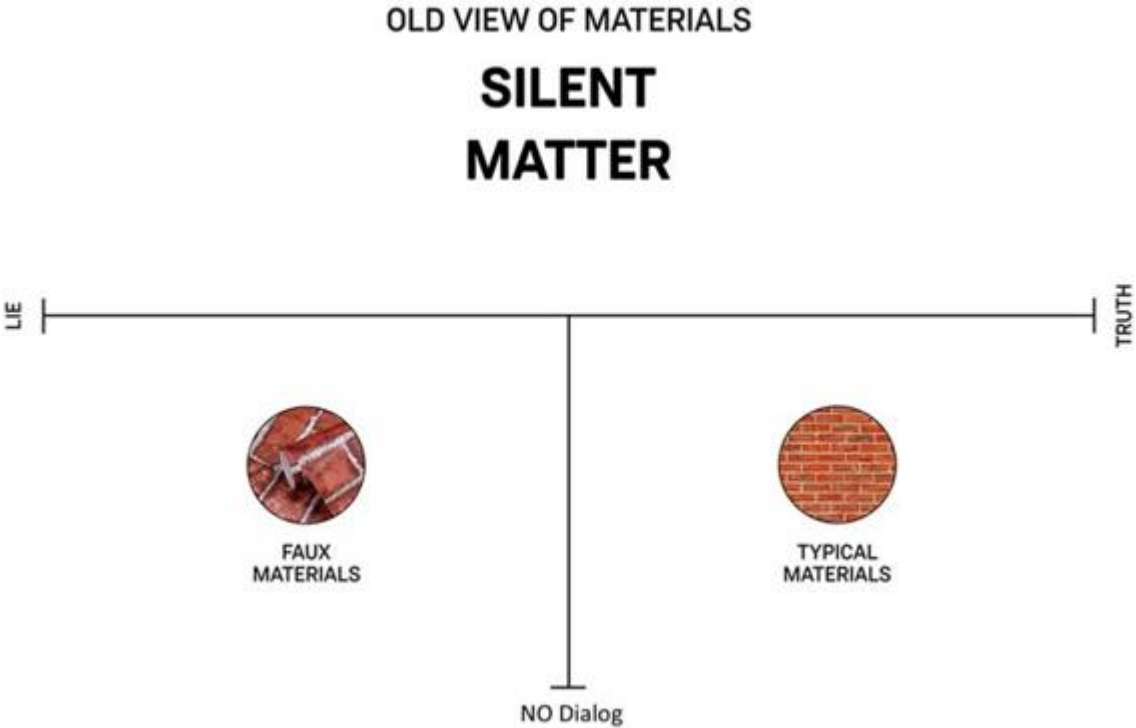
How new materials speak: analyzing the language of emerging materials observation as well as industry experience. In simplistic terms, clay bricks and wood doors would be considered baseline, or standard, building materials, whereas the inverse—wood bricks and clay doors—would not. That said, baseline varies with culture, geographic location, time, and other factors. For example, asphalt shingles are considered a baseline roofing material in the United States, but not in Europe; residential carpeting is likewise common-

place in the United States, but not in China. Notably, baseline is also a moving target: what is considered typical at a given moment and location inherently changes as new technologies and standards are introduced and adopted.

For architects and designers, it is critical to have a keen sense of baseline to impart meaningful material affects to observers. The aim should be to

FIGURE 2.12

Quadrant diagram.



2.8 Advancing material linguistics

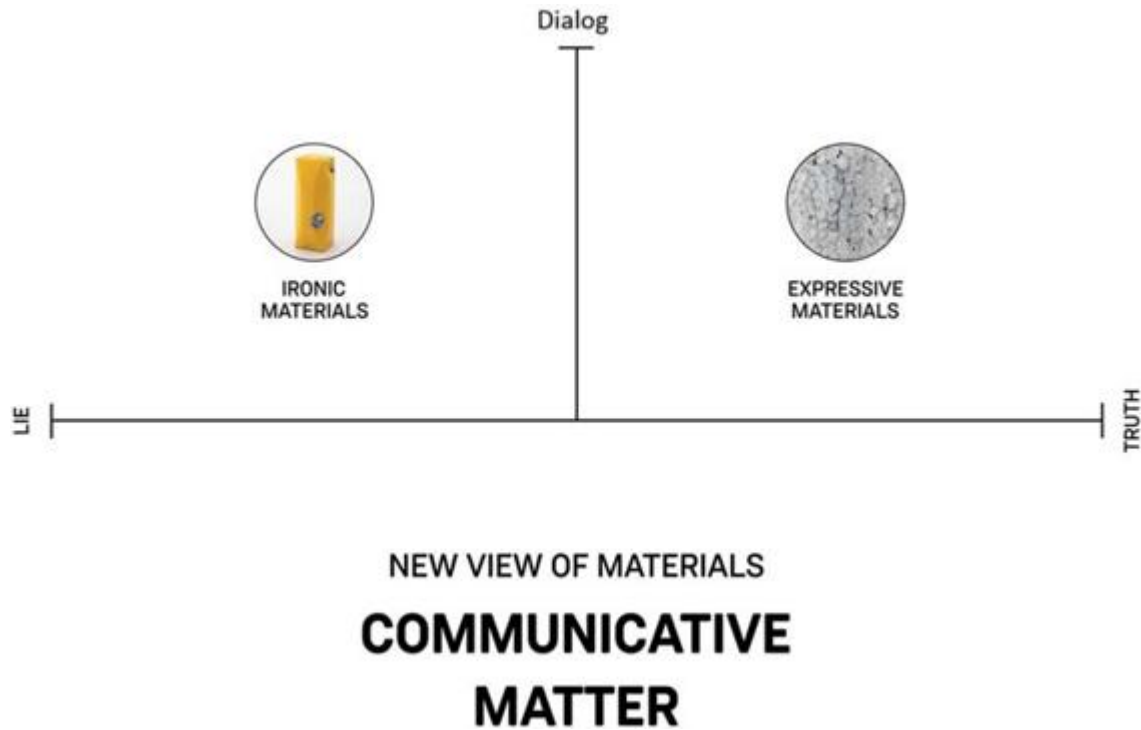
connect with the user consciously, with an uncommon material, application,

or both, to establish a dialog of material language. Such an approach demonstrates respect for users, acknowledging that they have an awareness of conventional materials and practices shaped by experience and that they can appreciate conceptually rich departures from the baseline. The nature of this acknowledgment can vary as directed by the designer. For instance, the new brick language in Jun Aoki's Aomori Museum of Art is subtle and likely unnoticed by most visitors, whereas the otherworldly visage of Heatherwick Studios' UK Pavilion is visually arresting for most audiences. Nevertheless, the ambition to create—and achieve—a dialog with the user is a fundamental differentiator between innovative and conventional material language.

[Fig. 2.12](#) transforms the linear gradient of “truth” in [Fig. 2.3](#) into a quadrant diagram with a second gradient called “dialog” ([Fig. 2.12](#)). In this way, one could argue that the traditional view of materials is that they stay silent; meanwhile, a contemporary perspective is that they are communicating vehicles ([Fig. 2.13](#) and [2.14](#)). Such a paradigm elevates material language to a higher place within the broad spectrum of human communication and accepts that the designed environment is at least as significant a linguistic milieu as literary and oratory spheres.

FIGURE 2.13

Quadrant diagram: silent matter.



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FIGURE 2.14

Quadrant diagram: communicative matter.

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C H A P T E R 3

Experiential craft: knowing through analog and
digital materials experience

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3.1

Introduction: crafting with analog and digital materials

This chapter investigates the intertwinement of analog and digital materials experience generated from within a process of handcrafting through digital

means. The work presented in the chapter is fundamentally an exploration of the relationship between the maker (i.e., the author), materials, and tools, or “craft,” carried out within the research through design framework ([Frayling, 1993](#)). In this exploration, the author’s design intentions reside in the hands executing her craft with judgment, care, and skill ([Pye, 1968](#)). Craft here is a means of thinking logically through sensing and immediate experience of materials ([Nimkulrat, 2010, 2012](#)) and “a dynamic process of learning and understanding through material experience” ([Gray & Burnett, 2009](#), p. 51). Such an experiential process entails “intimacy and affinity to human values and emotion and the ability to experiment and subvert” which are the essential characteristics and strength of craft ([Niedderer & Townsend, 2014](#), p. 631).

In addition, by incorporating digital fabrication and tools in craft processes, the work extends [Adamson’s \(2007\)](#) notion of craft as “a way of thinking through practices of all kinds” (p. 7).

Craft is generally concerned with “controlling the whole process from start to fin-

ish, adopting, adapting and improving tools as the need arises,” while the process

of working with digital technologies seems “‘hidden’ making understanding and

controlling the process from concept to end product seem more complicated .

..

and not craft” ([Shillito, 2013](#), p. 9). This raises questions about the role of the controlling hand in machine culture and Computer-Aided Design (CAD)

environments of industrial design where mechanized output is associated with ideas of

precision, certainty, and reproducibility. “[A]gainst the rigorous perfection of the

machine, the craftsman became an emblem of human individuality, this emblem

composed concretely by the positive value placed on variations, flaws, and irregu-

larities in handwork” (Sennett, 2008, p. 84). Pye (1968) relates craft to risk-taking: 33

Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00026-0>

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CHAPTER 3 :

Experiential craft: knowing through analog and digital materials experience

“[Craftsmanship] means simply workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined,. . . The essential

idea is that the quality of the result is continually at risk during the process of making” (p. 2). Traditional craftspeople make personal subjective decisions while

working with analog materials to form artifacts and generally have no digital his-

tory to retrace their decisions, that is, the only documentation is material artifacts

([Zoran & Buechley, 2013](#), p. 6). Today's craftspeople gain access to digital fabrication and tools, designing an object on a computer and then fabricating it by a

machine. Craft as expanded by digital media has the capacity to "reunite visual

thinking with manual dexterity and practiced knowledge" ([McCullough, 1996](#), p.

50). With their right approach, skills, and mindset, craftspeople can find the con-

nection between handcrafting and digital technologies ([Campbell, 2007](#)). The subjective decisions of the maker are still indispensable for the production of digitally fabricated artifacts, which in turn reflect their maker's skills, perspectives, and values ([McCullough, 1996](#)). Like handcrafted work, digitally fabricated work is at risk and its result as a material artifact acts as the documentation of the process.

Yet, as the digital craft practitioner has access to editable digital files that are a rich history of the process, it can be implied that digital craft is at significantly less risk than traditional analog craft.

3.2

Three concepts of materials experience: materialness,

material-driven design, and material agency

In order to examine analog and digital materials experience through own craft

practice, it probably is necessary first to grasp a broad subject matter of materi-

als experience. This section therefore aims to ground an understanding of the relationship between materials (i.e., the substance of artifacts) and experience

(i.e., a way to gain knowledge about the world), or how materials make us think, feel, and act ([Giaccardi & Karana, 2015](#)). Several concepts regarding materials and their role in forming meaningful objects have recently emerged, particularly in the disciplines of design, archeology, anthropology, and cognitive science, for example, materialness ([Nimkulrat, 2009](#)), material-driven design (MDD) ([Karana, Barati, et al., 2015](#)), and material agency ([Gell, 1998](#); [Knappett](#)

[& Malafouris, 2008](#)). While these concepts differ from one another in their detail and disciplinary contexts, the key point shared among them is the material's active role in the artifact and its relation to people.

Over a decade ago, the author's practice-led research into the expressivity of physical materials from a textile practitioner's experiential perspective proposed the concept of materialness for the design process of material-based craft

([Nimkulrat, 2009](#)). Developed from [Dewey's \(1934\)](#) notion of art as experience and [Heidegger's \(1962\)](#) and [Merleau-Ponty's \(1962\)](#) phenomenology, the

3.2 Three concepts of materials experience

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concept reveals the entirety of the creation that is rooted in a material, includ-

ing the elements of form, content, context, and time. Serving as an alternative

means to assist textile practitioners in the creation of artifacts using any mate-

rial, the concept formulates both the physical form and the subject matter of each artifact and its contextual application. In other words, the artifact is a formed material incorporating materiality and subjectivity. When a textile prac-

itioner experiences a tangible material, she not only feels its physical proper-

ties, such as strength or weakness and roughness or smoothness, but also associates these qualities to her own expressive capacity. By placing an empha-

sis on a selected material according to the materialness concept, a textile practi-

tioner can create the form and content of an artifact and bring the elements of context and time to her creation in order to design an overall experience for the viewer or user of the artifact. The physical qualities of a material affect the

ways in which the maker and others understand objects. Through material engagement, a textile practitioner learns through senses how to manipulate the

material at hand and is eventually able to improvise the manipulation technique

to create an inimitable artifact that represents the maker's authenticity. The arti-

fact thus becomes the physical embodiment of its maker's expressive thought; the creative and transformative act of creation embeds meaning in the material

artifact and the artifact, in turn, defines and expresses its meaning through its physicality.

The materialness concept resonates with MDD, a method to design with and for material experiences, offered by [Karana et al. \(2015\)](#). The method is grounded on the accounts of materials experience ([Karana et al., 2008](#); [Karana et al., 2014, 2015](#)) and experience design ([Desmet et al., 2011](#)).

Similar to the materialness concept, the method suggests the departure of a product design process from materials and shifts the designer's role from a passive recipient to an active explorer. The MDD method involves four steps: (1) understanding the material; (2) creating materials experience vision; (3) manifesting materials experience patterns; and (4) creating material/product concepts ([Karana et al., 2015](#), pp. 41-46). This is in contrast to the systematic approach of product designing, in which the formulation of problems and conceptualization of ideas would come first and then proceed to the translation of the concept into forms, functions, and materials embodied in a final design product ([Cross, 2008](#)). By utilizing the MDD method, both material and product are developed within a single design process, resulting in new material proposals and product application

concepts.

Although the MDD method arises from industrial design research that differs from the disciplinary context of the materialness concept which is from textile

craft research, both approaches are similar in their principle and focus on materials and design for experience. Both materialness and MDD aim to

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CHAPTER 3 :

Experiential craft: knowing through analog and digital materials experience change the way designers work with materials. With the materialness concept,

instead of beginning the design process by conceiving the idea of an artifact and sampling different types of material in order to find the right material

whose qualities elicit the response that corresponds with the idea, the textile practitioner starts with material selection and lets the chosen material leads

the creative process ([Nimkulrat, 2009](#), pp. 229 230). The experiential qualities of the material as understood by the textile practitioner not only inform

ways in which the concept and form of the artifact may be designed but also evoke possible manipulation techniques and tools to achieve the design inten-

tion. Likewise, the MDD method begins with understanding the material and

results in material and product concepts blended in one final outcome of design for experience ([Karana et al., 2015](#), p. 49).

In archeology, anthropology, and sociology, a notion that emphasizes active materials is material agency. While this concept is widely adopted in recent research in various fields of design, the concept of agency as such has been subject to several interpretations ([Robb, 2010](#)). One of the early accounts of agency is tackled from the perspective of anthropology of art; [Gell \(1998\)](#) considers art and artifacts as having “distributed agency” because they produce effects and cause people to feel—“Agency is attributable to those persons (or things. . .) who/which are seen as initiating causal sequences of a particular type, that is, events caused by acts of mind or will or intention, rather than the mere concatenation of physical events” (p. 16). Material objects according to [Gell \(1998\)](#) are positioned in social relations that are normally associated with persons, not with inanimate things, and can therefore be agents as long as humans interact meaningfully with them. On the contrary, [Knappett \(2005\)](#) argues that because objects are not alive they cannot have agency on their own, but they may act in a manner similar to that of an agent when they are imbued by humans with a purpose. The most relevant accounts of material agency to the design discipline probably are ones illustrated by [Malafouris \(2008\)](#) and [Pickering \(1995, 2010, 2013\)](#). Both see that agency emerges only when people and things are mutually related and interact with one another. [Pickering \(1995, 2010, 2013\)](#) proposes a way to understand natural sciences and knowledge production through a “dance of

agency,” a concept that deals with “actions, human or non-human, in the material world and the interplay of those” ([Pickering, 2010](#), p. 195). In this dance, there is a practice, a performance, or a set of ongoing interactions between humans and nonhumans, for example, a scientist is “trying this, seeing what happens, trying something else” ([Pickering, 2013](#), p. 81).

On the other hand, [Malafouris \(2008\)](#) brings together materials and people in the process of skilled practice in which action comes before intention and materials engage human agents in a dialog. He examines agency and intentionality as “the properties of material engagement, . . . where brain, body

3.3 Handcrafting through digital tools

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and culture conflate” ([Malafouris, 2008](#), p. 22) and suggests that they should be understood as a “distributed, emergent and interactive phenomenon rather than as a subjective mental state” (p. 33). His explanation through the case of pottery making in which the potter interacts with clay on a wheel highlights that the artifact should not be interpreted as a passive object of the maker’s intentionality but as “a functionally cosubstantial component of the intentional character of the potting experience” ([Malafouris, 2008](#), p. 33).

[Malafouris’s \(2008\)](#) point for discussing agency in relation to material engagement is to emphasize that agency is not a fixed attribute of either people or

objects but the spatiotemporally relational and emergent product of material

engagement existing as the flow of the situated, dialectic activity itself (p. 35). In

his later work, [Malafouris \(2013\)](#) argues for the differentiation between agency and sense of agency in the context of “real-world experience” and “situated

action” (p. 215). Taking the same example of pottery making, [Malafouris](#)

[\(2013\)](#) points out that what differentiates the potter from the clay and the wheel is the potter’s possession of sense or experience of agency, which enables

her to be an “experiencing enactive agent . . . conscious of being in control of one’s own actions” (p. 215). The material (i.e., clay), the maker (i.e., potter),

and the tool (i.e., wheel) are related in a material engagement situation

(i.e., pottery making). This line of thinking will be taken on to illuminate the

author’s real-world experience of craft practice through analog and digital materials in the next sections.

3.3

Handcrafting through digital tools

This section describes the initial process of handcrafting through digital means involved in a research project that attempts to understand how digital tools can be used to translate handcrafted objects in craft practice. The project addresses two research questions: (1) What forms of knowing and meaning making evolve in analog and digital craft practice? (2) What

does it mean to explore material in CAD through Virtual Reality (VR)?

The exploration which lasted for 2.5 months in the Digital Fabrication and Mixed Reality labs at Emily Carr University of Art 1 Design in Canada is by nature concerned with both analog and digital materials experience.

Prior to this investigation, the author's craft practice had utilized neither tool nor machine for over a decade. Manipulating paper string by hand without any tool or machine would leave no boundary between the material and the maker. This form of practice was initiated with an intention of examining the expressivity or active role of material in creative processes ([Nimkulrat, 2009](#)).



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Experiential craft: knowing through analog and digital materials experience

FIGURE 3.1

(A) Hand-knotting process of a small artifact from paper string in 2017 and (B) the original cup form made in 2007.

In order to begin her new experience with digital processes through a craft lens, the author hand-knotted a small artifact from paper string for further experimentation with digital tools ([Fig. 3.1](#)).

3D scanning and 3D printing seemed to be the most straightforward process for

translating the analog artifact into a digital format. Scanning using a high-

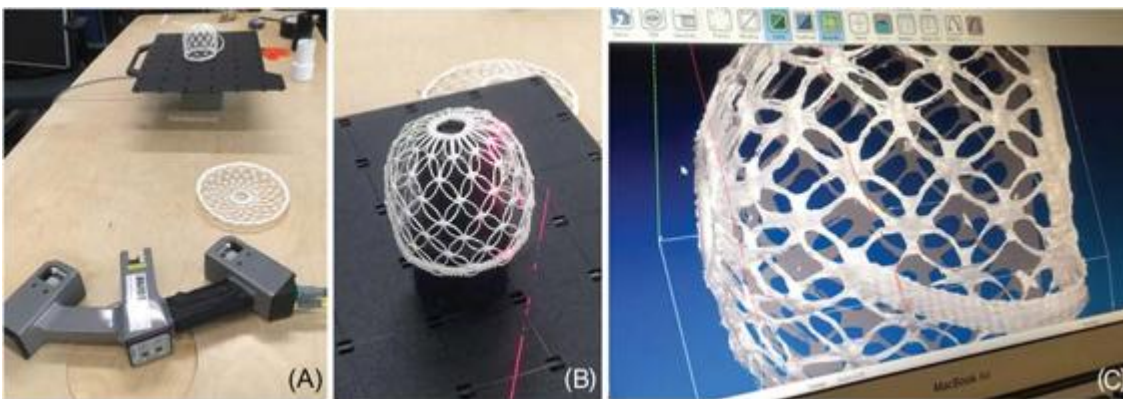
definition 3D laser scanner required the moving hand and eye coordination to

capture the rows and columns of knots ([Fig. 3.2](#)). Scans of the cup showed a line quality resembling the characteristic of paper string and the intricate handcraft.

Nonetheless, the files of the scans were too large to further process effectively in

CAD, causing computer crashes. This revealed that the properties and characteristics

of the handcrafted object were beyond the capacity of this digital tool.



3.4 Material engagement in digital fabrication

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FIGURE 3.2

(A) Polhemus Scorpion handheld 3D laser scanner, (B) the scanning process, and (C) the 3D scan file.

Freehand drawing on a photograph of the analog artifact with a stylus on a tablet

was the next approach adopted to produce a simplified model with manageable

amount of data. This approach followed [Campbell's \(2016, p. xxi\)](#) idea of abstraction to simplify the degrees of complexity in working with digital tools. Handling a

digital tool to interact with the CAD program resonates with [Clark & Chalmers's](#)

[\(1998\)](#) Extended Mind thesis, which considers the mind not necessarily residing in the brain or physical body but having a capacity to extend itself to elements of the

environment. In this case, the author's mind extended to the virtual software and

her hand to the digital tool to construct a CAD model of a three-dimensional array

of one section of knots that resembled the original hand-knotted cup ([Fig. 3.3](#)).

The work, to this point, was a record of materials experience according to ana-

log parameters (i.e., things that string does well such as self-friction, knot, and

bend) translated into a prescriptive CAD language according to the digital

parameters of the software. Several hours were invested in the development of

the 3D model and the navigation of the software's restrictions to achieve a

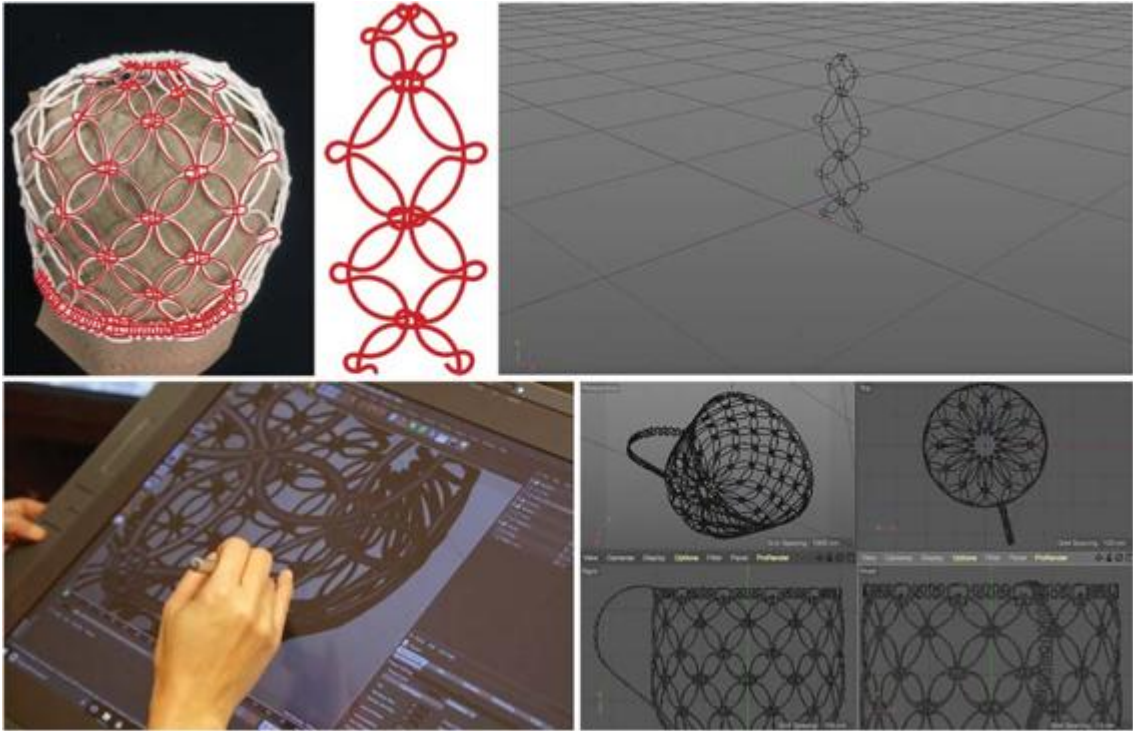
model suitable for output. During this process, most of the author's experience

was gained through the visual and the handling of digital tools but not so much through the tactile qualities of physical material. By engaging with the digital tools in the flow of this situated exploration, agency emerged here in the relational negotiation between the author's hand handling a tool and the visual on the tablet or the laser beam visible on the hand-knotted cup.

3.4

Material engagement in digital fabrication

With the author's little previous experience with digital fabrication, it was crucial for her to first gain a better understanding of the capacity of 3D-printing



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Experiential craft: knowing through analog and digital materials experience

FIGURE 3.3

The process of 3D modeling of the knotted cup.

technology in relation to the delicate cup form. The most common process of material extrusion was adopted, using a Fused Deposition Modeling printer and polylactic acid (PLA) thermoplastic made from renewable resources (e.g., corn starch) and thus biodegradable.

To understand the limits and possibilities of the selected process, details of the CAD model were set as small as 0.4 mm and used only partial support material. The printer could print the whole model, but the physical print was too fragile to retain the cup form ([Fig. 3.4](#)).

In search for the thickness suitable for the capacity of the machine while preserv-

ing the characteristics of knots, likeness of strings, and fidelity of hand-knotting,

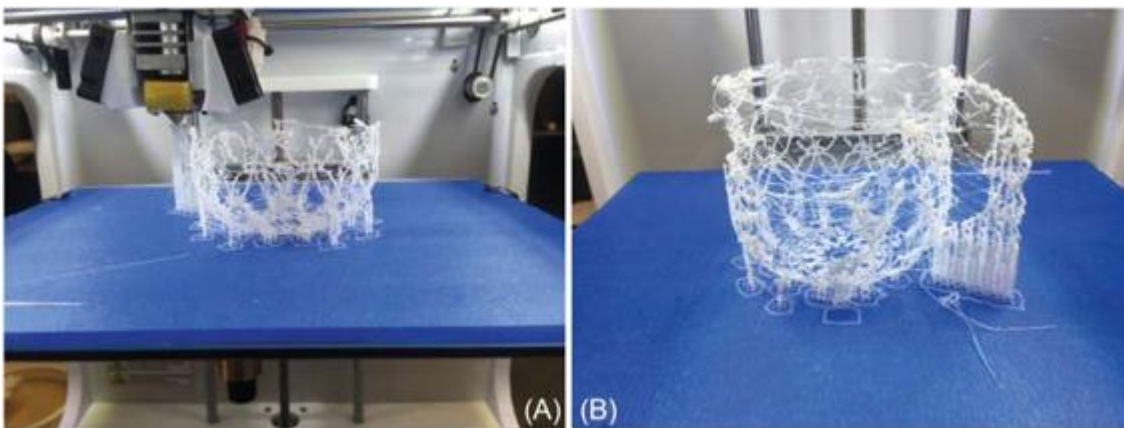
the CAD model's thickness was increased to 0.8, 0.95, and 1.2 mm and test printed, respectively. “[B]y making something happen more than once, we have

an object to ponder; variations in that conjuring act permit exploration of same-

ness and difference; practicing becomes a narrative rather than mere digital repeti-

tion” ([Sennett, 2008](#), p. 160). The comparison of the resulting prints showed that the 0.95-mm print was the most successful rendering and would be used for

further 3D printing using wood (approx. 30% wood fibers, 70% PLA) and



3.4 Material engagement in digital fabrication

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FIGURE 3.4

(A) The first 3D printing to test the limits and possibilities of the printer and (B) the resulting print.

copper (approx. 30% copper, 70% PLA) composite filaments, in addition to the

standard PLA. Printing the 3D model of the cup using various composite fila-

ments was expected to allow for a detailed comparison of the printed outcomes

and a consideration of how intrinsic material characteristics might influence the

form and meaning originated in the mediated artifact.

In the printing process, characteristics of natural components of wood and copper composites such as smell and texture were sensorially recognizable. To

explore each composite's properties, several iterations of parameter settings were made in the printer's software. The printer's settings such as temperature,

speed, density, and angle of support material were modified in order to find a solution to print each material successfully. As machines "demand a uniformity and standardization of material, not only in size but in density and consistency" in order to work efficiently ([Risatti, 2007](#), p. 197), these composite materials are in a standard form and size compatible with the 3D printers.

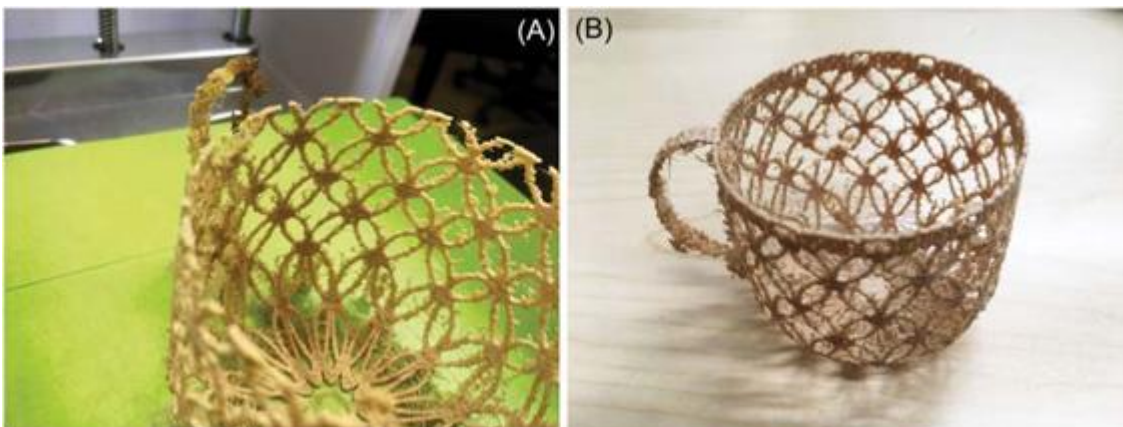
However, as the composites are partly made from natural components such as

wood and copper, irregularities occurred and caused problems to the performance of the printer. To overcome the problems, further modification of the CAD model itself was required when no successful results were attained after

the adjustment of parameters in the printer's software. For example, to solve the repeated clogging of the extruder nozzle caused by the wood composite's

fibrous and burnable properties, the speed for printing was gradually increased

and the temperature was decreased (from 220C to 210C) to achieve a better flow of filament. Despite the revised parameter settings, the resulting prints were still missing parts, hence calling for simplifying the model's geometry (Fig. 3.5). Although the author adopted neither the materialness concept nor the MDD method as such, she conducted these iterations of modeling and parameter setting by placing an emphasis on each material as to how its



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FIGURE 3.5

Printing of wood composite. (A) An incomplete print due to the clogging of the extruder nozzle and (B) a print with missing parts.

properties influenced the printing process. Again, this was a situated activity in

which the maker negotiated with the material and the tools—a relational dia-

lectic situation through which the agency of the material and the agency of the maker were enacted. The notion of agency here focused on the emerging prop-

erties of the materials and how they actively contributed to the way the design

activity progressed; it was not a fixed property instilled in the artifact but enacted in the relationship between people and artifacts. Materials became actors instead of insignificant artifacts to be acted upon.

After several iterations of parameter settings, CAD geometry, and printing, the

outcomes achieved a satisfying material conformity. Having observed the printed cups, the author noticed that each composite performed distinct material traits. The wood cup had a fibrous effect resembling the growth of roots and

was much lighter than the ones printed using copper and PLA. The printed cups

had their own characteristics as expressed by the material used and their appear-

ance comparable to the original cup ([Fig. 3.6](#)). The composite filaments that looked similar to one another prior to extrusion could result in the artifacts

with detailed features unique to the materials. Their true characteristics became

recognizable once they were passed through a heated extruder nozzle, layer by

layer according to the programmed models of the same cup form.

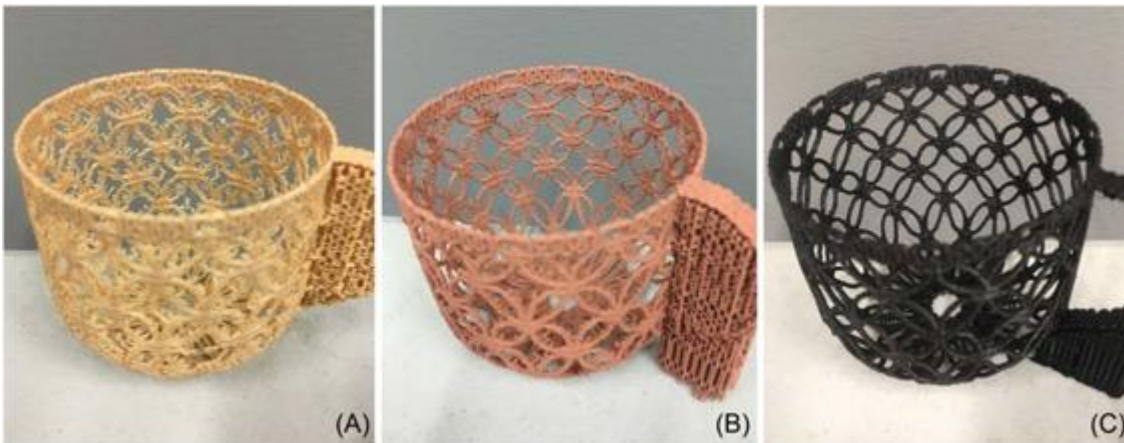
This material exploration has illustrated that the production of digitally produced artifacts still requires the maker's decisions ([McCullough, 1996](#)) as well as her judgment, care, and skill ([Pye, 1968](#)) similar to the production of handcrafted artifacts. This was due to the digital technologies being not as precise

and certain as assumed. What was key here is craft as “knowledge that empow-

ers a maker to take charge of technology” ([Dorner, 1997](#), p. 140).

Technology did not merely fulfill the author's creative intention of translating a handcrafted

artifact into a digital format. Instead, her engagement with digital fabrication



3.5 Gestural crafting in virtual reality

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FIGURE 3.6

(A) Wood print, (B) copper print, and (C) PLA print.

tools and materials in the creative action enabled technology and human to

inform each other. The material (i.e., a type of filament), the tools (i.e., CAD program; 3D printer and its software), and the maker were related in a material engagement situation (i.e., 3D modeling and printing).

3.5

Gestural crafting in virtual reality

Although the 3D-printed cups showed well the likeness of the original hand-knotted cup, the author felt that they missed the physical characteristics of knots, for example, continuity, flexibility, and bendability, or things that string does well. To represent the nature of knots, the next experimentation aimed to create a CAD model of flexible, loose knots. The same tools and methods—drawing with a stylus on a tablet—were employed to create a section of knot pattern for further 3D modeling. Notwithstanding the author's thirteen-year experience of hand-knotting three-dimensional artifacts, knotting virtually on a

2D screen was incomprehensible for her. She found that working on a 2D screen to create a 3D model did not amply illustrate or open up access to the positions and the interlinking of strands that construct knots. CAD is considered

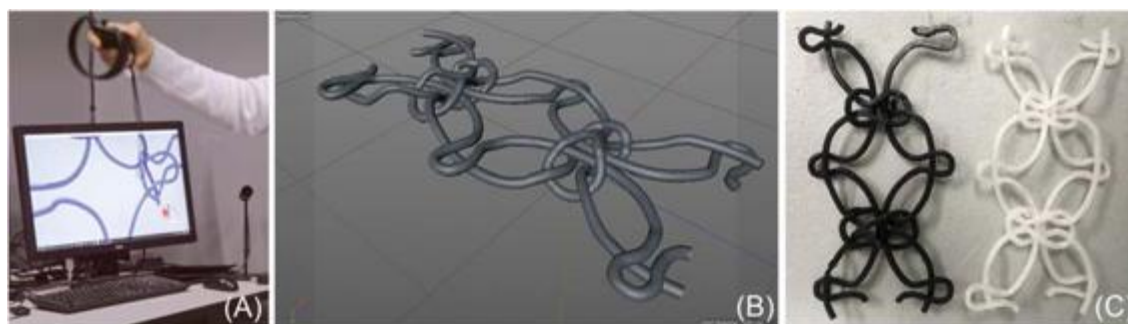
a disembodied or hands-off practice because it disconnects simulation and real-

ity and ignores relational understanding (Sennett, 2008, pp. 42-43). To overcome the shortcoming of virtual knotting, bodily engagement in the process of

drawing and/or 3D modeling would be helpful. One available tool in the Mixed Reality Lab was a VR station. The author's hands holding VR controllers

to draw in a three-dimensional VR space a scaled-up knot structure imitated a

gestural manner to real-world hand-knotting of string. Drawing in VR evoked her hands-on experience and relational understanding of positions of strands in



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Experiential craft: knowing through analog and digital materials experience

FIGURE 3.7

(A) Crafting the knot structure in VR, (B) a CAD model of a section of flexible knots, and (C) a print with missing parts and a complete print.

three-dimensional space that she had possessed while hand-knotting. The new

experience in gestural crafting in VR augmented the author's understanding of the positions of strands of knots and assisted her in finding a solution for making a CAD model of a section of knots ([Fig. 3.7](#)). Working with software is not always a disembodied practice as Sennett argues, as demonstrated by the author's experience of gestural crafting in VR.

Using the 3D model in [Fig. 3.7B](#) for 3D printing posed a challenge—the printing nozzle irritated an earlier printed area with a steep angle, causing it to shift from its original position on the support material and resulting in the detachment of the next printed layer. Upon the removal of the support material, initial prints came apart or had a fractured and uneven surface if they stayed intact. It was hypothesized that the printing problem might arise from two factors: the machine and the parameter settings on the printer's software. To test the hypotheses, first, the same 3D model was printed on different machines. The results improved, yet cracked surfaces still occurred. Then, the slicing parameters were set to produce a full grid of support material. A new print was successful, but the support material was too dense to remove. The testing proved that while the machine to some extent affected the printing process, the setting of printing parameters was a more vital factor. The support material was set to spread throughout, strong but reasonably easy to remove. After that, this approach was used to model and print multi-sectional loose knots which yielded satisfying results ([Fig. 3.8](#)).

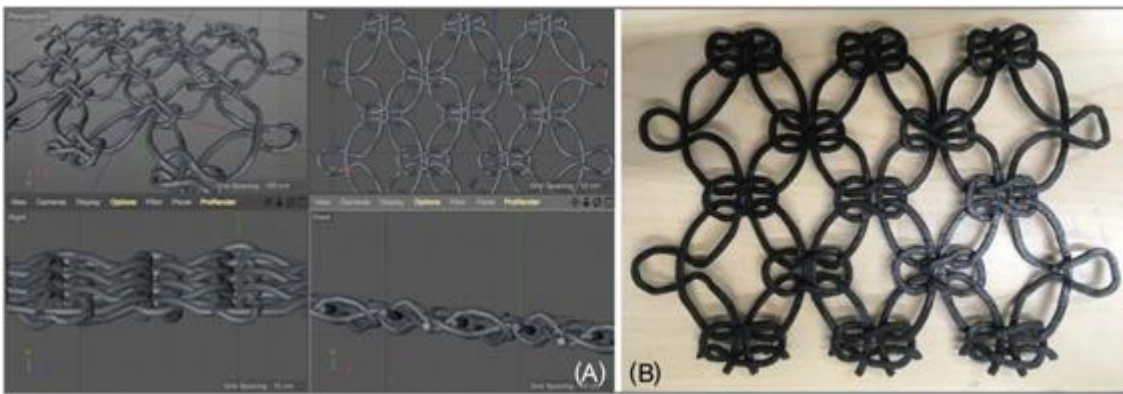
3.6

Translational craft: when digital meets analog

materials experience

The Digital Fabrication Lab obtained powder- and binder-based printing tech-

nology for mold making for use with castable materials, such as metal, glass,



3.6 Translational craft: when digital meets analog materials experience

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FIGURE 3.8

(A) A CAD model and (B) a print of multisectional loose knots.

and clay slip. The lab custom-made a material recipe workable with the Zcorp

310+ printer by combining three constituents of Hydroperm (i.e., gypsum-based plaster), calcium carbonate, and maltodextrin (i.e., a fine-grained sugar

used in the brewing industry) ([Robbins et al., 2014](#), pp. 134 135). While the combination of Hydroperm and calcium carbonate produces good

spreadability and relatively high resolution, maltodextrin diffusing through the com-

bined powder creates strong [“green strength” \(n.d.\)](#), that is, mechanical strength to withstand mechanical operations.

At first, the author could not relate her practice with this 3D-printing technology. However, after the accumulation of her digital craft skills the author real-

ized an opportunity offered by this 3D-printing method for giving function to the cup. The author’s newly acquired skills were combined with her knowledge

of mold making for prototyping and traditional ceramics obtained during her Bachelor degree in Industrial Design to create a CAD model of a two-piece mold for slip-casting a cup with a relief surface of the knot pattern ([Fig. 3.9](#)).

Based on the 3D model of the knotted cup used previously for

3D printing using PLA filament ([Fig. 3.3](#)), the 3D modeling process began with the creation of positive form of the cup and then a 1-in.-thick mold around it.

After being printed and removed from the printer, the mold was depowdered with compressed air, misted with water to increase plasticity, and when

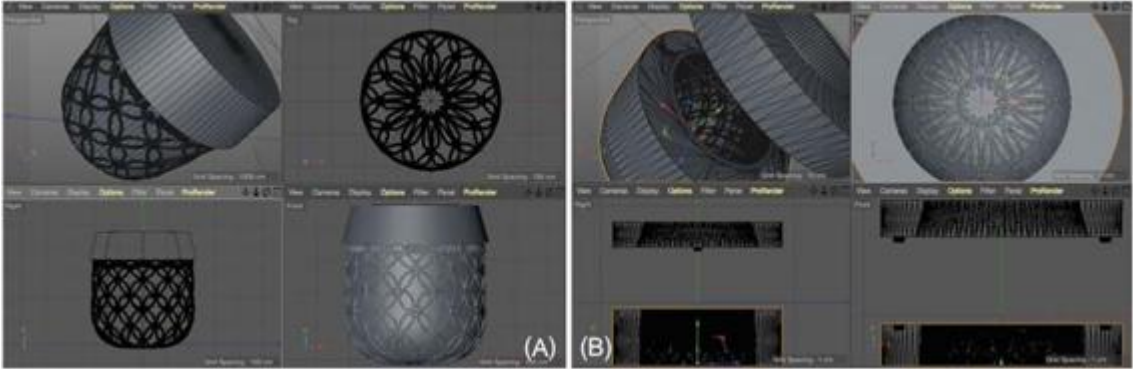
completely dry clay slip was cast in ([Fig. 3.10](#)). Due to the properties of the gypsum-based material of the 3D-printed mold, the principles of traditional slip-casting clay in a plaster mold could not be followed. For example, the material’s

higher density required significantly longer time for the cast piece to set, and its

brittleness did not allow for the tying of the two-piece mold together, thus turning

the mold upside down to drain the excessive slip according to the common prac-

tice was impractical. The meeting between the mold made of a nontraditional



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Experiential craft: knowing through analog and digital materials experience

FIGURE 3.9

(A) A CAD model of positive form of the cup which is used to make (B) a CAD model of a 1-in.-thick mold.

FIGURE 3.10

The mold is removed from the printer and the process of using it for slip-casting.



3.7 Discussion: knowing through analog and digital materials experience

FIGURE 3.11

(A) A cast cup before firing; (B) fired and glazed cast cups, the left being fully glazed inside and partially glazed outside while the right being fully glazed inside and unglazed outside.

material and clay slip which is a traditional material illustrated the agency of a

design material as an emergent relationship independent from its fundamental physical qualities. In other words, the relationship between the properties of clay

slip and those of the mold's material emerged, manifesting the way they should

be used in the casting process in which the clay was continuously shaping and

negotiating its ongoing dialog with the mold and the maker. The affordances of

the clay slip suggested that it can be cast but it is the agency of the slip or the emergent relationship the slip had with the mold that informed the maker how

to deal with this situated casting process in which her knowledge in traditional

ceramics needed to be adjusted.

The resulting cast cup revealed an inimitable texture that was the imprint of layers of the powder material, demonstrating the printing process of the mold ([Fig. 3.11](#)).

3.7

Discussion: knowing through analog and digital materials experience

Analog and digital materials experience is interconnectedly exercised in the craft

practice presented in this chapter. The practice involves action, doing things that

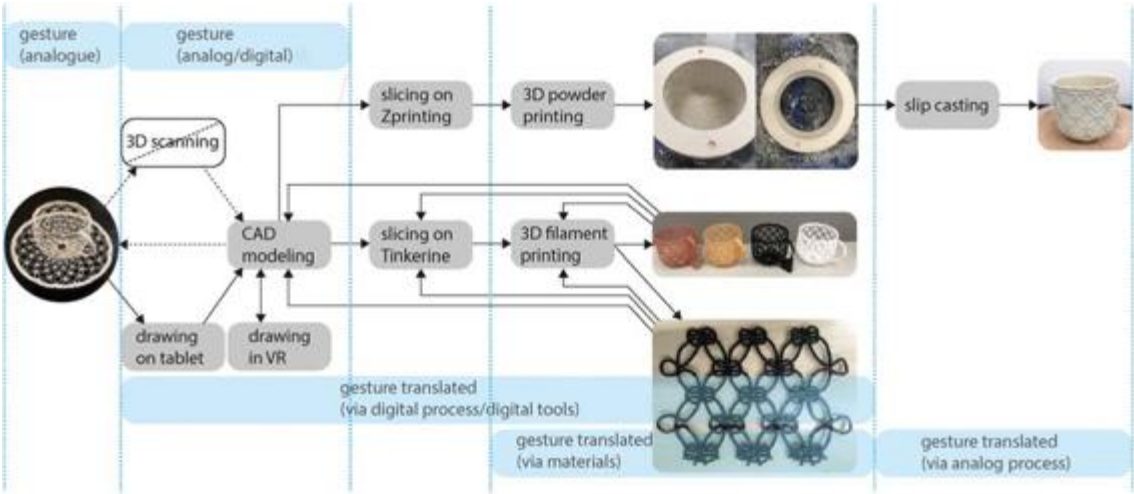
are consequential, or what [Pickering.\(2010\)](#) calls “performance” or “what agents do, whether human and non-human” (p. 195). Action here is agency, emergent

in and unknowable prior to a continuous ongoing performance between humans

and nonhumans in a specific context, or in this case, handcrafting through digital

means in a lab environment. When the author observed her sense of agency in the real-world experience of working with analog and digital materials in proxim-

ity, she felt that she was in a creative collaboration with the materials and tools



CHAPTER 3 :

Experiential craft: knowing through analog and digital materials experience

FIGURE 3.12

Work flow of analog and digital materials experience in translation.

that she used, through her gestures in the flow of the activity ([Fig. 3.12](#)).

Sometimes she acted as a human agent and then became passive when the digital

tool (e.g., 3D printer) and/or materials took over the active role—this series of

actions went back and forth, and eventually an artifact materialized. Without

adopting the materialness or the MDD approaches as such, when dealing with a

physical material, such as composite filament, the author's knowledge about these

approaches naturally influenced her to let the material take the lead and observed

its interaction with the printing process in order to decide on the next experiment.

Although the materials and tools have their specific properties and capabilities,

their agency or action in a material engagement situation like this craft practice is

not fixed but emerges in spatiotemporal relations when the material, the maker,

and the tool are interacting and negotiating ([Malafouris, 2008](#)), or in a “dance of agency” in [Pickering's \(2010\)](#) term. Materials can thus be understood not as having different states that change according to human action but as performing

agents that consequently change the situation. This continuous negotiation between the agents in a situated activity is similar to the notion of “reflective practice” ([Schön, 1983](#)), whereby the practitioner reflects on what has happened due to her action, by constantly asking herself where, how, and why it has happened.

In this situation, the practitioner can learn from the real-life practice and, with the lesson learned, improve her subsequent practice.

The agency’s aspect of unknowability in advance of performance can be looked at

from [Pye’s \(1968\)](#) “workmanship of risk” (pp. 20–24) or [Risatti’s \(2007\)](#),

3.7 Discussion: knowing through analog and digital materials experience 49

“craftsmanship” (p. 165) that encompasses an uncertain enterprise incorporating

material experiment, skillfulness, complexity, and intimacy over time, the results

of which is unforeseen. Direct experience with materials, whether physical or digital,

can therefore be considered phenomenological investigation. Craftsmanship

involves the dialogical/dialectical process that springs from “the formalization of

both idea-concept and form-concept in the hand as material is actually being worked via technique” ([Risatti, 2007](#), p. 184). Design, in general, may not involve such a process because the conceptualization stage may be separated from the

making stage.

While working in dematerialized settings such as drawing on a Wacom tablet or

in the VR space using a goggle and controllers, the author felt the need to inter-

twine overtly with gesture, the body, and materiality. The esthetic value of the

hand was not lost but rather dispersed into a different form. Moving the hand to draw on the tablet or moving the whole body to draw in VR was the act of sense making and that was how the author learned to understand the knot's construction virtually. In this activity, the maker's mind extended itself to the elements of a digital environment experienced through her body.

[W]e learn our bodies by moving and in moving both create and constitute our movement as a spatiotemporal dynamic. . . . [T]hat movement is the originating ground of our sense-makings . . . [that] we constitute space and time originally in our kinesthetic consciousness of movement. Flux, flow, a streaming present, a stream of thought, consciousness, or subjective life, a style of change—all such descriptive terms are in both a temporal and spatial sense rooted in originary self-movement: they are all primordially present not in the constitution of objects but in our original spontaneity of self-movement, in our original experience and sense of our dynamically

moving bodies. ([Sheets-Johnstone, 2011](#), p. 139)

Translation of material and form through the interactive use of analog and digital tools affords new opportunities by means of gestural action and tacit knowledge ([Polanyi, 1962](#)). The new experience with the digital tools can be combined with the previously acquired craft knowledge embodied in the maker. The flow in the material translation suggests the emergent material practice, in which an embodied understanding of meaning of the practice is gained by being close to the constantly changing material. Here, meaning is not “the product of representation but the product of a ‘conceptual integration’ between material conceptual domains” ([Malafouris, 2013](#), p. 90). The use of new tools and materials offers new outcomes and new meanings created through the maker’s interaction with materials and tools not only in space but also over time.

Shifting to a more immersive digital tool such as VR to give form and structure

of knots, the author was able to repossess her embodied experience of

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Experiential craft: knowing through analog and digital materials experience knotting string and create three-dimensional vector-line structures, even though the physical material was absent in the VR space. The embodied know-

ing in material practice was translated directly to her facility for virtual knotting. Embodied knowledge, according to [Merleau-Ponty \(1962\)](#), is “knowledge in the hands, which is forthcoming only when bodily effort is made, and cannot be formulated in detachment from that effort” (p. 166). Bodily sensorimo-

tor experiences play a fundamental role in the structure of our thinking

([Malafouris, 2013](#), p. 67). Embodied knowledge is sensory and grounded in bodily experience, situating “intellectual and theoretical insights within the realm of the material world” ([Ellingson, 2008](#), pp. 244 245). It is a way of knowing where the mind is inseparable from the body ([Lakoff & Johnson, 1999](#)) to gain insights into materials experience.

Craft knowledge can be derived from “intensive and extensive experience . . .

[that] includes the whole body sensitivity” ([Hardy, 2004](#), p. 181). Through experience, the craftspeople can identify different materials by using her senses and can

tell how a certain material will behave according to her manipulation or interaction with it.

“Craftsperson, medium, [and] tools . . . are of one unified gesture of

creativity; their boundedness is less metaphysical than physical” ([Hardy, 2004](#), p.

181). What craftspeople make is “a record of what went on in the studio between

maker and materials. Every mark left on an object is a record of a decision made

and action taken by the hand that formed it. . . . [T]he object represents a subtle

reenactment of maker with material” ([Fariello, 2004](#), p. 151). In the case presented in this chapter, the 3D-printed artifacts with their distinctive marks of miss-

ing details are physical objects that document not only the digital process and

material agency but also the author’s decision and action made in the manipula-

tion of the parameter settings of the 3D printer that in turn leave marks on the

resulting prints. The author works inductively and integrates material and experi-

ential sensibility into the design process. In so doing, the discovery and generation

of new problems can be part of problem-solving processes in prototyping com-

monly known in design processes. The inductive process has resulted in not only

the achievement of objects but also a new way of thinking. The craft practice pre-

sented in this chapter is an example of how a craft practitioner-researcher attempts

to discover ways of translating handcrafted artifacts into a new form of craft using

digital tools. The outcomes show how knowledge is gained through the experi-

ence of working in dialog with the analog and digital means and how the inter-

twined analog and digital materials experience emerges.

Acknowledgments

The author is grateful to the Material Matters Research Center, Emily Carr University of Art 1

Design, and faculty members there, including Aaron Oussoren, H el ene Day Fraser, Keith Doyle, Logan Mohr, Sean Arden, and Julie York.

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CHAPTER 4

Digital crafting: a new frontier for material design

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Digital machines and productive technologies in general allow for the production of an industrial continuum. From the mold we move toward modulation. We no longer apply a preset form on inert matter, but layout the parameters of a surface of variable curvature. A milling machine that is commanded numerically does not regulate itself according to the build of the machine; it rather describes the variable curvature of a surface of possibility. The image-machine organization is reversed: the design of the object is no longer subordinated to mechanical geometry; it is the machine that is directly integrated into the technology of a synthesized image.

Bernard Cache, *Earth moves: The furnishing of territories* ([1995](#)).

4.1

Introduction

The term “Digital Crafting” has its origins in architecture and describes the regained

capacity of the architect, empowered through novel design and manufacturing methods, to have a direct and personal impact on craftsmanship or even more so

to become self-active in artisanal processes. Just as in the early days of architecture, when the master builder was still involved in all areas of building—from initial

planning and ideation until its physical completion—these new technologies allow

a return to the exploration and testing of experimental design methods and the direct exchange with a multitude of different materials. Designing for and through

digital production techniques thus shifts the focus from formal design representa-

tions toward the physically realized. As such, material and tectonic thinking are

reintroduced as the very base and starting point of the design approach. Due to

this shift of focus a new type of design becomes possible with a formerly unknown

degree of complexity—both on a formal and on a functional level ([Sachs, 2012](#)).

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The French architect and theorist Bernard Cache, an early adopter of what he calls Computer-Assisted Conception and Fabrication systems, imagines that such thinking, where objects are not any more drawn but calculated, will enable the creation of highly complex forms that would be difficult or impossible to draw in a conventional way. Equally interesting he proclaims that such systems will incept a “nonstandard mode of production” where items from the same series can vary in size and shape by simply altering certain fabrication parameters. Since thus neither an object’s function nor its materiality is linked to a defined form but can vary constantly, the digital representation “takes precedence over the object” ([Cache et al., 1995](#), p. 97).

The core representation of an object is therefore not any longer its image but a model of simulation, an instance of numerical manipulation.

Digital crafting, therefore, refers to much more than just the use of digital technol-

ologies to produce objects. It is not only about the enhancement of the craftsman's

range of tools through devices such as Computer numerical control (CNC) milling

machines, three-dimensional (3D) printers, or laser cutters, but rather about the

unprecedented possibilities that these technologies reveal. For the laser cutter, it

makes no difference whether the shape being cut is a rectangle or a high-detail

fractal, as long as the required data are provided. The CNC milling machine does

not care if each of the objects it produces is unique or if it has to "work" overtime.

The 3D printer offers a 3D void of theoretically unlimited geometric opportunities.

For the designer, however, this new freedom means not only becoming aware of

each of these possibilities and likewise limitations, but above all understanding

and using them adequately.

But what does adequate mean when there are almost no restrictions? In

order to figure out what these processes and machines are best suited for,

one should perhaps follow the approach of Louis Kahn and very carefully try

to identify what our tools and materials really want.

You say to a brick, 'What do you want, brick?' And brick says to you, 'I like an

arch.' And you say to brick, 'Look, I want one, too, but arches are expensive and

I can use a concrete lintel.' And then you say: 'What do you think of that, brick?'

Brick says: 'I like an arch.' ([Kahn & Twombly, 2003](#), p. 270)

To understand what a 3D printer's printing process and material thus are best suited for and hence discover the true potential but also limitations of digital crafting, designers and architects alike must acquire new skills that go beyond

what is presently being taught and practiced with conventional methods. Digital

crafting therefore not only describes physical results but even more so a concept,

an idea, or a method, which—driven by current digital design and production techniques—implies a new way of dealing with, and a seamless connection of,

form, construction and materiality. It is not so much a matter of the classical design of products and their manufacture by means of computer-controlled

4.2 A brief history of digital design and fabrication

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machines, but rather of acquiring practical and theoretical skills in dealing with

digital processes for generating form and function.

To better comprehend the larger meaning of this concept it might help to have a

brief look at the history and evolution of digital design and manufacture.

4.2

A brief history of digital design and fabrication

The beginnings of numerical control (NC) are generally credited to John T.

Parsons, who in 1949 was asked by the US Air Force to develop a cost-effective,

automated method for the production of helicopter rotor blades. Parsons

teamed up with the Servomechanisms Laboratory at the Massachusetts Institute

of Technology, who back then was on the global lead of mechanical computing

and feedback systems, and together they created the computer-controlled “Card-

a-Matic Milling Machine” for three-axis contour milling. Even though the device

was relatively difficult to set up and only able to perform a small number of

operations it marked a revolution in automated manufacture. The invention

reduced labor, downtime, and waste material while increasing productivity, pre-

cision, and versatility through one single tool ([Caneparo, 2016](#)).

During the 1960s computing became more publicly recognized and a new gen-

eration of cyberneticists began wondering about design and its parallels to

cybernetic systems ([Spiller, 2009](#)). In 1963 Ivan Sutherland published Sketchpad, a pioneering effort in human-computer interaction, often credited as

the very first computer-aided design (CAD) tool. Sutherland himself described

Sketchpad as a system that, “by eliminating statements (except for legends) in favor of line drawings, opens up a new area of man-machine communication,”

which in the past “has been slowed down by the need to reduce all communica-

tion to written statements that can be typed.” Sutherland saw the benefits of his

innovation especially in the making of drawings where motion, analysis, high accuracy, or repetition was crucial, yet he conceded that “it is only worthwhile

to make drawings on the computer if you get something more out of the drawing than just a drawing” ([Sutherland, 1998](#), p. 17, 99, 110).

Graphical CAD tools were further enhanced in the 1970s and became accessible to

designers and architects. At the same time NC systems were improved and

computer-aided manufacturing (CAM) was developed. Its direct link to CAD

helped, in that it was rapidly accepted by various industries for the creation of com-

plex products such as ships or automobiles. While in the beginning the technology

was only practical for projects with large volumes developed by sizeable companies,

the continuous increase in computing power and the reduction in costs ultimately

led to the propagation of CAD/CAM and CNC in the fields of industrial design

(Computer-Aided Industrial Design) and manufacturing ([Corser, 2012](#)).

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In parallel, additive manufacturing, also known as 3D printing, appeared on

the market in the 1980s and quickly evolved through numerous companies

that invested in its development ([Gershenfeld, 2012](#)). Around the same time, industrial robots gained momentum due to their great versatility. Since the

“end-effectors, attached and controlled by these arms, are as diverse as the

materials they can process,” much of today’s research into digital fabrication

still focuses on the use of robotic arms ([Beorkrem, 2013](#)).

Neil Gershenfeld, head of MIT’s Center for Bits and Atoms, claims that continu-

ous evolution of these fabrication technologies will inevitably result in a “new

digital revolution,” empowering people “to design and produce tangible objects

on demand, wherever and whenever they need them.” Encouraged by the global

success and rapid growth of Fab Labs, he believes that the true power of such

technologies “is not technical; it is social,” enabled through their largely unregu-

lated but well-connected nature. Gershenfeld proposes that the ultimate capabili-

ties of what he refers to as “assemblers”—the future offspring of 3D printers—will

be “to create complete functional systems in a single process” without any waste

or left-overs ([Gershenfeld, 2012](#)).

4.3

The digital continuum

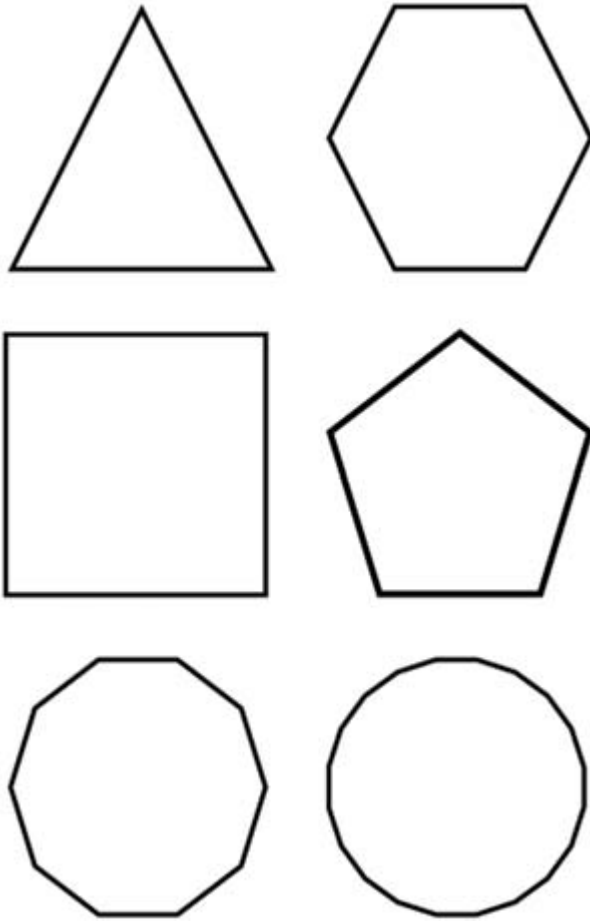
Today, digital design and fabrication technologies have arrived at almost every design and architecture school and many creative companies have established their own computation units and in-house fabrication and prototyping facilities. To eventually reach what Branko Kolarevic, Dean of the College of Architecture and Design at New Jersey Institute of Technology,

calls “a digital continuum from design to production” ([Kolarevic, 2003](#), p. 7) the focus in education should be on learning methods of digital form genesis, such as the examination of parametric processes, which no longer

describe a shape in concrete terms, but define it through the correlation of variables, parameters, and explicit rules. A parametrically designed object is not limited to a certain manifestation, but rather acts within a dynamic space of action and can be realized in any form between previously defined boundaries ([Böhm, 2001](#)).

For example, the following program, written in the Java-based programming language Processing, draws a regular polygon defined only by the two variables “radius” and “corners” ([Fig. 4.1](#)):

```
int radius = 10;  
int corners = 3;  
float angle = TWO_PI / corners;  
beginShape();
```



4.3 The digital continuum

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FIGURE 4.1

Different polygons created from a single basic algorithm.

```
for (float a = 0; a < TWO_PI; a += angle) {  
    float sx = width/2 + cos(a) * radius;  
    float sy = height / 2 + sin(a) * radius;  
    vertex (sx, sy);  
}
```

```
endShape(CLOSE);
```

Simply by changing the value of the two variables, any polygon can be drawn with any radius and any number of corners. Although this is a relatively banal example, it illustrates the difference to the classic use of CAD sys-

tems, which are merely a kind of electronic drawing board.

This approach becomes even more interesting when the computer no longer exclusively executes what is imagined (or programmed) by a human designer but gets integrated into the design process in a “creative” way. This technique, often defined as “generative” or “procedural” drawing or design, not only enables the creation of geometries and shapes with increased complexity and detail, but above all produces results that are not any longer directly predictable and controllable. For example, using a script similar to the

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previous, one can now generate an infinite variety of similar but yet unique forms ([Fig. 4.2](#)):

```
float[] x 5 new float[4];
```

```
float[] y 5 new float[4];
```

```
for (int a 5 0; a , 4; a11) {
```



```
x[a] 1 5 random(220, 20);  
y[a] 1 5 random(-20, 20);  
}  
beginShape();  
curveVertex(x[3] 1 width/2, y[3] 1 height/2);  
for (int a 5 0; a , 4; a11) {  
  curveVertex(x[a] 1 width/2, y[a] 1 height/2);  
}  
curveVertex(x[0] 1 width/2, y[0] 1 height/2);  
curveVertex(x[1] 1 width/2, y[1] 1 height/2);  
endShape();
```

One of the many advantages of this type of design approach is that by automatically generating endless variations, the designer's focus can shift away from manual drawing to other, possibly more exciting or important aspects of the design. The transfer of abstract thought constructs into drawn geometry gives way to an active selection process based on certain preferences. The

result, which is only vaguely known at the beginning, is only discovered and continuously developed as the process progresses. The result-oriented design thus becomes the process-oriented design.

Individual production

Another innovation resulting from parametric design concepts and digital fabrication methods is the so-called “Mass Customization.” Mass customization

describes the idea of adapting serially manufactured products to individual customer requirements without increasing costs or manufacturing effort. The pioneer

of digital production processes, Prof. Emeritus Yoram Koren, goes even one step

further when describing the factory of the future as a production facility that is

directly connected to the customer, producing individually tailored products. In

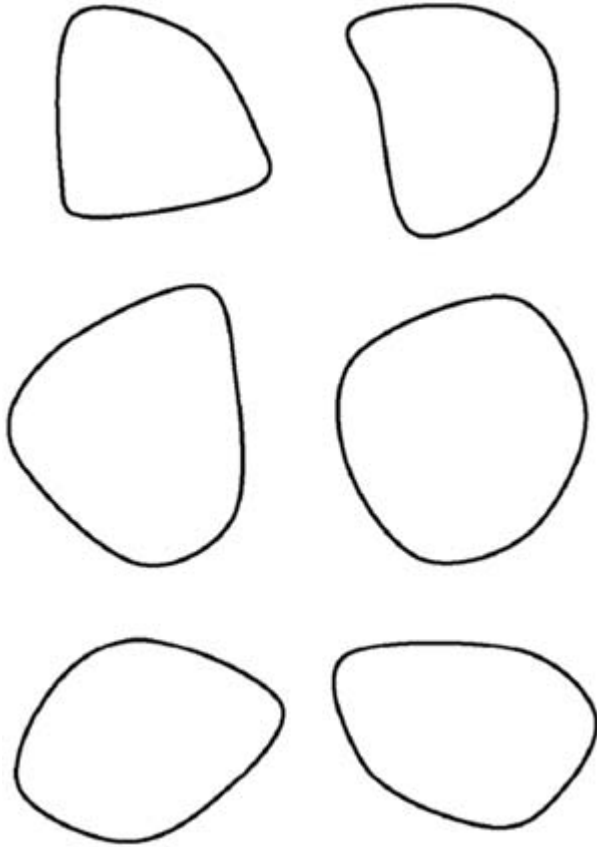
order to make this possible, current manufacturing procedures must be adapted

from mass to individual production and interface tools need to be developed that

allow the layperson to enter into a direct exchange with the manufacturing company ([Clifton, 2018](#)). Although the ideas of mass customization and individual

individual

individual



4.5 Toward a new esthetics

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FIGURE 4.2

Multiple organic forms created from a single simple script.

production have existed since the early 1990s, they to date have not been really

implemented, or at least only to a very limited extent ([Modrak, 2017](#)). The reasons for this are insufficiently mature digital technologies that cannot yet compete

with the established manufacturing cycles, industrial infrastructures that favor

existing systems over novel, more experimental approaches, and finally a lack of

understanding within the creative community for the potentials of such approaches and a lack of educational methods for their transfer.

However, this could soon change fundamentally. In his book “Makers: The New

Industrial Revolution,” Chris Anderson, former editor-in-chief of the magazine

“Wired,” describes the productive efficiency of the digital world and its impact on society. Anderson argues that with the advent of consumer-oriented digital

fabrication tools such as desktop 3D printers, as well as instant access to cloud-

based manufacturing facilities, information that was previously largely confined

to a “digital existence” is now finding its way back into the physical world. For

him, this transformation of bits into atoms is the logical development from

mass production to mass customization and thus represents the “third industrial

revolution” ([Anderson, 2014](#), p. 17).

4.5

Toward a new esthetics

This change is also noticeable in a new kind of esthetic formalization that goes hand in hand with digital processes. Things that were previously

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undrawable and perhaps even unimaginable can now not only be visualized, but also materialized instantaneously anywhere and anytime using 3D printing processes. Even if—in terms of large-volume production—the fabrication

costs of these products cannot yet fully compete with more traditional methods, a clear tendency becomes noticeable that explicitly distances itself from the minimalism and reductionism of the previous century. Intricacy, detail, and ornament return.

It remains exciting to see how the role of the designer will change and develop.

While in architecture, styles have often alternated with sometimes more and sometimes less ornamental decoration, the history of design is much younger

([Kretzer, 2017](#), p. 46). Design has its roots in the modern forms of mass production. Although Greek coins or Roman amphorae were already produced in

large quantities, it was basically craftsmen who were responsible for both their

design and their manufacture. It was only with the industrialization and mecha-

nization of production methods during the 18th century that this tradition was

broken, and the role of the designer was created. Designers were given the task

of creating practicable solutions for industrial production processes that required

considerable investment but could produce large quantities of identical objects

at a low cost. Detail, individuality, and uniqueness gave way to efficiency, sim-

plicity, and functionality.

Digital crafting undermines this ideal of modernity, the concept of identical reproduction for the masses. Because everything that is digital remains variable and changeable and thus stands in stark contrast to the idea of standardization and serial production. The theorist Mario Carpo calls this the first phase of digitalization, which inverts the industrial revolution and thus the necessity of mass manufacture. But Carpo goes even further and argues that now, enabled by artificial intelligence, we will experience a second phase: digitalization on an intellectual level. Since for him the first step means a return to traditional production methods and the reunification of the designer and the craftsman into one and the same person, he now believes that we will also find our way back ideologically, politically, and socially to prescientific, intuitive, even medieval systems and structures ([Sabin & Carpo](#),

[2017](#)).

Although the hope is that—as the term Digital Crafting suggests—the importance of the topic will remain primarily focused on its physical aspects and that an evolution in design and production methods will not be accompanied by social regression, its relevance to the field of design and architecture is undeniable.

To understand these new approaches less as a replacement of existing systems and processes, but rather as a necessary addition, the designer's task will be to navigate within this spectrum of possibilities and select the most

4.6 Digital crafting in educational practice

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appropriate solution according to context, client, and demand. In this context—to mediate the meaning and possibilities of digital crafting—students should be encouraged to focus on the new opportunities that arise from the unification of design and fabrication. This includes the examination of different manufacturing techniques and new technologies, but most of all the experimental study of materials and their confluence with digital methods. The playful exploration of such processes, the growing confidence in their usage, and the autonomous navigation in related communities and networks are essential skills that today's students need to develop.

4.6

Digital crafting in educational practice

The following are a selection of projects, realized as part of an ongoing collaboration with the German car manufacturer AUDI, where digital crafting as a method to design and fabricate form, was used to investigate scenarios of future mobility. The focus was particularly on subjects like autonomous driving and car-sharing platforms, which will increase the need for personal customization and adaptation of the vehicle's interior.

The first project, "Concept Breathe," was realized within 3 months with a group of 10 second and fourth semester Bachelor students from the Braunschweig University of Art in 2017. It aimed at rethinking the image of the classical car seat. The project began with an intense ideation phase, looking particularly into patterns and structures that can be found in nature. The team then studied how these inspirations can be described using computer scripts and algorithms in order to lead to a design language that deviates from conventional forms and to develop a structurally sound, lightweight system to house an array of active components. After computationally designing numerous organic forms, 3D printing was chosen as the most viable method for the 1:1 realization of a prototype mock-up. Supported by BigRep, a Berlin-based producer of large-scale 3D printers, the design was

printed from Pro-HT Plastic, a biodegradable polymer with high-strength properties. In addition to the 3D-printed structure, the seat contained 38 custom-made, active silicon cushions that were incorporated into its surface to dynamically alter its visual and haptic properties. The components were intended to increase the seat's ability to respond to changing driving conditions and particularly to enhance the user's identification with the animate object through motions of breathing. Finally, a number of customized cushions from a high-performance fabric were added in five separate areas to guarantee the necessary comfort and stability ([Fig. 4.3](#)).

Building upon the experience from the first project, a second collaboration took place in 2018, this time at the Dessau Department of Design, Anhalt



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University of Applied Sciences, and with a focus on the middle console. The students worked in groups of four, each developing their own specific scenario and design approach. Requirements, which each group had to address, were functional aspects (e.g., tray or cup holder options), formal expressions (using parametric/generative processes), technological production (applying digital fabrication techniques), sustainability (e.g., materiality and recycling), interaction with and adaptation of the system, and finally embedding the object into a larger narrative context. The project “Alcyon” proposed a bio-inspired center console produced by 3D printing, using a biodegradable filament made from algae. The structure was further planted with reindeer lichen—an organism consisting of algae and fungi, living in symbiosis without the need for human intervention. Lichens were used as bioindicators to demonstrate habitable air quality while the algae provided oxygen through photosynthesis, impacting and improving the indoor climate. The project “Okura” focused on the identification of the driver with the vehicle. While today a driver is an active part of a large system, the shift will be more toward passive scenarios where the user will become a mere passenger. To

compensate for loss of control, alienation, and a lack of security, the connection between driver and machine must be improved. Okura represented an

FIGURE 4.3

Concept Breathe was a 3D-printed car seat, which incorporated active components to dynamically alter its surface to suit varying driving situations.



4.6 Digital crafting in educational practice

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interactive surface, which informed, adapted, and reacted. The dynamic scales

of the surface moved according to behavioral patterns, translating (e)motions into the interior and thus establishing trust in autonomous driving and artificial intelligence. Moreover, the surface could change its color from black to white in response to a change in temperature, which improved the interior climate ([Fig. 4.4](#)).

The most recent collaboration with AUDI, which took place in 2019, was called “Adaptive City Car” and was a joint course between the Dessau

Department of Design and the Dessau Institute of Architecture. Focusing on the future of urban mobility, which is facing tremendous challenges such as increasing traffic, air pollution, and a lack of car-free zones, the goal of the 3-month course was to build a 1:1 model of an autonomous shared car, since most of today's car-sharing alternatives are missing a number of important factors in comparison to owning a private vehicle. The Adaptive City Car

project aimed at radically breaking with current industry standards and offering a hypothetical solution for a more sustainable urban vehicle that would provide better air quality, room for different activities during driving, and most of all the feeling of occupying a personal space. The organic design of the car was based on generative principles that tried to provide an alternative

to the artificial and standardized appearance of ordinary vehicles. In addition to a structure that seemed naturally evolved, certain areas of the shell were designed to encourage the growth of moss and lichen to filter air pollutants entering the car's interior. The asymmetric shape of the vehicle allowed for more internal space but also the integration of large skylights, made from opacity-changing smart glass, that directed the visual focus of passengers from unpleasant traffic situations to the environment. Sensors that responded to the presence of individuals controlled integrated light and

FIGURE 4.4

Left: Alcyon was a 3D-printed center console based on an algorithm that simulates coral growth. The structure was covered with lichen intended to produce oxygen and improve the indoor climate. Right: Okura was a surface made of 1200 dynamic scales that could move and change their color in order to increase the passenger's identification with the vehicle.



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audio feedback, in order to increase the passengers' identification with the self-driving vehicle. The 1:1 model was robotically produced from 92 bespoke components that were hand-coated with up to three layers of polystyrene adhesive, sanded, and then assembled together. Once all units were in place the completed vehicle was painted and the adaptive technologies and organic materials were installed ([Fig. 4.5](#)).

Digital crafting as a design tool and method allows projects such as those described in this chapter to depart from traditional forms and thinking and

instead explore new territories of digital shape genesis, (automated) fabrication, and experimental materiality. Likewise, certain aspects of the design process have lost their importance while others have become more prominent. Especially the creation of drawings, diagrams, and imagery, usually used to communicate the design intent to related fabricators and craftsmen, is being replaced through digital code, readable by the involved machines. However, to reach Kolarevic's digital continuum still many things have to change and evolve. Most of all, there needs to be a shift in thinking and education, raising awareness of the unprecedented opportunities these technologies offer. At the same time the involved tools need further improvement and development in respect to specific design demands and economic viability. And lastly, software and programs need to be simplified, since one of the largest obstacles for their larger impact are their complex interfaces. However,

in regard to the current situation, in the middle of a global pandemic with a society gradually transforming into a digital age, it is nowadays more important than ever to engage in new concepts and developments and explore the opportunities that lie within.

FIGURE 4.5

The Adaptive City Car project was a full-scale 1:1 mock-up of a vision for the future of urban mobility. The digitally designed and robotically produced

vehicle sensed human presence and responded by changing the opacity of its windows and through light and sound. Porous cork elements penetrated the sinuous surface and encouraged the growth of moss and lichen to filter air pollutants entering the car's interior.

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Manuel Lukas. Supervision:

Sina Mostafavi, Prof. Manuel Kretzer. AUDI Support: Mike Herbig. CG Artist: Mohammed

Mansour. Robotic Support: Carl Buchmann. Video: Yoshua Wilm, Esteban Amon. Additional

Support: Vanessa Rüprrich, Anton Roppeld, Mo Sayed Ahmad, Yulia Surova, Melissa-Kim

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CHAPTER 5

Surface texture as a designed

material-product attribute

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5.1

Introduction

The research in this chapter comes from the initial phase of the textureface proj-

ect—a portmanteau of “textured surface”—which sets out to investigate and ideate

the role of texture as a surface characteristic of products. The end goal of the tex-

tureface project is to develop principles for texture designs that can demonstrably

influence action tendency ([Somneveld & Schifferstein, 2008](#))—that is, tendency to touch a product (tactual attraction) or tendency to avoid touching (tactual aver-sion). It is well known that tactility is good for us: that our sense of well-being

can be increased through diverse touch experiences and that aiming for “pleasant

tactility” within a product ([Somneveld & Schifferstein, 2008](#)) can be a route to satisfying the hedonic element of [Hassenzahl’s \(2003\)](#) functional-hedonic user needs analysis. However, although texture provides a means to define product personality, add interest, and increase perceived value, the particular interest in surface texture for this chapter, as will become apparent, is not esthetic expression but rather

the less investigated perspective of functionality.

The chapter digs into the subject of how a product’s function can be enhanced or

delivered through surface textures, and thus how surface texture can be a contrib-

utor to the functional element of Hassenzahl’s user needs analysis. Existing

literature gives only hints about what may be termed as functional texture.

A common point is the improvement of grip during the user product interaction

([Özcan, 2008](#); [Zuo et al., 2016](#); [Zuo, 2010](#)). Texture-based wayfinding systems within the floors and walls of buildings, especially for visually impaired people,

are another example ([Herssens & Heylighen, 2010](#)). Researchers have also examined biomimetic approaches to functional texture, for example, to design product

surfaces with enhanced adhesion or hydrophobia, associated with the surfaces of

certain biological species ([Bhushan & Sayer, 2007](#); [Fratzl, 2007](#)). [McCardle](#)

([2015](#)) abstracted skin textures of aquatic animals to create 3D-printed surfaces on products required to possess low surface friction while operating in an

immersed liquid environment.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00021-1>

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While all these examples are interesting, they are specialized, dispersed, and inaccessible to designers. Relatively few research studies on texture and tactil-

ity have had intention to directly feed into designers' decision-making pro-

cesses. This is despite the fact that information on the tactile characteristics of

materials is highly requested by professional designers ([Karana et al., 2014](#)).

Research for tactility within multisensorial frameworks is, however, gaining prominence ([Bakker et al., 2015](#); [Spence & Gallace, 2011](#)), with one new design tool—the “experience map” specifically mentioning surface texture in

supporting the overall UX vision for a product ([Camere et al., 2018](#)). Within the product design field, such research is driven by a motivation to better

understand how tactility can mediate the user product interaction and resultant experiences, especially over relatively long periods of product ownership

and use ([Fenko et al., 2010](#)).

One of the initial aims for the textureface project was to conduct a wide-ranging and systematic analysis of functional texture, the outcomes of which could be used to provide designers with strategies and practical advice. To achieve this, two principal research objectives were set. The first objective was

to clearly define and describe texture from a product design perspective. To do this, a characterization of surface texture was carried out, analyzing four key criteria: (1) texture interpretations (what is meant by texture); (2) links between surface texture and senses (visual texture vs tactile texture); (3) scale

as a determinant of texture (micro-texture vs macro-texture), and (4) the

origin of texture (inherent texture vs texturization). The results of the characterization are presented in the first half of the chapter, one criterion at a time, leading to the creation of a surface texture roadmap for product design. The second research objective was to build a typology of texture linked to product functionality. To do this, a photographic analysis of products was made, sourcing product images by visiting retail stores and making online searches. The typology is presented in the second half of the chapter.

5.2

Texture interpretations

Texture is a wide-ranging term used in many different contexts. A vista across

a textured landscape is full of content and contrast. When plants are left free to grow over the outside walls of a building, the result can be a texture of natural and synthetic layers. In biting into a gourmet chocolate, the texture provided by each layer of the chocolate, created through contrasting ingredi-

ents, provides a rich taste and oral tactual sensation ([Fig. 5.1](#)). A textural sound is one that is sonically stationary as opposed to dynamic or evolving

([Grill et al., 2011](#)). Within the performing and fine arts, texture is discussed as an element of photographs, paintings, cinematography, and musical performances ([Shen et al., 2006](#)). Paintings can have a visual texture with regard



5.2 Texture interpretations

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FIGURE 5.1

Biting through the texture of a gourmet chocolate provides multiple tactual sensations, contributing to the enjoyment of eating.

r Owain Pedgley.

to the layered use of color or shade, but also tactile texture originating from the physicality of the paint itself or the grain of the paper or canvas onto which the paint is applied ([Lauer & Pentak, 2015](#)).

In the world of two-dimensional design, texture sits alongside line, shape, color, and value as a basic element ([Tersiisky, 2004](#)). The visual weight of a flat surface having a complex texture is said to be greater than that with a simple texture or an absence of texture ([Arntson, 1998](#)). In three-dimensional

design, texture has increased complexity. Referring to interior design, [Mitchell](#)

[\(2019\)](#), states that “. . . textures remind us of nature. They provide the eye with something interesting to look at, but they’re also incredibly soothing. (. . .)

Without enough textured elements, a space can feel cold and sterile.” Texture

can be added to a room by manipulating color, wall coverings, flooring, and

furnishings ([Martin, 2005](#); [Bowers, 2004](#)). For textiles, the Bauhaus-educated designer Anni Albers wrote of texture as the dominant attribute of woven

materials ([Albers, 1938](#)). Texture is an integral facet of the physical hand of a textile or fabric, having a great influence on perceived quality. In the world of

manufactured products—on which this chapter focuses—textures are associ-

ated with the way a product looks on the outside and feels on the surface:

commonly referred to as the skin of the product ([Menzi, 2010](#); [Lupton, 2002](#)).

The personality of a product relies heavily on visual and tactile cues from its

surfaces—for which order, proportion, shape, color, and texture are paramount

([Ashby & Johnson, 2014](#)). Accordingly, for product designers, surface texture falls within the scope of CMF (colors, materials, and finishes) decision-making

and can be used to influence people’s product experiences.

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Common to all these examples is the unifying principle that texture brings character and interest and therefore has potential to influence all four components of a materials experience (esthetics, meanings, emotions, behaviors).

Accordingly, the psychology and cognitive science communities have for decades

worked toward understanding people's sensory discrimination of tactile qualities of things, including texture ([Tiest, 2010](#)), as well as the vocabulary used to differentiate sensorial qualities of textures, which is often tied directly

to surface and bulk material properties ([Sakamoto & Watanabe, 2017](#)). For example, through an iterative clustering process, [Bhushan et al. \(1997\)](#)

arrived at a set of 98 words to describe different textures (e.g., bumpy, furrowed, matted, scaly, and studded), demonstrating the breadth of vocabulary required to convey different texture qualities.

5.3

Visual versus tactile texture

Vision dominates human information processing and cognition ([Hutmacher,](#)

[2019](#)), so it is no surprise that the visual properties of product design are prominent in designers' decision-making, leaving tactual properties—and

other sensory information—relatively underattended ([Zuo et al., 2014;](#)

[Wastiels et al., 2013;](#) [Miodownik, 2005](#)). This said, a huge body of research exists on tactual perception of product surfaces, covering fundamental

understanding (mostly cognitive science and psychology research, e.g., [Hutmacher,](#)

[2019](#); Sakamoto & Watanabe, 2017; [Klatzky & Lederman, 2010](#); [Bhushan et al., 1997](#); [Hollins et al., 1993](#)) as well as specific applications (mostly engineering and design research, e.g., [Georgiev et al., 2016](#); [Post et al., 2015](#);

[Elkharraz et al., 2014](#); [Jakesch et al., 2011](#); [Chen et al., 2009](#)). Links between surfaces, material properties, and affective response (in users) are common

among these studies. [Zuo et al. \(2014\)](#) made a particularly comprehensive study on surface tactility in relation to the user product interaction, creating

a conceptual framework that fuses a material dimension and an experiential

dimension, typical of work in the area. The material dimension encompasses objective physical or chemical properties (of the material/product itself), as well as effects of shaping processes and product assembly. The experiential dimension is more subjective, encompassing senses, perception, and user experience, especially with regard to visual, tactile, kinesthetic, and audible effects of material interaction.

From a designer's perspective, texture has been defined as: "tiny marks or shapes in a rather even distribution covering the surface of a shape. These can be slightly irregular or strictly regular, forming a pattern" ([Wong, 1993](#)).

Note that this definition of texture—as with many others put forward by designers or scholars close to design practice—purposefully avoids constrain-

ing texture to a two-dimensional or three-dimensional attribute (if "shape" is

5.3 Visual versus tactile texture

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interpreted to also include "form"). Nor does the definition imply any hierarchy on visual or tactile experiences from texture. However, distinctions between visual texture and tactile texture are fundamental within the scientific literature, elaborating not only on the physical dimension of texture but also on how texture is practically experienced. These distinctions are impor-

tant to grasp as a part of foundational discourse on surface textures.

5.3.1

Visual texture

Visual texture is the mainstay of computer visualization of materials ([Shen et al.](#),

[2006](#)), for example, in computer games, CGI (computer-generated imagery) animations, or CAD (computer-aided design) product development. What is seen on

screen is a visually simulated texture, albeit highly convincing. Visual texture on a

three-dimensional product gives the impression that there is a tactual effect to be

sensed on a surface, but in reality, beyond any inherent texture of the substrate

on which the visual texture is applied, no such three-dimensional effect is present.

This kind of texture is essentially a graphic finish, also referred to as optical texture or illusory texture. On the surface of a physical product, visual texture has a physically flat presentation. Oftentimes designers use visual textures as analogies to real

materials, in which case the visual texture presents as a faux version of the real

material. For example, a kitchen countertop can possess the visual qualities of

wood grain on an otherwise homogenous and flat thermosetting plastic surface

(see [Fig. 5.2](#) for further examples). As demonstrated by the examples, a common way to create visual texture is to reproduce the visual surface impression of real

three-dimensional objects or materials. Photographic or digital creation techniques

are both applicable. The use of dark and light shading can suggest the shadows

and highlights that fall on three-dimensional surfaces. Under certain viewing con-

ditions, visual textures can appear highly realistic and convincing.

5.3.2

Tactile texture

Tactile texture has a volumetric, spatial dimension ([Shen et al., 2006](#)). In the world of three-dimensional design, texture enters conversations alongside other

prominent design elements such as form, color, material, and weight. The sur-

face of a tactile texture is palpable through the deviations from a smooth unin-

terrupted surface: the physical peaks and troughs present on the surface can be

felt through the skin, most commonly through the fingertips or hands ([Lauer &](#)

[Pentak, 2015](#)). Tactile texture, also referred to as real texture or true texture, is the antithesis of uninterrupted smooth, shiny surfaces ([Fig. 5.3](#)). Under strong tangential lighting conditions, tactile texture can cast visually arresting shadows,

which in turn affect the perception and personality of the textured surface and product. This raises a crucial point: tactile texture encompasses the provision of

both visual and tactual sensorial information ([Lauer & Pentak, 2015](#)).

Variations





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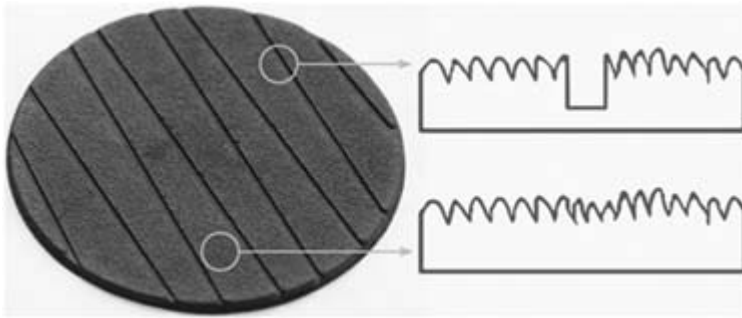
Surface texture as a designed material-product attribute

FIGURE 5.2

Visual texture applied to product surfaces, clockwise from top left: sandstone wallpaper, charmed faceted-effect vinyl skin for Xbox-One, leopardskin effect hydrographics, and digitally printed aluminum siding—cherry wood chocolate. Sandstone wallpaper: r MuralsWallpaper; charmed faceted-effect vinyl skin for Xbox-One: r DecalGirl, Art by FP; leopardskin effect hydrographics: r Liquid Concepts LLC; digitally printed aluminum siding—cherry wood chocolate: r Dizal.

FIGURE 5.3

Verner Panton classic chair: stunningly curvaceous and absence of surface texture. Image Creator: Marc Eggimann, r Vitra.



5.4 Micro- versus macro-texture

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FIGURE 5.4

Macro- and micro-textures on IKEA Pannå coaster. r Bahar ,Sener.

in surface geometry can be assessed not only by the eye—usually as the initial

mode of sensory experience—but also by the touch.

5.4

Micro- versus macro-texture

Scale is a crucial matter in texture characterization, as demonstrated through

the IKEA Pannå coaster in [Fig. 5.4](#). This simple product is helpful for highlighting an important distinction between what may be termed micro-texture

(small scale, appearing as a surface finish/roughness) and macro-texture (large

scale, appearing as surface form features). The grooves on the coaster provide a

tactile macro-texture, whereas the uneven surrounding surfaces provide a tac-

tile micro-texture. Distinctions between macro- and micro-textures are not so clear in the literature, but parallel distinctions are made between, for example,

macro-geometric versus micro-geometric stimuli ([Spence & Gallace, 2011](#)); macrostructure versus microstructure ([Klatzky & Peck, 2012](#)); coarse versus fine texture ([Goldstein & Brockmole, 2016](#)); and large surface features versus microtextural features ([Hollins et al., 1993](#)). Product design researchers investigating tactile texture have focused almost exclusively on the micro-scale ([Zuo](#)

[et al., 2016](#)), especially because of its agency to simultaneously improve grip (increase friction) and to disperse light (creating satin and matte visual effects

as a contrast between adjacent material surfaces).

A complicating matter is that there is no consensus on the point at which a micro-texture transitions to a macro-texture. For example, as extremes, [Jee & Sachs \(2000\)](#) define macro-texture as submillimetric ($1000 \mu\text{m}$ wide) surface features, whereas [Pardo-Vicente et al. \(2019\)](#) describe texture in general as an attribute at the level of product form. [Klatzky & Lederman \(2010\)](#) state that texture is a surface geometry property that is distinguishable from the

geometry of the host product. They suggest micro-texture transitions to macro-texture if the distance between texture elements (termed as horizontal transition or spatial period) is $200 \mu\text{m}$ (0.2 mm), but this is not a universally adopted definition. The spatial period is important experientially for

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tactile textures since it defines how much lateral fingertip or hand movement is needed to perceive a tactual change. Further complicating the perception of tactile texture is uncertainty surrounding the role of protrusion height or depth—and therefore vertical fingertip or hand movement—in sensory discrimination of texture ([Tiest & Kappers, 2007](#)).

As a general observation among research studies, tactile textures described at a

micrometer (μm) scale usually present as a surface roughness and, therefore, fit both quantitatively and qualitatively into the category of micro-texture.

Tactile micro-texture exists as sub- and supersurface disturbances that individu-

ally are not easily discernible to the eye, but create an overall surface-wide visual effect (e.g., lustered and matted) and tactual effect (e.g., roughened).

Practically, micro-texture is realized at the level of material surface finishes, through industrial processes that either roughen or deposit a coating, for example, mold tool spark erosion, shot-blasting, splattering, and powder coat-

ing ([Brainard, 2005](#)). The tactility of a micro-texture is conventionally evaluated on a smooth-rough perceptual scale; in essence, a scale that tends

toward

macro-texture as roughness perception increases ([Hollins et al., 1993](#)).

In contrast, tactile macro-texture as a term seems best reserved for relatively small-scale surface form features that are obvious to the eye (. 1 mm wide, but often much wider depending on the area of the surface to be textured),

with at least as wide—often much wider—spatial period. See, for example, the

textured surfaces of products showcased in the Form Fächer guide ([Zurich University of The Arts, 2009](#)), which exemplify this definition. Macro-texture form features may be variously described as bulges, ridges, ribs, protrusions,

and raised edges (examples of supersurface, embossed, elevated, protruding, or

high relief features) or dents, recesses, furrows, channels, and dimples (exam-

ples of subsurface, debossed, depressed, sunken, or low relief features). Blind

holes, depending on their abundance on a surface, may create a form of low

relief texture. However, thru-holes, perforations, and grilles, where a surface is

pierced ([Fig. 5.5](#)), are not strictly within the scope of texture, even though running one's finger across the surface would reveal a series of troughs disrupting

an otherwise flat surface. The tactility of macro-textures has been evaluated on

a flat-bumpy perceptual scale ([Hollins et al., 1993](#)).

5.5

Inherent texture versus texturization

It is often the case that a material possesses micro-texture or macro-texture that is

attributable either to underlying material properties or to ways in which a material

is processed into a semifinished material (for subsequent use in a product) or

directly into an artifact. In such cases, a texture is said to be inherent to the mate-

rial or its processing, for example, the relief and cracks associated with leather, the





5.5 Inherent texture versus texturization

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FIGURE 5.5

Queen Anne's Lace tea strainer from etched silver, Ted Muehling Studio: beautiful, but through holes are not strictly a type of texture.

r Loring McAlpin.

FIGURE 5.6

Inherent material textures, clockwise from top left: gray flock on tan fabric, leather bag and belt, Stone Forest Wabi Vessel washbasin, mycelium and timber stool (developed by designer and maker, Sebastian Cox and design thinker, Ninela Ivanova), synthetic fleece, and fallen palm leaf round bowl. Gray flock on tan fabric: r New Creation Inc.; leather bag and belt: r Dean Neitman | Dreamstime.com; Stone Forest Wabi Vessel washbasin: r Stone Forest; mycelium and timber stool: Photograph by Petr Krejci; synthetic fleece: r Berghaus; fallen palm leaf round bowl: r Bionic/Naturally Chic.

hand of piled fabric, or the hard undulations of carved stone ([Fig. 5.6](#)). The processing of concrete in architecture, for example, can lead to surface

textures that mirror the formwork shuttering used, such as wooden planks with pronounced wood

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grain, or smooth panels with regularly placed ties ([Hegger et al., 2007](#)). Grown materials and DIY-Materials—especially those formed of bio-ingredients ([Rognoli et al., 2015](#))—can have remarkably textured surfaces.

Familiarity with textures that are inherent to materials and their processing is an

important part of the designer's materials knowledge and may create a launch point for new product designs ([Alesina & Lupton, 2010](#)). Furthermore, material aging and wear through product use can bring about changes to inherent textures

or introduce new textures that were not originally present, such as peeling

finishes, crease marks, or dents ([Lilley et al., 2019](#); [Pedgley et al., 2018](#); [Rognoli &](#)

[Karana, 2014](#)). In contrast to inherent texture, texturization refers to the purposeful introduction of texture through a design and application process. In essence,

texturization results in a texture on a material surface that would not be present

without a concerted effort by the designer to plan and realize such a texture.

5.6

Surface texture roadmap

[Fig. 5.7](#) provides a roadmap that summarizes the surface texture characteristics reviewed in phase 1 of the textureface project. The roadmap provides a

new practical starting point for discussion and action on product surface textures among designers and design researchers.

5.7

Functional texture

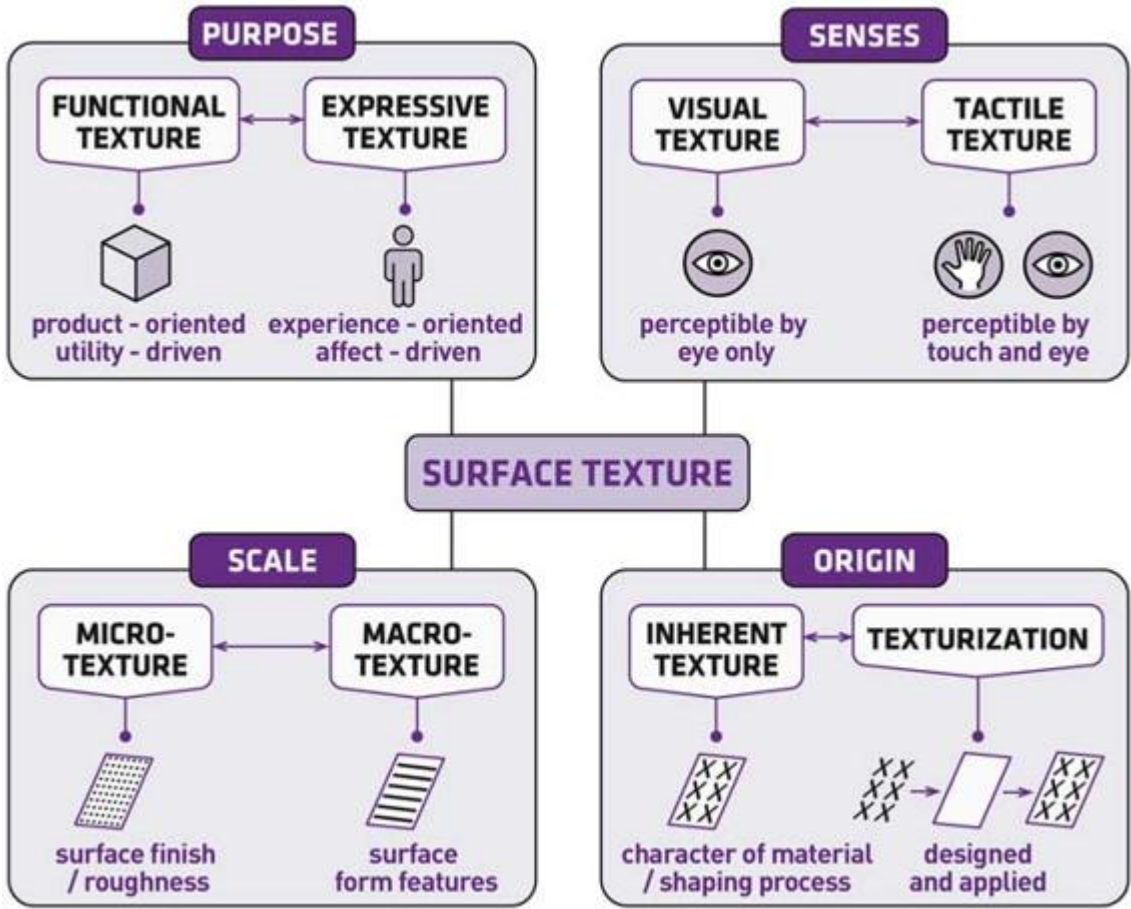
The second research objective for phase 1 of the textureface project was to build

a typology of texture tied to product functionality. The work commenced with a field study visiting retail stores in the United Kingdom and Turkey to photograph surface textures on products, supplemented by sourcing of online images. The photographs and images combined to form a diverse database of textured product examples falling within the roadmap category {purpose 5 functional texture; senses 5 tactile texture; scale 5 macro-texture; origin 5 texturization}. Diversity in product examples (n 5 200 1) was achieved through the choice of stores (e.g., department stores selling products across many sectors) and careful choice of search terms for Google's image search engine. The photographs and images were compiled into montages and cut-and-paste posters to aid multiple rounds of cross-comparison and analysis by

the research team. Two criteria were used to construct the typology:

G Functionality. How does the texture contribute to—or deliver—product function?

G Topography. What parameters describe the variation of geometries/forms for functional texture?



5.7 Functional texture

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FIGURE 5.7

Surface texture roadmap. r Bahar ,Sener/Owain Pedgley.

5.7.1

Analysis by functionality

In total, 11 categories of functional texture were identified, creating a typology of functional texture visualized in [Fig. 5.8](#). In some cases, the texture achieves the main function for the product; in other cases, it provides a supporting role. To assist the categorization, the user product and product product domains of interaction by [Sener & Pedgley \(2019\)](#) were used.

Under the user product interaction category, people purposefully try to achieve

something through interacting with a product (instrumental interaction) and the

texture assists the achievement of the task. The subcategory Fingertip Grip

describes cases where texture supports dexterous and precision (pinch) grip, allow-

ing users to make a controlled movement of a component (e.g., twist, slide, and

push) by providing a secure purchase on the surface of that component with the

fingertip. Examples include rotary controls, rotary demountable components (e.g.,

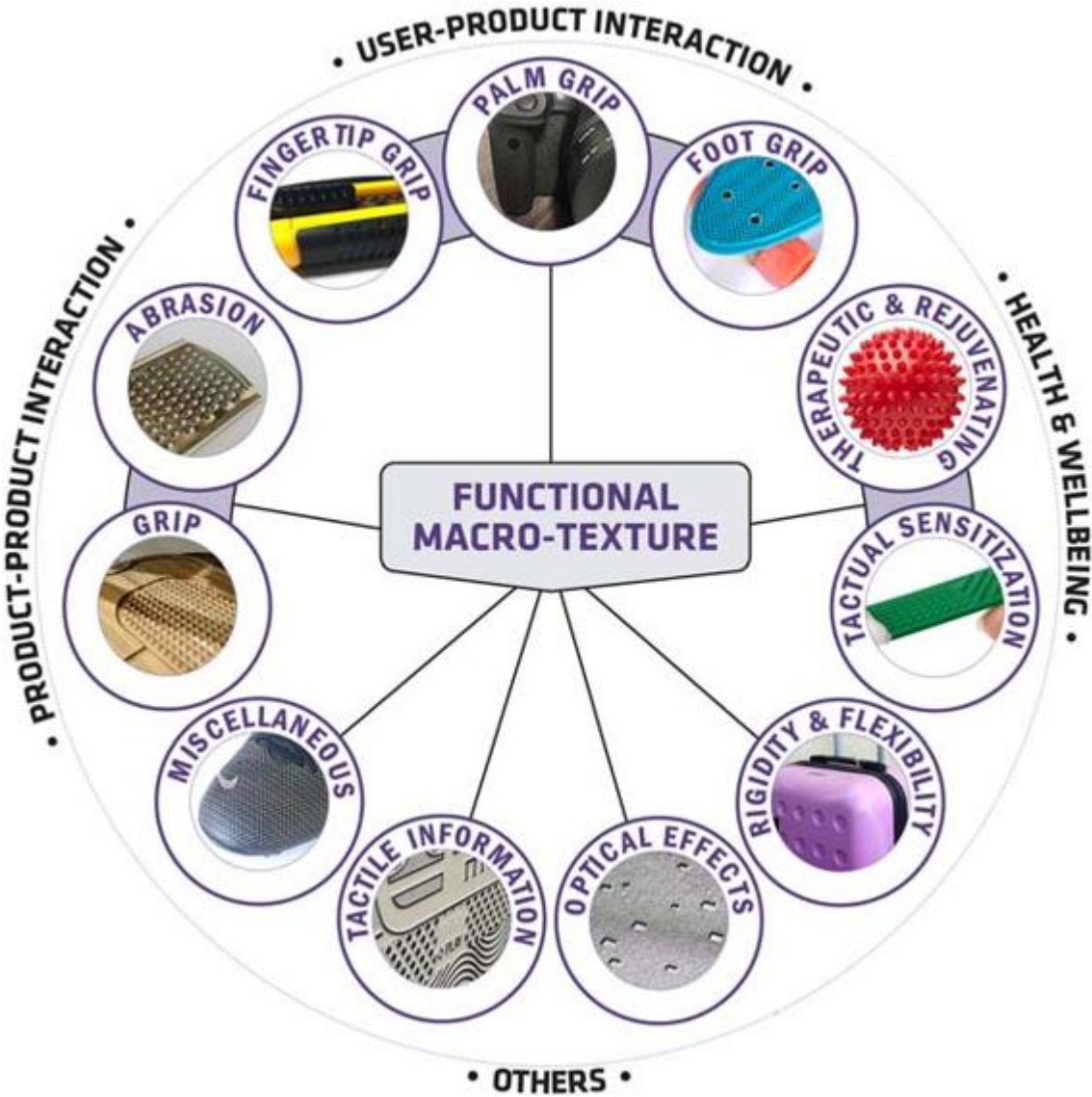
bottle tops) and sliding switches, controls, or catches (e.g., craft knife).

Oppositely, a secure purchase may also be required where movement should be

prevented—in other words, in cases where fingertip interaction should result in a

firm grip. Examples include pen and pencil shafts, hand tools, and handheld pro-

ducts where grip is imperative for security or safety (e.g., razors).



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FIGURE 5.8

Typology of functional macro-texture, with examples: grip (chopping board), abrasion (cheese grater), fingertip grip (craft knife), palm grip (camera and lens), foot grip (penny board), therapeutic & rejuvenating (massage ball), tactual sensitization (flat textured spoon), rigidity & flexibility (suitcase), optical effects (flat glass), tactile information (tactile map), and miscellaneous (football boot). r Bahar ,Sener/Owain Pedgley. Use of flat textured spoon image granted by Ark Therapeutic; use of tactile map image granted by ClickAndGo Wayfinding.

The subcategory Palm Grip describes cases where texture contributes to the achievement of a grasping, grabbing, or holding power grip, during which a product can be held securely without slippage or movement. In this subcategory, there is a blurring between the contribution of texture toward achieving grip and the contribution toward visual esthetics on relatively large surfaces. For example, when texture is located on a handle, on a control, or on a control/grip surface, the contribution is more obviously functional. When texture is located on the main body, away from areas of interaction, the contribution to function is less obvious. In the latter case, the texture can offer improved grip to pick up and hold a product securely, but this is a rather tenuous connection since it is carried out rarely and not a part of instrumental interaction. Instead, for the majority of the time, such texture is appreciated as something to behold and appreciate visually. Examples include artifacts that

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may occasionally be moved (e.g., vases, pots, and jars); containers with more frequent interaction (e.g., drinks glasses, drinks bottles, perfume bottles, tea-pots, and mugs); textured covers over smooth product surfaces (e.g., mobile phone cases); control/grip surfaces on products (e.g., shavers and kitchen gloves); handles (e.g., racquets, baby strollers, bicycles, handheld products, steering wheels, torches, and toothbrushes); fragile items needing to be transported or carried securely (e.g., cameras and portable hard disks); and oversized controls on products (e.g., chair tilt adjustment and water bottle lids).

The subcategory Foot Grip describes cases where texture contributes to achieving a secure connection between somebody's foot and the surface of a product, for the purpose of preventing movement (nonslip). Examples include bathmats; flooring; product foot controls (e.g., car pedals and pedal bin); and standing surfaces (e.g., skateboard).

Under the Product Product Interaction category, people purposely try to achieve something through the action of one product on another product or object. In other words, functionality is achieved through surface texture interactions. The surfaces involved do not have direct user intervention. The subcategory Grip describes cases where the functionality is related to

maintaining control, grip, and ensuring no slippage between surfaces.

Examples include clothing (on shoulders, to prevent rubbing and movement of accessories such as rucksacks); storage areas, shelving, and coasters (to pre-

vent rolling or movement of placed items); chopping boards (to keep food still during cutting); jar openers (combined with high friction materials to provide extra secure grip); toys (to provide friction fit to join parts, such as Lego); and shoe outer soles and tire treads (to provide grip and lift water).

The subcategory Abrasion covers a special case where texture is realized in a

durable material for the specific purpose of providing abrasive (material removal) properties. Examples include sheet metal textures (in cheese/food graters); ground metal textures (in workshop files); and ground glass textures (in nail files).

Under the Health & Well-being category, texture is provided on the surface of products for the purpose of stimulating the skin and muscles. The subcategory Therapeutic & Rejuvenating describes cases related to relief and relaxa-

tion, for example, from the application of pressure onto muscles/skin (e.g., foam exercise rollers, massage balls, baby and pet teethingers) and through to gentle touch (e.g., massaging face mittens to promote skin renewal).

In the subcategory Tactual Sensitization, texture serves to stimulate or regulate the tactile sense. For example, feeding spoons that are textured to provide added tongue stability and awareness at eating time for babies transitioning from puréed to solid/textured foods; sensory play toys for

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babies, having variety in textures and material properties to simulate brain development and develop the sense of touch; and sensory sticks, textured to treat sensory (tactual) processing disorders such as hyperesthesia (oversensitivity, leading to tactile defensiveness) or hypoesthesia (undersensitivity, leading to tactile seeking).

Under the Others category, texture is put to a wide variety of use. The subcate-

gory Rigidity & Flexibility covers the application of textures to increase or decrease the structural stiffness of a part (increasing or decreasing the second

moment of area). Examples of increased rigidity through texturization—which

often involves much larger than millimetric features—include metal panels on

cars or white goods, plastic panels on suitcases, silicone cake molds, and poly-

ethylene terephthalate (PET) water bottles that otherwise have poor structural

properties. Examples of increased flexibility through texturization include creat-

ing localized subsurface textures on gloves and indentations on watch straps.

As raised earlier in the chapter, texture on a micro-scale is often used to cre-

ate optical effects such as visual contrasts and matte finishes as an alternative

to high gloss. The subcategory Optical Effects covers the use of macro-

texturization to achieve functional optical effects. Examples include obscured

flat glass panels for privacy (such as used for internal walls, shower cubicles,

and door panels); texturized glass or transparent plastic in car headlight fix-

tures, to help distribute light from the point source of a bulb; and texturized

plastic car dashboards, giving low levels of reflection and reduced glare to

avoid driver distraction.

The subcategory Tactile Information describes the use of texture as an alterna-

tive to graphical/verbal instruction. Examples include braille—surface texture

perceived by the fingertips that is organized into a language alternative to

words; and other applications to assist the visually impaired, such as bumps

on pavement tiles to help wayfinding, with different texture designs and directions indicating different information.

The final subcategory Miscellaneous captures functional uses of texture that do not fit into the preceding categories. Products in this category include paper coffee cups (relief on the cup surface traps air for insulation and reduces surface contact area to avoid burning hands); silicone cake molds (dots on the base surface help release cakes easily); paper towels (texture increases paper volume and improves absorbency); cotton blankets (embossing gives softness and structural stability); roller paint trays (ridges control movement of the liquid paint); golf balls (dimples provide aerodynamic control); golf clubs (grooves provide aerodynamic control); football boot uppers (texture gives traction for ball contact and aerodynamic control); and heat sinks (texture increases surface area to dissipate heat from components such as LED lights and audio amplifiers).

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5.7.2

Analysis by topography

Analysis of the 200 1 textured products revealed some common descriptive points that can be used to help describe surface texturization in a systematic

manner. The descriptions are presented under three categories: Geometry, Bipolar Scaling, and Arrangement. Note that these descriptions are at a general

level and are not specific to any product sector. Effects of topography on func-

tionality are not implied, but future research studies could use the descriptions

as texturization variables to measure effects on, for example, usability, task achievement, or visual and tactile attractiveness within specific product sectors.

Under Geometry, macro-texture form elements can be defined as follows.

G Extruded polygon, for example, circle (dot), triangle, square, rectangle, diamond, and hexagon;

G 3D volume, for example, prism, pyramid, hill, dome, and scallop (inverse dome);

G Longitudinal, for example, notch, ridge, channel, strip, and lozenge;

G Irregular, for example, globular, cellular, emblem, figure (heart, star, etc.), wave, material imitation, and decorative pattern.

Obvious differences between macro-textured surfaces can be defined using

Bipolar Scaling (semantic differential scaling) as follows:

G Single size elements multisize elements

G Small relative size large relative size

G High-density elements low-density elements

G Subsurface supersurface (exception: faceted textures create a fully undulating surface)

G Flat surface application curved surface application

G Sharp edge elements - smooth (filleted) edge elements

Arrangement refers to other dimensions that influence the final macro-texture.

G Boundary. Defines the extent/edge of texturization on the product surface (sometimes a texture is gradually tapered or faded out to flat, rather than ending abruptly).

G Tessellation. Defines the way in which the texture elements are brought together, often using geometrical arrangements (e.g., X-Y spacing, linear placement, radial placement, and concentric placement) or with irregularity.

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Successful product design is frequently attributed to excellent functionality combined with satisfaction and pleasure from appearance and interaction

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([Norman, 2013](#)). As the topics of discussion have shown throughout this chapter, material surface texture has the potential to influence product success against all these criteria. The chapter has worked toward the use of pur-

posefully designed and applied textures to supplement or extend product functionality in manufactured products. In such cases, surface texturization often provokes actions from users, directly addressing the performative aspects of materials experience.

Such functional gains cannot be considered in isolation; as is inevitable in design, those functional enhancements have implications for sensorial-expressive effect. Wider esthetic, emotional, and meaningful experiences must still be considered as part of the functional texture concept. In this regard, a subset of the product examples listed in the chapter can be regarded as possessing “functional pleasant tactility” ([Fennis, 2012](#)), which describes a situation where designers have made an effort for a surface texture to feel tactually pleasant in use as a cooperative attribute to the functional gains brought by the texture. Texture can also be used playfully. [Rognoli \(2015\)](#)

gives an example of how designers are adept at working with texture at differ-

ent levels: for example, creating macro-texturization through embossing the leather on the outside of a handbag, which in turn mirrors the smaller scale texture of the stitching on the inside of the bag. Texturization can still, of course, be conceived without any particular functionality in mind. From this

perspective, the texture characterization criteria presented earlier in the chapter, and summarized in the surface texture roadmap, are informative and relevant to designing what may be termed expressive or decorative textures. As observed from the analysis of 200 products, texture is often used to enhance the grip of products. To amplify the nonslip effects of texture, designers sometimes specify materials having a high coefficient of friction, such as thermoplastic elastomers or rubbers. Stylistically, this often results in high-grip components that are visually strongly discernable from the main body of a product, both regarding color choice and texture. Coinjection molded toothbrushes are a very well-known example of this phenomenon. In more demanding contexts, such as the nonslip grips of sports products, surface texturization can be a fruitful area of research bridging sporting performance, design research, and macro-scale tribology.

The physicality of tactile texture is important from the point of view of providing product durability. When considering the Tactile Information subcategory from the typology of functional textures, then unlike applied graphics, texture is not at risk of rubbing off over time. Furthermore, the physicality of

texture gives rise to the possibility of blind interaction: in situations where gazing at the point of interaction is not possible or desirable, functional textures can guide us tactually about where to grip or interact with a product.

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One example can be in the use of textured driver controls out of the line of vision, building upon principles laid out for highly tactile interfaces reliant predominantly on form ([Porter et al., 2005](#)). Continuing with the automotive theme, trends in automotive human machine interaction/interface

(HMI) have seen a gradual increase in the size and reliance of touchscreens to access functionality, away from dedicated tangible controls. This is a consequence of the general processes of dematerialization, involving a shift from physical products to digital apps ([van Campenhout et al., 2013](#)).

Nevertheless, a balance in interaction modalities is often aimed for in highly interactive environments such as automotive HMI—mixing the digital and the physical—in which case, textures on tangible controls or interior surfaces can provide a “design antidote” ([Pond, 2014](#)) to the materially diminished touch experiences of touchscreens and high gloss surfaces. Playful interactions can be achieved through textures: for example, several concept designs

exist for scratchable controllers, where scratching a texture creates a sound signature which in turn is mapped to activating/deactivating certain product

functions ([Murray-Smith et al., 2008](#)).

It is worth mentioning at this point the related emerging field of tactile displays, which can be regarded as a dynamic extension of surface macro-texturization. Tactile displays possess changeable surface forms or textures, which on a macro-scale can be achieved through smart materials, actuators, and computational materials. The result is a surface that can change its tactile character, either automatically or by intervention. [Jung et al. \(2010\)](#) made inflatable cup and tactile mouse conceptual designs based around these principles. Metamaterials defined as materials possessing a designed and geomet-

rically complex internal microstructure that can controllably deform and reshape through various means (e.g., motors, pneumatics, shape memory polymers, electromagnets, thermal response, light-activation, and hydrophilic action) have also been demonstrated as a route to creating dynamic surface textures, which can influence action tendency ([Ion & Baudisch, 2020](#); [Ion et al., 2018](#)). In another emerging field, texture is explored through the medium of biomaterials, for example, by encouraging plant roots to grow into intricate repeated structures (see, e.g., grown products by Diana Scherer showcased in [Karana, 2020](#)). Such applications can be conceived with functional or expressive applications in mind.

Surface texture has been known for some time to be highly suited to direct materialization via 3D-printing methods. As such, it offers a plausible route,

among others, to realize mass customization ([Campbell et al., 2003](#)). In recent years there has been a large expansion in practical advice about how

to

model

complex

textures

using

industry-standard

software

(e.g.,

SolidWorks, Rhino) and visual programming plug-ins (e.g., Grasshopper)

paying attention to the 3D printability of the texture. As the resolution of

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3D printers becomes greater, so too does the ability to create one-off surface textured artifacts or master patterns for volume production, including at the macro micro-scale boundary.

For all of the benefits that surface textures can bring, there are still negative effects that must be striven to be avoided. Textured surfaces are prone to catching dirt and can therefore be harder to clean and maintain good hygiene

compared with nontextured surfaces. Durability can also be a concern, if the materialized texture is fragile or susceptible to getting knocked.

5.9

Conclusion

Materials are often processed or formed to leave a surface texture that adds value to a product. If texture does not come inherently, through the material itself or through its shaping and finishing, then the designer must consciously texturize the material surface. This chapter has reported on the first phase of the three-phase textureface project, making a detailed examination of the characteristics of surface texture and a review of how texturization of an otherwise plain surface can be functionally beneficial. The presented surface texture roadmap provides a launch point for designers and design researchers to consider how to use surface texture in product designs.

The textureface project has also provided the first systematic analysis of how texturization can deliver or support product function. Eleven categories of functional texture were identified as a typology, providing informative and inspirational examples for designers to use texturization to support or deliver product function. The chapter has contributed an investigation of the pragmatic uses of texture, which complements the far more commonly discussed sensorial-expressive qualities of materials and texture, mostly concerned with

user affect and designer expression.

Acknowledgments

Funding for the work reported in this chapter was received from the BAP Project (Scientific Research Projects) scheme of Middle East Technical University, under Grant No. BAP-02-03-2014-001 “Research into 3D Surface-Texturization for Functional and Hedonic Product

Enhancement.” Thanks are extended to Yavuz Paksoy for his involvement. A follow-up work package conducted at the University of Liverpool, School of Engineering, entitled “Exploration and

Application

of

3D

Surface-Texturization

for

Functional

and

Hedonic

Product

Enhancements” was funded under the Brazilian student mobility scheme Science Without Borders.

Thanks are extended to Karolyne Santos de Castro for her involvement. Thanks are also expressed to students of ENGG220 Product Development 2 course at the University of Liverpool, who designed textured travel mugs and textured chocolates under the authors’ guidance, helping to test out many of the principles put forward in the chapter.

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CHAPTER 6

Material change: transforming experience

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6.1

Introduction

Scenario 1: “You open the door of your rental car; it’s sunny, the car is hot and

humid, the smell of stale cheese and onion crisps hits your nostrils full force. You

feel slightly nauseous. The steering wheel is sticky, residue from the previous user's fizzy drink. You think about reaching for the wet wipes to attempt to remove the thin layer of sweaty film from the hot plastic surface, but why bother?

Your time in this vehicle is fleeting—a means to get from A to B. You reach your

hotel. It is bland, clinical, a sea of homogeneous white towels and crisp cold bed

sheets. You could be anywhere. The pillows are flat but serviceable. You sit down

at a small desk, the surface of a thin layer of wood veneer chipped on one corner

to reveal the low-cost chipboard within. You drop your car keys onto the desk

with a clatter; the already scratched surface and cheap construction does little to

elicit your respect. You reach down for your leather satchel and feel a sense of

calm as your eyes work their way over the familiar textures and patterns of the

worn leather, the deep scratch that vividly reminds you of a close-call with a rhinoceros in Mozambique, the suppleness of the leather gained through years of

care and nourishment. You pull out a well-thumbed book, a gift from an

anonymous fellow traveler keen to facilitate its onward passage. The spine is

creased, scrawled notes emphasize meaningful passages, reflections on words

you read afresh with the lens of others before you.”

We are constantly interacting with the material world around us, and these interactions, in turn, change the natural and man-made materials embodied in our streetscapes, buildings, and products. Our relationship with materials, and

the materials themselves, are constantly changing. Designers and manufacturers

typically focus on the pristine object that entices the purchaser, with little con-

sideration of how materials will change over days, years, or centuries of use

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00027-2>

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[\(Nobels et al., 2015\)](#), and how in turn this will influence the product's life: from careful use to abuse and from reuse to disposal.

Since the Industrial Revolution, mechanized “perfection” has steadily replaced

craftsmanship. In *The Nature and Art of Workmanship* David [Pye \(1968\)](#) describes

“workmanship of risk” “in which the quality of the result is not predetermined,

but depends on the judgement, dexterity and care which the maker exercises as he

works” (p. 20). In contemporary society workmanship of risk has been replaced

by “workmanship of certainty.” A combination of homogeneous man-made mate-

rials (such as plastics, metals, and glass) and an array of increasingly sophisticated, automated manufacturing processes have enabled designers to deliver immaculately smooth, indistinguishable objects. But from the moment of purchase the

surface of these objects is exposed to a diverse range of stimuli including heat,

light, moisture, wear, and impact. A complex interaction of physical, chemical, and

biological processes results in changes to the material surface, altering both the

look and feel of the object ([Fig. 6.1](#)). Environmental stimuli include moisture, FIGURE 6.1

Materials change. Clockwise from top left: a plastic spade is severely faded by sunlight despite being designed for outdoor use; paint wears away from floor boards, revealing the grain of the wood and highlighting the routes that people walk; denim fades from dark blue to white with repeated washing and use, this appearance is highly valued and many products are “preaged” by the manufacturer by stone washing; white limestone blocks have slowly been colored by water running down from a copper roof above.

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light, temperature, growth of mold and fungi, and reaction with oxygen and other

chemicals in the atmosphere. Physical interaction includes handling, carrying, and dropping an object resulting in impact, ablation (chipping of the surface), abrasion (scratching and polishing), and accumulated dirt. There is also deliberate interaction with the material surface, which ranges from care (cleaning, nourishing with wax or oil, and polishing) to repair and personalization. These stimuli combine to create a complex surface patina, which varies both spatially (across the surface of an object) and temporally.

Materials communicate to us on many levels signaling their provenance, worth,

and capabilities. The patina or “traces of use” ([Giaccardi et al., 2014](#)) evident in their surfaces are “a type of material history . . . inscribing a unique and personal

semantic narrative into the objects through material experiences” ([Odom & Pierce, 2009](#), p. 3796). Material surfaces can tell a story of the object’s past life while semantically conveying how they may be used in the future. In stark contrast, material change may also be perceived negatively as damage, degradation,

or contamination: “Plastics cease to be pristine, and become evidently worn, in a

particular way. They do not patinate; they gather dirt rather than ‘charm,’ and then may elicit particularly strong feelings of disgust” ([Fisher, 2004](#), p. 30). Fisher links this negative reaction to a particular material, but more generally people’s

response to materials is determined by “a societal preoccupation with what an

appropriate condition is for certain typologies of material and objects to be in”

([Chapman, 2014](#), p. 141). Unfortunately, a designer cannot simply determine the

“appropriate condition” for certain materials in certain contexts to achieve a par-

ticular response from the user. Previous studies have shown that attitudes to material aging are highly variable, subjective, and shaped by myriad factors

([Bridgens & Lilley, 2017](#); [Lilley et al., 2016, 2019](#)), which include both individual and societal influences, which we will explore later.

6.2

The interaction of material change and material experience

By combining insights from user studies (e.g., [Lilley et al., 2016, 2019](#);

[Manley et al., 2015](#)) with the existing literature, we have pieced together a tentative framework for understanding the influence of material change

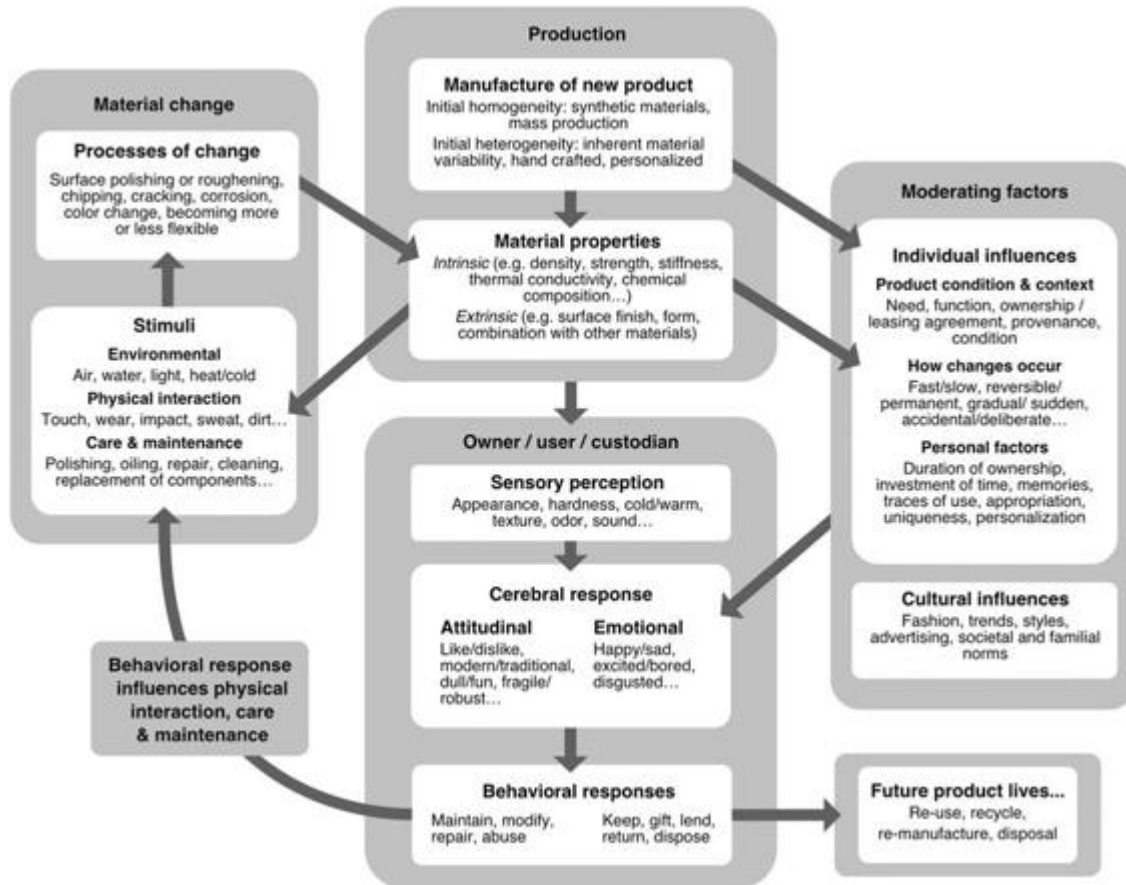
on people’s experience of the material world which surrounds us. At the

heart of the framework is the pioneering work of Nathan Crilly who pro-

vided a conceptual framework for understanding consumer response to

product visual form ([Crilly et al., 2004](#)). Crilly’s framework has been expanded to include an understanding of both materials engineering

(manufacturing, material properties, and processes of change) and recent work on “materials experience” exemplified by [Karana et al. \(2015\)](#)'s



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“Material Driven Design” methodology and wider contributions described in *Materials Experience: fundamentals of materials and design* ([Karana et al., 2014](#)). These works provide a basis for understanding the factors which influence a person’s response to a particular material in a particular context. We have extended this work by considering the condition of the

object, how its condition will change with use, and how this will influence people's response to that object ([Fig. 6.2](#)). While "object" is a convenient word to describe the use of a material in a particular context, the framework is equally applicable to material surfaces at any scale, including, for example, furniture, vehicles, the interior and exterior of buildings, and public spaces.

FIGURE 6.2

The interaction of material change and material experience.

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6.2.1

Individual influences

The framework shown in [Fig. 6.2](#) identifies numerous "moderating factors," which influence how an individual responds to a particular material, in a particular condition, in a particular context. These are not discrete factors that can be considered individually; they form a complex interdependent web which, when considered in its entirety, describes the elusive difference between graceful aging and degradation.

Change is perceived by comparing the current state of an object or material surface to a remembered previous condition. This observation may sound trivial, but it elucidates two fundamental factors that influence how material

change is perceived: the initial condition of the object and the rate at which changes occur.

The initial condition of an object is critical in understanding how material change will be perceived. The “initial condition” might describe a pristine new product that the user fondly remembers removing from its packaging in its “box fresh” state, a well-worn object that was received as a gift or was purchased second hand, or a shared material surface such as a bus seat or the wall of a building, for which the user may not know the original condition and is left to speculate about its past. The “pristine new product” is a generalization of a broad spectrum of materials and manufacturing methods, which result in different reference points for subsequent perception of material change. The vast majority of products are mass-produced using highly regulated man-made materials such as metals and plastics with exquisitely controlled surface finishes, exemplified by the smooth, sleek perfection of portable electronic devices. This uniform, flawless esthetic has insidiously infiltrated into almost every product category, from Ikea’s plastic and foil covered particleboard bookshelves to the immaculately smooth painted surfaces of cars. A thin veneer or coating of high-quality material finish is vulnerable to chipping, scratching, and denting, with two problems: first the contrast with the pristine original surface is perceived nega-

tively and second these materials (e.g., unlike solid wood) often cannot easily (or economically) be repaired.

In a backlash against this uniformity, natural materials and “hand-crafted” objects have seen a resurgence of popularity. Unfortunately, they are seen as premium products, and a high price is usually paid for variability and uniqueness. The natural variation inherent in wood, stone, and leather enables unique products to be mass-produced, relying on material variability to distinguish objects of identical shape. Crucially, variability is more often accepted and appreciated in these materials, whereas it is seen as a manufacturing flaw in plastics or metals. These “natural” materials also bene-

fit from surfaces with complex variations in color and texture, making initial

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changes to the surface less obvious than the first scratch on a polished metal or painted surface. Ceramics and glassware have come full circle from their hand-crafted origins, through mass production of identical pieces, through to “mass customization,” which introduces variability into the manufacturing process either by manual intervention (by shaping or decorating) or by adding a random element to an automated manufacturing process. Here the

designers are trying to conflate “unique” and “hand-crafted”; time will tell if random variation has the enduring appeal of a craftsman in dialog with a material.

The second fundamental factor relates to the rate of change. Attitudes to changing material surfaces are strongly influenced by when changes occur in the cycle of ownership and how quickly or slowly these changes manifest. Sudden changes, for example the first scratch on a pristine manufactured surface, elicit negative reactions due to the jarring change in the product appearance. Gradual changes, however, such as build-up of accumulated dirt or abrasion, allow time for acclimatization and are more likely to be perceived neutrally or positively ([Manley et al., 2015](#)). Let's return to our description of the perception of change as the difference between the current condition of a material surface and a remembered previous state. For the first scratch, this stark change is compared to recent memories of the pristine surface and perhaps memories of the moment of purchase. For gradual change, which may only be noticeable over a period of years, memories of the original condition of the object fade and the remembered state alters with time and is never far from the current condition of the object. In extreme cases material change may only be perceptible over decades or centuries. Stone steps and paving slabs wear so gradually that the change is unlikely to be noticed within one lifetime,

but worn stones provide a compelling reminder that many generations have lived before us, and that we should design and build not just for ourselves but for future generations.

Materials are not experienced in isolation but in context, forming the visual and tactile interface with the world around us, from toasters to bicycles to buildings. As depicted in [Fig. 6.3](#), just as our response to a material (or more commonly an assemblage of materials) is strongly determined by context ([Hekkert & Karana, 2014](#)), our response to material change is equally dependent on context. “Traces of use” on sports equipment or hand tools is often treasured as a record of accomplishment and a reminder of past times, changes to the surface of home furnishings—perhaps the fading of fabrics in sunlight, accumulation of dirt or stains, or a pet cat scratching a sofa—are perceived negatively as damage. Here the distinction seems clear: for a tool or piece of sports equipment the material change occurred as a result of proper use of that equipment and provides a reminder of an



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FIGURE 6.3

Diverse forms of material change show the importance of time, context, and esthetics in influencing how material change is experienced. Clockwise from top left: a solid brass doorknob has changed slowly over several decades resulting in a desirable patina on a once homogeneous, pristine material surface; celebrating beautiful repair with Lego (inspired by Jan Vormann); a wooden chair shows intensely personal marks from a baby's teeth; "No Waste" vases by Ikea made from imperfect or damaged glass vases discarded during production, which are melted together and mouth-blown into new, uniquely patterned vases.

enjoyable activity. The changes that have occurred to the home furnishings are accidental; the owner would have preferred that they had not happened.

But is this distinction clear, or could the “traces of use” on the home furnishings be widely celebrated as a reminder of good times, with greater consideration of how materials may change during design and material specification?

Public “shared surfaces” provide a particular challenge. Without a feeling of personal ownership, changes to the material surface are more likely to be perceived as damage, accumulation of dirt is more likely to be seen as contamination, and the user is less likely to care for and maintain the object.

Returning to our scenario at the outset of the chapter, little care was given to protecting the surface of the cheap, already damaged desk nor to maintaining the interior of the rental car, a common behavior which [Bardhi & Eckhardt \(2012\)](#) observed during their research study.

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An object’s “intrinsic value” to the individual is also pertinent. Objects can become

inextricably woven into our lives as tangible manifestations of past experiences

and memories, or discarded when undesirable, superfluous, or outdated. The life-

span of objects is highly variable: from rapidly discarded “fast fashion” to heir-

loom objects which outlive many generations of owners. Care and maintenance

can extend the lifespan of treasured objects indefinitely, or less cared for objects

can be rapidly replaced. The greater our regard for an object, the higher our toler-

ance (or appreciation) of material change. Valued but “worn out” possessions

may be judged less critically, their imperfections overlooked or celebrated, their

failings forgiven and their surfaces rejuvenated or repaired; “we are less likely to

dispose of objects we are emotionally invested in; similarly we are more likely to

repair such objects than we are ‘insignificant’ things” ([Harper, 2017](#), p. 61).

Repair is practiced with the intention to restore function or renew appearance

([Zijlema et al., 2017](#)). Depending on its execution and the prevailing esthetic aim, repair activities can irrevocably alter the sensorial qualities of an object

and its material constituents; [Zijlema et al. \(2017\)](#) refer to these changes as

“traces of repair.” These traces can manifest in esthetic alteration (e.g., wood veneer repaired in a contrasting color, *ibid*) and/or sensorial alteration

(a necklace fastening which became inflexible postrepair, *ibid*). If undertaken with restorative qualities in mind, repair can be seamless and undetectable, rendering an object “as good as new,” conversely obvious and unapologetic repair can enhance and give greater esthetic and emotional value making an object “better than new” by virtue of its unique, personalized esthetic. In rare cases obvious repair can increase the monetary value, the prime example being the practice of Kintsugi in which broken ceramics are repaired with gold. Investment of time and effort in repair and maintenance builds an emotional bond with an object. Here the owner takes control of the “processes of change,” in contrast to the unavoidable change caused by environmental stimuli or physical interaction which is seen as an external influence. Once material change becomes a conscious, deliberate activity, it is much more likely that the outcome will be seen as a desirable and meaningful patina. However, while skilled maintenance and repair that is material and object appropriate may lead to accrual of value, poor-quality repair may result in a diminished object value (both monetarily and emotionally) unless the act of repair itself is linked to cherished memories or personal achievement. The art of esthetically bold repair, popularized by Sugru who eulogize “the art of beautiful repair,” resonates with the celebration of material change. “In a world where almost everything you buy is mass-produced, isn’t

it nice to have something that is totally unique because of its scars?” ([Sugru, 2017](#)). The popularity of Sugru, exemplified through #mysugrufix, demonstrates a growing desire to prolong the life of objects through elevating repair

beyond functional or esthetic improvement into a new genre of product

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esthetic. Yet, the decision not to repair an object is equally revealing. The wish to preserve an item “as it always was” or “as it was remembered” can also be a powerful indication of sustained attachment ([Zijlema et al., 2017](#)).

6.2.2

Cultural influences

There are distinct parallels between the preoccupation with youthful perfection

and a desire for flawless mass-produced goods: “. . .our concepts of the ageing

of manufactured objects are heavily dependent on their association with our own ageing and with the passing of time measured in human terms” ([Scarre, 2016](#), p. 88).

The prevailing esthetic is one of perfection “in every sphere of human life: the body, the style of life, artifacts and their materials” ([Rognoli &](#)

[Karana, 2014](#), p. 147). However, “just like living beings mature and get older, so too artifacts degrade, and their surfaces show signs of aging” ([Rognoli &](#)

[Karana, 2014](#), p. 150). Are negative perceptions of aging possessions driven by deeper systemic cultural, esthetic, and philosophical responses to human

aging? Could an understanding of the relationship between people's responses

to the esthetic aging of objects and their own aging inform design strategies to

combat esthetic obsolescence? ([Bridgens et al., 2019](#)).

The pressure to conform to “plasticized” beauty belies the value of irregularity,

imperfection, and authenticity inherent in the philosophies of wabi-sabi which

prizes “the beauty of faded, eroded, oxidized, scratched, intimate, rough,

earthy, vanishing, elusive, ephemeral things” ([Salvia et al., 2010](#), p. 1580) and kintsugi—in which “the beauty of that which was broken and visibly mended”

is celebrated ([Buetow & Wallis, 2019](#)). The concealment and eradication of wrinkles, lines, and visible scars erases “traces” of the past; the inscription and

repository of time and memories represented within the skin's surface. These

“ephemeral patterns” are “signs of . . . an ongoing engagement with life.”

Perhaps they should not be hidden or obscured but celebrated, valued, and

appreciated ([Buetow & Wallis, 2019](#)), in the same way that “traces of use” on a material surface can reveal its narrative “in the same way that the scar on a

lover's leg or the wrinkles around his eyes appear beautiful . . . because they

contain the stories about the time he fell off his bicycle . . . aesthetic decay possesses qualities that make an object more valuable” ([Harper, 2017](#), p. 77).

To achieve such a mindset requires a shift in cultural ideals and changes to current notions of beauty and perfection. It might be argued that this is beyond the reach of designers’ influence. But as the creators of the material world, architects of commoditized communities and purveyors of dreams and ideals are not designers perfectly placed to challenge such embedded attitudes? By cultivating greater tolerance of material change and aging in our objects, might we affect a wider cultural transition toward an acceptance (or even celebration) of our aging selves?

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6.3

Material change as a design strategy

In *Materials Experience: fundamentals of materials and design* ([Karana et al., 2014](#)), the promise of graceful aging as a design strategy to combat early obsolescence is highlighted. In this chapter we ask, “what if ‘material change’

was an overt design strategy?” What if designers could carefully orchestrate

material change through the life of an object, could determine or influence how the look and feel of objects would change in response to use and better understand and control how these changes would alter people's attitudes toward owned or shared objects, and the object's treatment, lifespan, and future? How might an increased appreciation of changing material surfaces alter our experiences of, and relationships with, objects? We propose that if designers harnessed material change, they could actively choose to halt, slow, hasten, or modify material transformations to manipulate how a material looks, feels, smells, and sounds as it ages. Examples exist that utilize material change as a communicative strategy, from syringes which change color to signal when they are no longer sterile and packaging which indicates when food is still safe to eat, or to address functional needs such as crack-closers which can close on their own, car bodies that can recover their original shiny appearance by themselves and mobile phones which can detect and fix cracks in their screens. However, little consideration has been given to how material change may direct, inform, and create user experiences through shifting attitudes and behavior. Designs that embody material change as a strategy, as seen in [Fig. 6.4](#), are few in number and are often conceptual prototypes.

What might material change as a design strategy look like?

How might it be manifested in the design of objects and environments?

It is not easy to predict how people will respond to material change, but we argue that designers can use materials more effectively to ensure their intentions for evoking particular attitudes and behaviors are realized when interacting with designed objects or environments and the materials they embody. Through increased focus on user behavior, designers can purposefully shape the way users interact with products (and by extension materials) to leverage more sustainable use patterns. We call this approach Design for Sustainable Behavior ([Lilley et al., 2017](#)). When considering the suite of strategies available (see [Lilley et al., 2017](#) for a comprehensive overview), the approaches that are most suitable for designing with material change are the

provision of olfactory, aural, or esthetic feedback and the use of the physical, sensorial, or semantic characteristics of the materials or their affordances (explicit potential actions) and constraints (explicit potential limitations), an approach we call “behavior steering” (ibid). Let’s consider two scenarios that

place these approaches in a materials context:



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FIGURE 6.4

Material change as design strategy. Clockwise from top left: Underfull table cloth <https://design-milk.com/underfull-table-cloth-by-kristine-bjaadal/>; ENDURE concept <https://youtu.be/iEQzNMawTjg>; Stain TeaCup <http://www.bethanlaurawood.com/work/stain/>.

In the context of public “shared surfaces” the default design strategy is to use highly durable materials that will endure constant public use with minimal change, resulting in gleaming, impersonal, echoing public spaces lined with glass, stainless steel, and polished granite. But these shared surfaces can provide opportunities to incorporate material change in design, by guiding and

recording the behavior of large numbers of people. The result is “desire paths” worn through landscaped areas, old stone steps worn from hundreds of years of use, and on ticket machines the most popular destinations clearly signposted by the wear and polish on certain buttons (before the advent of touch-screen interfaces). Deliberate use of materials that wear, polish, and change in response to use has scope to transform our public spaces into places where people feel that the space is shaped by them, and the environment is richly laden with semantic clues about how to navigate an otherwise unfamiliar realm.

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And within the context of the home:

Scenario 2: “The shiny red surfaces of your polypropylene dining chairs reflect the intense summer sun which floods your dining room. Each chair is uniquely patinated in response to variations in UV exposure and their position in your home. You marvel at their beauty, so much more at home than they were when you unpacked six identical, plain red chairs last year. You sit, the curves of the seat folding around you, melding its contours to yours. Your hand rests on the simple white, damask tablecloth which

reveals the rich tapestry of last night's dinner with friends. Carla's wine spilt during a lively Brexit debate immortalized in the joyous flight of butterflies dancing across the surface. Your eyes rest on your children's highchair and a burst of images of Jake flit through your mind. The initial gleam of varnish has faded, the bite marks on the backrest a bittersweet reminder of nights spent comforting your teething baby. You reach for your teacup and smile. Time and tannin have stained its surface. You feel the warmth of the cup in your hands and ponder the passing of time. Life is fleeting but the familiar 'traces of use' remain."

6.4

Conclusion

Materials change. We experience the world around us by interacting with constantly changing material surfaces. Our responses and attitudes to these material transformations are as complex as the changes themselves. There is an expectation that the engineered surfaces of "man-made" materials should somehow be impervious to change, coupled to a widely held belief that "natural" materials age well. In truth, neither perception is entirely accurate as "the social values affixed to the aging of material surfaces are intensely complex" ([Chapman, 2014](#), p. 141). Our experience of material surfaces in a state of flux varies from disappointment and disgust to cherishing objects to which we feel a deep emotional connection.

We see enormous potential for designers to influence material experience beyond the moment of purchase, by considering material change as a fundamental part of the design process. But manipulating or orchestrating material change is not straightforward. To leverage this approach, designers must be cognizant of the capabilities of different materials and the stimuli that result in surface changes, how people will interact with the materials, and how they will respond to the resulting changes. In addition to this knowledge and understanding, designers must also develop a clear and deliberate strategy for material change, interrogating their own intent (which behaviors do they wish to encourage/discourage? what experiences are they aiming to create?) as well as the ethical implications of intended and unintended behavioral

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outcomes ([Lilley & Wilson, 2013](#)). Those among the profession practicing responsibly should seek to use material change as a force for good, creating virtuous loops (care, maintenance, and prolonged life) rather than destructive behaviors (premature disposal, misuse, and damage).

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PROJECTS

Around The Corner: Recent and

Ongoing Research in Materials and

Design

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P R O J E C T 1

Design touch matters: bending and

stretching the potentials of smart material

composites

Bahareh Barati

Faculty of Industrial Design Engineering, Delft University of Technology,
Delft, Netherlands Supervisors: Prof. Dr. Elvin Karana and Prof. Dr. Paul
Hekkert

My PhD thesis on the topic of understanding the experi-
that creativity in materials and design often involves
ential qualities of smart material composites in their early
discovering novel material affordances that are not
development stages was developed through the compila-
anticipated or intended without the benefit of tinker-
tion of three peer-reviewed journal papers and one ACM
ing and physical processing of the materials.
conference paper on human factors in computing systems
In addressing the main research question (i.e., how do
(CHI' 18). Across the papers, I describe how I employed
designers unlock the potentials of underdeveloped
various design research methods, including design pro-
smart material composites?), the notion of “affor-
jects, research through design (in developing a toolkit to
dances as materials potential” was introduced and

prototype the dynamic and performative qualities of used to discuss the creative materiality contribution of these materials), and semistructured interviews.

designers that goes beyond product novelty. An imme-

The first exploratory study in my research focused on diate benefit of the affordance concept for capturing

the situation of designing with an underdeveloped

the “potential” of a material was that it enables

smart material composite, as experienced in the LTM

descriptions of the material in terms of process abili-

(Light. Touch. Matters) project. Observational studies

ties. By contrasting the two design situations (i.e.,

and interviews with LTM designers suggested that

departing from an actual material, vs descriptions of

dynamic and performative qualities of smart material

its properties), I identified and laid bare the limita-

composites are hardly able to be represented through

tions of product-oriented approaches that characterize

a listing of their physical and functional properties. In

underutilized smart material composites as “black-

response, as well as developing and testing a hybrid boxes,” in contrast to investing in understanding and prototyping toolkit (combining physical and digital exploring their unique affordances.

prototyping tools), the research took a fundamental

Barati, B., & Karana, E. (2019). Affordances as materials

turn to investigate the role of material tinkering and

potential: What design can do for materials develop-

fabrication in unlocking novel material potentials.

ment. *International Journal of Design*, 13(3), 105–123.

Consequently,

I

initiated

several

material-driven

design projects, focusing on electroluminescent (EL)

Barati, B., Giaccardi, E., & Karana, E. (2018). The mak-

material and supported designers in directly working

ing of performativity in designing [with] smart mate-

with the physical material, rather than considering

rial composites. In Proceedings of the 2018 CHI
just the specifications of its properties. The material-
conference on human factors in computing systems
driven design processes provided empirical evidence
(CHI'18) (pp. 5:1–5:11). Montreal: ACM.

Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00030-2>

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P R O J E C T 1 :

Design touch matters

Why is the research needed?

depart from a material), and a material-driven design
strategy (for creating performative smart material

The research sought to understand what and how
composites).

“design” (as a profession, as a way of thinking, as an
activity, etc.) can contribute to the early stages of

developing new smart material composites. The EU-

What is the next big challenge for

funded project, Light. Touch. Matters (LTM, 2013–17)

the research area?

and its organization set a departure point and provided the context for further investigations.

The challenge lies in educating and supporting the next generation of designers who can effectively collaborate with scientists and engineers in materials

Which aspects of “materials development.

experience” does the research valorize?

Which publications most inspired

The research elaborates on the performative level of or informed the research?

materials experience in designing [with] smart material composites.

Glaveanu, V.P. (2014). Distributed creativity: Thinking outside the box of the creative individual. Springer Science & Business Media.

How will the research impact on

Bergström, J., Clark, B., Frigo, A., Mazé, R., Redström,

designers?

J., & Vallgård, A. (2010). Becoming materials: Material forms and forms of practice. *Digital Creativity*, *Designers' relationships with materials are challenged* 21(3), 155–172.

—the research articulates designers' creative contribu-

Miodownik, M. (2007). Toward designing new sen-
sation to upstream collaborative materials development,
soaesthetic materials. *Pure and Applied Chemistry*, 79
which directly questions the taken-for-granted sepa-
(10), 1635–1641.

rated roles of designers and scientists to, respectively,
conceptualize products and develop materials.

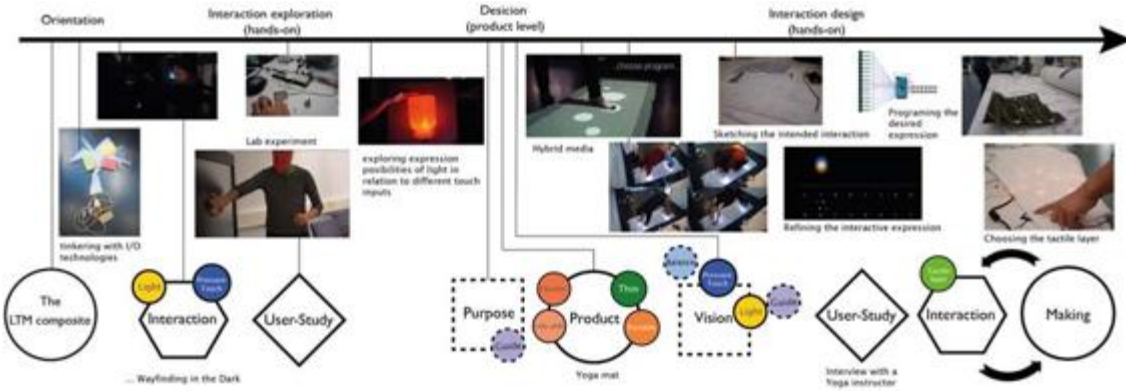
Gaver, W.W. (1996). Situating action II: Affordances
for interaction: The social is material for design.
Ecological Psychology, 8(2), 111–129.

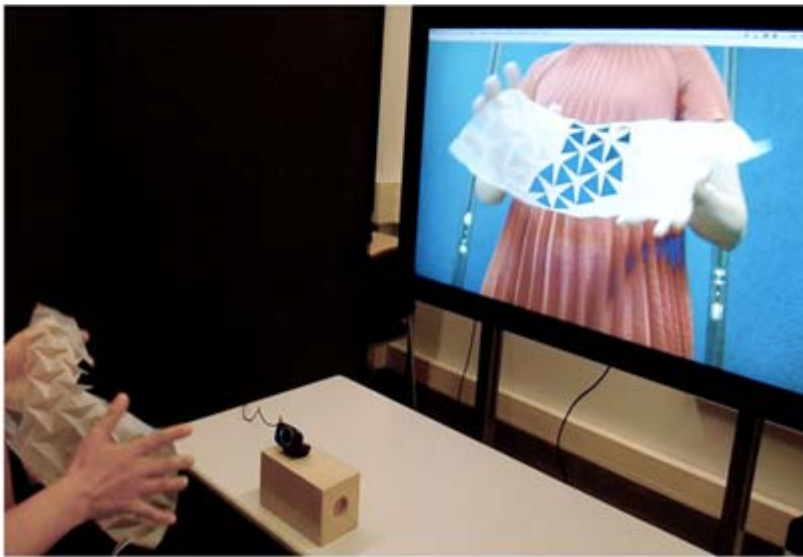
What outcomes have been achieved
or are foreseen?

Acknowledgments

The research provided a theoretical framework (aim-

This work was part of the European Union (EU) project Light Touch Matters and received funding from the EU's Seventh Framework Program (FP7/2007–2013) under grant agreement number 310311.





Bahareh Barati

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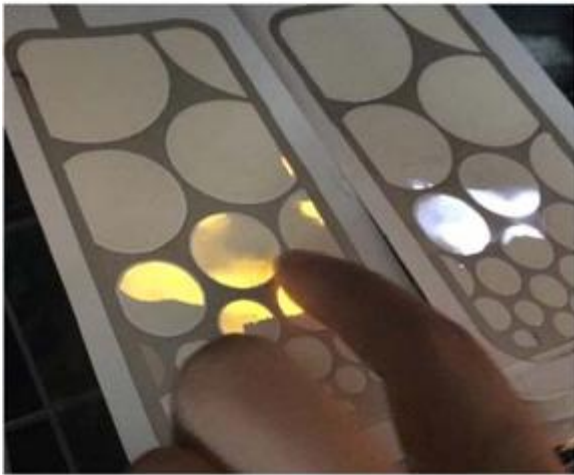
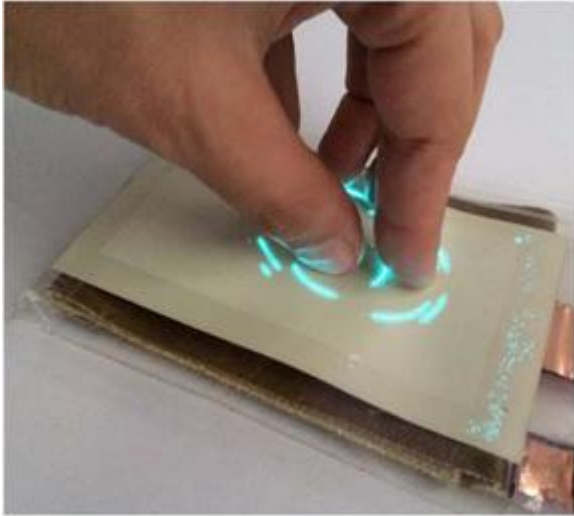
FIGURE 1

Analysis of the activities and the prototypes across a design process departing from physical and functional descriptions of LTM

materials. The design project was carried out by master's students of Interactive Technology Design course, TU Delft, 2014.

FIGURE 2

Chroma key prototyping toolkit proposed to support exploration and communication of experiential qualities of an underdeveloped smart material composite: preparation of the physical mock-up by adding velvety stickers (top) and the appearance of the real-time Chroma-key effect on the screen (bottom). Design and photo credits by the author.



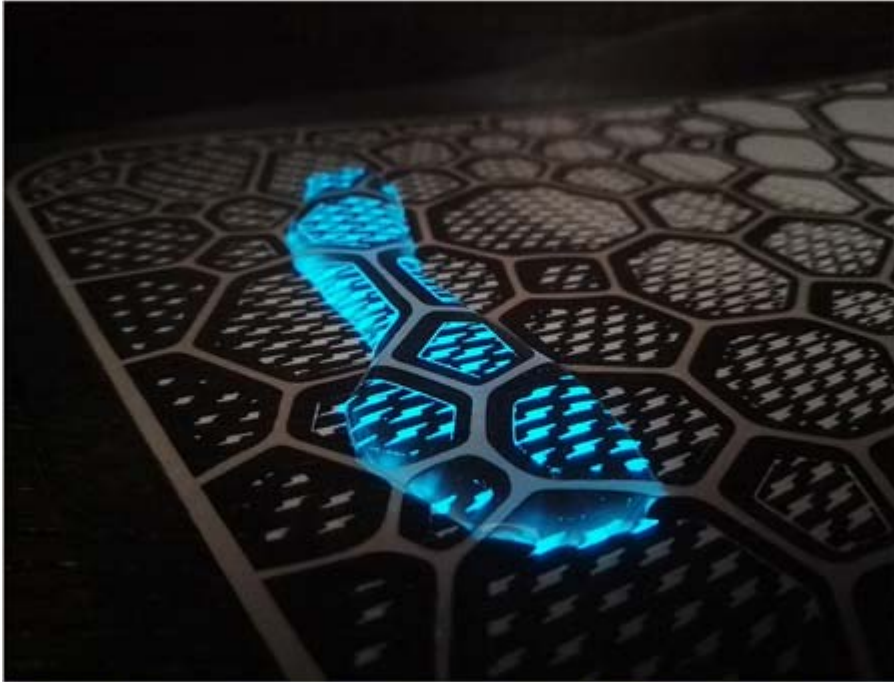
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PROJECT 1:

Design touch matters

FIGURE 3

Designers encourage new actions through alterations to the basic ingredient, structure, form, and elements of computation when processing electroluminescent samples: pressing and pinching to see the hidden texture (top), brushing the wet surface with the fingers (center), squeezing and kneading to spread the light (bottom). Design credits by Stan Claus (top and middle) and the student of Material Driven Design course (bottom), TU Delft, 2016–2017.



Bahareh Barati

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FIGURE 4

The final concept of a material-driven design process pushes for a novel experience of rain, using the custom-made water-activated EL

print (top). Master's graduation project by Stan Claus, TU Delft, 2016. Photo credits: Wiersma Brothers.

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P R O J E C T 2

Design for hybrid material systems: a material augmentation framework for meaningful experiences

Stefano Parisi

Design Department, Politecnico di Milano, Milan, Italy

Supervisor: Assoc. Prof. Dr. Valentina Rognoli

My research focuses on Hybrid Material Systems, methods, approaches, procedures, and guidelines defined as material-based systems combining inactive ([Fig. 1](#)). These are grounded in material-driven design, materials, stimuli-responsive smart materials, and systemic design, speculative design, metaphors and embedded sensing, computing, and actuating micro-analogies, and biomimicry. Hybrid Material Systems technologies. They arise as emerging materials and

based on alternative bio-based materials with embedded technologies to be introduced as tangible interfaces in embedded electronics and smart components are revealing a wide range of sectors for esthetic enjoyment and excellent potential as a raw material for tinkering and functional enhancement.

iterative experimentation, soft robotics, and ephemeral interface applications, while also responding to the demand for more sustainable materials ([Fig. 2](#)).

The research adopts a speculative approach due to the presence of current technological limitations that will eventually be overcome through miniaturization and

Parisi, S., Rognoli, V. (2021). Design for ICS Materials: advancement. I aim to identify meaningful and purposeful ways for designing with and for Hybrid the development of tools and methods for the inspiration and ideation phases. In: V. Rognoli, V. Ferraro Material Systems. Indeed, the integration of such (Eds), ICS Materials: interactive, connected, and smart materials into everyday design practice and into appli-

materials, 203-217. Design International series. Franco

cations that foster people's appreciation and accep-

Angeli. http://ojs.francoangeli.it/_omp/index.php/oa/

tance implies complex and novel experiences that

[catalog/book/641](#)

designers need to comprehend and master.

Parisi, S., Rognoli, V., Spallazzo, D., & Petrelli, D.

What are the meaningful experiential patterns Hybrid

(2018). ICS materials: Towards a re-interpretation of

Material Systems enable and imply for users and

material qualities through interactive, connected, and

designers? What are the relations and entanglements

smart materials. In Proceedings of DRS 2018 interna-

between their material qualities and their interactive beha-

tional conference of the design research society vol-

vivors? To obtain answers, my research uses a mixed-

ume 4 (pp. 1747 1761). Limerick: University of

method design, collecting mainly qualitative data through

Limerick.

a set of studies based on observations of projects,

questionnaires, and research through design using Do-It-Yourself (DIY) materials and material tinkering.

Why is the research needed?

I have progressively organized the results and findings

The research aims to support designers and design students from each study into a framework composed of tools, methods in understanding, conceptualizing, and designing

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00014-4>

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P R O J E C T 2 :

Design for hybrid material systems

with and for complex materials systems with dynamic,

What is the next big challenge for

interactive, and smart behaviors—named as “Hybrid the research area?

Material Systems”—for meaningful experiences that foster people’s appreciation.

Sustainability represents a challenge and a topic to

explore when dealing with Hybrid Material Systems,
in particular, regarding the use of organic materials or
the implementation of bio-sensors and bio-actuators

Which aspects of “materials
to replace electronics.

experience” does the research
valorize?

Which publications most inspired

The research unfolds and discusses significant and
or informed the research?

recurrent experiential patterns enabled by materials
with interactive qualities. It articulates the relations
Giaccardi, E., & Karana, E. (2015). Foundations of
between their static and temporal forms, emphasizing
materials experience: An approach for HCI. In
the fluctuating nature of materials experience.

Proceedings of the 33rd annual ACM conference on human
factors in computing systems CHI'15 (pp. 2447-2456).

New York: Association for Computing Machinery.

How will the research impact

Razzaque, M. A., Delaney, K., & Dobson, S. (2013).

Augmented materials: Spatially embodied sensor network designers?

works. *International Journal of Communication Networks and Distributed Systems*, 11(4), 453-477.

Designers and design students can benefit from novel and

systematically

organized

tools,

methods,

Vallgård,

A.

(2009).

Computational

composites:

approaches, and notions when designing with and for

Understanding the materiality of computational technology

complex material systems with dynamic behaviors, to

[PhD thesis, The IT University of Copenhagen,

more easily comprehend and enhance meaningful

Copenhagen].

experiences.

Ritter, A. (2006). Smart materials in architecture, interior architecture and design. Basel: Birkhauser.

What outcomes have been achieved

Acknowledgments

or are foreseen?

The research has been partially funded by Fondazione

The research proposes an ontology and taxonomy of

F.lli Confalonieri. Parts of the research have been

Hybrid Material Systems and identifies a framework

carried

out

in

cooperation

with

the

projects

to design with and for them. This is implemented into

ICS_Materials (<http://www.icsmaterials.polimi.it>) and a set of tools, methods, procedures, guidelines, and

InDATA (<http://www.indata.polimi.it>) at Politecnico learning contents, which have been applied and tested

di Milano, with the Digital Materiality Lab at Sheffield

mainly in design workshops with students, delivering

Hallam University and the Institute for Material

concepts and prototypes ([Fig. 3 and 4](#)).

Design at Offenbach School of Arts and Design.



Stefano Parisi

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FIGURE 1

Applying and testing tools and methods in the workshop “NautICS Materials” with Master in Yacht Design students at POLI.design, Milano,

with Arianna Bionda and Andrea Ratti, 2018. r Author.



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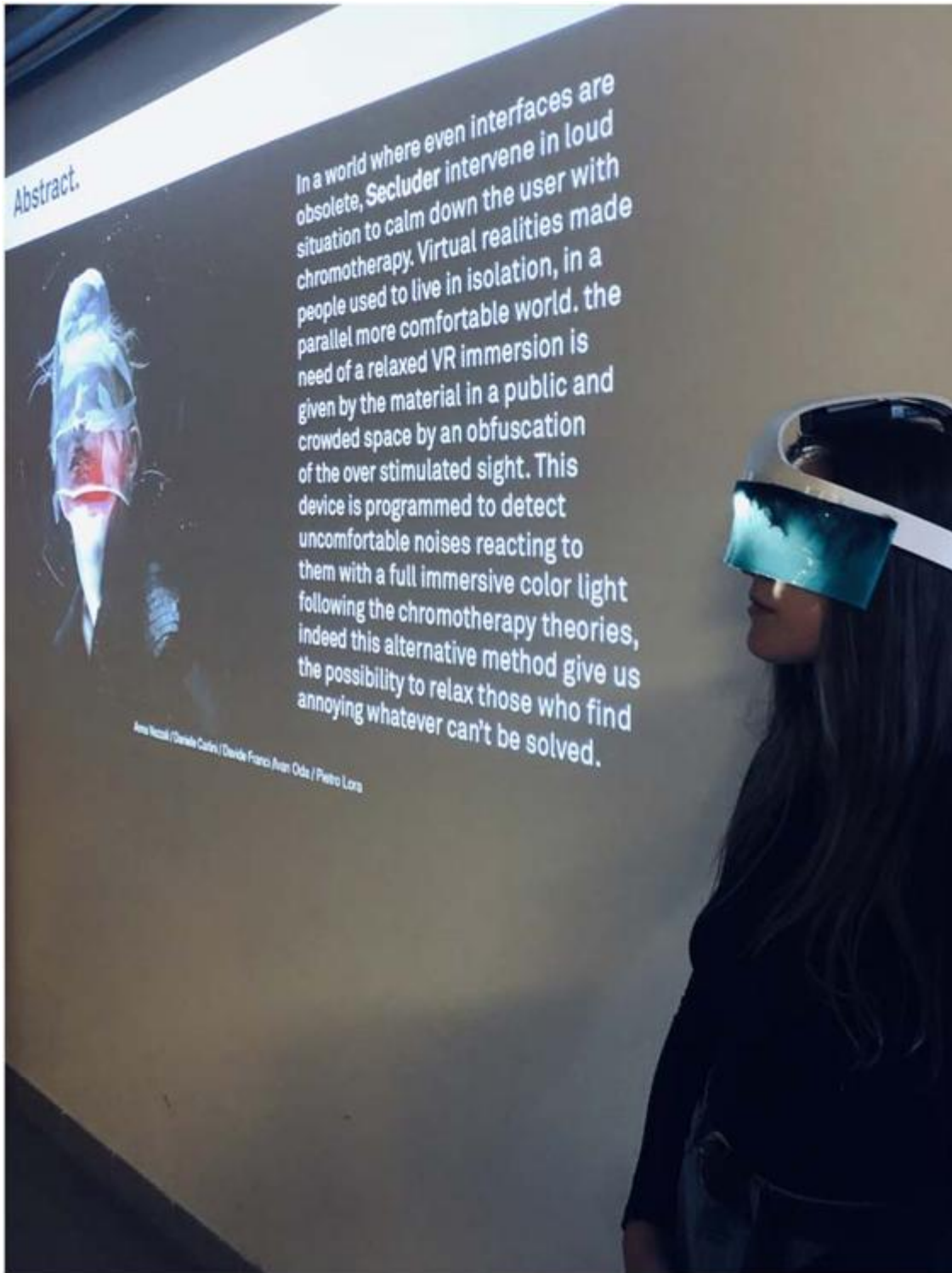
PROJECT 2 :

Design for hybrid material systems

FIGURE 2

Tools and guidelines were applied in the production of light-emitting bioplastic samples due to the inclusion of light-emitting diodes (LEDs), in the workshop “Coded Bodies” by Giulia Tomasello at the Politecnico di Milano, School of Design, Design for the Fashion System Studio (Prof. Paola Bertola), 2019. Samples realized by Mara Iannoni, Shiva Jabari, Aleksandra Obradovid, and Yang Xiaoxuan.

r Author.



Stefano Parisi

FIGURE 3

Responsive light-emitting visor from “Data , . Materials” Hackathon with the InDATA project team (with Ilaria Mariani, Patrizia Bolzan, Mila Stepanovic, and Laura Varisco), at the Politecnico di Milano, School of Design, 2019. Prototype and concept realized by Anna Vezzali, Daniele Carlini, Davide Franci, Ivan Oda, and Pietro Lora. r Author.



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PROJECT 2 :

Design for hybrid material systems

FIGURE 4

Touch-sensitive vibrating and light-emitting bio-skin and responsive light-emitting mask from “Data , . Materials” Hackathon with the InDATA project team (with Ilaria Mariani, Patrizia Bolzan, Mila Stepanovic, and Laura

Varisco) at the Politecnico di Milano, School of Design, 2019. Prototypes and concepts realized by Emanuele Belà, Marjia Nikolic, Li Chen, Aurelie Glaser, Davide Minighin, Leonardo Saletta, Andrea Torrone, and Elena Ukulova. r Author.

P R O J E C T 3

An investigation of the esthetics and technologies of photochromic textiles

Dilusha Rajapakse

School of Arts and Design, Nottingham Trent University, Nottingham, United Kingdom

Supervisors: Prof. Amanda Briggs-Goode and Prof. Tilak Dias

The ability to transform the expression of a material stages of the research process were complemented surface through changes in colors and decorative patterns with critical reflective practice. This enabled me to obtain an in-depth insight into the behavior of the materials because of the huge potential for creating a dynamic materials and translate my experiential learning into effect but also with respect to esthetic and emotional documented explicit knowledge. pleasure. If these transformations repeatedly and

The exploration of the visual characteristics, experientially occur as a response to external environment of flat-bed screen printing processes, and stimuli and then gradually disappear without leaving different activation technologies revealed a number of interesting traces, they can be visually stimulating and decisive parameters that could be executed to obtain an aesthetically pleasing for observers. The concept behind new level of dynamic photochromic aesthetic outcomes my practice-based design research project was to be applied on textile surfaces.

to invent and integrate such transformable dynamic aesthetic experiences onto textile surfaces with the Rajapakse, D. (2019). An investigation of the application of smart photochromic materials.

tion of multi-colour changing photochromic textiles. Journal of Textiles and Engineer, 26(114), 196-208.

By adopting a “research through design” approach, I examined the creative textile design potential of photochromic materials. Rajapakse, D., Briggs-Goode, A., & Dias, T. (2015).

tochromic materials (water-based photochromic inks)

Electronically controllable colour changing textile design.

in relation to the areas of (1) associated visual charac-

In V. Popovic, A. Blackler, N. Nimkulrat, B. Kraal,

teristics, (2) flat-bed screen printing as a method of

Y. Nagai & D. Luh (Eds.), Proceedings of IASDR 2015 inter-

the application process, and (3) solar UV (ultraviolet)

play (pp. 1743 1759). Brisbane: The International

radiation, artificial UV light sources and SMD (surface

Association of Societies of Design Research.

mounted device) UV LEDs (light-emitting diodes) as

potential activation methods for the excitation of pho-

tochromic colorants on textile surfaces. My design

thinking and print design practice were employed as

Why is the research needed?

leading

methods

of

inquiry,

generating

textual,
numerical, and visual data directly through experi-
This research attempts to investigate the unexploited
mentation with materials, print processes, activation
material characteristics and related design potential of
methods, and related technologies. During the experi-
photochromic colorants on textile surfaces to create
mental stages of the research, specific visual data cap-
new material experiences. The research further high-
turing procedures were consistently executed, and all
lights
the
possibilities
of
creatively
integrating

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00019-3>

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PROJECT 3 :

An investigation of the esthetics and technologies of photochromic textiles

multicolor-

and

pattern-changing

photochromic

What is the next big challenge for

effects onto textiles without compromising the core

the research area?

textile properties of softness, flexibility, washability,

drapability, and comfort.

The identification of methodological and technical

approaches for the quantification of multicolor-

changing photochromic effects will be an important

Which aspects of “materials

next step.

experience” does the research

valorize?

Which publications most inspired

The research exploits the functional and expressive/

or informed the research?

animated color-changing characteristics of photochromic materials which can add to the visual experience

Stylios, G., & Chen, M. (2016). Psychotextiles and in daylight conditions.

their interaction with the human brain. In V. Koncar (Ed.), *Smart textiles and their application* (1st ed.)

(pp. 197-239). Cambridge: Woodhead Publishing

How will the research impact on

Ltd.

designers?

Viková, M., Christie, R., & Vik, M. (2014). A unique device for measurement of photochromic textiles.

The theoretical and technical knowledge generated

Research Journal of Textile and Apparel, 18(1), 6-14.

in this research can guide future design practitioners

to take informed approaches to the handling of

Little, A., & Christie, R. (2011). Textile applications of photochromic materials on textile surfaces.

photochromic dyes. Part 3: factors affecting the techni-

cal performance of textiles screen-printed with commercial photochromic dyes. *Coloration Technology*, 127(5),

What outcomes have been achieved

275-281.

or are foreseen?

Worbin, L. (2010). *Designing dynamic textile patterns*

[Doctoral thesis, University of Borås, Borås]. , <http://>

A design-centered approach has been articulated that

urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-3552.

introduces a number of generalizable decisive para-

Accessed 08.06.20.

meters associated with design, application, and activa-

tion of dynamic photochromic effects on textile

surfaces.

Furthermore,

a

unique

collection

of

Acknowledgments

expression-changing photochromic textile samples/

prototypes has been produced, each capable of

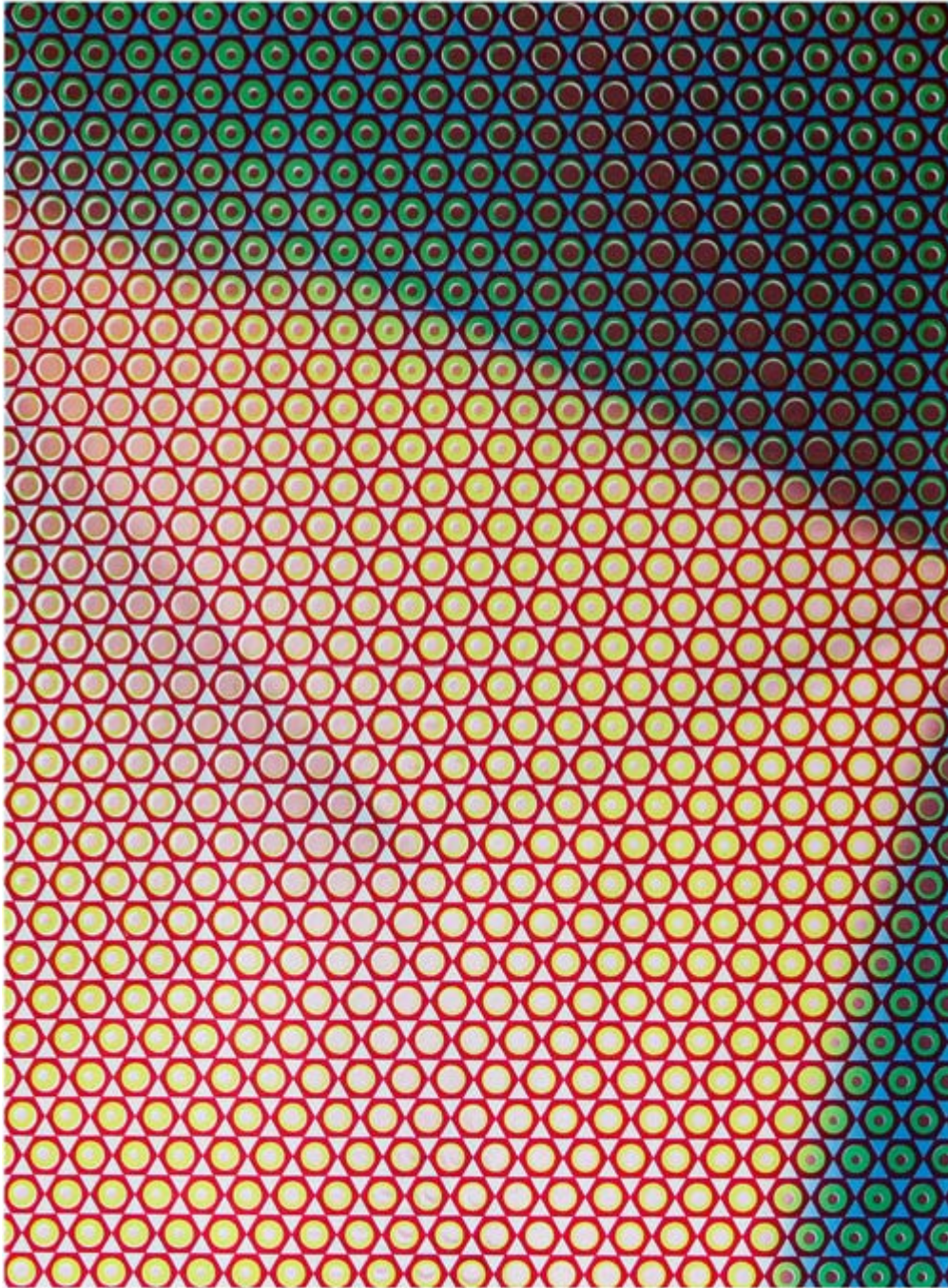
This research is fully funded by the Vice-Chancellor's

instantly transforming from one expression to another

PhD Scholarship provided by the Nottingham Trent

when exposed to UV radiation.

University.



Dilusha Rajapakse

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FIGURE 1

Upon exposure to UV, the printed geometrical design morphs reversibly between complementary color expressions. r Author.



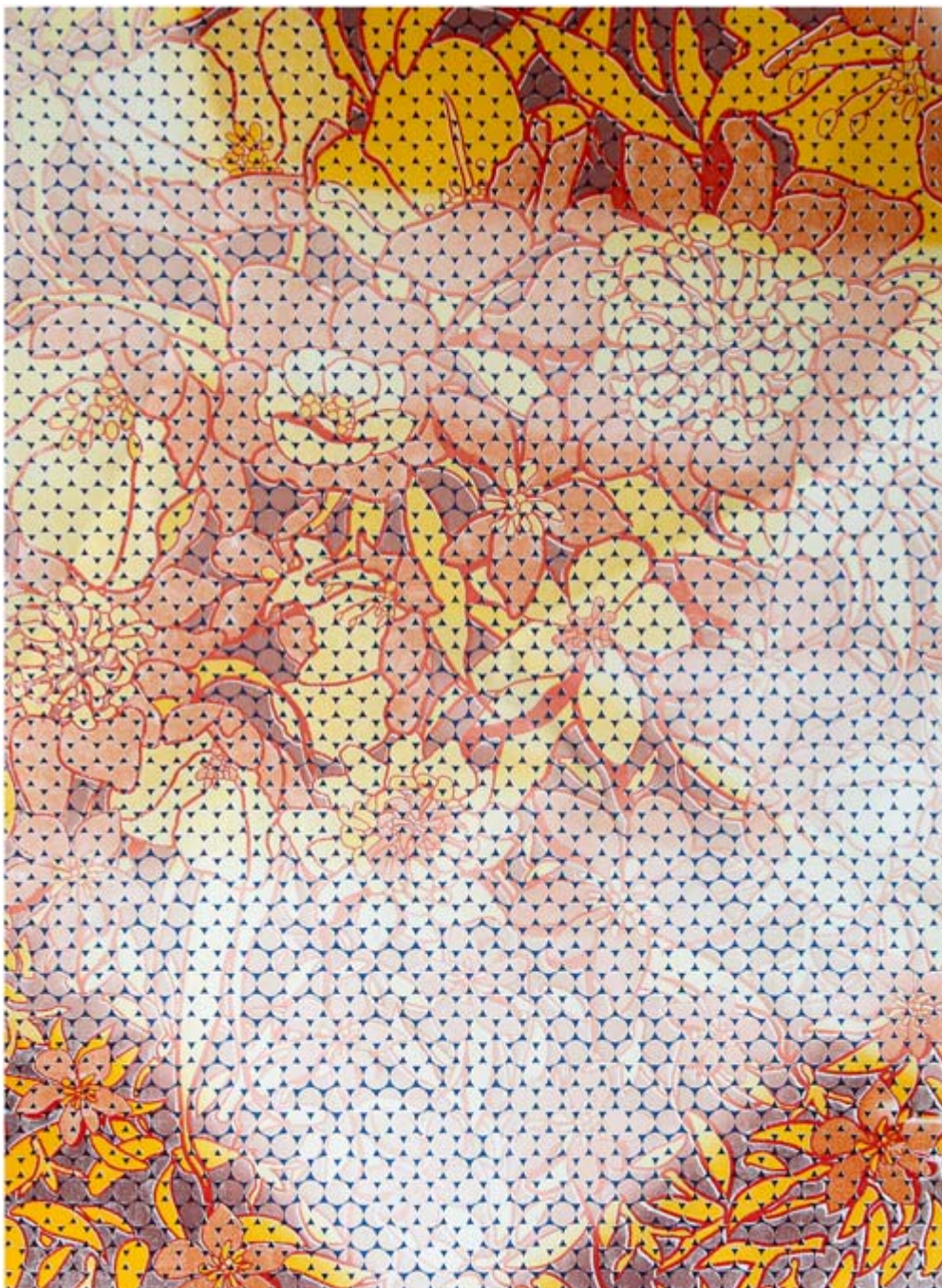
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PROJECT 3 :

An investigation of the esthetics and technologies of photochromic textiles

FIGURE 2

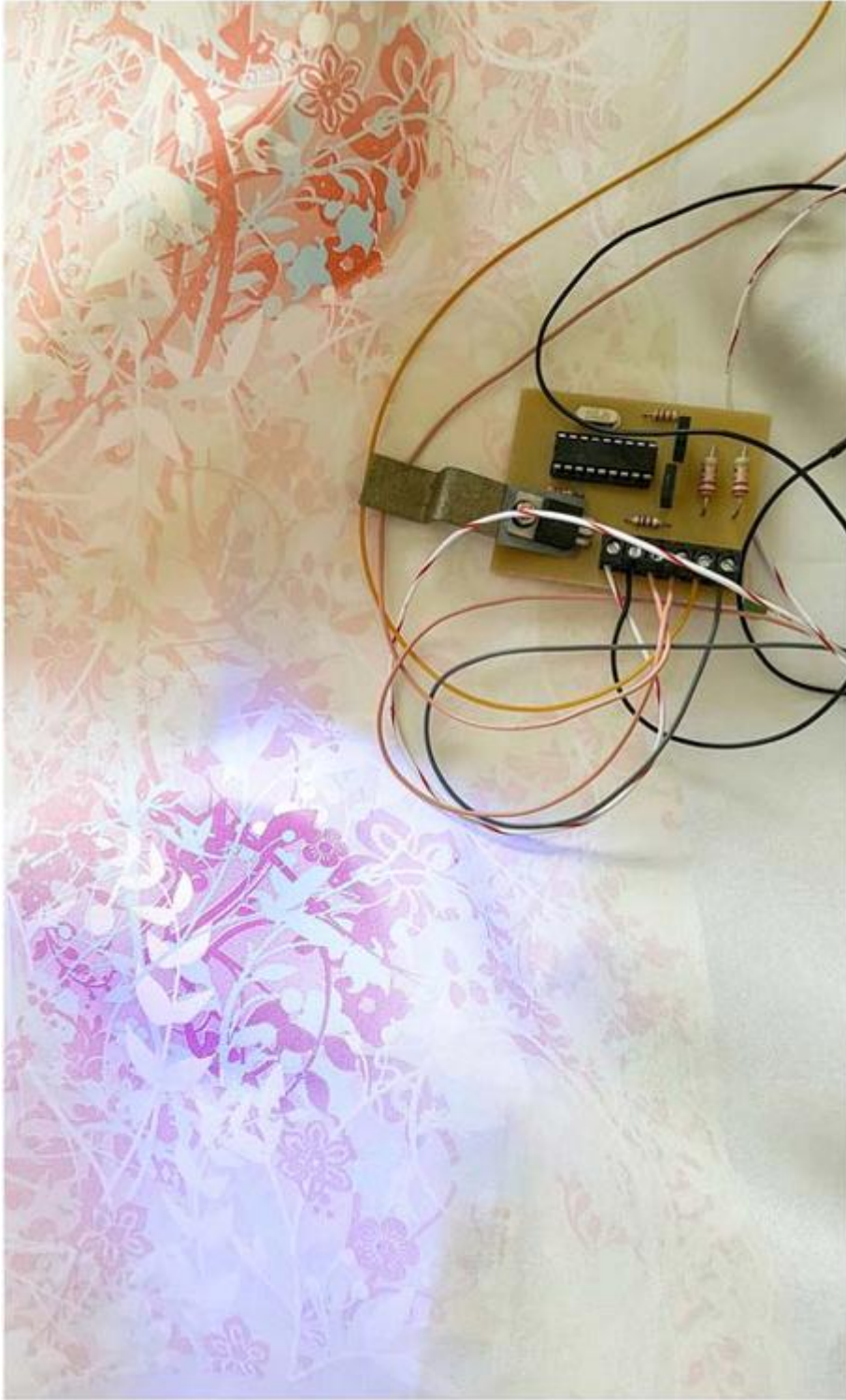
Under UV light, the textile surface changes from a monochromatic design to a multicolored floral design. r Author.



Dilusha Rajapakse

FIGURE 3

Under UV light, the textile surface changes from a geometrical pattern to a multicolored floral design. r Author.



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PROJECT 3 :

An investigation of the esthetics and technologies of photochromic textiles

FIGURE 4

Electronically activating and controlling the dynamic photochromic effect on textile surfaces. r Author.

P R O J E C T 4

Reflective weaving practice in smart textile

material development process

Emmi Anna Maria Pouta

Department of Design/Department of Communications and Networking,
Aalto University, Espoo, Finland Supervisors: Assoc. Prof. Kirsi Niinimäki
and Asst. Prof. Yu Xiao

Jussi Ville Mikkonen

Department of Electronics and Communications Engineering, Tampere
University of Technology, Tampere, Finland Supervisor: Prof. Dr. Jukka
Vanhala

Our work is research-through-design, examining how
first experiment integrated sensors that react to a mov-
electrical and sensorial properties can be merged in com-
ing magnet, while the second involved a development
plex woven structures to expand the experiential quali-
of a weaveable component yarn containing a micro-
ties of woven smart materials in user interface design.

processor. These examples allowed an examination of
The main methods combine prototyping practices from
the separation of the material and the material interac-
electronics and textile design, emphasizing the first
tion behavior, highlighted by the electrical material
author's reflective weaving practice and user testing in a
qualities during an interaction.

controlled environment. The analysis of the research is
grounded on transdisciplinary evaluation—electronics
Design experiments 3 6 focused on developing
engineering and textile design. We discuss prototypical
touch-sensitive structures by utilizing different fibers,
material examples through the lens of reflective weaving
weaves, and visual elements. The focus shifted from a
practice, in particular, woven e-Textile design that con-
thorough investigation of the electrical potential of
siders a synthesis of different interaction design, elec-
multilayer structures to the sensorial properties of
tronics engineering, and textile design aspects. We have
woven e-Textiles. The seventh design experiment was

explored the use of different weaving techniques, such as an interactive hand-puppet, situated in a user-centered process as jacquard weaving, fil coupé-technique, and multilayer smart textile development process. The user experience double cloth in seven design experiments, consisting of and preferred interactions were a guideline for the e-multilayer circuitry and component integration, touch-Textile design process, dominating the development sensitive sensor structures, and a fully integrated woven of the technical construction.

user interface. The seven design experiments form a con-

Our woven samples informed the textile behavior and

tinuum,

evolving

from

an

electronics-centered

to

weaving experience, providing cases with which to

material-centered process.

analyze how the material guided the weaving process. In the first two design experiments, we explored digital textiles by integrating electronics components to a material thinking process. Through analyzing the reflective notes and materials in these processes, we examine how textile thinking weaves from a traditional electronics circuit perspective, and the materiality of interaction intertwines with providing a basis for electronics-led discussion. The Schön's concept of "reflective practice."

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00018-1>

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PROJECT 4 :

Reflective weaving practice in smart textile material development process

Pouta, E., & Mikkonen, J. (2019). Hand puppet as

What outcomes have been achieved

means for eTextile synthesis. In Proceedings of the thir-

or are foreseen?

teenth international conference on tangible, embedded, and

embodied interaction (TEI '19) (pp. 415 421). Tempe:
First, hand-woven e-Textile samples have been created.
ACM Press. [doi:10.1145/3294109.3300987](https://doi.org/10.1145/3294109.3300987).

The samples aid understanding of how sensorial and
Mikkonen, J., & Pouta, E. (2016). Flexible wire-
electrical properties of e-Textile materials intertwine in
component
for
weaving
electronic
textiles.

In
complex woven textiles. Second, a reflective weaving
Proceedings of IEEE 66th electronic components and tech-
practice for smart textiles has been developed, com-
nology conference (ECTC) (pp. 1656 1663). Las Vegas:
prising a method for guiding multilayer weaving of
IEEE. [doi:10.1109/ECTC.2016.180](https://doi.org/10.1109/ECTC.2016.180).

smart materials through an analytical process.

What is the next big challenge for

Why is the research needed?

the research area?

The research focuses on investigating how materiality

For the future, a better understanding is needed of

of interaction—a key part of materials experience—

what a textile-specific interaction can be, with the abil-

and textile thinking can be comprehensively applied

ity to develop suitable e-Textile interfaces in an inter-

to woven e-Textile development, through a reflective

disciplinary team.

weaving process, and how the design and develop-

ment process of a smart textile artifact can be synthe-

sized in woven eTextile design.

Which publications most inspired

or informed the research?

Devendorf, L., & Di Lauro, C. (2019). Adapting dou-

Which aspects of “materials

ble weaving and yarn plying techniques for smart tex-

experience” does the research

tiles applications. In Proceedings of the thirteenth

valorize?

international conference on tangible, embedded, and embodied interaction (pp. 77 85). Tempe: ACM.

The work extends the understanding of reflective

Gowrishankar, R., Bredies, K., & Ylirisku, S. (2017).

smart material development, more specifically on how

A strategy for material-specific e-Textile interaction

electrical and sensorial properties of the materials

design. In S. Schneegass & O. Amft (Eds.), Smart tex-

translate into functional and experiential qualities of

tiles:

Fundamentals,

design,

and

interaction

user interfaces.

(pp.

233 257).

Cham:

Springer

International

Publishing.

Poupyrev, I., Gong, N., Fukuhara, S., Karagozler, M.,

How will the research impact on

Schwesig, C., & Robinson, K. (2016). Project jacquard:

Interactive digital textiles at scale. In Proceedings of the designers?

2016 CHI conference on human factors in computing systems (pp. 4216-4227). San Jose: ACM.

Woven multilayer e-Textiles is an uncharted domain, requiring a deep understanding of woven structures

Veja, P. (2014). An investigation of integrated woven and material behavior in an interdisciplinary context.

electronic textiles (e-textiles) via design led processes

Our research provides guidelines on how to navigate

[PhD thesis, Brunel University, London]. , [http://bura.](http://bura.brunel.ac.uk/handle/2438/10528)

the area.

[brunel.ac.uk/handle/2438/10528](http://bura.brunel.ac.uk/handle/2438/10528). Accessed 22.04.20.



Emmi Anna Maria Pouta and Jussi Ville Mikkonen

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FIGURE 1

Collection of capacitive and piezoresistive touch and pressure sensor fabrics. r Pouta, Emmi. (2019) Touch Interwoven. Aalto University, Espoo.

FIGURE 2

Digital textile explorations on magnetic field sensing (left) and microprocessor integration (right). r Pouta, Emmi. (2016) Woven circuitry. Aalto University, Espoo.



PROJECT 4 :

Reflective weaving practice in smart textile material development process

FIGURE 3

Child interacting with the hand puppet through the fully integrated touch-sensitive user interface. r Pouta, Emmi. (2019) Interactive hand puppet. Aalto University, Espoo.

FIGURE 4

The loom provides a stable base for the textile construction versus a free-flowing finished textile. r Pouta, Emmi. (2019) Touch Interwoven. Aalto University, Espoo.

P R O J E C T 5

Sound as a project requirement: evolution of an
experimental tool for psychoacoustic evaluation
of materials in architecture and design

Doriana Dal Palù

Department of Architecture and Design, Politecnico di Torino, Torino, Italy

Supervisors: Prof. Claudia De Giorgi and Prof. Arianna Astolfi

Co-supervisors: Dr. Beatrice Lerma and Dr. Eleonora Buiatti

Describing a product sound in simple words, in order to
processes derived from sensorial analysis matter and
create a clear communication between designers and
adopted to give a qualitative characterization to the

end-users, is a complex issue (Dal Palù et al., 2018).

mechanical sounds. Furthermore, subjective data were

Each mechanical product sound is generated by the

compared to objective acoustic and psychoacoustic mea-

interaction between materials, configuration forms, and

surements (i.e., loudness, sharpness, roughness, fluctua-

excitation modes (Dal Palù & De Giorgi, 2018). The rela-

tion strength, and tonality).

tion between sound perception and description and mate-

The comparability of sounds obtained with the

materials experience is, therefore, fundamental. In 2011, an

SounBe method and from the real object in action,

interdisciplinary research group from Politecnico di Torino

which was assumed as a reference, was proved.

(Polito)—to which I am part—developed SounBe, an

Consequently, I arranged a set of tests adopting the

innovative patented tool and method conceived to support

semantic differential technique, disclosing the possi-

designers in their selection of the most suitable materials

bility to also adopt this technique to sounds obtained

within the possible hyperchoice, taking into consideration with the SounBe tool. The final step of my research sound as a project requirement. However, an effective validation of the efficacy of SounBe as a tool and method was interest in investing in the technology.

lacking. My research looked to validate the SounBe tool and method, verify its accuracy as a design tool as well as Dal Palù, D., De Giorgi, C., Lerma, B., & Buiatti, E.

the effectiveness of the possible research on product sound (2018). *Frontiers of sound in design: A guide for the development of product identity through sounds*. Cham: Springer International Publishing AG.

Starting from MATto, the Polito Material Library, I carried out the experimental phase in the anechoic chambers in A new disciplinary sub-field? / Il suono nel design: Un Polito and IRCAM (Institut de Recherche et Coordination

nuovo

sottoambito

disciplinare?,

DIID

Disegno

Acoustique/Musique) in Paris. Office chair rolling sounds

Industriale Industrial Design, 65, 70 77.

represented the main case study of the experimentation

because of the known relationship between workspace

soundscapes and workers' health, job satisfaction, and

Why is the research needed?

well-being. More than 90 participants carried out listening

tests performed under ecologic, laboratory, and SounBe

The SounBe method and tool is informed by the sen-

conditions, comparing the results of the descriptive

sory analysis techniques adopted to describe wines

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00031-4>

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PROJECT 5 :

Sound as a project requirement

and foods, involving the human being as a central element—exploring a database of sounds connected with material of the evaluation process. It can be applied to colors, shapes, and gestures—on the one hand—and every sort of material to provide a new layer of information—descriptive and shared labels—on the other hand. Information focused on designing a product sound.

What is the next big challenge for

Which aspects of “materials

the research area?

experience” does the research

valorize?

After the PhD, a new working prototype of SounBe

was developed, with one firm now improving its

This research has contributed to a widening of the

product sound through the use of the tool and

materials experience sphere into the domain of

method—a challenge is to increase the commercial

“designed sound,” that is, intentional sounds from uptake.

materials that are planned before being produced and reproduced.

Which publications most inspired

How will the research impact on

or informed the research?

designers?

Byron, E. (2012, October 24). The search for sweet sounds that sell. Household products’ clicks and Sound design, tied to materials sound experience, can hums are no accident; light piano music when the be extended from the luxury products domain—traditionally interested in the global quality perception—to http://homepages.cae.wisc.edu/Bme349/info/sweet_sounds.pdf.

the professional and general consumer products

[pdf](#). Accessed 07.05.20.

domain.

Ferreri, M., & Scarzella, P. (2009). Sound objects, the

invisible dimension of design. / Oggetti sonori, la dimen-

What outcomes have been achieved

sione invisibile del design. Milan: Electa.

or are foreseen?

Norman, D. A. (2004). Emotional design: Why we love

(or hate) everyday things. New York: Basic Books.

The validation of SounBe, a previously patented tool

and method for the psychoacoustic evaluation of

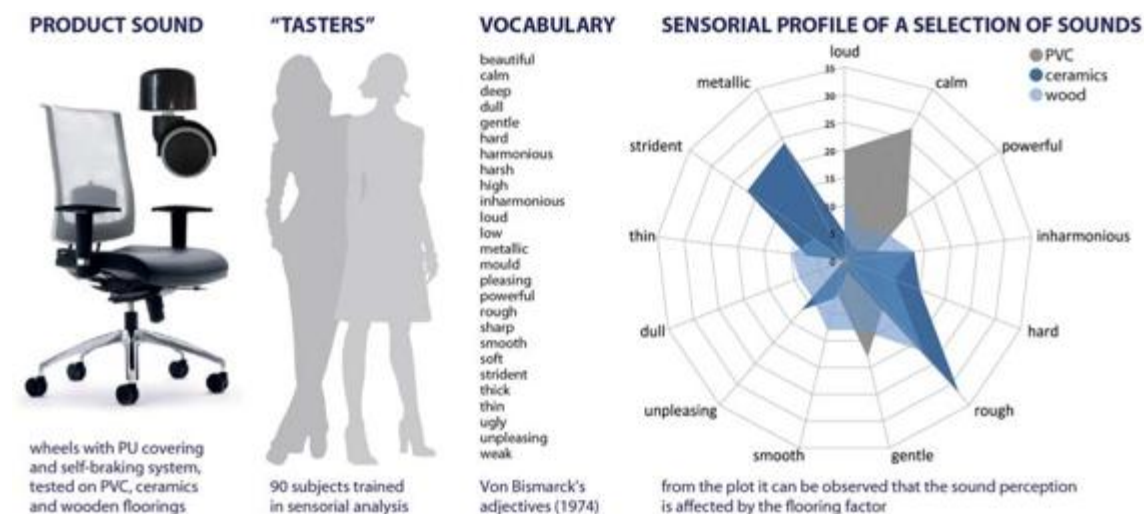
Schafer, R. M. (1977). The soundscape: Our sonic envi-

ronment and the tuning of the world. Rochester: Destiny

of data on the perceived sound quality of materials,

Books.

Books.





Doriana Dal Palù

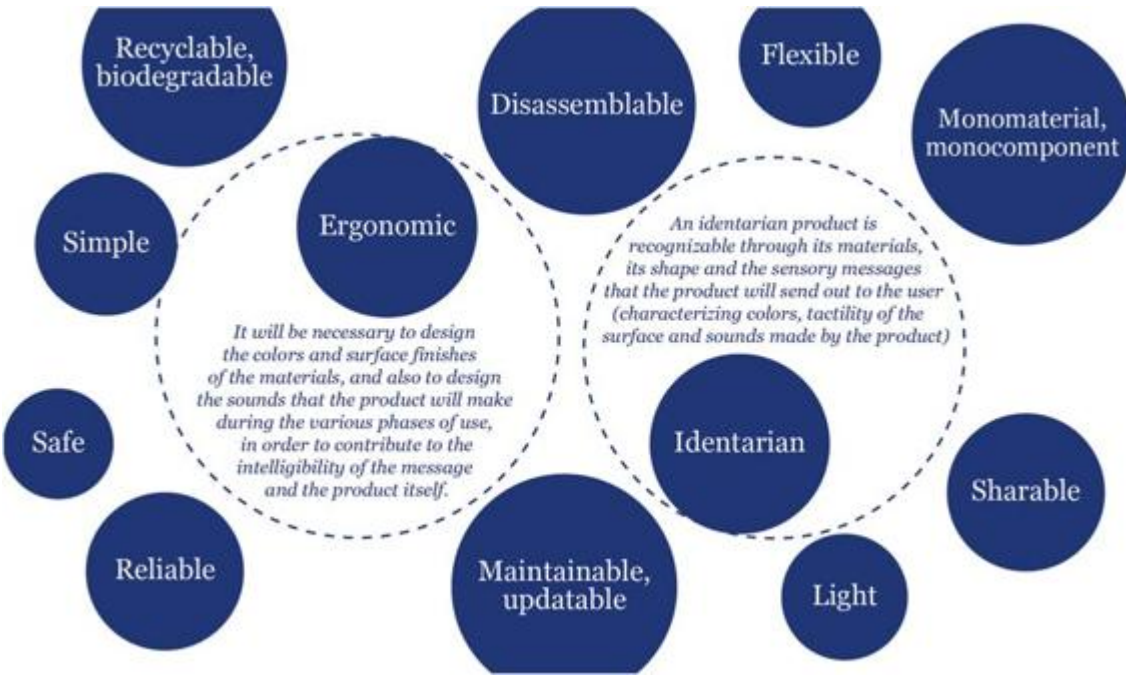
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FIGURE 1

Version of the industrialized SounBe tool. r Doriana Dal Palù and Giulia Pino.

FIGURE 2

A synthetic view of the possible results of a sound design investigation. r Author.



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PROJECT 5 :

Sound as a project requirement

FIGURE 3

Improved set of product requirements, following the sound design integration. r Doriana Dal Palù and Claudia De Giorgi.

FIGURE 4

The possibility to design product sounds from luxury to everyday products. r Author.

P R O J E C T 6

Animated puppet skin design: material
narratives in visually experienced objects

Vincenzo Maselli

Department of Planning, Design and Technology of Architecture, Sapienza University of Rome, Rome, Italy Supervisors: Prof. Carlo Martino and Prof. Cecilia Cecchini

In my work, I conducted qualitative research into
In the third phase, an interpretation of symptomatic
both puppet animation and the product design field
meanings was made. I established four themes (creation,
following the three main phases. In the first phase,
control, nostalgia, and imperfection) and investigated the
I outlined a theoretical framework. I brought together
aspects through which each short film suggests the
research about invisible significances of materials

themes. In summary, the combined parameters and developed in the material design field, in addition to resources used for the research were as follows:

research that values material features in the analysis of

(1)

anthropological

meanings

of

used

materials,

animated puppet films. In the former research, I was

(2) anthropological meanings of manufacturing pro-

informed and inspired by the studies of Eleonora

cesses, and (3) relationships between the aforementioned

Fiorani, Valentina Rognoli, Marinella Levi, Elvin

meanings and the diegetic level of the analyzed films.

Karana, and others. In the latter, the evocativeness of

Maselli, V. (2019). Performance of puppets' skin

the surface material qualities of puppets in the analy-

material: The metadiegetic narrative level of animated

sis of stop-motion films drew upon the work of puppets' material surface. The International Journal of Suzanne Buchan, Peter Hames, Barry Purves, and Jane Visual Design, 13(2), 17-37.

Batkin. Unlike the experience of material objects, in the filmic experience users are spectators who interact

Maselli, V. (2018). Puppets animati e materiali:

visually with materials. They experience only the

Analisi dei meta-racconti di oggetti esperiti visiva-

superficial layer of the object, leading me to adopt the

mente. In R. Riccini (Ed.), Sul metodo/sui metodi.

ideas of "haptic approach" and "tactile looking" from

Esplorazioni per le identità del design (pp. 327-335).

the field of film studies developed, respectively, by

Milano: Mimesis (in Italian).

Laura Marks and Jennifer Barker.

In the second phase, I selected short films that belong

Why is the research needed?

to a specific subgenre, defined "self-reflexive." In these

narratives, the interaction between puppet-makers and

The research investigates invisible meanings of the materials—that takes place before the shooting—is a material skin of stop-motion puppets, by reframing and connecting relevant element of the diegesis. I analyzed these films by treating puppets as design objects, while the materials of studies: product design and film studies. These meanings and fabrication processes used in the making of puppets provide new levels of narrative, and the suggested the puppets were investigated from a technical point methodology of analysis ultimately unlocks new interpretations of view. In this phase, explicit and implicit meanings according to a background settled with material, of each film’s diegesis were also defined. fabrication, and anthropological aspects.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00002-8>

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PROJECT 6 :

Animated puppet skin design

Which aspects of “materials

set of tools with which to interpret the material

experience” does the research

aspects of puppets.

valorize?

The research valorizes the analyses recently developed

What is the next big challenge for

by design scholars who have studied materials as vehi-

the research area?

cles of emotions and have focused on concepts such as significances, interpretation, and subjectivity.

The four symptomatic meanings associated with the narratives of the material (creation, control, nostalgia, and imperfection) deserve a more thorough study

How will the research impact on achieve unprecedented results.

designers?

The work provides a deeper understanding for those

Which publications most inspired

involved in puppet design on the role of surface material- or informed the research?

ity in the manufacturing process of puppets and frames

room for improvement applicable to this process.

Levi, M., & Rognoli, V. (2011). *Il senso dei materiali per il design*. Milano: FrancoAngeli. (in Italian).

What outcomes have been achieved

Barker, J. (2009). *The tactile eye: Touch and the cinematic*

or are foreseen?

experience. Los Angeles: University of California Press.

Fiorani, E. (2000). *Leggere i materiali: Con l'antropolo-*

By merging the cultural references validated by the

gia, con la semiotica. Milano: Lupetti. (in Italian).

field of product design in the analysis of fabrication

processes and material qualities, with the principles of

Marks, L., & Polan, D. (2000). *The skin of the film:*

indirect experience (tactile looking, haptic approach)

Intercultural

cinema,

embodiment,

and

the

senses.

coming from film studies, the research presents a new

Durham: Duke University Press.

FIGURE 1

Still frame, *Ab Ovo* (2012) by Anita Kwiatkowska-Naqvi. r Anita Kwiatkowska-Naqvi.



Vincenzo Maselli

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FIGURE 2

Still frame, *Ossa* (2015) by Dario Imbrogno. r Dario Imbrogno.

FIGURE 3

Still frame, *Komaneko's Christmas: The lost gift* (2009) by Tsuneo Goda. r Dwarf Studio, r TYO/dwarf-Komaneko Film Partners, and r Amis de Komaneko.



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PROJECT 6 :

Animated puppet skin design

FIGURE 4

Still frame, *Walter, a dialogue with the imagination* (2010) by Niels Hoebers. r Niels Hoebers.

PROJECT 7

Material visualization and perception in

virtual environments

Mutian Niu

School of Film and TV Arts, Xi'an Jiaotong-Liverpool University, Suzhou, P.R. China,

Department of Civil Engineering and Industrial Design, University of Liverpool, Liverpool, United Kingdom Supervisors: Dr. Cheng-Hung Lo, Dr. Richard Barrett, Prof. Yue Yong and Dr. Bingjian Liu Material representation has always been an impor-digital representation types within an automobile

tant part of design visualization. The common

interior design setting. Taking a car seat as a test

method for digital visualization is to adjust the

model, Substance Designer and Unreal Engine 4

bidirectional

reflectance

distribution

function

applications were used to deliver renderings of

model to simulate material attributes in the ren-

leather and fabric car seats. Roughness and specular-

dered scene. The evaluation of product materials

ity were used as adjustment variables. Participants

often relies on the rendering outputs of two-

were exposed to visualizations created in VR and on

dimensional (2D) displays; however, the tradi-

a 2D screen and asked to give a score for each on a Likert scale against the criteria of glossiness, roughness, reflectance, and saliency. Participants were found to more acutely detect changes in material properties under VR, especially for glossiness and saliency. Participants' more acute detection may be attributed to the visual depth in VR, which will be investigated in future research.

limited. This stimulated us to ask whether the perception in virtual environments. In T. Ahram (Ed.),

Niu, M., & Lo, C. (2020). An investigation of material perception in VR is different from that in

“

traditional” 2D digital representations, as well as Advances in human factors in wearable technologies and the possibility of using VR as a design tool for facility design (AHFE 2019)/Advances in intelligent systems facilitating users’ material evaluations.

and computing Vol. 973 (pp. 416 426). Cham: Springer.

In the first study of this research, I explored differences in material perception between VR and 2D digital material representations. I selected metal and plastic as the test materials, and a cube and sphere

Why is the research needed?

as the 3D rendered forms. Thirty participants compared the rendered VR and 2D materials and then

The research investigates to what extent the real-world evaluated the visual performance of the two digital experience of material perception can be delivered in representation types. In my second study, I explored a virtual environment. In the context of VR technology, material perception differences between the two studies are made on how the depth and

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00006-5>

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P R O J E C T 7 :

Material visualization and perception in virtual environments

immersion provided by VR may influence the user's

What is the next big challenge for

perception of visual qualities of materials.

the research area?

In the near future, evaluation of vivid depth (depth perception of the material authenticity) may provide an

Which aspects of "materials

important additional dimension of information to extend

experience" does the research

the use of VR toward the most convincing material

valorize?

appearances.

By examining the perceptibility of material qualities in

digital renderings, the research extends understanding

Which publications most inspired
of the relationship between VR technology and mate-
rial visualization?
or informed the research?

Fleming, R. (2017). Material perception. *Annual Review of Vision Science*, 3(1), 365-388.

How will the research impact on

Tang, B., Guo, G., & Xia, J. (2017). Method for indus-
try design material test and evaluation based on user
designers?

visual and tactile experience. *Chinese Journal of*

The research intends to offer designers and design

Mechanical Engineering, 53(3), 162-172 (in Chinese).

researchers insights into how to integrate VR technol-

Papagiannidis, S., See-To, E., & Bourlakis, M. (2014).

ogy in the product design process, focused on material

Virtual test-driving: The impact of simulated products
decisions.

on

purchase

intention.

Journal

of

Retailing

and

Consumer Services, 21(5), 877-887.

What outcomes have been achieved

Sharan, L., Liu, C., Rosenholtz, R., & Adelson, E.

or are foreseen?

(2013). Recognizing materials using perceptually

inspired features. *International Journal of Computer*

So far, the research has established perceptual differ-

Vision, 103(3), 348-371.

ences between VR and 2D (screen-based) material

visualization methods, using standard forms and

automotive seating as the experiment stimuli. *Design*

Acknowledgment

guidelines are being created from the experiment

results, aiming to support material selection in design

This research is partially funded with the Research

processes making use of VR technology, including the Development Fund provided by Xi'an Jiaotong-university development of suggested good practice.

Liverpool University (Project Ref. No. RDF 16-22-02).

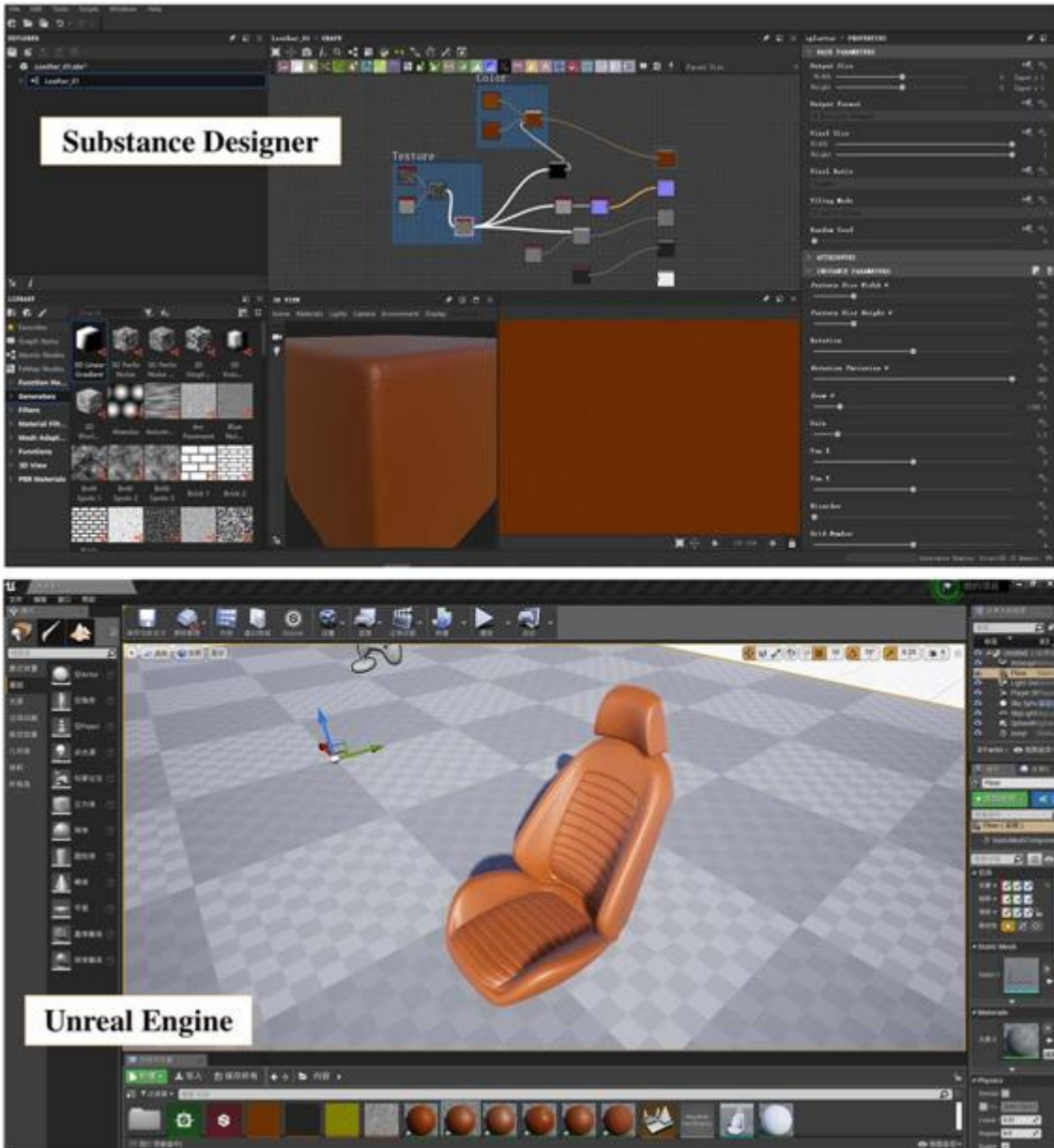


Mutian Niu

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FIGURE 1

Virtual reality (VR) testing process (left) and visual effects in VR (right). r
Author.



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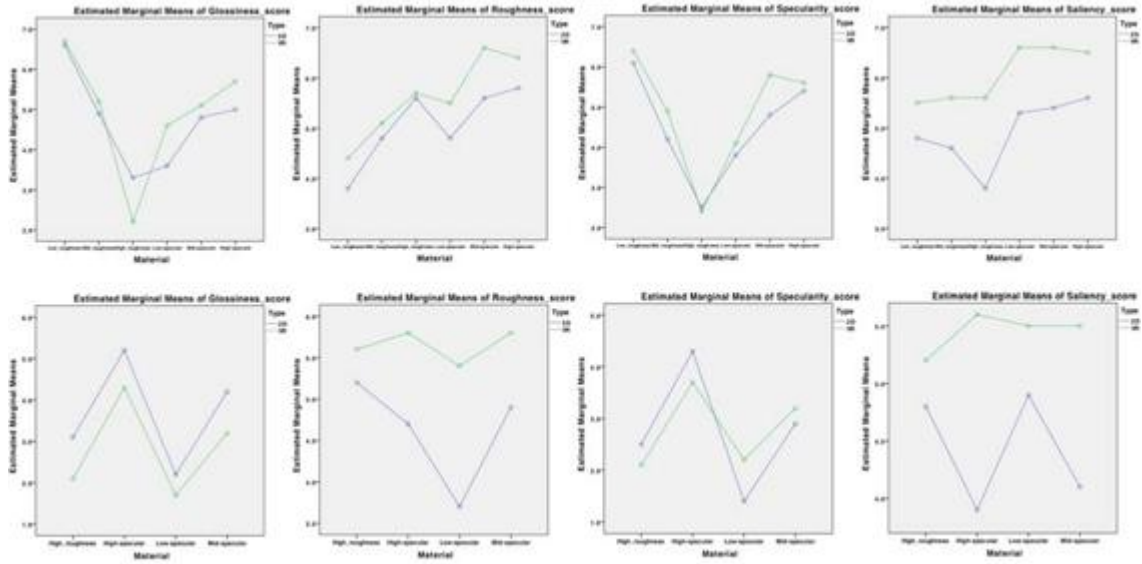
PROJECT 7:

Material visualization and perception in virtual environments

FIGURE 2

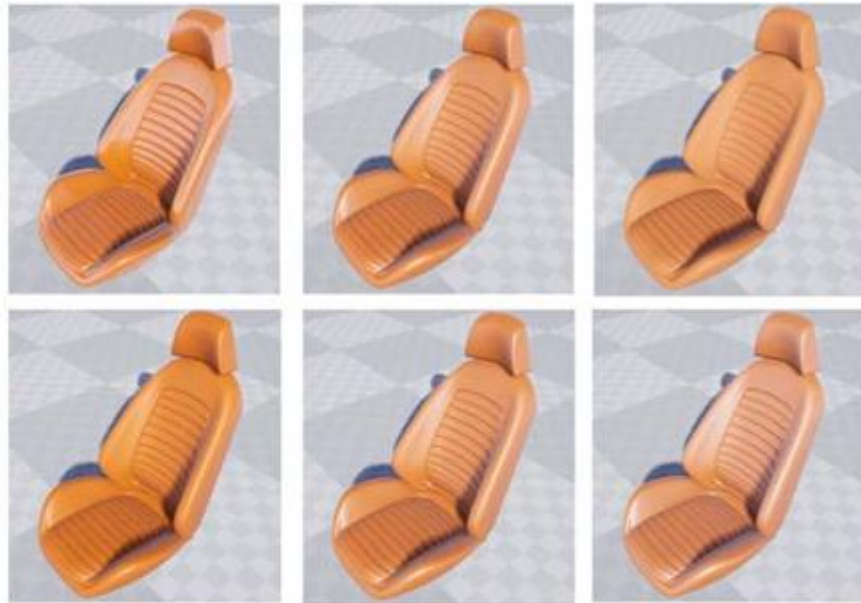
Material attribute editing interface and test model in Unreal Engine 4. r
Author.

Leather



Fabric

Leather



Fabric



Mutian Niu

FIGURE 3

Applying materials to 3D models of automobile seats. r Author.

FIGURE 4

Mean plots of main effects on material perception. r Author.

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P R O J E C T 8

End-of-life care through design: visualizing

places of death

Michelle Knox

Department of Medicine, University of Alberta, Edmonton, AB, Canada

Supervisor: Assoc. Prof. Aidan Rowe

Death and dying is an increasingly medicalized phenomenon and experiences of a “good death.” Through ethnographic exercises conducted at a small, independent, suburban hospice and an intensive palliative care unit in an urban hospital, I generated a critical commentary in healthcare environments and, by extension, in palli-

of two very diverse palliative locations. Analyzing
ative spaces. While the evidence-based design (EBD)
research findings from site visits, field observations,
movement has vastly improved hospital and hospice
photographic material, and interview data, I presented
architecture over the decades, relatively little research
recommendations for the design of future palliative
has applied the EBD principles specifically to build-
facilities. Finally, findings were contextualized within
ings associated with terminal illness and death. As
rapidly changing health landscapes, where future tech-
such, end-of-life care is too frequently situated within
nological, industrial, and social transitions will need
the clinical realm, with its sites of operation often
further
design-led
interrogations
to
continually
charged with exhibiting the material and nonmaterial

reconfigure healthcare experiences.

features and qualities of medical paternalism.

Knox, M. (2021). Locating death anxieties: End-of-life care

In this study, I argued that design has the potential and

and the built environment. *Wellbeing, Space and Society*, 2,

power to disrupt hegemonic medical paradigms and

100012. <https://doi.org/10.1016/j.wss.2020.100012>.

practices—by reframing palliative care as a fundamen-

tally human activity and the palliative environment as

Rowe, A., Knox, M., & Harvey, G. (2020). Re-thinking

a deeply personal realm—where designers might

health through design: Collaborations in research, edu-

“humanize” what are often seen as primarily “func-

cation and practice. *Design for Health*, 4(3), 327–344.

tional” clinical spaces. To do this, I first reviewed rele-

<https://doi.org/10.1080/24735132.2020.1841918>.

vant scholarly literature, identifying the key gaps

between research and practice across architectural,

material, and experiential design, particularly noting

Why is the research needed?

transformations across locations of death over the decades. Next, drawing upon anthropological perspectives, This study investigated the effects of built environment. I analyzed how time and aesthetics manifest in architectures on the experience of dying-in-place, with the tectural and material artifacts, relate to human anxieties aim to understand how we might design better material spaces around mortality, and affect individual conceptions of material spaces for the end-of-life.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00004-1>

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P R O J E C T 8 :

End-of-life care through design: visualizing places of death

Which aspects of “materials

experiences” does the research

addressed, addressing tangible ways in which design

should attend to individualized needs for social, cul-

tural, emotional, and sensorial experience.

valorize?

This work extends our understanding of how the structural, ambient, and symbolic qualities of materials and

What is the next big challenge for

spatiality enrich tacit relationships with the places we the research area?

occupy, particularly facilitating the experience of dying well.

The places where people have been spending their last days have shifted constantly to reflect social, medical, and industrial trends—interdisciplinary scholarship

How will the research impact on

can help designers to better understand the future needs of palliative architecture.

designers?

The role of designers is often overlooked in healthcare contexts—this work demonstrates how design furthers

Which publications most inspired

the objectives of whole-person care and human-or informed the research?

centered experience.

Adams, A. (2016). Home and/or hospital: The architectures of end-of-life care. *Change Over Time*, 6(2), 248-263.

What outcomes have been achieved

Pallasmaa, J. (2016). Inhabiting time. *Architectural*
or are foreseen?

Design, 86(1), 50-59.

Jencks, C., & Heathcote, E. (Eds.). (2010). *The architecture of hope: Maggie's cancer caring centres*. London: Frances Lincoln Ltd.

Furthermore, a framework outlining six in-depth recommendations

Worpole, K. (2009). *Modern hospice design: The architecture of palliative care sites* has been generated. London: Routledge.



Michelle Knox

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FIGURE 1

Shared room, intensive palliative care unit (general hospital). r Author.



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PROJECT 8 :

End-of-life care through design: visualizing places of death

FIGURE 2

Communal dining area (hospice facility). r Author.



Michelle Knox

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FIGURE 3

Assisted bathing area (hospice facility). r Author.



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PROJECT 8 :

End-of-life care through design: visualizing places of death

FIGURE 4

Lounge area (hospice facility). r Author.

P R O J E C T 9

Material experiences of menstruation

through symbiotic technologies

Marie Louise Juul Søndergaard and Ozgun Kilic Afsar

Media Technology and Interaction Design, KTH Royal Institute of
Technology, Stockholm, Sweden Supervisor: Assoc. Prof. Madeline Balaam

Our research explores how the materiality of menstruating
menstrual blood. First, we envisioned a sonic perfor-
bodies can be used to create new material experiences that
mance through the changing resonant frequency of
stimulate awareness, appreciation, and knowledge about
the menstrual cups as the blood is collected. Second, we
menstrual cycles ([Søndergaard et al., 2020](#)). In our collab-
measured and monitored the volume of blood that is
oration, we bring together knowledge in women's health
lost during a single cycle by reverse-calculating the vol-
([Søndergaard, 2018](#)), material science, and design research
ume from the resonant frequency of the vessel. Finally,
([Giaccardi & Karana, 2015](#)) to design symbiotic technolo-

the visual encounter utilized wearable microfluidics. We
gies that reconfigure the perception of bodily fluids as
speculated on a design scenario using microfluidics in
body waste toward a material that can be appreciated and
which a wearable chip provides the facility of an infor-
repurposed. We experimented with repurposing menstrual
native color-tracking tool throughout the period. This
blood using various technologies and DIY (do it yourself)
application explores how a more accessible control of
scientific instruments to facilitate a deeper engagement for
the biofluid could support menstruators in understand-
the menstruator. We prototyped three encounters with
ing and repurposing their own menstrual blood. As an
menstrual blood (tactile, acoustic, and visual).

initial step, we probed a DIY microfluidic device to
unleash this low-cost instrument's interactive potential

The tactile encounter involved soft robotic actuators. We
for designers beyond medical diagnosis.

designed soft on-skin actuators made from silicone with
a variety of shapes and patterns actuated by air or blood.

Woytuk, N., Søndergaard, M., Felice, M., & Balaam, M. (2020). Touching and being in touch with the menstruating body. In Proceedings of the 2020 CHI conference on human factors in computing systems (CHI'20) (pp. 1-14). New York: ACM. <https://doi.org/10.1145/3313831.3376471>.

Søndergaard, M., Afsar, O., Felice, M., Woytuk, N., & Balaam, M. (2020). Designing with intimate materials and movements: Making “menarche bits.” In Proceedings of the 2020 DIS conference on designing interactive systems (DIS '20). New York: ACM. <https://doi.org/10.1145/3313831.3376471>.

strual cup, we explored sonic encounters with collected

doi.org/10.1145/3357236.3395592.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00007-7>

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PROJECT 9 :

Material experiences of menstruation through symbiotic technologies

Why is the research needed?

change the perception of menstrual blood from being

a waste product to a design material that allows peo-

The research explores how menstrual blood and men-

ple to touch, hear, and see it in ways that make them

struating bodies can become materials in designing

feel comfortable, curious, and confident in their body.

symbiotic technologies that make space for experi-

ences of menstruation. The purpose is to design tech-

nologies that enable a menstruator to engage with

What is the next big challenge for

their menstrual blood in ways that move it beyond a

the research area?

waste product.

The next big challenge is to move beyond proof of concept technologies to robust and reliable designs,

Which aspects of “materials

which can be used sustainably over the longer term.

experience” does the research

valorize?

Which publications most inspired

The research valorizes menstrual blood as something to or informed the research?

touch and explore ([Campo Woytuk et al., 2020](#)); a material full of interactional and energetic opportunities that

Höök,

K.

(2018).

Designing

with

the

body:

have yet to be fully explored.

Somaesthetic interaction design. In K. Friedman & E. Stolterman (Eds.), *Design thinking, design theory* (p. 272). Cambridge: MIT Press.

How will the research impact on

Giaccardi, E., & Karana, E. (2015). Foundations of material designers?

materials experience: An approach for HCI. In Proceedings of the 33rd annual ACM conference on human factors in computing systems

Designers

of

women's

health

technologies

are

putting systems (CHI'15) (pp. 2447-2456). Seoul: ACM

intended to be impacted by the research, working

Press. <https://doi.org/10.1145/2702123.2702337>.

closer to/with the materials of the menstruating body

to create and deepen situated knowledge of the body

Søndergaard, M. (2018). Staying with the trouble

([Höök, 2018](#)).

through design: Critical-feminist design of intimate technology [PhD thesis, Aarhus University, Aarhus]. <https://doi.org/10.7146/aul.289.203>.

What outcomes have been achieved

or are foreseen?

Acknowledgments

Three artifacts have been designed that reconfigure the

This research was funded by the Swedish Research

material experiences of menstruation. The artifacts

Council under Project 2017-05133.



Marie Louise Juul Søndergaard

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FIGURE 1

Materials involved in the soft robotic actuators: silicone, electronics, tubing, fittings, casing, molds, and stencils. r Authors.



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PROJECT 9 :

Material experiences of menstruation through symbiotic technologies

FIGURE 2

Pneumatically actuated silicone parts with battery-powered unit that uses pressure-sensing to control air flow inflation/deflation.

r Authors.



Marie Louise Juul Søndergaard

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FIGURE 3

Scientifically blown glass Helmholtz resonators preserving the menstrual blood throughout one menstrual cycle. r Authors.



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PROJECT 9 :

Material experiences of menstruation through symbiotic technologies

FIGURE 4

DIY microfluidics speculating on the analysis of chemical and biological elements of menstrual blood. r Authors.

PROJECT 10

The salt material house project: designing
for death

SunMin May Hwang

Human Factors and Ergonomics, University of Minnesota, Minneapolis, MN,
United States of America Supervisor: Brandon Clifford

In the conventional practice of architecture, “obsolescence over time” is undesirable. In this project, obsolescence over time is one of the essential elements, important aspect of this method is that it leaves no harmful impact on the ecology. Forms will vary in the project by designing a salt-cured seasonal residential diameters, heights, and angles depending on the mixture, which will gradually and naturally be demolition of earthen elements, lending uniqueness and varied over a designated period through natural ability each time a house is built with this method. weathering agencies such as wind, water, and degradation. The building life expectancy will be precisely set out from the beginning to the end, purporting each

Why is the research needed?

step of its life cycle, from occupation to demolition.

Some parts of the building will obviously remain for

We as architects consider ourselves creators. Yet, we
a longer period, depending on its structural integrity.

work under the false assumption that buildings will

As a result, the big picture is that the residence will evolve

last forever. This project challenges the conventional

over time, varying not only in its form but also in its

notion of building sustainability. The research illus-

function. The material deformation will provide subtle

trates a proof of concept for a redefined meaning of

changes at different times of the day and year, which will

sustainability by reversely mandating a building's life

then cause to serve different functions at different stages

expectancy.

of the building's lifespan. To implement this idea, I used

building materials all from natural resources including

salt, soil, gravel, sand, and coconut fiber. Water and heat

are the binding solution of the building structure,

Which aspects of "materials

whereas wind and rain serve as the demolition agents.

experience" does the research

Regarding the building form, reposed mounds built
valorize?

out of earth will define the formwork (or mold) for
the house. Using the angle of repose as the formwork

The reversal of the concept of sustainability gives rise

allows the internal space to follow the size of the

to a whole new palette of materials, such as natural

mound. Additional material—coconut fiber—is lay-

agents, without compromising the avoidance of

ered on top of each mound to become the building

adverse impacts on the environment.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00023-5>

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P R O J E C T 1 0 :

The salt material house project: designing for death

How will the research impact on

new paradigm of sustainability—more so than the

designers?

replication of the method.

Not only should this project invoke persistent effort in testing new materials, but more importantly, it should also stimulate a shift toward new paradigms of sus-

Which publications most inspired
tainability in our design practices.

or informed the research?

What outcomes have been achieved

Ness, D. A. (2019). The impact of overbuilding on people
or are foreseen?

and

the planet. Newcastle-Upon-Tyne:

Cambridge

Scholars Publishing.

The research has evoked a quintessentially unique materi-

Guy, B., & Ciarimboli, N. (2008). DfD: Design for dis-
als experience to the convention by shifting the way we, as
assembly in the built environment: A guide to closed-loop
architects, operate. Newly defining building sustainability,
design and building. Hamer Center for Community

designing for death as opposed to perpetuity, has sparked
Design, Pennsylvania State University.

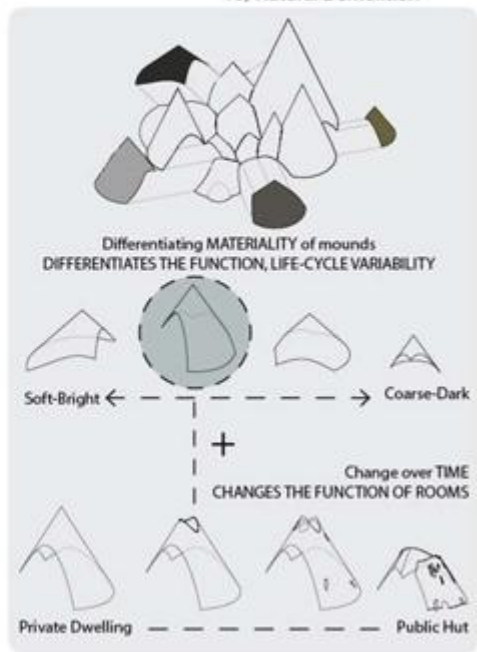
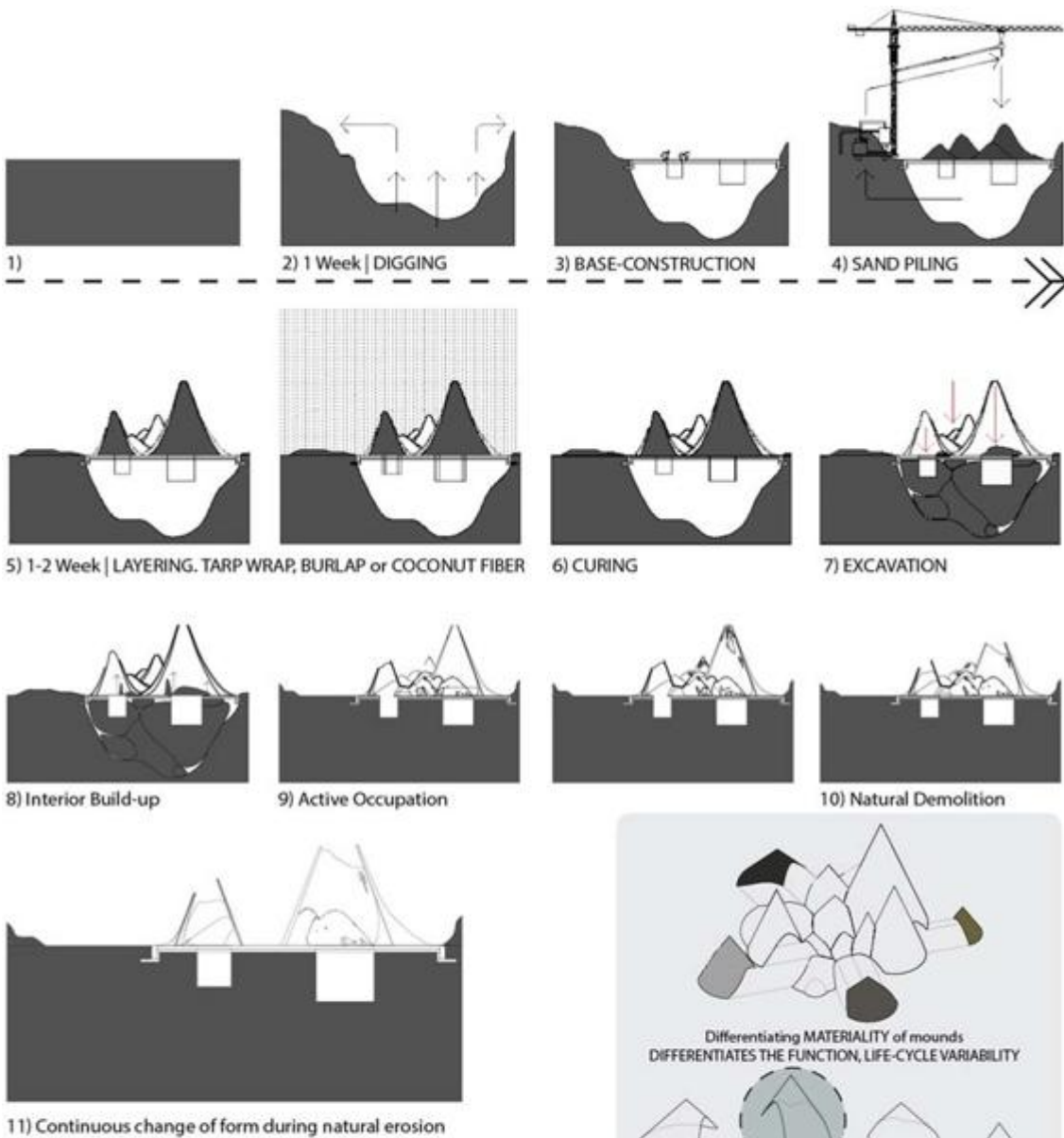
a vitality to achieve eccentric expressions of lifestyles
through the unique selection of natural materials and the
Crowther, P. (2003). Deconstruction: Techniques, eco-
use of natural forces for construction and deconstruction.
nomics, and safety. Brisbane: Queensland University of
Technology.

What is the next big challenge for

Kibert, C. J., Chini, A. R., & Languell, J. (2001).

the research area?

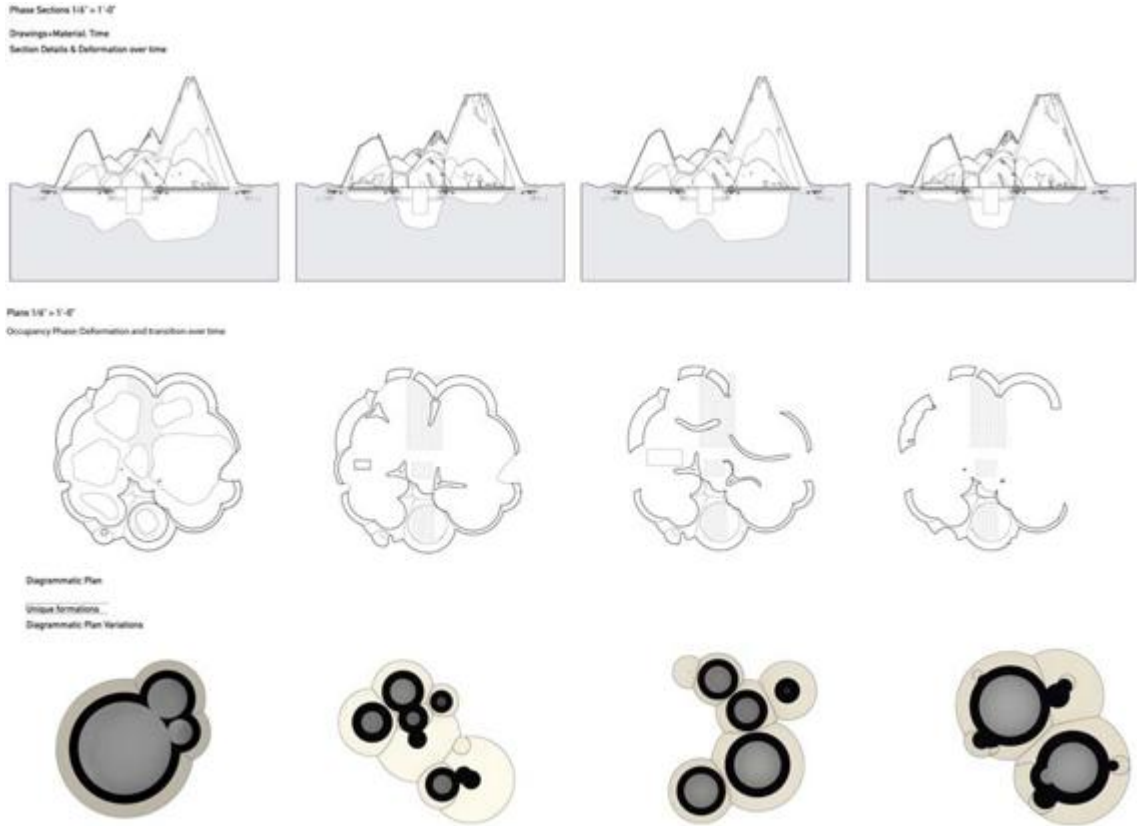
Deconstruction as an essential component of sustain-
able construction. In J. Duncan (Ed.), Proceedings of CIB
Challenges lay in the scaling-up from proof of con-
world building congress (Paper: Nov 54). Wellington:
cept, specifically on the impediments of shifting to a
Branz.



SunMin May Hwang

FIGURE 1

Building construction diagram. r Author.



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PROJECT 10 :

The salt material house project: designing for death

FIGURE 2

Life cycle architectural drawings. r Author.

MATERIAL TEST: Salt Crystallization
Coconut Fiber | Basswood | Corrugated Cardboard | Cotton Fabric



SALT SOLIDITY TEST:
Oven Baking | Boiling | Microwave | Natural Evaporation



DEMOLITION TEST:

Agent:
Rain water

Building Material:
Cured Salt +
Coconut Fiber



SunMin May Hwang

FIGURE 3

Material experiments. r Author.



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PROJECT 10 :

The salt material house project: designing for death

FIGURE 4

Exterior view of The Salt Material House Project. r Author.

PROJECT 11

Reflecting on material interactions as a
way of being with the world

Bilge Merve [Akta](#),

[sa](#) and Camilla Groth**b**

aDepartment of Design, Aalto University, Espoo, Finland,

bDepartment of Visual and Performing Arts Education, University of South-Eastern Norway, Notodden, Norway In this research, we present the Human Material

one, in which humans do not dictate and exploit

Interaction course that was offered to an interdisciplinary

materials but rather follow a more responsible

group of undergraduate university students. In this course

interaction.

we used craft-making as a pedagogical platform to be

Akta,s, B.M., & Mäkelä, M. (2019). Negotiation

able to reflect on materiality and its extended meanings

between the maker and material: Observations on

to us in a concrete and experiential manner. The students,

material interactions in felting studio. International

who were novices to a large degree, reflected on material

Journal of Design, 13(2), 55 67.

interactions and shared their experiences in the group.

The course incorporated both theoretical lectures and

Groth, C. (2017). Making sense through hands: Design hands-on creative studio sessions. In the lectures, the tea- and craft practice analysed as embodied cognition

chers, who are also the authors of this project, presented [Doctoral dissertation, Aalto University, Aalto ARTS recent theories in the field of material studies and experi- Books, Helsinki].

ential knowledge. The approach draws on the works of Tim Ingold, Lambros Malafouris, Jane Bennett, and others in this vein.

Why is the research needed?

In the studio sessions, students worked with clay or

The research examines human material interaction

wool and familiarized themselves with these materi-

through first-hand experiences to facilitate a discussion about how humans collaborate with their processes by utilizing a reflective diary. By facilitating discussions in class, we examined how using first-hand experiences of materials, gained through craft practice, enabled reflections on everyday material interaction, paying extra attention to our dependency on and coexistence with various materials. Through this study, we discuss how experiential knowledge about materials, gained through craft practice, can become a medium for critically reflecting on the impact of our everyday material interaction experience” does the research

in general.

Which aspects of “materials

practice, can become a medium for critically reflecting on the impact of our everyday material interaction experience” does the research

tions

and,

on

a

large

scale,

contemporary

valorize?

environmental issues. The students' reflections indi-

cate that gaining first-hand experiences renews their

Materials experience here tackles materials as active

relationship with materials toward a more dialogical

entities and refers to experiences with and of raw

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00012-0>

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PROJECT 1 1 :

Reflecting on material interactions as a way of being with the world

materials and their qualities, affordances, and resis-

What is the next big challenge for

tances and to the meanings generated during the

the research area?

interaction.

In the next phases, the challenge is to find ways to share knowledge gained through materials experiences and craft-making with other disciplines, to explore How will the research impact on potential crossovers and benefits.

designers?

The pedagogical method and the theoretical discus-

Which publications most inspired

sion can navigate designers when they reflect on their or informed the research?

own relationship with materiality to see their personal role, position, and behavior in material interactions.

Mäkelä, M. (2016). Personal exploration: Serendipity and intentionality as altering positions in a creative practice. *FORMakademisk*, 9(1), 1-12.

What outcomes have been achieved

Ingold, T. (2013). *Making: Anthropology, archaeology, art and architecture*. New York: Routledge.

or are foreseen?

Malafouris, L. (2013). *How things shape the mind: A the-*

The research has resulted in a pedagogical methodology of material engagement. London: MIT Press.

that utilizes material-based craft-making as a platform

Nimkulrat, N. (2012). Hands-on intellect: Integrating to facilitate interdisciplinary discussions on societal craft practice into design research. *International Journal of Design, 6(3)*, 1-14.

FIGURE 1

At the beginning of the course, each student worked at the potter's wheel while blindfolded to grasp the material's behavior. r Authors.





Bilge Merve Akta,
s and Camilla Groth

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FIGURE 2

A design student worked with clay to develop material-based textures rather than textures dictated by the maker. r Authors.

FIGURE 3

A computer science student developed a form based on material features, examining the durability of wool fibers. r Authors.



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PROJECT 1 1 :

Reflecting on material interactions as a way of being with the world

FIGURE 4

A business student worked with the feelings that the clay evoked in her, such as experiences of sandy beaches, and made a form that embodied material connotations from previous experiences with the material. r Authors.

P R O J E C T 1 2

Beyond biomimicry: developing a living
building realm for a postanthropocene era

Assia Stefanova

School of Architecture, Planning and Landscape, Newcastle University,
Newcastle upon Tyne, United Kingdom Supervisors: Prof. Rachel Armstrong
and Dr Ben Bridgens

The built environment that we have fashioned for our-
more importantly we establish collaborative environ-
selves is predicated on separating humanity from the rest
ments between species, where the designer assumes
of nature through the use of impermeable manmade bar-
the role of an orchestrator of desirable behavior of liv-
riers. My research examines the potential for a new living
ing biota, by providing encouragement in the form of
technology in the form of living materials that interface
conditions for those microorganisms to live and
with nature and our own ecology, mediating between the
develop in a favorable manner. By working with living
two and selectively facilitating exchanges. I use microor-
biota, we accept a degree of responsibility and estab-
ganisms to create biocomposite materials that have living

lish a practice of care that is vital in this emerging field
metabolic functions for the useful part of their lifecycle.
and that distinguishes it from working with inanimate
These materials are capable of feeding on waste products
matter, hence creating a new material practice.

from our environment and are able to improve the air
Stefanova, A., In-Na, P., Caldwell, G. S., Bridgens, B., &
quality of building interiors, reducing the need for
Armstrong, R. (2020). Architectural laboratory practice
mechanical ventilation. My research challenges modern

for
the
development
of
clay
and
ceramic-based

ideas of hygiene and proposes ways of creating living
photosynthetic biocomposites. Technology|Architecture +
modules that can be integrated within our buildings that

Design,

4(2),

200 210.

[https://doi.org/10.1080/](https://doi.org/10.1080/24751448.2020.1804764)

would allow other species to flourish. The materials

[24751448.2020.1804764](https://doi.org/10.1080/24751448.2020.1804764).

developed provide healthier environments for human

habitation while encouraging a more inclusive built

Stefanova, A., In-Na, P., Caldwell, G. S., Bridgens, B., &

environment.

Armstrong, R. (2021). Photosynthetic textile biocom-

posites: Using laboratory testing and digital fabrica-

My material testing involves the use of cross-disciplinary

tion to develop flexible living building materials.

laboratory practices that follow protocols for assessing the

Science

and

Engineering

of

Composite

Materials,

viability of the biocomposites regarding compatibility

28(1), 223-236. <https://doi.org/10.1515/secm-2021-0023>.

between substrate and organism, longevity, and the abil-

ity to function within an open setup. The material devel-

opment

is

accompanied

by

experimental

digital

fabrication in the form of 3D printing. This aspect of my

Why is the research needed?

work is focused on the development of new ways of fab-

ricating with living materials and the generation of com-

It is important to develop new testing methods and

ponents that can be scaled for mass production.

set out ways of conducting interdisciplinary research

that ventures outside of established design practices in

Through developing living materials, we develop net-

order to be able to effectively participate in the developments of collaboration within research practices, but development of living materials. By engaging with materials

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00016-8>

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P R O J E C T 1 2 :

Beyond biomimicry

at such a fundamental level, we are able to introduce between the human and nonhuman species as a an ethical aspect to the work that challenges established framework for sustainable coexistence.

lished perceptions of matter.

Which aspects of “materials

What is the next big challenge for

experience” does the research

the research area?

valorize?

Sustaining highly specialized organisms within an

The work focuses on the development of biological uncontrolled setting presents challenges of managing material alternatives and their integration into the build-contamination in a sustainable manner as well as cul- ing realm and by extension into new material experi- tivating maintenance practices that encourage a feeling ences. It explores ideas of cohabitation and codesign of responsibility within inhabitants.

through collaborative human/nonhuman interactions.

How will the research impact on

Which publications most inspired designers?

or informed the research?

Hird, M. J. (2009). *The origins of sociable life: Evolution*

The research will present a methodological blueprint after science studies. New York: Palgrave Macmillan.

for developing living materials and creating systems for sustaining their metabolic functions.

Merchant, C. (1980). *The death of nature: Women, ecology, and the scientific revolution.* San Francisco: Harper

and Row.

What outcomes have been achieved

Proksch, G. (2018). Built to grow: Blending architecture or are foreseen?

ture and biology. *Technology | Architecture 1 Design*, 2(1), 118-119.

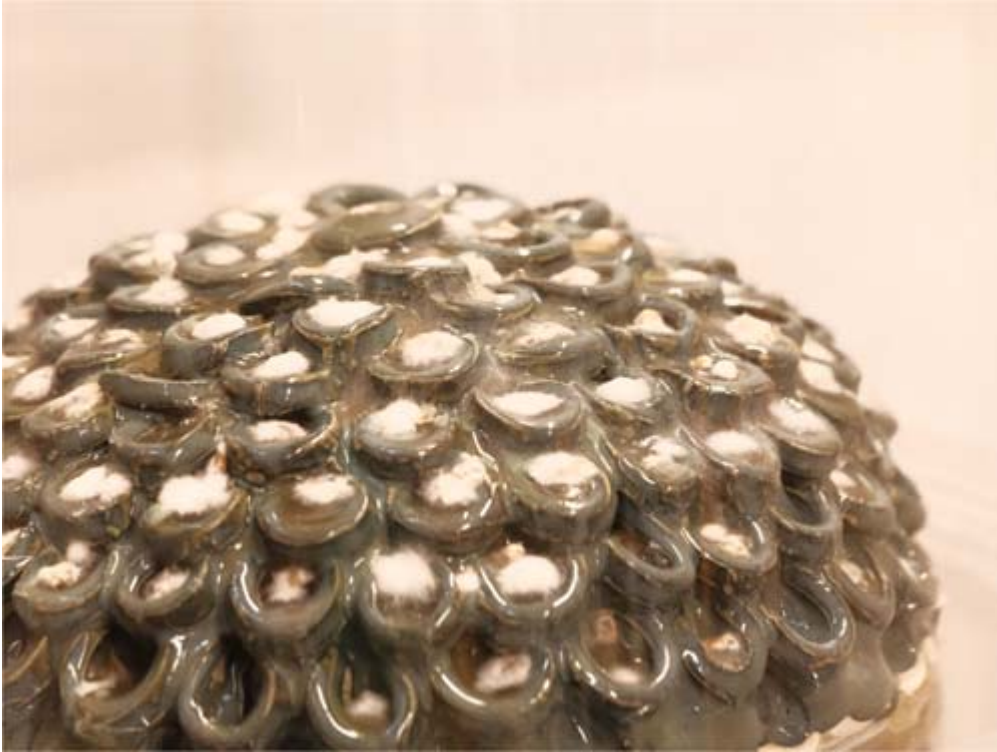
The aim of the research is to develop a system that eliminates pollutants through the use of natural meta-

Armstrong, R. (2015). *Vibrant architecture: Matter as a code-*

bolic processes as well as to foster a relationship

signer of living structures. Warsaw: De Gruyter Open.





Assia Stefanova

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FIGURE 1

Living mycelium on glazed ceramic, by Assia Stefanova and Dilan Ozkan (Yggdrasil Exhibit, London Design Festival, 2019). r Author.

FIGURE 2

Ceramic scaffolds for growing algae in repeated cycles by Assia Stefanova. r Author.



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PROJECT 12:

Beyond biomimicry

FIGURE 3

Biocomposite prototype of living algae on porcelain, by Assia Stefanova (Yggdrasil Exhibit, London Design Festival, 2019). r Author.

FIGURE 4

Chlorella vulgaris, microalgae growing on a multifaceted ceramic laden with nutrient media, by Assia Stefanova (Yggdrasil Exhibit, London Design Festival, 2019). r Author.

P R O J E C T 1 3

Healing materialities from a biodesign

perspective

Barbara Pollini

Design Department, Politecnico di Milano, Milan, Italy

Supervisor: Assoc. Prof. Dr. Valentina Rognoli

The shift from a linear economy to a circular one still has

Interest toward biodesign has increased substantially in

a long way to go, but innovative and disruptive design

the last 10 years, yet a dedicated methodology and struc-

approaches are already emerging. In this context, the

tured studies on the field are still to come. Focusing on

focus of my research is on “healing materialities,” mean-

biofabricated materials, my research aims to define new

ing those material scenarios based on the regenerative approaches and guidelines to design life-enabling material processes of resources instead of depletion. Including materialities, grounded on material-driven design, sustainable both living materials (made with living organisms) and design (including life-cycle design and circular design), life-enabling materials (e.g. bioreceptive ones), my biodesign, biomimicry, multispecies and more-than-research aims to define the boundaries of newly designed human design, and speculative design.

materialities where the final goal is to support life.

Pollini, B. (2020). Sustainable design, biomimicry and

This research intersects the constantly evolving con-

biomaterials: Exploring interactivity, connectivity and

cept of sustainability, the material design discipline,

smartness in nature. In V. Rognoli & V. Ferraro (Eds.),

and biodesign—the latter being a radical approach

ICS materials: Interactive, connected, and smart materials.

based on the integration of living organisms as func-

Milan: Franco Angeli

tional components in a design process. In my work I
Pollini, B., Pietroni, L., Mascitti, J., & Paciotti, D.
apply a transdisciplinary approach to understand the
(2021). Towards a new material culture: bio-inspired
implications that living materials can have on sus-
design, parametric modeling, material design, digital
tainable design and behavior change, mainly focus-
manufacture. In XII National Assembly SITdA Design in
ing on the relationships among living and nonliving
the digital age: Technology, nature, culture. Naples:
agents,
alongside
a
more-than-human
design
University of Naples Federico II.
perspective.

Which materials can be defined as “healing” in a sus-
tainable design context? Which material features
Why is the research needed?

become relevant, introducing the variable of living organisms into design? How can designers enhance Given the young age of biodesign, basic research is living/nonliving interactions to support life? To needed. Bio-based materials' sustainable features are answer these research questions, I am collecting and the main trigger for designers' experimentation—even analyzing qualitative data through a mixed-methods though biofabricated ones have yet to be analyzed research: reviewing projects, carrying out expert inter-through sustainability metrics. Filling this gap would views, and experimenting with various biofabricated encourage innovative future productions, fitting the materials using a biotinkering approach. requirements of the emerging circular economy.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00008-9>

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P R O J E C T 1 3 :

Healing materialities from a biodesign perspective

Which aspects of “materials

Which publications most inspired

experience” does the research

or informed the research?

valorize?

Myers, W. (2012), *Bio design: Nature science creativity*.

The relationship with living materials enables unique

London: Thames & Hudson.

experiences; a fundamental aspect to investigate is

Camere, S., & Karana, E. (2018). *Fabricating materials*

how the sense of care for living materials could bring

from living organisms: An emerging design practice.

sustainable behavior changes.

Journal of Cleaner Production, 186, 570-584.

Gatto, G., & McCardle, J. (2019). *Multispecies design*

How will the research impact on

and ethnographic practice: Following other-than-

humans as a mode of exploring environmental issues.

designers?

Sustainability, 2019, 5032.

Biofabricated materials, with their potential and lim-

Guillitte, O. (1995). Bioreceptivity: A new concept

itations, require new approaches and methodologies

for building ecology studies. Science of the Total

Environment, 167(1-3), 215-220. <https://doi.org/>

and a strong multidisciplinary will be the basis of

[10.1016/0048-9697\(95\)04582-L](https://doi.org/10.1016/0048-9697(95)04582-L).

these new design tools.

What outcomes have been achieved

Acknowledgments

or are foreseen?

The research is funded by Politecnico's PhD scholar-

ship. As of now part of the study has been nurtured

Biodesign is still missing an established vocabulary. A

by the MADE project (materialdesigners.org) and glossary is under

definition, based on a taxonomy

through participation at "Circular sPRINT: Additive

derived from the fundamental features of biofabricated

Manufacturing to foster Circular Design" organized by

materials emerging through the research. Guidelines to Ghent University and the Doctoral School of BSE define and design life-enabling materials are under definition, while more research will be needed to frame biofabricated ones within sustainability metrics.

The ongoing research is partly shared on the observatory healing-materialities design <https://healing-materialities.design/home/>.

What is the next big challenge for

The title of the research is the same as a lecture held the research area?

within the conference “Caring Matters,” organized within the project TAKING CARE by the Research Center For

The change toward more sustainable productions

Material Culture, where I presented the ongoing research

must be supported by a radical vision and manage-

in a workshop session named “Healing Materialities,”

ment of material within a design project. A transdisci-

defining the potentialities of biofabricated materials that

plinary approach oriented to a more-than-human
have emerged so far under this perspective.
design practice needs further development.



Barbara Pollini

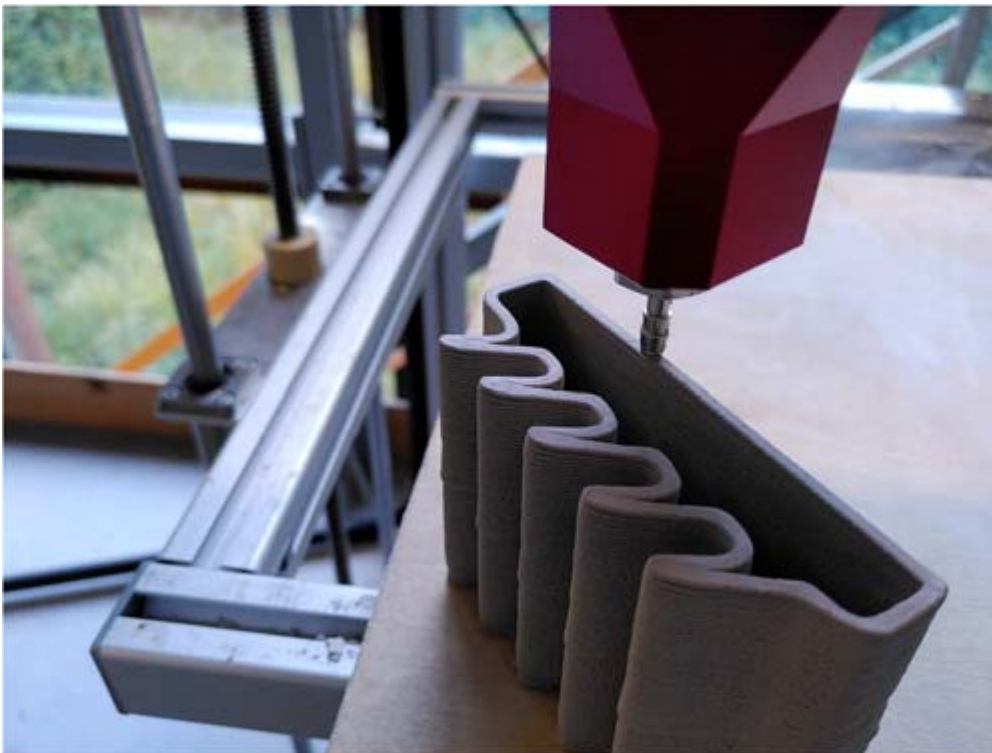
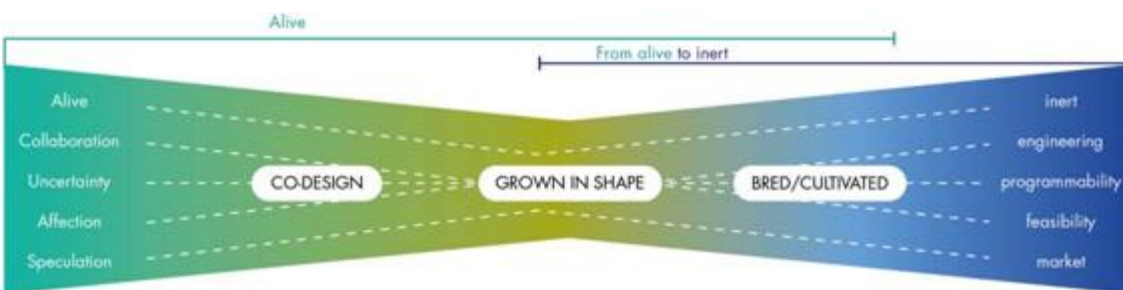
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FIGURE 1

Sample of bacterial cellulose grown by the author. r Author.

FIGURE 2

Demonstration of the recipe of a bioplastic during the MADE workshop given by the author. r Author.



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PROJECT 13 :

Healing materialities from a biodesign perspective

FIGURE 3

Prototyping of ceramic 3D-printed tiles for the Circular sPRINT, designed by the author for the development of bioreceptive circular materials and objects, printed in the Biofablab of Ghent University. r Author.

FIGURE 4

Taxonomic scale developed to analyze the case studies under three main aspects of the project: the speculative or feasible nature, the live/inert state of the organism, and its degree of involvement in the design phase.

P R O J E C T 1 4

Demonstrating a material making process

through the cultivation of fungal growth

Dilan Ozkan

School of Architecture, Planning and Landscape, Newcastle University,
Newcastle upon Tyne, United Kingdom Supervisors: Prof. Dr. Martyn Dade-
Robertson and Dr. Beate Christgen

Today, mycelium is used as a biomaterial in many dif-

ferent ways such as packaging, acoustic panels, wall

parametrize and systematize the growth. In conclu-

sion, designing my tools (robotic mold) in order to

insulation, bricks in buildings, textiles, and as a raw

interact with the fungus and changing its morphology

material in designed products including furniture. All

will help further manipulations of fungi for different these applications are realized through molding, which intended purposes.

is an example of a constraining intervention, currently Stefanova, A., Arnardottir, T. H., Ozkan, D., & Lee, S.

used in biodesign. In other words, cultivation is based (2019). Approach to biologically made materials and

on forming a predefined structure such as with a mold, advanced fabrication practices. In Proceedings of the

where the organism's cells fill the negative space in a international conference on emerging technologies in archi-

confined setting. For fungal material production, this tectural design (pp. 193 200). Toronto: Ryerson

process is very restrictive, reduces the degrees of free- University.

dom, and there is no room for emergence. Biomaterials

lose their inherent potentials that come from owning a metabolism capable of material growth in an almost

limitless way. Within my research, I am investigating

Why is the research needed?

fungi by posing the question: “how we can guide a living material [fungus] that has its own tendencies and This research demonstrates a new biological fabrication method and moves beyond the traditional ways cultivate it with minimum intervention?”

tion method and moves beyond the traditional ways

The first phase of my study involves experimentation of producing biomaterials. Robotic molding helps by paying close attention to factors that might cause a standardized production with its interactive and adaptive difference in the behavior of mycelium, to understand its properties and nature. After having understood its behavior in response to different factors such as oxygen concentration, humidity, light intensity, temperature, and nutrient sources, the research will continue by guiding the growth of fruiting bodies. Integrating computational tools into the biofabrication process

its properties and nature. After having understood its behavior in response to different factors such as oxygen concentration, humidity, light intensity, temperature, and nutrient sources, the research will continue

Which aspects of “materials fabrication, and nutrient sources, the research will continue by guiding the growth of fruiting bodies. Integrating experience” does the research

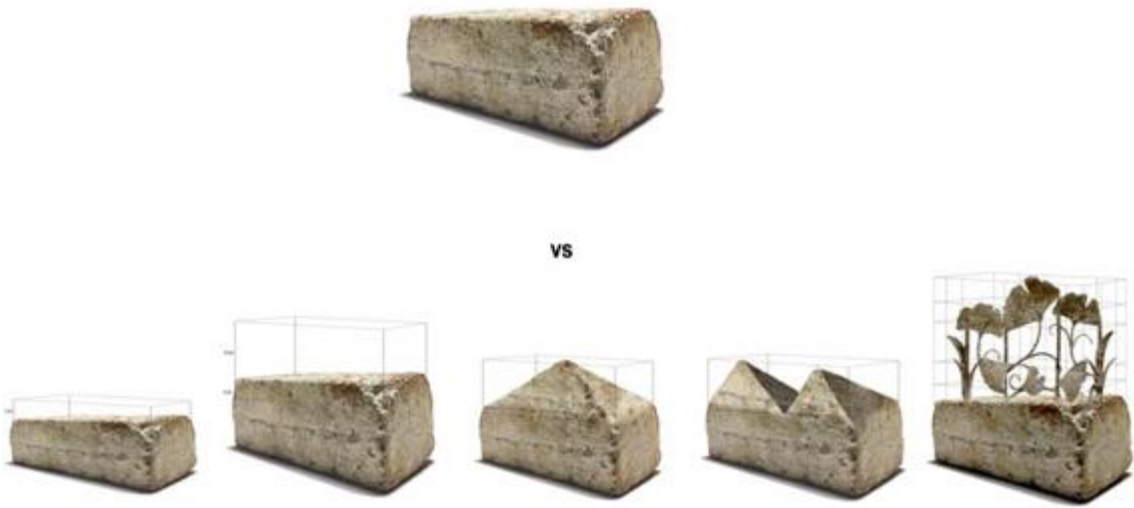
computational tools into the biofabrication process valorize?

will aid designers to manipulate their living material robotically. Building a growth chamber regulated by The research furthers the implementation of morpho-sensors, algorithms, and finite state machines such as ogy—the communication and dynamic interaction a fan, humidifier, light, and heater will help to between a crafter and a living material—by which an

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00011-9>

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PROJECT 14 :

Demonstrating a material making process

organism changes its form in response to modifica-
organisms or materials can be seen as the next chal-
tions made by the designer.

lenge for the research.

How will the research impact on

Which publications most inspired

designers?

or informed the research?

Building a dialog with an organism demonstrates a new

Adamatzky, A., Ayres, P., Belotti, G., & Wosten, H.

kind of material making process, contributing to the

(2019). Fungal architecture (pp. 1 19). Unpublished

architectural legacy of biomaterial tectonics and enhancing

article

submitted

to

International

Journal

of

existing practices through opportunities for innovation.

Unconventional

Computing.

, <https://arxiv.org/abs/>

[1912.13262](https://arxiv.org/abs/1912.13262). Accessed 05.06.20.

What outcomes have been achieved

Hamann, H., Soorati, M. D., Heinrich, M. K.,

or are foreseen?

Hofstadler, D.N., Kuksin, I., Veenstra, F., Wahby, M.,

Nielsen, S.A., Risi, S., Skrzypczak, T., Zahadat, P.,

In the initial phases, the parameters that manipulate

Wojtaszek, P., Støy, K., Schmickl, T., Kernbach, S.,

the morphogenesis of fungus have been illustrated.

Ayres, P. (2017). Flora robotica: An architectural sys-

According to these parameters, an automated device

tem combining living natural plants and distributed

has been proposed and developed capable of influenc-

robots (pp. 1 16). Unpublished article. , [http://arxiv.](http://arxiv.org/abs/1709.04291)

ing the growth of fungi remotely. This device facili-

[org/abs/1709.04291](http://arxiv.org/abs/1709.04291). Accessed 05.06.20.

tates

growth

by

sensing,

thinking,

and

acting,

therefore it can be called a robot.

Zolotovskiy, K. (2017). Guided growth: Design and computation of biologically active materials [PhD thesis, Massachusetts Institute of Technology, Cambridge]. , <https://dspace.mit.edu/handle/1721.1/113925>.

What is the next big challenge for
<https://dspace.mit.edu/handle/1721.1/113925>. Accessed 05.06.20.

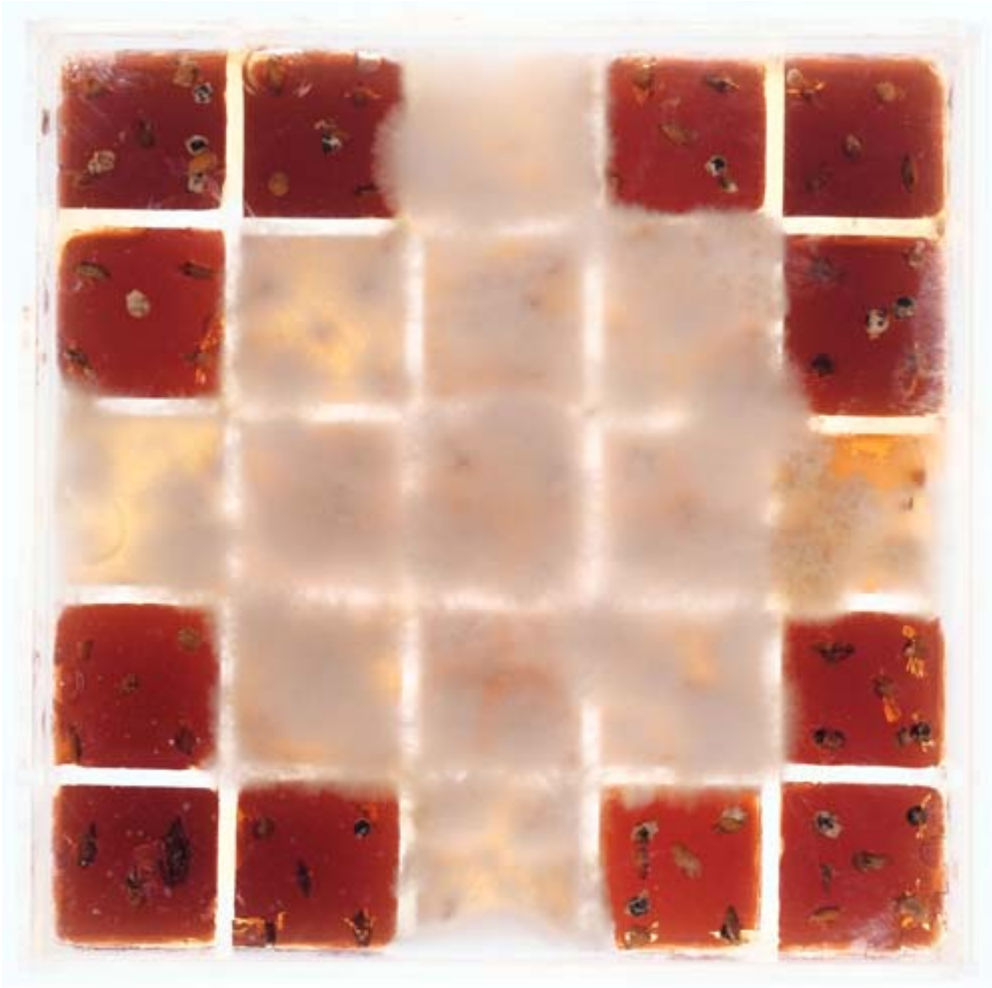
the research area?

Ingold, T. (2000). Making things, growing plants, raising animals and bringing up children. In *The perception of the environment: Essays on livelihood, dwelling and skill* (pp. 77-88). London: Routledge.

FIGURE 1

Possibilities of mycelium objects. r Author.





Dilan Ozkan

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FIGURE 2

Going beyond the brick. r Author.

FIGURE 3

Mycelium growth in nutritionally heterogeneous environments. r Author.



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PROJECT 14 :

Demonstrating a material making process

FIGURE 4

Fruiting bodies of *P. Ostreatus* (oyster mushroom): (A) Horizontal cut of fruiting bodies, (B) hyphae aggregate, and (C) vertical cut of fruiting bodies.
r Author.

PROJECT 15

Malfunction, maintenance, and materials

Alexandra Karakas

Doctoral School of Philosophy, Eotvos Lorand University, Budapest, Hungary

Supervisor: Assoc. Prof. Mihály Héder

Most studies in the field of both philosophy of technology and design theory tend to focus on the problem of reception of designed objects? The scope of the research covers malfunction both from a design function and its varied nature, but there has been little research perspective and from an ethical perspective. discussion on malfunction. I argue that not only function Karakas, A. (2019). Maintenance, function, and malfunction in technology. *Információs Társadalom*, 2019/4, 1-12. but also malfunction is the fundamental characteristic of technical artifacts, since this concept only applies to human-made objects and it establishes the judgments attached to particular artifacts as well. Malfunction as Why is the research needed? such can refer to several different anomalous scenarios, Even though malfunction and failure are crucial features including poor design and manufacturing mistakes. In all features of technology and design, their role and status

cases, malfunction indicates an artifact's inability to perform its intended function. In my research, I argue that malfunction is embedded in the material of an artifact, and that malfunction, as a spatiotemporal quality, defines lenses of materiality and to construct a taxonomy of different notions of malfunction.

functional features. Achieving a better understanding of artifacts, and specifically the relation between malfunction and materials, is not only a philosophical question, but a

Which aspects of "materials path to practical consequences. In my research the experience" does the research emphasize is on how malfunction is embedded in the material of a particular object—with a focus on aluminum—and how the combination of material and mal-

functional features. Achieving a better understanding of artifacts, and specifically the relation between malfunction and materials, is not only a philosophical question, but a

The research emphasizes the connection between function relates to social and historical circumstances. materiality and malfunction through the material experiences of aluminum.

The aim of the research is to construct a taxonomy of malfunction, focusing on the role of materiality. What happens when a material is not suitable for a particu-

How will the research impact on lar design, it wears out too fast, or the material cannot designers?

be maintained? How can designers manipulate consumption through the choice of certain materials?

As well as philosophical arguments, the research seeks How can malfunction be embedded in the material of to outline the practical consequences of malfunction artifacts, and how do certain materials determine the in design and technology.

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PROJECT 15:

Malfunction, maintenance, and materials

What outcomes have been achieved

Which publications most inspired

or are foreseen?

or informed the research?

Malfunction is increasingly a major problem in technol-

Kroes, P. (2010). Engineering and the dual nature of
ogy and design. Through the research, a theoretical frame-
technical artefacts. *Cambridge Journal of Economics*, 34
work for malfunction is proposed that analyses the notion
(1), 51-62.

of failure in order to offer guidelines to designers and to

Karana, E. (2009). Meanings of materials [PhD thesis,
initiate a philosophical investigation about malfunction.
Delft University of Technology, Delft].

What is the next big challenge for

Preston, B. (2009). Philosophical theories of artifact
function. In A. Meijers (Ed.), *Handbook of philosophy of
the research area?*

technology and engineering sciences (pp. 213-233).

Burlington: North Holland.

Currently the research focuses on physical objects, but software errors are becoming a major issue—the next

Franssen, M. (2006). The normativity of artefacts.

step can be to analyze both the materiality of software

Studies in History and Philosophy of Science Part A, 37

and to develop a taxonomy for software malfunction.

(1), 42–57.

FIGURE 1

Women using aluminum cookware (Hungary, 1970).

Creative Commons 3.0, CC BY-SA 3.0.

FIGURE 2

Flea market with aluminum artifacts (Hungary, 1916).

Creative Commons 3.0, CC BY-SA 3.0.



Alexandra Karakas

FIGURE 3

Cookware shop (Hungary, 1959). Creative Commons 3.0,
CC BY-SA 3.0.

FIGURE 4

Open fire cooking (Hungary, 1942). Creative Commons
3.0, CC BY-SA 3.0.

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P R O J E C T 1 6

Open-Ended Design: how to intentionally
support change by designing with
imperfection

Francesca Ostuzzi

Department of Industrial Systems Engineering and Product Design, Ghent
University (Campus Kortrijk), Ghent, Belgium Supervisors: Prof. Dr. Ing.
Jelle Saldien and Prof. Dr. Ing. Jan Detand

My work is explorative. It adopts qualitative research
To this end, I formalized a set of “lenses” that prompt
methods focusing on the design practice and creation
different perspectives for the designer during both obser-
of knowledge “through design.” My thesis articulated
vation and anticipation phases. What changes? Why?

six studies, as follows.

When? Where? How much? How fast? With which goal?

Is the change reversible?

Study 0 (observation) analyzed more than 100 industrial products that embed ingenious and rather intuitive

Designers are no longer asked to think only with referential ways to meaningfully embrace change in design.

ence to standardization where design solutions are

Examples included products that are designed with

given and remain “perfect” and stable in time. I challenge

imperfections that make them more resilient when

challenge designers to acknowledge the dynamicity of

facing out-of-control possibilities of breakage, aging,

design outcomes, which are time- and context-related,

etc. Specifically, in the arena of product environment

out-of-control and undisciplined, but nevertheless

interaction (inhabited by human and nonhuman

capable of anticipation (although not “prediction”) by

actors), materials have a dynamic nature that conveys

an intentional design act.

information and elicits new meanings. Materials'

Ostuzzi, F., De Couvreur, L., Detand, J., & Saldien, J.

imperfections allow emergence, crucial for the open-

(2017). From design for one to open-ended design:

endedness of products.

Experiments on understanding how to open-up con-

Studies 1 4 (anticipation) observed the creation of

textual design solutions. *The Design Journal*, 20 (Suppl.

more than 70 original and intentional Open-Ended

1: Proceedings of the 12th European Academy of

Design outcomes. The aim was to understand how we

Design conference—Design For Next), 3873 3883.

can create Open-Ended designs (e.g., what should be

Ostuzzi, F., Rognoli, V., Saldien, J., & Levi, M. (2015).

left open and what strictly defined?) and how we can

1 TUO project: Low cost 3D printers as helpful tool

effectively distribute them.

for small communities with rheumatic diseases. *Rapid*

Prototyping Journal, 21(5), 491 505.

Study 5 reached a closure, unifying all my understand-

ing into a proposal of an Open-Ended Design approach intended to support designers. The approach is not rigid in its structure and does not aim to be prescriptive. It is Why is the research needed?

structured as an iterative process where the designer is asked to constantly switch from observing the dynamic Products are anything but static, predictable, or under nature of reality, to anticipating it, through a design act. control. In fact, they are dynamically subject to

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PROJECT 16 :

Open-Ended Design

constant transformations. The motivation for this

Ended

Design

outcomes

are

suboptimal,

error-

research was a need to properly describe this “phenomenology of change” in relation to designed products. What is its role and potential value? How can incomplete definition of their features.

designers intentionally embrace the (often unavoidable) process of change?

What is the next big challenge for

Which aspects of “materials

the research area?

experience” does the research

The emergent topics of biological materials in design,

valorize?

growing materials, and, more generally, the Circular Economy strongly relate with Open-Ended Design—
Moving on from values attributed to imperfect material how can we support these paradigm shifts using material esthetics (e.g., accumulation of usage traces or Open-Ended Design?

aging processes), the research provides an approach through which dynamic materials' experiences become outcomes of intentional design acts.

Which publications most inspired or informed the research?

How will the research impact on designers?

Dubberly, H., & Pangaro, P. (2015). Cybernetics and design: Conversations for action. *Cybernetics and Open-Ended Design* aims at triggering reflections on *Human Knowing*, 22(3), 73-82.

the way we design and interact with products that is, ultimately, the way we participate in creating more or

Nelson, H., & Stolterman, E. (2012). The design way:
less sustainable futures.

Intentional change in an unpredictable world. London:
MIT Press.

What outcomes have been achieved

Redström, J. (2008). RE: Definitions of use. Design
Studies, 29(4), 410-423. [10.1016/j.destud.2008.05.001](https://doi.org/10.1016/j.destud.2008.05.001).

or are foreseen?

Wakkary, R., & Maestri, L. (2008). Aspects of every-
Open-Ended Design is proposed as an approach to
day design: Resourcefulness, adaptation, and emer-
observe (post-factum) and generate (ante-factum) the
gence.

International

Journal

of

Human-Computer

conditions under which changes in products become

Interaction,

24(5),

478 491.

[10.1080/](#)

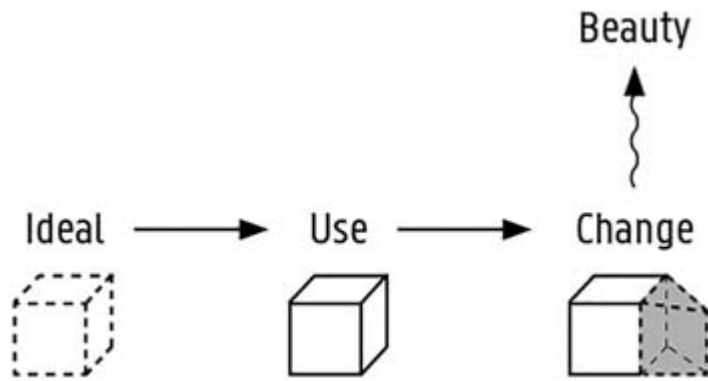
less disruptive or sometimes even desirable. Open-

[10447310802142276.](#)

FIGURE 1

Examples of dynamic product uses, due to changes at the users' interpretation level. r Author.





Francesca Ostuzzi

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FIGURE 2

Examples of dynamic product appearances and uses, due to changes at the materials level. r Author.

FIGURE 3

Reading feedback from the traces in a product: an Open-Ended house that triggers reappropriation. r Elemental (elementalchile.cl)

FIGURE 4

Beauty is not created with the product but emerges in time and through use. r Author.

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P R O J E C T 1 7

Material information platform for designing

environmentally friendly products

Indji Selim

Department of Industrial Design, Ss. Cyril and Methodius University
Skopje, Skopje, Republic of North Macedonia Supervisor: Prof. Dr. Tatjana
Kandikjan

The industrial designer creates a product by balancing
browsing the most suitable materials. Based on the val-
between consumers' needs and manufacturers' require-
ued alternate material criteria, I assembled four different
ments, in which selecting the most suitable material for
EFM alternatives for the single-use water bottle using
that particular product is an inherent task of the designer's
different online sources. In the final phase, I tested the
process. However, the unfamiliarity of attributes of
suitability of each material by presenting a table of five
recently discovered environmentally friendly materials
inherent attributes. Having the PDD method in perspec-
(EFM) presents a challenge to designers in the material
tive, the outcome of the research is to develop an assis-
selection process. My research focuses on the role of the
tive tool referred to as MIP by accommodating further
industrial designer within the scope of EFM selection.
material groups and product-related attributes.

The material information platform (MIP) that I pro-

Selim,

I.,

Lazarevska,

A.

M.,

Mladenovska,

D.,

pose aims to emulate the human decision-making

Kandikjan, T., & Sidorenko, S. (2020). Identifying

process, in this case, the decision-making process

material attributes for designing biodegradable pro-

for product-driven design (PDD) and its evolution

ducts. In I. Karabegovic (Ed.), *New technologies, develop-*

throughout the material selection process, focused on

ment and application (pp. 633-639). Cham: Springer.

EFM. For this purpose, I conducted research to sup-

Selim, I., Lazarevska, A. M., Kandikjan, T., & Sidorenko, S.

port a five-phase PDD materials selection method,

(2019). Multi-attribute material information platform. In

visualizing the process and the material decisions

N. Börekçi, D. Jones, F. Korkut, & D. Özgen Koçyıldırım

through the example of a single-use water bottle.

(Eds.), Proceedings of DRS Learn X Design 2019—fifth inter-

In the first phase, I used a multiattribute decision-

national

conference

for

design

education

researchers

making (MADM) method to define fixed and alternate

(pp. 531 541). Ankara: Middle East Technical University.

product criteria. Product attributes mutually required by

the designer, consumer, and manufacturer were denoted

as fixed product criteria, while the remaining attributes

Why is the research needed?

that were outside the mutual cross-section were denoted

as alternate product criteria. Based on the associative

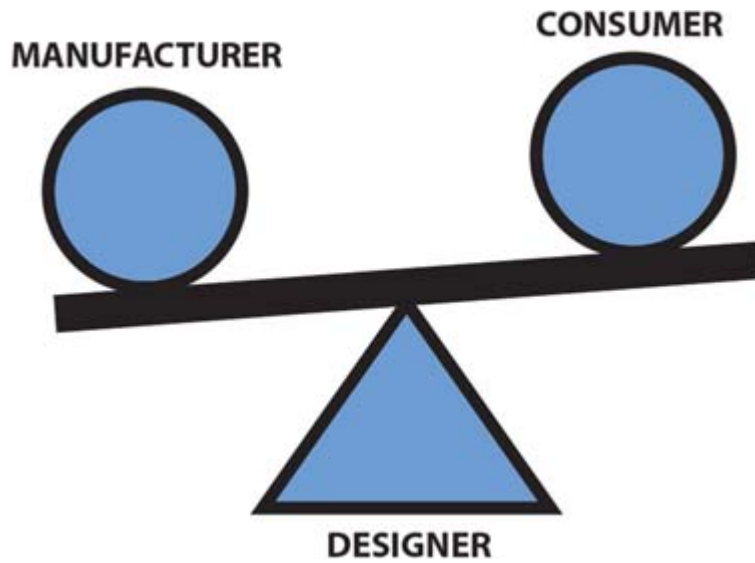
The aim of this research is to develop a MIP as an assis-

description concept, I mapped the product attributes
tive tool that collects and aggregates product require-
onto the attributes of a generic material. By considering
ments—based on both consumers’ and manufacturers’
whether the mappings related to fixed or to alternate
preferences—and thus offers designers substantial infor-
material criteria, I developed a material criteria chart to
mation regarding EFM and their features. The assistive
provide the decision-maker (designer) with an evalua-
tool suggests an optimal set of materials that matches
tive approach toward materials selection, in favor of
the predefined product requirements.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00035-1>

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PROJECT 17 :

Material information platform for designing environmentally

Which aspects of “materials

learning algorithms will be proposed and possibly

experience” does the research

incorporated in line with the refined MIP architecture.

valorize?

What is the next big challenge for

Based on the knowledge incorporated in previously pro-

the research area?

duced products (i.e., gathering and categorizing significant

materials experience), the MIP provides assistive guidance

The method developed through this research refers to the designer, throughout the EFM selection process. EFM alternatives—however, the creation of the refined MIP architecture and the incorporation of MADM tools and machine learning algorithms is the next big challenge.

How will the research impact on designers?

Which publications most inspired

The MIP saves time, is able to keep updated with constantly changing information, and gives more options and opportunities to designers otherwise reliant on

Karana, E., Barati, B., Rognoli, V. & Zeeuw van der personal experience.

Laan, A. (2015). Material driven design (MDD): A method to design for material

experiences.

International Journal of Design, 9(2), 35-54.

What outcomes have been achieved

Karana, E. (2009). Meanings of materials [PhD thesis, or are foreseen?

Delft University of Technology, Delft].

Ashby, M., & Johnson, K. (2002). Materials and design:

So far, various EFM are accumulated and aggregated

The art and science of material selection in product design.

according to the PDD method. The next step is to

Oxford: Butterworth-Heinemann.

cross-reference the EFM-related data (attributes) and

enlarge the MIP with additional product examples.

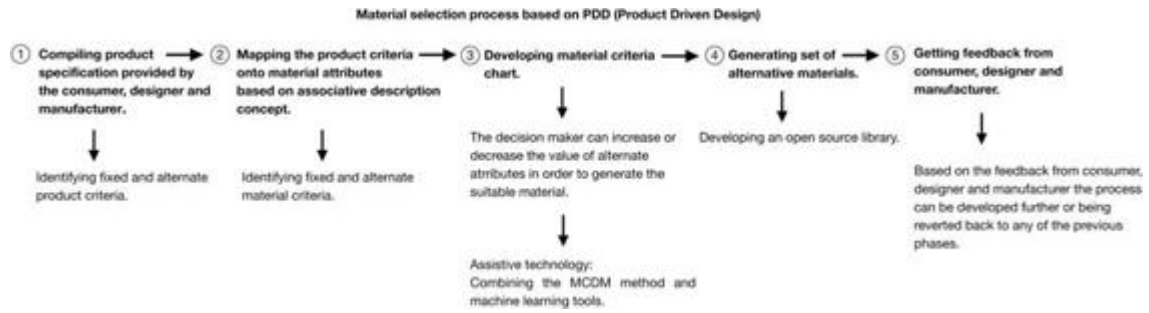
Keeney, R. (1982). Decision analysis: An overview,

Progressively, suitable MADM tools and machine

Operations Research, 30(5), 803-838.

FIGURE 1

The industrial designer's pivot and balancing role. r I. Selim, M. A. Lazarevska, D. Mladenovska, T. Kandikjan.

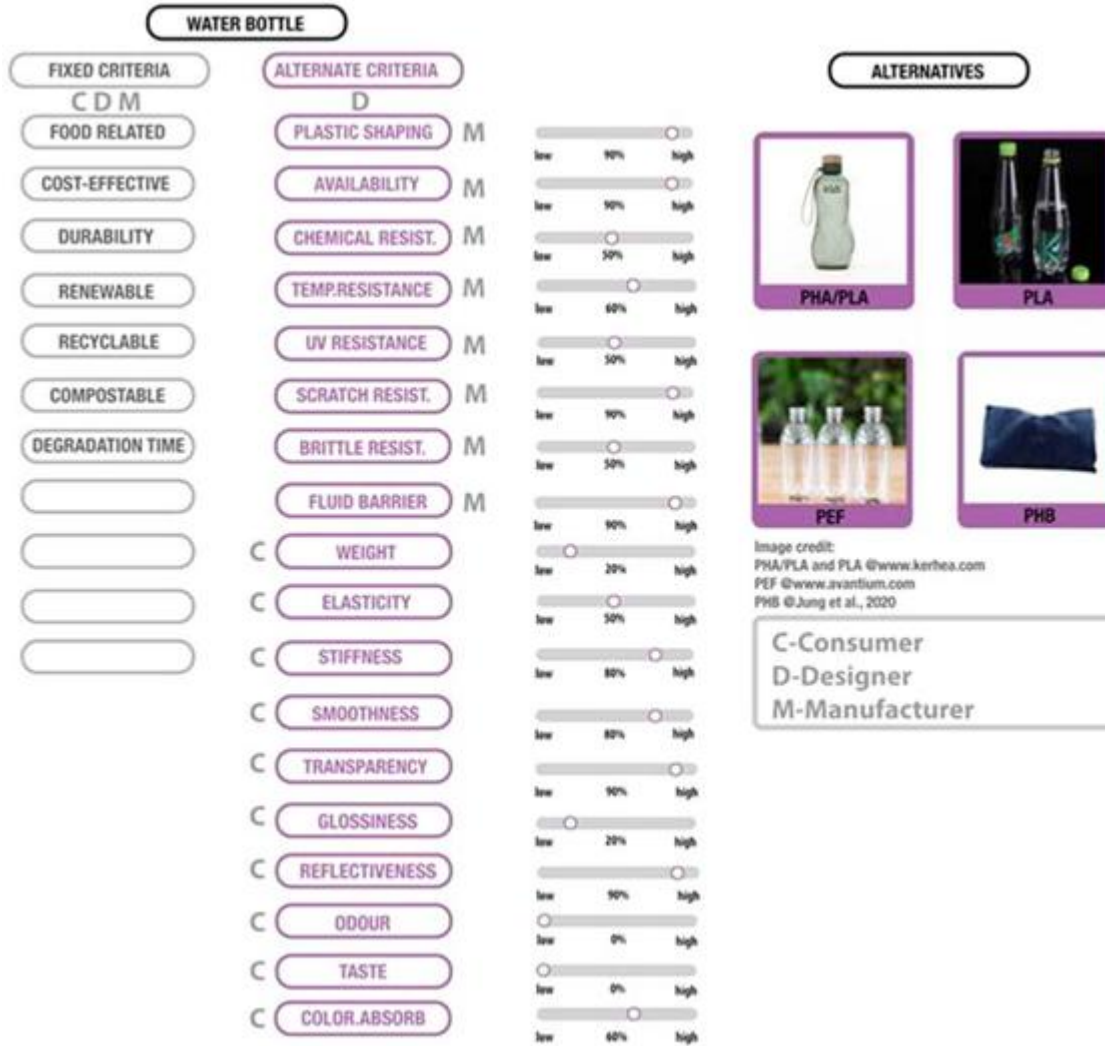


Indji Selim

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FIGURE 2

Material selection process based on product-driven design (PDD). r I. Selim, M. A. Lazarevska, T. Kandikjan, S. Sidorenko.



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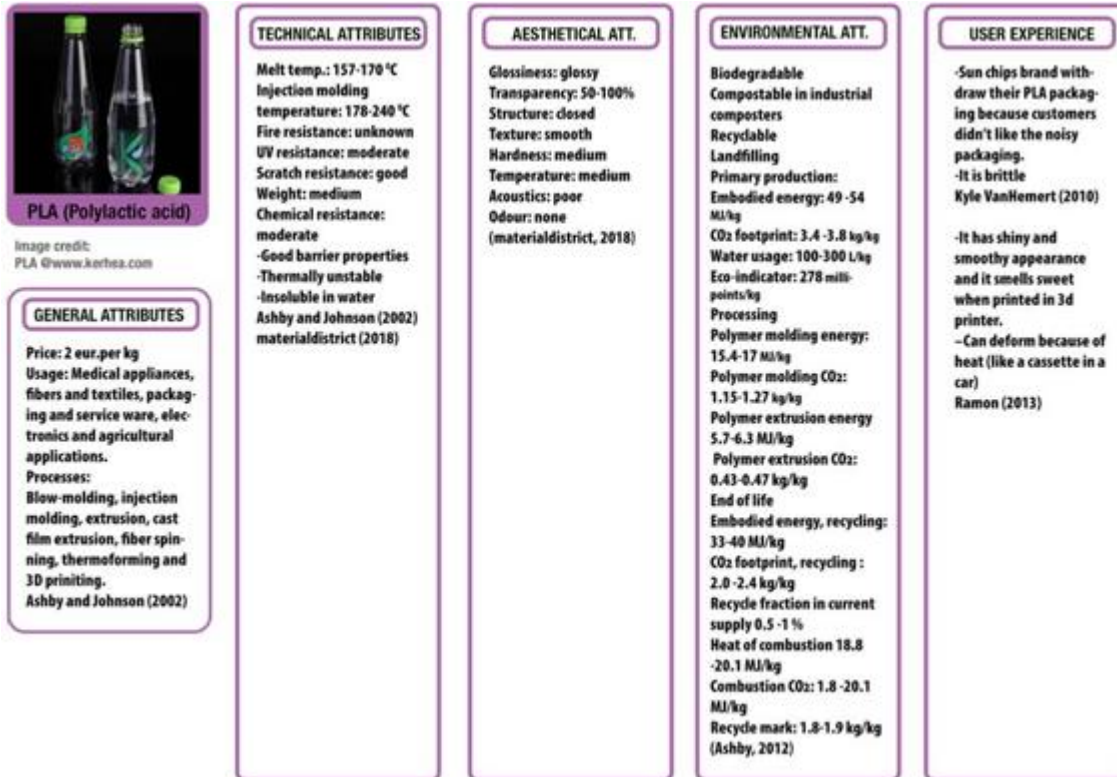
PROJECT 17:

Material information platform for designing environmentally

FIGURE 3

Categorization of material criteria (fixed and alternate) accompanied by suitably matched material set. r I. Selim, M. A. Lazarevska, T.

Kandikjan, S. Sidorenko.



Indji Selim

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FIGURE 4

Categorizing the material attributes for one of the matched materials. r I. Selim, M. A. Lazarevska, T. Kandikjan, S. Sidorenko.

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P R O J E C T 1 8

Material education in design: engaging material experimentation and speculation

Ziyu Zhou

Design Department, Politecnico di Milano, Milan, Italy

Supervisor: Assoc. Prof. Dr. Valentina Rognoli

Co-supervisor: Assoc. Prof. Dr. Manuela Celi

In the last 15 years, we have witnessed the growing

At the moment, I have advanced the assumption

importance of the expressive sensorial dimension of

(Phase 3) of possible educational models on the

materials with the birth of the materials experience

aspects of thought, practice, and communication.

concept, and this has influenced materials for design

I formulated an assumption around materials question-

education. Today in some schools around the world,

ing, experimentation, and integration. Thus, working

students are being encouraged to experiment with

toward the implementation of a new materials educa-

materials and to use, more or less consciously, practi-

tional model in seminars or design courses, I am look-

cal approaches to manipulate those materials by

ing forward to observing and verifying the assumption

designing their qualities and identities.

through the application of my ideas in a real class.

My research started with an investigation on the world
Zhou, Z., & Rognoli, V. (2019). Material education in
of materials education, to understand its evolution and
design: from literature review to rethinking. In: Proceedings
the fundamental aspects essential for the contemporary
of the 5th international conference for design education research-
training of the designer. How can we implement and
ers (DRS Learn-X 2019) (pp. 111 119). Ankara: Middle
strengthen the designer's knowledge in the field of mate-
East Technical University, Department of Industrial Design.
rials? What tools and methods could we give to students
Zhou, Z., Rognoli, V., & Ayala-Garcia, C. (2018).
to help them explore materials and technologies and to
Educating designers through Materials Club. In:
facilitate their intervention or contribution to the evolu-
Proceedings of the 4th international conference on higher
tion of the material world?
education
advances
(HEAD'18)

(pp.

1367 1375).

To compile an exhaustive study of state of the art

València: Editorial Universitat Politècnica de València.

(Phase 1), using the tools for desk research, I browsed

many materials' courses from design schools all over

the world and highlighted the essential aspects of the

Why is the research needed?

thinking and practice of materials and design, as well

as the courses' relevant pedagogical approaches.

The main aim of the research is to improve materials

Afterwards,

I

conducted

ethnographic

research

education in design and make it coherent with the

(Phase 2), by including the construction of experience,

contemporary world of materials, which is continu-

the practical approach with materials, the blending of

ously changing and evolving. The particular focus is personal interests and cultural backgrounds, the search on the possibility of including multidisciplinary exper- for alternative resources, and the critical and specula- imentation in the designer's education alongside a tive attitudes toward materials.

critical and speculative approach.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00024-7>

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P R O J E C T 1 8 :

Material education in design

Which aspects of “materials

What is the next big challenge for

experience” does the research

the research area?

valorize?

The next big challenge is for materials-centered educa-

The research enhances the materials experience con-

tion to become an internationally recognized research
cept in all its aspects, because future designers have to
area, in which design schools can share similar and
learn to manage all its different nuances and varia-
complementary educational paths.

tions from an educational perspective.

Which publications most inspired

How will the research impact on

or informed the research?

designers?

Dunne, A., & Raby, F. (2016). *Speculative everything: Design, fiction, and social dreaming*. Cambridge: MIT
By elevating awareness of the multiple roles of materi-
Press Ltd.

als, designers will improve their skills and competen-
cies to choose and design the right materials for their

Drazin, A., & Küchler, S. (Eds.) (2015). *The social life
projects*.

of materials: *Studies in materials and society*. London:
Bloomsbury.

Karana, E., Pedgley, O., & Rognoli, V. (Eds.) (2014).

What outcomes have been achieved

Materials experience: Fundamentals of materials and design. Oxford: Butterworth-Heinemann.

or are foreseen?

Martinez, S. L., & Stager, G. (2013). Invent to learn:

The aimed outcomes are primarily pedagogical

Making, tinkering, and engineering in the classroom.

guidelines to outline a customizable course or edu-

Torrance: Constructing Modern Knowledge.

cational program that can enhance experimentation

and speculation with materials. The materials, and

practices around the materials, can be promoters of

Acknowledgment

new visions and give rise to reasoning on the mate-

rial

qualities

and

possible

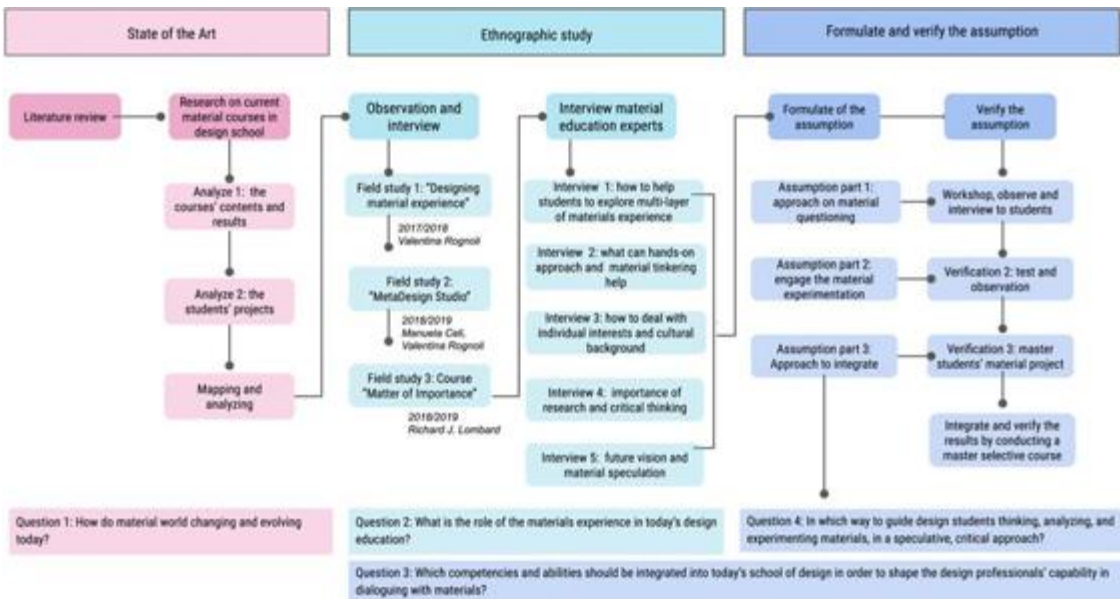
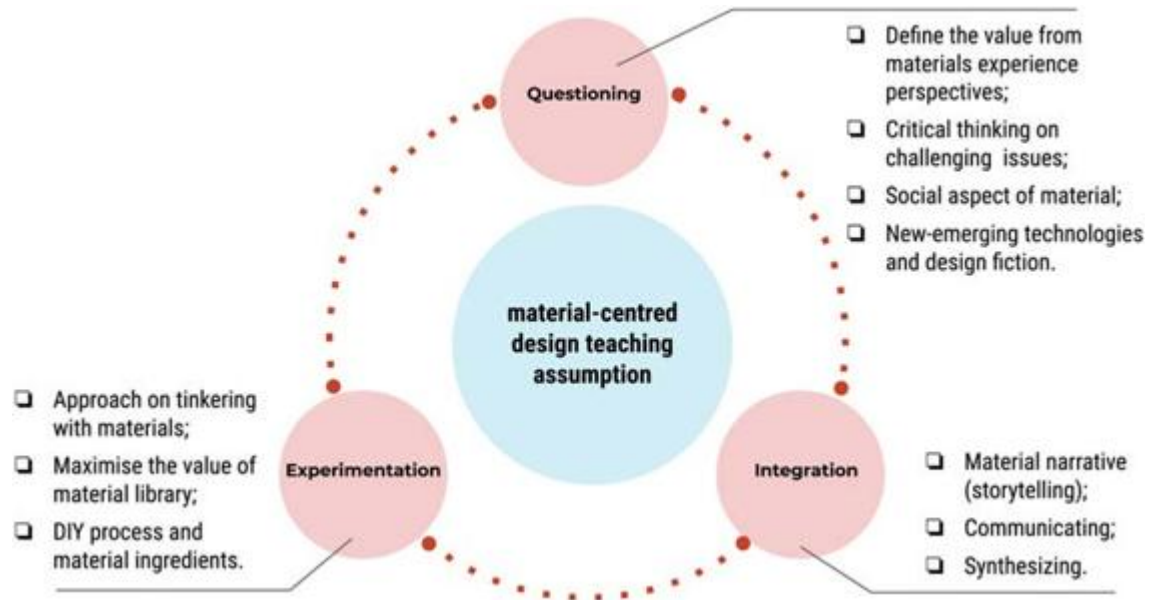
and

preferable

This research is funded by the China Scholarship

applications.

Council.



Ziyu Zhou

FIGURE 1

Research methodology framework. r Author.

FIGURE 2

Framework: material-centered design teaching assumption. r Author.

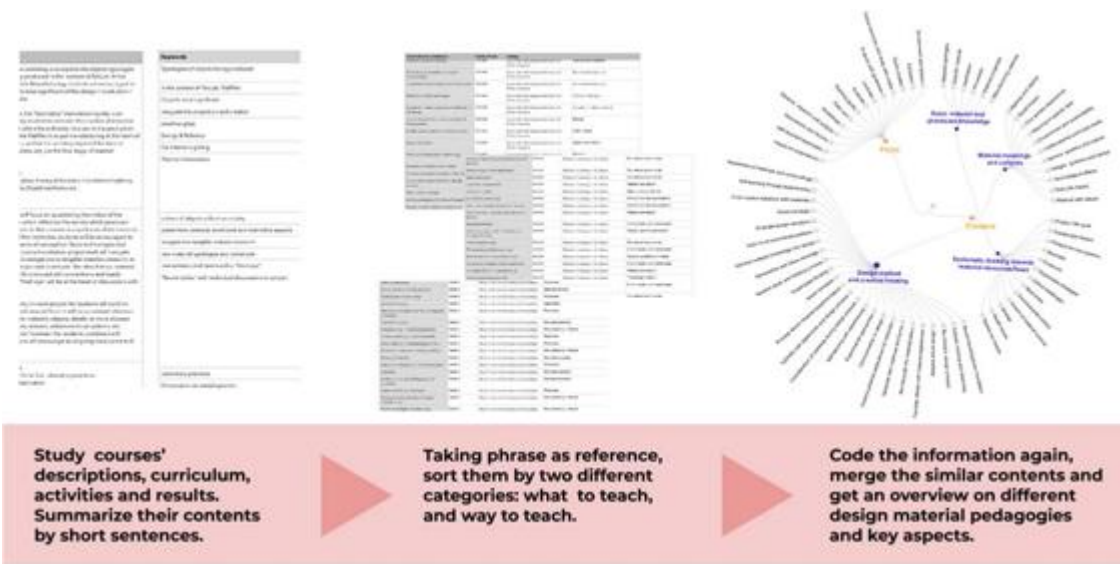


FIGURE 3

Research progress: analysis of material courses, screenshot in 2019. r Author.

CHAPTER 7

A renewed recognition of the materiality of design in a circular economy: the case of bio-based plastics

Conny Bakker, Ruud Balkenende

Faculty of Industrial Design Engineering, Delft University of Technology,
Delft, Netherlands 7.1

Introduction

In [1989 Ezio Manzini](#) wrote *The material of invention*. In the book, he argues that designers have been freed from the constraints that materials pose. In Manzini's

vision, materials can now be engineered to fit the needs of the designer, instead

of the other way around. These “materials made to order” (p. 37) herald a new

age where material selection is no longer needed and where the choice of mate-

rials becomes, in fact, design. More than two decades later, [Graedel et al. \(2015\)](#),

tentatively raise the alarm, as they see an escalating trend in material consump-

tion, with today's technologies employing nearly every material in the periodic

table of elements. They note that this had led to increasing materials complexity,

while recycling rates remain low, the associated environmental impacts of virgin

materials production high, and options for material substitution limited. The

use of so many materials, they state, “is a carefully calculated effort to achieve

increasingly high performance in products simple to complex” (p. 6295). In

other words, it is an act of design.

We have thus become highly dependent upon a wide range of materials for our modern technologies, and this has come at a cost. According to the United Nations, “the extraction and processing of materials, fuels and food make up about half of total global greenhouse gas emissions and more than 90% of biodiversity loss and water stress” ([IRP, 2019](#)). In addition, with 55% of materials currently being recycled in the European Union ([Eurostat, 2019](#)), but with recycling rates of 30 out of the 60 different metals in use at less than 1% ([United Nations, 2011](#)), we need to have a long hard look at the way we design products and, therefore, select and use materials.

In particular, designers need to better understand the (impacts of the) origin and composition of the materials they design with, and, perhaps even more importantly, their recovery and end-of-life options. This makes the circular

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00020-X>

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CHAPTER 7 :

A renewed recognition of the materiality

economy such an interesting concept for designers. The circular economy is defined as an industrial system that is regenerative and restorative by design

(EMF, 2013). One of the aims of a circular economy is to attain high-value and high-quality material cycles ([Korhonen et al., 2018](#)) where products and materials can loop back into the economy without much (or any) loss of quality and value, or where products and materials can be safely “fed back” into the biosphere to be regenerated. If we would have a well-functioning circular economy, we would be able to recover and reuse products and materials many times over, which would vastly reduce greenhouse gas emissions for the production of virgin materials, as well as a lot of unnecessary waste. In other words, a circular economy would transform the way we make, use, and recover products and materials.

In this chapter we intend to sketch the opportunities and challenges of designing products and materials that fit a circular economy. We also want to take a longitudinal perspective with a focus on managing vital resources for the long term. We thus take as our starting point the phase-out of fossil fuels, which is inevitable given the escalating climate crisis. This chapter will therefore focus on bio-based materials in a circular economy. Bio-based materials are made from renewable resources. While wood, leather, etc., are well-known bio-based mate-

rials, this chapter will look at bio-based plastics in particular, because these can

substitute for fossil-based plastics and contribute to the phase-out of fossil fuels

and because plastics are used at a large scale in industrial product design.

The main objective of this chapter is to explore the opportunities and challenges

of designing with bio-based plastics in a circular economy. We will show that

the often-used “butterfly” model of the circular economy, which distinguishes

between a biocycle (biological cycle) and a technocycle (technical cycle), is not

very useful when we consider bio-based plastics from a design perspective. This

leads us to propose an alternative framing of the circular economy with a limited

number of recovery pathways. Based on this framing, we will show that

bio-based plastics can provide new combinations of properties for new applications,

as well as the straightforward replacement of existing fossil-based polymers.

It follows that designers will be given new opportunities and will need to

deal with new challenges as these complex and exciting bio-based materials

enter the market in increasing numbers.

7.2

Bio-based and biodegradable plastics: a short

review

While most designers have a working knowledge of natural and renewable materials such as wood, cork, cotton, and wool, they remain relatively ignorant of the material opportunities offered by bio-based plastics. Following

7.2 Bio-based and biodegradable plastics: a short review

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[Lambert & Wagner \(2017\)](#), we define bio-based plastics as plastics derived from renewable feedstock. It is important to realize that a plastic produced from renewable feedstock is not necessarily biodegradable (biodegradable plastics can decompose through the action of microorganisms) and that plastics produced from fossil resources can be biodegradable. In this chapter we will talk about bio-based plastics and not bio-plastics, because the term bio-plastics are confusingly used for both bio-based plastics and biodegradable plastics. What follows is a short explainer and state-of-the-art review of the field of bio-based and biodegradable plastics.

7.2.1

Bio-based plastics

The bio-based plastics we discuss in this chapter are made from well-defined

monomers obtained after processing of (parts of) plants or microorganisms such as algae. Often-used examples of bio-based plastics that can be used for engineering applications are PLA (polylactic acid) and PHA (polyhydroxyalkano-

ate). Common polymers like PE (polyethylene) and PP (polypropylene), that are currently mainly associated with fossil fuels, can also be formed upon fur-

ther chemical processing of bio-based molecules (often via a bioethanol route).

This results in bio-PE and bio-PP, also referred to as “drop-in” polymers, because they have the same properties as their fossil-based equivalents. Even

partially bio-based polymers exist. Bio-polyethylene terephthalate (e.g., used in

the Coca Cola “Plant bottle”) is an example, in which one of the constituting monomers is bio-ethylene-glycol, while the other monomer is terephthalic acid

made from fossil sources, implying that bio-PET consists of 30% plant-based

materials ([Sheldon, 2014](#)). Polymers that directly use biomass such as chitin, cellulose, and starch are all biodegradable, but due to their properties they are

less suited for engineering applications. See [Table 7.1](#) for an overview.

The production of bio-based plastics has been criticized for competing with

resources for food production. The “first-generation” feedstocks that used, for

instance, edible seeds or corn ([Sheldon, 2014](#)) have sparked the development of Table 7.1 Examples of bio-based and petro-based polymers. The table shows both biodegradable and nonbiodegradable examples.

Petrochemical

Partially bio-based

Bio-based

Not biodegradable

PE, PP, PET, PS, PVC

Bio-PET (“drop-in”)

Bio-PE (“drop-in”)

Vulcanized polyisoprene

Biodegradable

PBAT, PBS(A), PCL

Blends with starch

PLA, PHA, cellophane, cellulose, starch

PBAT, Polybutylene adipate terephthalate; PBS(A), polybutylene succinate/adipate; PCL, polycaprolactone; PHA, polyhydroxyalkanoate; PS, polystyrene; PVC, polyvinyl chloride.

Source: Adapted from Molenveld, K., & Van den Oever, M. (2014). *Catalogus biobased verpakkingen*. Wageningen UR Food & Biobased Research. ISBN 978-94-6173-704-5.

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second-, third-, and even fourth-generation biostrategies. These use nonedible,

fast-growing crops or agricultural by-products (second generation), algae biomass

(third generation), or, as a new development on the horizon, “fourth generation”

genetically modified algae and other microbes as feedstock ([Azmah et al., 2016](#)).

In deconstructing and synthesizing raw biomaterials (feedstock) into chemicals

for polymer production, there is a wide range of industrial processing techniques

involved, which will not be discussed here. Just like fossil-based polymers, bio-

based polymers will need additives such as antioxidants, plasticizers, colorants,

and fillers to adapt their physical properties and improve their suitability for a

particular use. According to [Lambert & Wagner \(2017\)](#), “because different manufacturers will add different additives at various concentrations, materials made

from the same polymer should not be considered chemically identical.” This may

hamper their biodegradability and/or recyclability.

7.2.2

Biodegradable plastics

Biodegradable plastic is often confused with bio-based plastic. The term “bio-based” provides information regarding the renewable origin of the carbon source used for manufacturing the plastic. In contrast, “biodegradable” provides information on a potential degradation mechanism, which is completely unrelated to the carbon source. Biodegradable plastics can be made from fossil fuels as well as bio-based sources (see [Table 7.1](#) for examples). Biodegradation thus does not affect the production phase of a material, but its disposal phase, its “degradation pathway.”

For designers it is important to realize that when talking about biodegradability, there are a number of degradation pathways that all tend to be captured under the term biodegradability, but which are however very different and not all of them environmentally benign. [Lambert & Wagner \(2017\)](#) distinguish between degradation, biodegradation, and composting.

G Degradation is a process by which a material disintegrates. It can, for instance, take place as a result of natural daylight (photodegradation of plastics) or because special additives were added that help a plastic break down into small fragments over time (oxodegradable plastics).

Oxodegradation of plastics can lead to the accelerated formation of microplastics.

G Biodegradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. Biodegradation results in the lowering of the molecular masses of the macromolecules that form the plastic; and in the case of “ultimate” biodegradation, in the complete reduction to simple molecules like carbon dioxide and water.

G Composting is a form of biodegradation that results in carbon dioxide and compost (water and biomass), which contains valuable nutrients

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and is used as a soil improver. Composting is often misunderstood as a process that happens “naturally” when a biodegradable polymer ends up somewhere in the open environment. However, very few biodegradable polymers break down successfully at ambient temperatures in a reasonable timeframe. Most can only be composted under carefully controlled conditions, in industrial composting plants. The EU has a standard for determining compostability (EN 13432), which requires at least 90% disintegration after 12 weeks and 90% biodegradation in 6 months. A recent French standard has specified the

requirements for home composting: at least 90% decomposition within 12 months at ambient temperature (NF T51-800).

The (bio)degradation of a polymer is affected by its structure, the additives used

in the production of the material, and the exposure conditions such as humidity, temperature, pH, salinity, and the presence of sufficient oxygen ([Lambert &](#)

[Wagner, 2017](#)). These need all to be taken into account when designing with such polymers. In the presence of oxygen, biodegradable plastic is converted into water and CO₂ by microorganisms. However, under anaerobic conditions,

methane can be produced, which is a potent greenhouse gas.

7.2.3

Sustainability issues of bio-based and biodegradable polymers

From a sustainability perspective, the substitution of fossil-based plastics by bio-

based plastics generally leads to lower nonrenewable energy use and greenhouse

gas emissions ([Mülhaupt, 2013](#)). The greenhouse gas emission reduction, however, may be counteracted by direct and/or indirect land-use change (Oever

et al., 2017). There are, however, some possibilities for a sustainable coproduc-

tion of biofuels, bio-based plastics, and food; this may serve as a stabilizer for

food prices, providing farmers with more secure markets and contributing to social sustainability (ibid). Regarding the genetically modified organisms (GMOs) in fourth-generation biofeedstock, the potential release of GMO to the

environment is considered a serious risk ([Azmah et al., 2016](#)).

In the case of oxodegradable plastics, the [European Commission \(2018\)](#) concluded that there is no evidence that the fragmentation of oxodegradable plastic

in the open environment (land or sea) is sufficiently rapid to allow subsequent

biodegradation to take place within a reasonable timeframe. Remaining plastic

fragments and microplastics will lead to pollution of land and sea. Moreover,

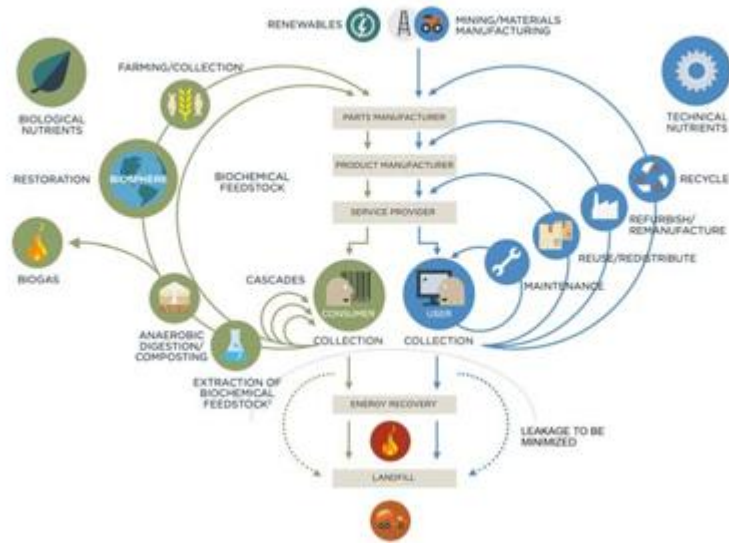
there are concerns within the recycling industry that the presence of oxodegrad-

able plastic in a conventional plastic recycling system can lead to poor quality

recyclate. It has led the European Commission to “start a process to restrict the

use of oxo-plastics in the EU” ([European Commission, 2018](#)).

**CIRCULAR ECONOMY
THE BUTTERFLY
DIAGRAM**



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When it comes to biodegradation, a bio-based plastic will have to be pure, or

safe, enough to prevent the quality of the final compost from declining, for example, because the plastic contains additives with heavy metals or fluorine.

However, this is not sufficient. If we want to avoid plastic pollution, we need to

assess the degradation process in a reasonable timeframe and not in terms of hundreds of years. This also implies that the degradation conditions should be

taken into account. This is directly notable when looking into compostable poly-

mers, which often can only be composted at elevated temperature under indus-

trial conditions. PLA, for instance, will take hundreds of years to decompose under aquatic conditions (i.e., in the sea). It follows that designers need to be acutely aware of the kind of bio-based and biodegradable polymers they design

with, in order to prevent unwanted negative sustainability effects.

7.3

Circular economy

The circular economy distinguishes between resource loops in the biocycle and the technocycle (EMF, 2013), as illustrated in [Fig. 7.1](#). In the technocycle materials loop back into the economy without much (or any) loss of quality through reuse and industrial recycling. The ideal scenario in the technocycle

FIGURE 7.1

The butterfly diagram of the circular economy, showing the biocycle and technocycle. Courtesy Ellen MacArthur Foundation , <http://>

www.ellenmacarthurfoundation.org.

7.3 Circular economy

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is a slow but continuous cycling through “everlasting” loops. In the biocycle biodegradable materials are cycled back into the biosphere to be regenerated (either industrially or naturally). This should be done in consecutive cycles,

named cascades, that see the materials lose quality until they are no longer fit for use. The ideal scenario is that materials in the biocycle cascade slowly and then enter the biosphere through (industrial) biodegradation.

7.3.1

Biocycle versus technocycle

We argue here that, from an industrial product design perspective, distinguishing between the biocycle and technocycle is not very helpful. Given the “ambiguous” nature of many materials (for instance, mixtures of biodegradable materials and nonbiodegradable additives) and the fact that bio-based materials are also used and recycled in industrial processes, the rigid distinction becomes confusing rather than helpful.

It is more useful to think in terms of options, rather than a dichotomy. Designers

always need to take into account the recovery and end-of-life pathways of the spe-

cific products and materials they work with instead of worrying about whether, for

instance, a bio-based polymer should go in the technocycle or the biocycle. Our

new model gives an overview of recovery options and makes it easier to assess the

risks of materials not ending up in the right recovery pathway (see [Fig. 7.2](#)). Instead of the technocycle biocycle division, we propose to visualize the circular economy as an economic system with a range of options, or recovery pathways, for products and materials.

G Maintenance and repair (product integrity focus)

G Direct reuse and redistribution (product integrity focus)

G Refurbishment and remanufacturing (product integrity focus)

G Recycling (material integrity focus)

G Molecular decomposition (carbon cycle focus)

The repair, redistribution, and refurbishment/remanufacturing loops of the “technocycle” remain similar to the technocycle in the butterfly diagram (see [Fig. 7.1](#)). The recycling and molecular decomposition loops change and are explained in more detail as follows.

7.3.2

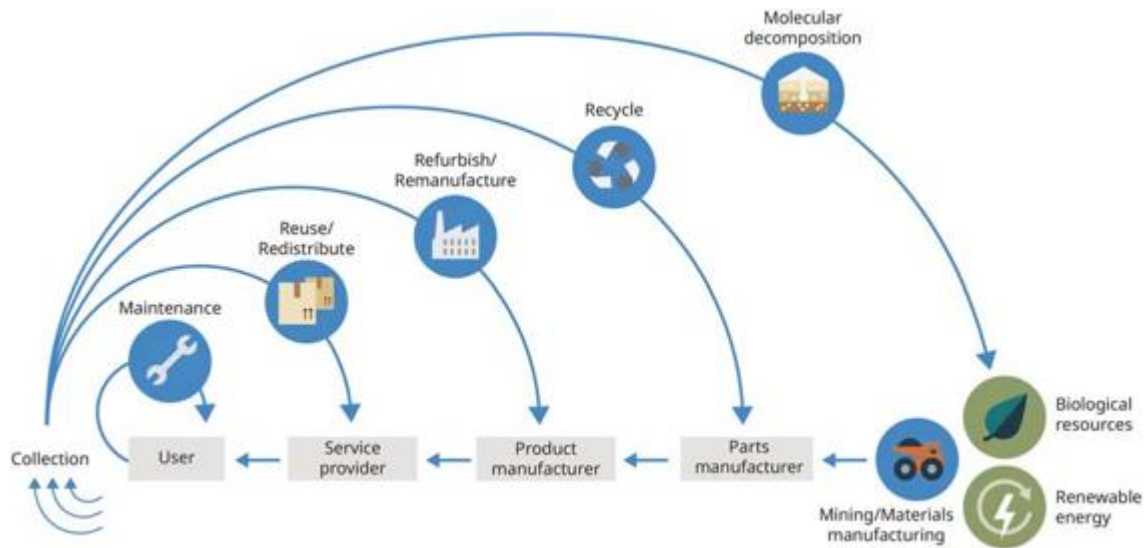
Recycling of bio-based plastics

(both nonbiodegradable and biodegradable)

Two types of recycling of bio-based plastics are possible; these are available for

both biodegradable and nonbiodegradable polymers ([Table 7.2](#)). The first is mechanical recycling; this process consists of well-known physical mechanical

steps such as the grinding, washing, separating, drying, regranulating, and



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FIGURE 7.2

Adapted circular economy diagram giving an overview of available recovery pathways for products and materials. Adapted from Ellen MacArthur Foundation.

Table 7.2 Overview of recycling options for bio-based plastics (biodegradable and

nonbiodegradable).

Recycling

options

Description

Benefits and challenges

Mechanical

The processing of waste plastics by physical

G Mainly for thermoplastic materials.

recycling

means (grinding, shredding, melting) back to

G Prone to thermomechanical degradation which

plastic products. To mechanically recycle

negatively affects the structure and morphology

postuser plastics waste, it has to be collected,

of the polymer and limits the number of

sorted, separated, ground, washed, and

recycling loops ([La Mantia, 2004](#)).

reprocessed before it can be reused.

G Results in prolonged carbon sequestration in

products.

G For biodegradable plastics it is important to

determine whether they are sufficiently stable to

be recycled in multiple cycles.

G Some biodegradable plastics may cause

contamination if they end up in the recycling

stream of nonbiodegradable plastics.

G Relatively low energy requirement.

Chemical

Any process by which a polymer is chemically

G Is currently being used for polyether, polyester,
recycling

reduced to its original monomer form so that it
and polyamide (nylon).

can be processed (repolymerized) and remade

G Energy-intensive process.

into new plastic materials.

G The monomers can in some cases be

repolymerized endlessly, giving them the

qualities of virgin resin.

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compounding of (thermoplastic) plastics. Usually, the resulting plastic
proper-

ties are less well defined than those of virgin plastics. Second, for some
plastics,

especially condensation plastics, chemical recycling is possible. This is a depo-

lymerization process that converts a plastic back into monomers, making it pos-

sible to repolymerize the polymer. This second option thus allows via a number

of chemical processing steps the recovery of the pure polymer, but is more energy intensive than the first option.

7.3.3

Molecular decomposition

The molecular decomposition pathway looks at different ways that bio-based plastics can break down to a molecular level. The focus in this recovery path-

way is the carbon cycle. Ideally, the decomposition of bio-based plastics is carbon neutral: when they break down, the carbon that was sequestered in the plastic becomes available again on a relatively short timescale (so, not hundreds of years).

There are five pathways ([Table 7.3](#)): plastics-to-fuel recycling, incineration with energy recovery, industrial biodegradation, anaerobic digestion, and unmanaged biodegradation. The first option, plastics-to-fuel recycling, is a thermal depolymerization process that results in biofuels and chemical feedstock, and which can be useful if the plastics are difficult to recycle in the recycling pathway. The resulting feedstock can be used for the production of new bio-based plastics. The second recovery pathway is incineration with

energy recovery. Energy recovery aims to use the released energy obtained during the incineration (or “thermal” recycling) of plastics waste. These two routes are carbon neutral in the case of bio-based plastics, whereas they directly lead to an increased carbon footprint in the case of fossil-based plastics. The third and fourth recovery routes are only suitable for biodegradable plastics: industrial biodegradation and anaerobic digestion. Based on current knowledge and understanding, the fifth recovery pathway of “unmanaged biodegradation” should be avoided if possible, as it can lead to extremely slow and/or incomplete biodegradation.

Biodegradation is often considered a “regenerative strategy” for its ability to free

up nutrients that feed the biocycle (EMF, 2013). From an economic perspective,

however, the breakdown of a high-value material such as a bio-based plastic into carbon and water (or into other molecules such as methane) is essentially a

form of value destruction. Designers therefore need to carefully consider how

the products they develop will be used and recovered or discarded, and only specify biodegradable plastics if the application necessitates this. In all other cases, it may make more economic and environmental sense to design for prod-

uct and material integrity as well as high-quality recovery, because this allows

value to be retained (and captured) over a longer period.

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Table 7.3 Overview of biodegradation options for biodegradable plastics.

Molecular

decomposition options

Description

Benefits and challenges

Plastics-to-fuel recycling (or

Processes that turn plastic waste into bio-

G Suitable for both biodegradable and

feedstock recycling)

based oil or gas, which can be refined

nonbiodegradable bio-based plastics.

into biofuel, or converted into chemical

feedstock such as bioethanol.

Incineration or thermal

Combustion of plastic waste in

G When bio-based plastics are incinerated recycling (with energy incinerators. As plastics have a high with energy recovery, the energy recovery) energy content, the resulting heat from produced is carbon neutral because their combustion can be used directly CO₂ has first been sequestered into the (i.e., heating homes) or for the production bio-based plastic. of electricity.

G Incineration with or without energy recovery of biodegradable bio-based plastics has a similar climate effect as the incineration of nonbiodegradable bio-based plastics.

Industrial biodegradation

This process takes place in a relatively

G Composting (under aerobic conditions)

(or industrial composting,
short period of time and runs under
is CO₂ neutral.

or aerobic digestion)

specific process parameters with regard

G Composting of bio-based plastics

to humidity, temperature (exceeding

does in itself not produce compost

56C), oxygen, etc. It is controlled by

(only CO₂ and water).

humans.

G There can be cobenefits such as

increasing the amount of food waste

collected to be composted.

Anaerobic digestion (or

The production of biogas by fermentation

G Not all biodegradable plastics can be

anaerobic organic

of biodegradable plastics. This process is

digested through anaerobic digestion.

recycling)

controlled by humans.

G The process is CO₂ neutral if the biogas is subsequently used as fuel.

Unmanaged

The uncontrolled release of biodegradable

G Home composting of biodegradable

biodegradation (ambient

plastics in the environment (soil, sea,

bio-based plastics is often considered

conditions, can be aerobic

space), where they may or may not break

unmanaged biodegradation, because

or anaerobic)

down or biodegrade in a reasonable

few people manage to actually control

timeframe under ambient conditions.

the heat and aerobic conditions in

their compost bin to the extent

needed for the composting of

common biodegradable polymers.

Even perfectly biodegradable, bio-based polymers such as PLA and PBS can end up polluting oceans and soil if they biodegrade under uncontrolled conditions ([Narancic et al., 2018](#)).

7.3.4

Monstrous hybrids

Sidestepping the division between technocycle and biocycle of the butterfly diagram also eliminates another problematic concept that the circular economy inherited from Cradle to Cradle monstrous hybrids. Monstrous hybrids are defined as mixtures of both technical and biological materials, neither of

7.4 Designing with bio-based polymers

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which can be salvaged after their current lives ([McDonough, 2015](#)), and which should therefore be avoided. But as most modern materials (including bio-based plastics) consist of composites or blends or are improved through additives, making a rigorous distinction between technical and biological materials is very difficult, if not impossible. On a product level this becomes even more complicated, as replacing all fossil-based plastics with bio-based plastics inherently will imply that plastic containing products in the techno-

cycle will become monstrous hybrids. This makes the concept of monstrous hybrids less useful for designers.

7.4

Designing with bio-based polymers in a circular economy: opportunities and challenges

There is an enormous diversity of biopolymers and as their production will inevitably

be scaled up in the coming decades, the areas of application are expanding

rapidly. Scientific developments indicate that bio-based equivalents of high-end

engineering plastics, like Liquid Crystal Plastics and PEEK, will become available

([Nakajima et al., 2017](#)). Moreover, the production of bio-based plastics is no longer only motivated from a desire to substitute fossil resources, as we are seeing

the development of bio-based polymers with improved or even completely new

properties compared to fossil-based polymers. Examples are bio-based PEF and

PTF that have excellent gas barrier properties and can substitute for PET

([Andreeßen & Steinbüchel, 2018](#); [Nakajima et al., 2017](#)).

These developments create opportunities as well as challenges for industrial

designers, which we will describe here. Among the many opportunities that bio-

based materials offer, the one that stands out most is the fact that a completely

new playing field for designers is opening up. Designers can begin to increase the

demand for bio-based polymers by specifying “drop-in” bio-based polymers and

bio/fossil blends (such as bio-PET). These polymers have similar properties to

their fossil-based alternatives and their application is therefore without much risk.

As a next step, designers can specify bio-based and biodegradable polymers for

specific applications such as single-use packaging, hygiene applications, and agri-

cultural products. This is more challenging because biodegradable polymers have

different properties and because their recovery pathways can differ from tradi-

tional polymers. It requires designers to really understand and address the end-of-

life options that are not open to nondegradable plastics, such as composting and

anaerobic degradation ([Narancic et al., 2018](#)).

Taking a more forward-looking approach, there are opportunities for

designers to work closely with material scientists to develop new kinds of bio-based polymers, for instance, the development of polymers with desirable characteristics that break down successfully in unmanaged conditions.

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The collaboration between material scientists and designers will ensure that these new materials will not only meet functional specifications, but are esthetically and experientially pleasing as well, and will be applied in such a way as to maximize their potential ([Barati & Karana, 2019](#)).

In this chapter, we focused on bio-based plastics as these are most likely to help designers in substituting the current range of plastics used at a large scale in a variety of products. We would also like to briefly mention interesting developments in a complementary field of bio-based materials, which explores the use of living materials ([Camere & Karana, 2018](#)). Designers in this field showcase new ideas based on small-scale experimentation, for instance, the use of algae in building facades through building-integrated microalgae photobioreactors ([Elrayies, 2018](#)) or the use of fungi to create and grow products.

One of the major challenges that need to be overcome is the lack of knowledge

among designers about the properties and possibilities of bio-based materials

(and, in particular, bio-based plastics). Designers need to be brought up to speed

on the quantitative physical properties of these materials, and not just on their

experiential qualities, in order to enable collaboration with material scientists and

industry. Bio-based plastics are not (yet) part of the curriculum in design schools,

which may lead to a bias against bio-based plastics as having inferior properties.

Next, the specification of a bio-based polymer always needs to be done on the

basis of its characteristics as well as its recovery and end-of-life pathways. This too is a challenge—materials are usually specified based on their properties, without

considering potential recovery pathways. If we are serious about achieving a circu-

lar and sustainable economy, this needs to change. Designers need to learn about

the way bio-based plastics perform and degrade over time, how this affects their

physical and experiential properties, and what recovery pathways are preferred

given the application at hand. Finally, it should be stressed that the use of bio-

based plastics is not necessarily a sustainable choice. For example, the impact of

biodegradable plastics that are released into the environment in an uncontrolled

way could be highly disruptive to natural ecosystems. Although bio-based plastics

are made from renewable materials, those materials should come from sources

that are replenished at a rate equal to or greater than the rate of depletion in order

to be considered a sustainable choice. Overall, many sustainability and ethical

challenges remain, and designers should make conscious decisions when specify-

ing bio-based plastics.

7.5

Conclusion

We argue in this chapter that the world Ezio Manzini described in 1989, of “materials made to order,” is about to be replaced by a world of “limits,”

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where fossil-based plastics will no longer be available and where supply of alternative materials with negative sustainability impacts will be restricted.

This may initially hamper design choice, but it will also open up a new and exciting world of bio-based materials waiting to be explored.

This chapter contributes to design practice and research in three ways. First, it

positions the recovery pathways of bio-based plastics in a circular economy and in doing so creates a new conceptual model of the circular economy that combines “technocycle” and “biocycle” in one. The new model gives a clear overview of the different recovery options available for bio-based and biode-

gradable plastics. Second, we argue that the choice of a particular bio-based polymer always needs to be done on the basis of its properties as well as its recovery and end-of-life pathways, if we want to support a circular and sustainable economy. This is currently not a standard procedure in design.

Finally, we argue that one of the main challenges we currently face is to educate designers about bio-based materials in all their complexity.

Through this chapter we hope to contribute to a renewed recognition of the materiality of design. The material basis of design was taken for granted for a

long time, and designers may have grown somewhat complacent as a result.

With the transition toward bio-based materials, the material basis is however back on the agenda and needs to be addressed urgently. It has never been

more important that designers reengage with it in novel ways in order to help create a more sustainable future.

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CHAPTER 8

Biotextiles: making textiles in a context of
climate and biodiversity emergency

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8.1

Introduction

With 10 years ahead of us to halve our greenhouse gas emissions as recommended by the International Panel for Climate Change ([IPCC, 2018](#)) and with the loss of one million species confirmed by the latest report from the

Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem

Services ([IPBES, 2019](#)), every industry needs to explore and implement systemic change. The textile and fashion industry consists of a complex range of

globally interconnected activities that all lead to detrimental and measurable impacts on land, water, biodiversity, and the atmosphere, alongside consider-

able human and social challenges. In the past 10 years, there have been unprecedented acknowledgments and efforts to better analyze and frame

textile- and fashion-specific environmental challenges (The Sustainable Coalition, Ellen McArthur Foundation, Copenhagen Fashion Summit, The

Sustainable Angle), with a growing number of global and local initiatives that support a transition to a more sustainable and circular industry (EU

Textile Circular Economy, WRAP, Fashion Positive, Textile Exchange, Common Objectives) as well as funded support for disruptive innovation labs and startups (H&M Global Challenges, Fashion for Good, Kering Material Innovation Lab, LVMH Maison/0). The urgency of a global response

to climate change is also more prominent than ever with activists such as Greta Thunberg and the Extinction Rebellion movement being front page news. Yet our growing world population and consumerist model keep increasing pressures on our natural resources: in three decades the global pro-

duction of textile fibers has almost tripled ([EEA, 2019](#)) and the fashion industry has not demonstrated an ability to implement change fast enough to counterbalance its projected expansion ([Lehmann et al., 2019, 2020](#)).

Sustainability is not enough anymore. Instead of minimizing our environmental impact using incremental improvements and cleaner technology, we need to rapidly progress to a restorative and regenerative mindset by

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00029-6>

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adopting a living systems approach so that what we design and make has a positive impact on our climate and biosphere ([Birney, 2017](#); [Pawlyn, 2019](#); [Webster, 2017](#)). This applies to the textile and fashion system which is on a current trajectory to use “26% of the carbon budget associated with a 2C pathway” by 2050 ([Ellen MacArthur Foundation, 2017](#), p. 21). We must envision and shape a new regenerative textile industry with disruptive design and fabrication strategies. And this is beginning to happen with the emergence of alternative propositions for textile materials and finishing processes arising from biodesign, biotechnology, and textile research.

This chapter examines key recent innovative bioalternative textile materials and processes and proposes an analysis of their potential contribution to lessening the environmental impact of the textile industry. With the emergence of biodesign and biotextiles, new questions arise. How can biodesign help reshape the textile industry? Can design-led biology research be scaled up to leverage circular principles for the bioeconomy? And how can biodesign help address textile-specific sustainable development goals? [Section 8.2](#) situates textile material innovation in an environmental crisis context.

[Section 8.3](#) reviews the emergence of biodesign and its role in textile innovation, and [Section 8.4](#) explores biotextile strategies mapped against living systems and biomimicry principles.

Textile material innovation in an environmental
crisis context

8.2.1

From textile evolution to material revolution

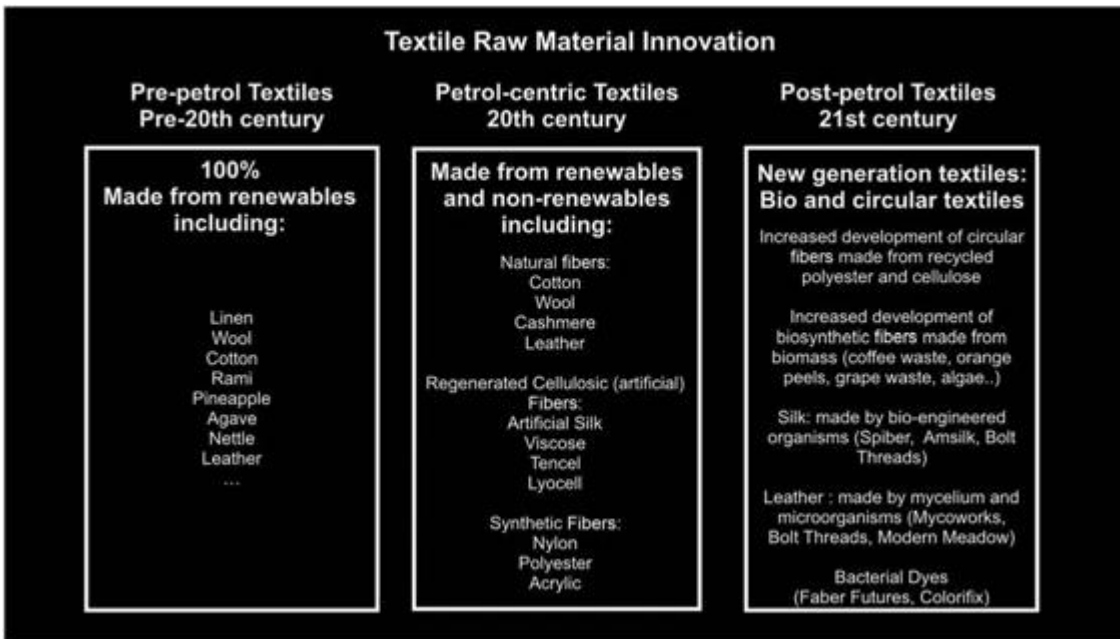
Human evolution is deeply connected with the history of textile craft and production. Indeed, traces of dyed linen fibers have been found in the Dzudzuana cave in the republic of Georgia dating 32,000 YBP and anthropological research shows evidence that we started wearing cloth between 42,000 and 72,000 years ago ([St. Clair, 2018](#)). Crafting our textile materiality started with local knowledge but expanded with trade and global exchange.

The silk road testifies to the influential development of textile fabrication across cultures with secrets of production fiercely guarded and/or stolen ([St. Clair, 2018](#)). Today, the textile industry includes small, cottage local industries as well as large global multinational companies with complex tiered

supply chains, but it still relies on material knowledge and processes mastered long ago, such as dyeing, spinning, weaving, and knitting.

When it comes to sourcing raw materials for textiles, we can categorize textile

production as follows (see [Fig. 8.1](#)):



8.2 Textile material innovation in an environmental crisis context

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FIGURE 8.1

Mapping key textile raw material innovation pre- and post-petrol economies ([Collet, 2019](#)). Data gathered via the literature review of textile material innovation, biotechnology, and biodesign.

G a pre-petrol textile era where materials are made from natural renewable sources;

G a petrol-centric era where synthetic fibers dominate the production of textiles, and where petrochemistry is also heavily used in the production of natural fibers such as cotton in the form of synthetic pesticides and fertilizers;

G a post-petrol era where recycled, circular, and bioinformed new

materials and processes are fast emerging as alternatives to unsustainable conventional textiles.

Until the end of the 19th century, textiles had been made from natural materials. They were either plant-based such as linen, cotton, rami, bark cloth, pineapple, agave, and nettle; or animal- and protein-based for the production of wool, cashmere, silk, and leather. Material innovation laid in the skills and ability to know how to transform harvested or foraged materials into functional textile fibers. How do we process a flax plant to extract its fiber? How do we cultivate silkworms? However, in 1855, a major invention

took place with the development of artificial silk or rayon (made from
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chemically processed plant cellulose), which was first commercially produced

in 1910 ([Shaikh et al., 2012](#)). From the cave of Dzudzuana up until 1855, plant- and animal-based materials were transformed into fibers by mechanical or handmade processes, not by chemistry. The invention of artificial silk

broke thousand years of tradition in terms of harvesting and sourcing material for the production of fibers and marked the beginning of a quest for a

different kind of raw material sourcing. This was to come with the invention of synthetic fibers starting with Nylon in 1935 ([Raber, 2010](#)) and Polyester in 1941 ([Sterlacci & Arbuckle, 2017](#)). Since its invention, Polyester has radically disrupted the entire textile production system. Made from nonrenew-

able crude oil it is much less expensive to produce than natural fibers, and as such has facilitated the development of fast fashion. Today, 70 million barrels of oil are used every year to produce polyester clothing and over 8000 different chemicals are used to turn raw material into textiles with 25% of the world's chemicals used for textile production ([Common Objectives, 2018a](#)). Within a few decades, the millennia-old textile industry has shifted from a reliance on natural renewable fiber production to a dependence on nonrenewable crude oil.

By the end of the 20th century and the beginning of the 21st century, there have been numerous developments in the production of biosynthetic fibers.

Biosynthetics are polymers made from sugar, starches, and lipids from renew-

able sources such as corn, sugar, cane, beets, and plant oils; and although not new, they are becoming a viable alternative to oil-based synthetic fibers

([Textile Exchange, 2018c](#)). We are seeing increasing development of new types of biosynthetics made from waste biomass such as coffee, orange, or

grape waste. But where radical textile material innovation lies is in the devel-

opment of a new breed of fibers derived from research in synthetic biology. Made with living organisms and relying on the inherent properties of biological organisms to biofabricate at ambient temperature with no toxic by-products, these new biotextiles have galvanized public interest. Key collaborations across biotech companies and fashion/sportswear brands have transformed unrivaled hi-tech material innovation into fashionable and desirable products. For instance, biotech firm Spiber collaborated with the North Face to launch the Moon Parka in 2015. It is made with Brewed Protein silk ([Rhodes, 2015](#)) and was shortly followed in 2016 by the launch of Adidas first shoe made with Biosteel by Amsilk. In 2016, Bolt Threads biofabricated the first tie made with silk grown by yeast, and later partnered with Stella McCartney to design a dress made with their bioengineered Microsilk for the milestone exhibition: Items: Is Fashion Modern at the Museum of Modern Art. The partnership continued when Adidas and Stella MacCartney launched the first biodegradable Microsilk tennis dress in 2019. These radical new biotextiles will be discussed in [Section 8.2](#).

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8.2.2

Making textiles for a growing world population

The current environmental impact of the textile and fashion industry has become more widely recognized by policy-makers, consumers, and manufacturers, yet, as early as the 1800s, “evidence of public disquiet about pollution from the textile industry can be found in newspapers” ([Erhman, 2018](#), p. 45).

Business values and economics prevail above the protection of nature. Inscribed

within a culture of endless material growth, where “Nature is accorded an almost infinite capacity to take care of various wastes and pollutants and render

them harmless” ([Wijkman & Rockström, 2012](#), p. 4), the production of textiles whether natural, artificial, or synthetic has led to fundamental and critical environmental issues. “Textiles are the fourth highest pressure category for the use of

primary raw materials and water, after food, housing and transport, and fifth for

greenhouse gas emissions” ([EEA, 2019](#), p. 10).

There are two key factors to consider in terms of textile raw material provenance. First, the environmental impact directly linked to the production process of the raw material. For instance, cotton that accounts for 25% of global fiber consumption is highly damaging in terms of biodiversity, land toxicity, and water scarcity when produced with conventional petrochemical intensive agricultural methods. In addition to a large amount of water, it uses high

levels of pesticides, fertilizers, and chemicals that affect human health and pol-

lute local ecosystems ([Shepherd, 2019](#)). Polyester represents over half of the entire fiber market and over 75% of all synthetic fibers. This equals a sevenfold

growth since 30 years ago ([Textile Exchange, 2018c](#), p. 9). Made from crude oil, a limited nonrenewable supply, it has a high carbon footprint: emissions

of CO₂ for polyester in clothing, at 282 billion kg in 2015—are nearly three

times higher than those for cotton, at 98 billion kg ([Cobbing & Vicaire, 2016](#), p. 4). Although recycled polyester is an alternative to using virgin oil, a critical

issue linked to synthetic fibers is their release of microfibers into water streams

during the washing cycle. The accumulated amount of microfiber entering the

ocean between 2015 and 2050 would exceed 22 million tons—about

two-thirds of the plastic-based fibers used to produce garments annually

([Ellen McArthur Foundation, 2017](#), p. 39). Second, we need to take into account the growing quantity of the global material flow related to population

and consumption growth patterns: global fiber production saw a 10-fold

increase from 1950 to 2017 from 10 million mt to over 100 million mt

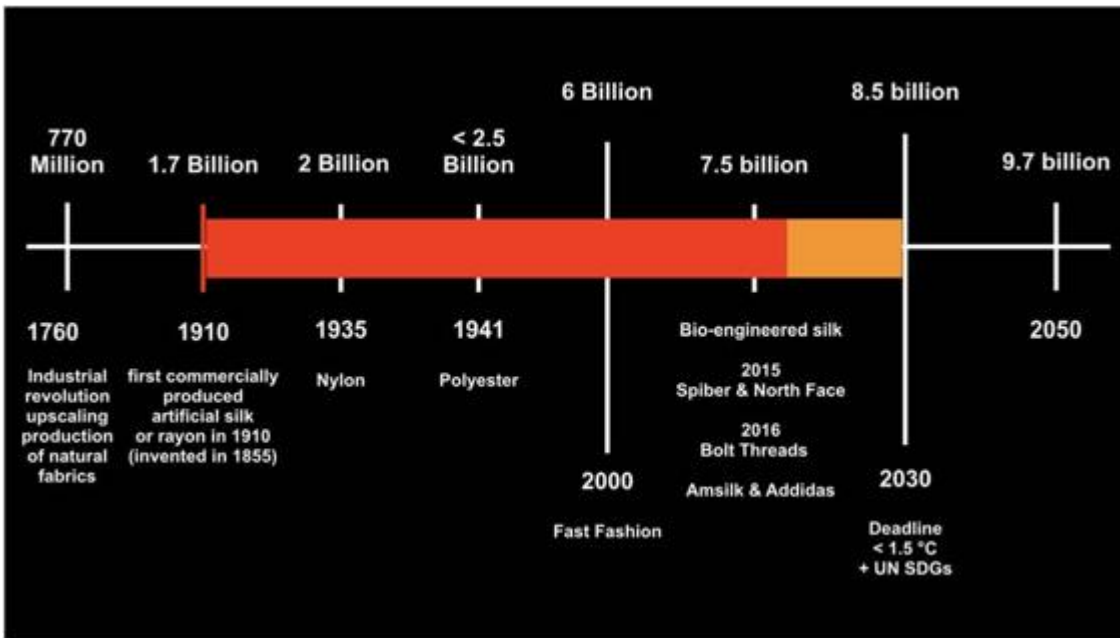
([Textile Exchange, 2018a](#), p. 6). [Fig. 8.2](#) maps raw textile material innovation together with world population which is predicted to reach 9.7 billion people

by the year 2050 ([United Nations Worldometer, 2020](#)).

We can see that at the time of the first commercialization of artificial silk in

1910, the world counted 1.7 billion people and less than 2.5 billion when poly-

ester came to market in 1941. Sixty years later, the population has reached



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FIGURE 8.2

Mapping key textile material innovation with world population growth (Collet, 2019). Data gathered from: United Nations, from 1950 to current year: elaboration of data by United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2019 Revision; from Worldometers (<http://www.worldometers.info>) and literature review of textile material sourcing.

6 billion. In 2015 16, when the first bioengineered silk made by microorgan-

isms is launched (Spiber, Amsilk, Bolt Threads), the world counted 7.5 billion

humans ([Worldometer, 2020](#)). By 2030, when we should have halved our greenhouse gas emission to stay within the 1.5C temperature increase ([IPCC, 2018](#)) we will be an extra 1 billion compared to 2015. So how do we generate textiles and clothing for another 1 billion people while transitioning to a post-carbon economy? Nothing short of a material revolution is needed and it has

begun to materialize with advances in biological sciences paralleled with the emergence of biodesign. [Section 8.3](#) will develop how biodesign and biotextile alternatives are beginning to disrupt the textile industry.

8.3

Textile innovation in the context of the emergence of biodesign

While cotton and polyester remain forecasted as the leading fibers for the foreseeable future ([Ellen MacArthur Foundation, 2017](#); [Grose, 2015](#);

8.3 Textile innovation in the context of the emergence of biodesign

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[Textile Exchange, 2018c](#)), environmental pressures have become a catalyst for the development of alternative textiles. In a shifting context where a transition to the circular economy promotes recycling, upcycling, and closed-loop

systems, there is an increase in the use of recycled raw materials, cotton and polyester included ([Textile Exchange, 2018a](#)). However, this section will focus specifically on the more radical recent textile material innovations that

exist at the crossing of design and biology and will ask: how do we design for a post-carbon textile bioeconomy using the intrinsic ecological values of biological systems (cyclic, solar, local) to develop a regenerative blueprint for

textiles? For the purpose of this chapter, we will examine biodesign and more specifically biotextile innovation within a 10-year timeframe.

2010 marked a profound step in human history, when US scientist Craig Venter and his team claimed the creation of the first synthetic organism on Earth, designed on a computer ([Pennisi, 2010](#)). This breakthrough marked a time when biology became a powerful technology, one that we aim at controlling to generate new biologically driven microfactories that can be pro-

grammed, localized, and customized ([Collet, 2015](#), p. 197). In parallel to scientific advances, the field of biodesign began to emerge. Informed by strategies found in nature, biodesign goes beyond referencing nature and relies

on active collaboration with biological organisms to propose new ways of making ([Myers, 2012](#)). Biodesign was celebrated in the inaugural exhibition *Alive, New Design Frontiers* at the EDF Foundation curated to reevaluate the process of design when confronted with the “living” ([Collet, 2013](#), p. 6). By understanding that “design can be a means to unlock new world of knowledge but also an efficacious tool for managing current technological transfor-

mations and transgression” ([Doll et al., 2016](#), p. 1) we can explore the potential of biodesign to offer novel perspectives on what change could look like, for ourselves and other living things ([Ginsberg & Chieza, 2018](#)).

Inscribed within a discourse of biomimetics, the field of biodesign is recent enough that its definition evolves as it expands and the “phenomenon of growing design is still scarcely understood” ([Camere & Karana, 2017](#), p. 101). Here, we understand biodesign “as a means to incorporate the inherent life-conducive principles of biological living systems into design processes—to transition into a more holistic, sustainable future” ([Collet, 2019](#)).

While multifarious terms are used, such as bioinformed design, biointegrated design, growing design, biomimetic design, each with their own interpretation of a design activity hybridized with biological principles and/or living systems, there are two key streams of innovation. One is led by designers, and the other is led by scientific research and biotechnology. Both have adopted the terminology of “biodesign” to manifest biointegrated processes.

Biodesigners have been particularly active in the field of textiles and have col-

laborated with a range of living systems to reinvent our future textile

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materiality with the help of organisms such as bacteria (Lee, Chieza, Keane) and mycelium (MycoTEX, Montalti, Collet). Others have incorporated inert biomass into the development of new materials such as algae (Algiknit,

Vegea, Orangefiber). Synthetic biologists, on the other hand, have pushed the limits of biology to create plastic with methane eating bacteria (Mango Materials), or reprogram yeast to express silk proteins (Bolt Threads, Amsilk, Spiber), or to scale up biological processes that can radically alter textile pollution resulting from the dyeing process (Colorifix, Pili, Tinctorium).

As the field of biodesign grows, we can begin to develop a new interpretation of material innovation by mapping different design and fabrication strategies.

Curatorial research developed for the exhibition discussed above Alive, New

Design Frontiers in 2013 referred to five key design strategies to negotiate design

relationships with the natural world and to locate designers operating “within a

sliding scale of a natural nature and a new programmable nature in the quest for

innovative ecological models” ([Collet, 2013](#), p. 6). This initial framework was devised to map the practice review of the very nascent field of biodesign when

developing the proposal for the exhibition in 2011. The plagiarists, the new artisans,

the bio hackers, the new alchemists, and the agents provocateurs were the titles used in the exhibition to communicate biodesign strategies to a broader

public. They correspond to five different approaches: nature as a model, a coworker, as well as

reprogrammed, hybridized, or conceptualized nature. The choice was made to

include a “conceptualized nature” section as many designers, short of accessing

actual biology laboratories and tools, were exploring speculative concepts to develop an imaginary of biotechnology and propose an ecological bioinformed

future. Three years later the framework was simplified with three key strategies

([Fig. 8.3](#)), excluding conceptualized and fictional nature as more designers began to actively engage with living systems and developed a “DIY-Material practice”

([Rognoli et al., 2015](#)). This testifies to the rapidity of the development in the field with pioneers Suzanne Lee, Phil Ross, and Maurizio Montalti at its helm.

As the field continues to expand, so does its taxonomy. Another key and more recent model proposes four interconnected approaches to biodesign:

Growing Design, Augmented Biology, Biodesign Fiction, and Digital

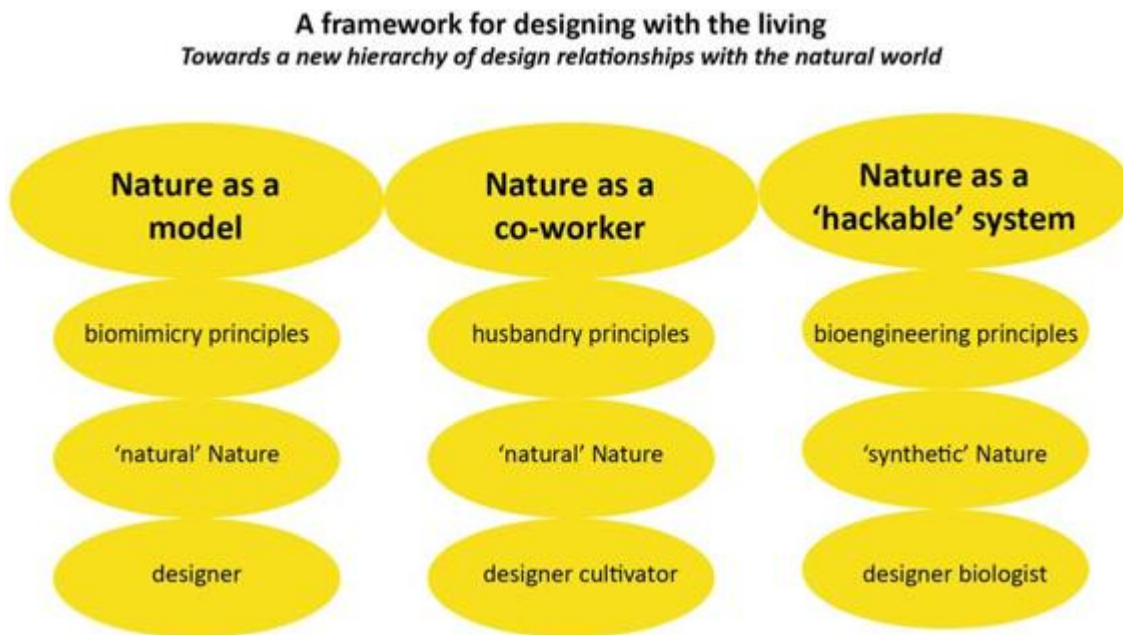
Biofabrication ([Camere & Karana, 2018](#)). This model provides a more agile intersected framework centered around the practice of biodesign and the possibilities to merge different approaches together.

8.4

Strategies for designing textiles with living

systems

When it comes to textiles, the conventional and classical taxonomy refers to three main categories of materials based on their nature and origin: natural



8.4 Strategies for designing textiles with living systems

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FIGURE 8.3

From Biomimicry to Biofacture. r Carole Collet, Design & Living Systems Lab, Central Saint Martins UAL, 2016.

fibers, (agriculture), regenerated artificial fibers (manufacture), and synthetic fibers (manufacture). In 2015 a revisited version informed by the latest development in synthetic biology and the UK roadmap for synthetic biology was published to include biofiber and biofabric categories for biofactured

material systems ([Collet, 2015](#), p. 194) and situates textiles in a context where there is a disconnect “between the ways in which clothing is made and the ways in which it might be made” ([Antonelli, 2017](#), p. 9). There are many other ways to map textile materials; here we are concerned with an examination of biotextile materials in relation to environmental issues. How do we examine the sustainable value of biodesign and biotextile propositions in relation to material innovation and origins? Below is a list of key recent biomaterial innovations examined via the lens of principles of natural living systems ([Benyus 1997](#); [St. Pierre, 2015](#), p. 40). Benyus advocates the adoption of nature’s law to address critical human-made ecological challenges.

“Nature runs on sunlight. Nature uses only the energy it needs. Nature fits form to function. Nature recycles everything. Nature rewards cooperation. Nature banks on biodiversity. Nature demands local expertise. Nature curbs excess from within. Nature taps the power of limits.” ([Benyus, 1997](#), p. 7).

The examples below do not represent an exhaustive list of biotextile innovations but are referenced as a means to develop a living system critique of biotextile practices as well as to identify key research gaps. By adapting

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Benyus’s principles into design questions, we can begin to frame the emer-

gence of biotextiles in relation to biomimicry principles.

8.4.1

Textiles made with living organisms:

(does it reward cooperation?)

Two key organisms have inspired the development of new biofabricated material systems' fashion textiles. Bacteria that naturally produced cellulose were first introduced to the fashion world by Suzanne Lee via the Biocouture Atelier founded in 2003 to explore compostable and sustainable biofabricated materials ([Lee, 2013](#), p. 19). Since then, many iterations of bacterial cellulose materials have been developed but have demonstrated limited ability to scale

up to viable alternative textiles for fashion, in part due to their lack of resistance to the humidity level. Jen Keane revisited the technique for her final Master project "This Is Grown" on MA Material Futures at Central Saint Martins UAL in 2018. By inventing a microbial weaving technique where a fiber matrix is embedded in the cellulose during the growing phase. This allows for the production of stronger biodegradable materials that are also shaped during their growth: "nature doesn't make its materials in sheets, dye, cut and assemble. It produces just what it is needed as it is needed" ([Keane, 2019](#), p. 4). "This Is Grown" has been further developed with two collaborations. A residency at Bolt Threads in 2019 helped to further refine and

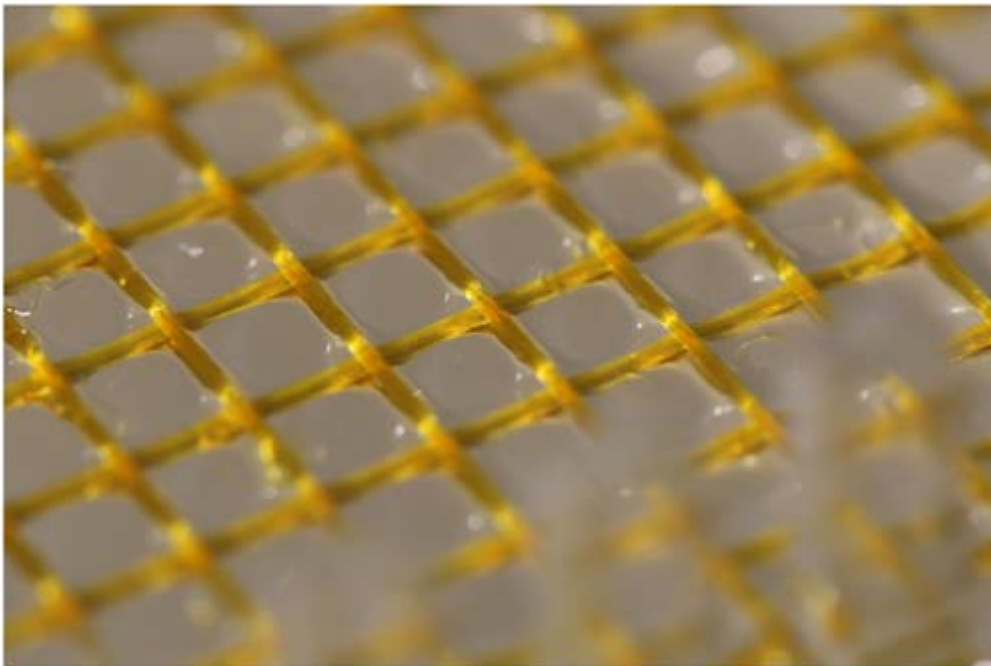
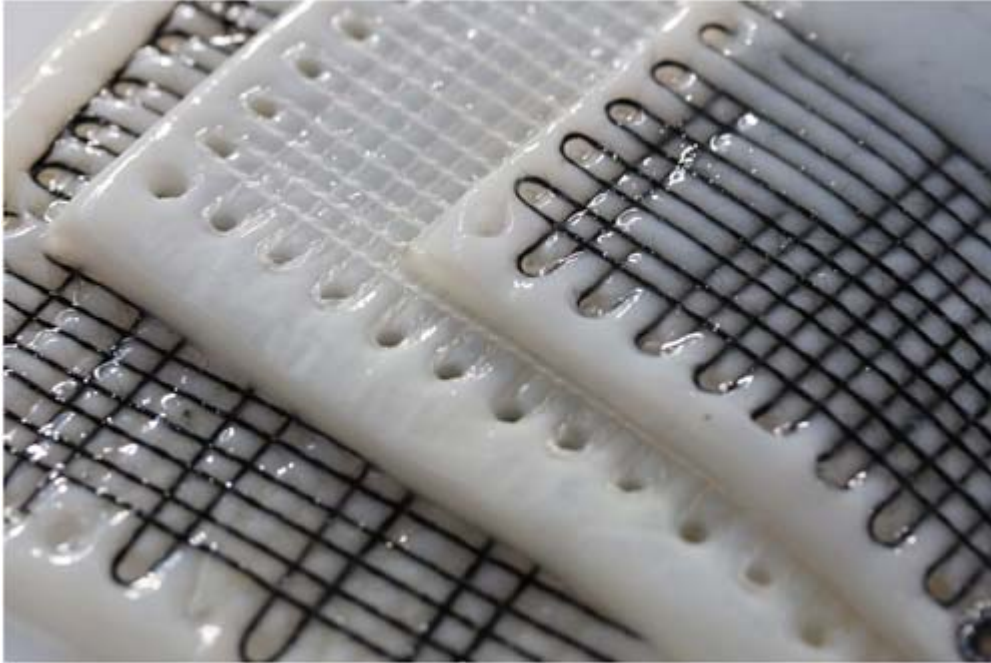
develop microbial weaving techniques and includes using Bolt Threads Microsilk in the woven matrix ([Figs. 8.4](#) and [8.5](#)).

Another collaboration was established with the synthetic biologist Marcus Walker, PhD candidate in the Tom Ellis Lab at Imperial College London in 2019 with the support of Mills Fabrica and Hong Kong Innospace. Walker “has used genetic engineering techniques to develop a self-dyeing bacterium that produces both cellulose and melanin, a natural pigment found in squid ink, hair, and skin. Employing this bacterium in Keane’s microbial weaving process, together they have grown the first sneaker-upper woven and dyed by a single genetically modified organism” ([Keane, 2019](#), p. 7) ([Figs. 8.6](#) and [8.7](#)).

Jen Keane’s work embodies two different types of symbiotic cooperation.

First, in the material itself, as bacterial cellulose is produced by an ecosystem

of bacteria and yeast that depend on one another to thrive. Second, in the collaboration between synthetic biologists who bring an expert understanding of biological systems and the designer whose knowledge of the material and design world can guide and respond to scientific experiments. The intersection of different sets of expertise provides a new type of cooperation that can help discover new approaches to making textiles.



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FIGURE 8.4

This is Grown. r Jen Keane. Microbial woven samples produced by Jen Keane during her residency at Bolt Threads 2019.

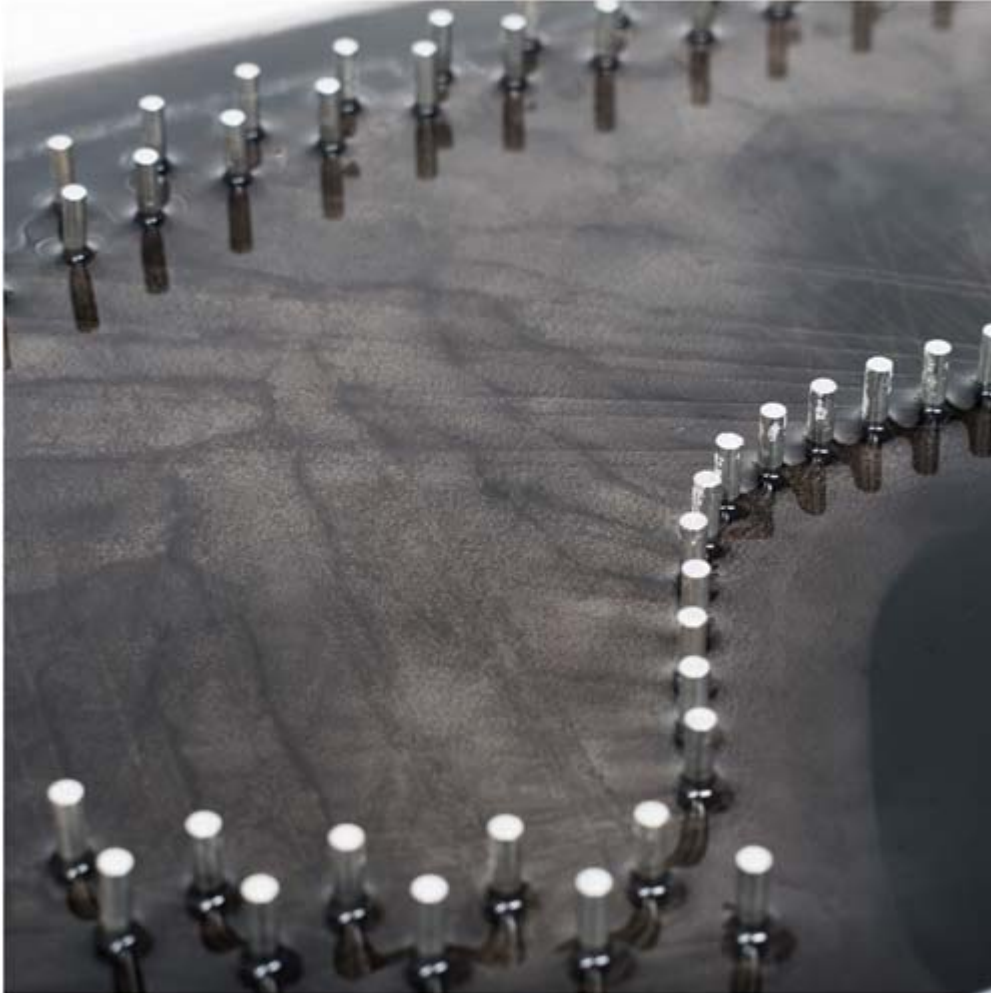
FIGURE 8.5

This is Grown. r Jen Keane. Microbial woven samples produced by Jen Keane during her residency at Bolt Threads 2019. Details of Microsilk (yellow fiber) embedded in bacterial cellulose.

Parallel to bacterial cellulose developments, there are many successful exam-

ples of artists, designers, and biotechnologists exploring the potential of living mycelium to grow materials. Pioneered by artist Phil Ross who integrated

mycelium in his practice in the 1990s before to establish Mycoworks in the United States. In the past decade, the majority of mycelium research has focused on the design and production of solid materials for product,



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FIGURE 8.6

This is GMO. Jen Keane in collaboration with Marcus Walker. Detail of the liquid microbial culture. Photography: Jen Keane.

packaging, and architectural design proposals (Ecovative, Ross, Montalti, Mogu, Klarenbeek, Benjamin). In terms of textiles, Aniela Hoytink designed

the first dress made with mycelium material and was awarded the H&M Global challenge with MycoTEX in 2018 (Global Change Award). Ross launched the first mycelium-based leather material with Mycoworks in 2016, shortly followed by the introduction of Mylo made by Bolt Threads.

Ecovative and Mogu have also developed foam-like materials. The latest leather, Reishi, was launched for New York fashion week by Mycoworks in February 2020. As a vegan alternative to animal-based leather, mycelium leather is one of the most promising new biotextiles in terms of sustainability. It can grow on waste biomass in a matter of days compared to months for the production of cow hides which are detrimental to our biodiversity (deforestation and land use to produce food stock for cattle) and have a high environmental cost ([Common Objectives, 2018b](#)). Cooperation with mycelium has proven to be an effective means to develop new biocircular textile

materials, which can be upscaled from laboratory research to industry standards and propose concrete, viable alternatives for sustainable textile fabrication processes.



8.4 Strategies for designing textiles with living systems

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FIGURE 8.7

This is GMO. Jen Keane in collaboration with Marcus Walker. Photography: Ed Tritton.

8.4.2

Textiles patterned with living systems:

(does it reward cooperation?)

Textile finishing processes that include dyeing, printing, and coating currently rely on petrochemical processes which left untreated are toxic for our water effluents. Natural dyes do not offer a realistic alternative to synthetic dyes due to the sheer volume required at global scale. Traditional textile dye recipes require the use of mordants to help fix the dye onto fibers and become color fast. These mordants include heavy metals, which are toxic for the environment. A huge amount of plants would also be needed and compete for land currently used to grow food. So natural dyes are not a viable alternative, but cooperation with living microorganisms can help us reinvent



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new processes to pattern our clothes. Designer Natsai Audrey Chieza, founder

of studio Faber Futures, has been promoting the development of microbial

dye since 2011. In collaboration with Professor John Ward, University

College London she developed a series of recipes to dye silk with bacteria.

Project Coelicolor culminated at Ginkgo Bioworks where Chieza initiated a res-

idency to explore how to transition from producing petri dish size samples

to a length of microbial dyed fabrics (Faber Futures). Her influential work

embodies the quest for more sustainable and alternative ecological futures as

she was awarded the Index Award 2019 for the chemical-free and water-saving dye process she developed as a designer ([The Index Project, 2019](#)).

With the same ambition, several startups are now driving disruptive change for the textile finishing sector (Pili, Tinctorium, Colorifix). Using synthetic biology tools Colorifix programs microorganisms to both grow and fix a range of colors onto either natural or synthetic fabrics ([Fig. 8.8](#)) using “no additional specialist equipment or toxic chemicals and one-tenth of the water of standard processes” ([Colorifix, 2020](#)).

Mycelium Textiles ([Collet 2016 2019](#)) explores another approach for textile patterning with living systems and investigates the possibilities of combining the

dynamic active properties of mycelium with traditional textile know-how to develop sustainable textile embellishment techniques for a post-petrol textile industry. As discussed above, research into mycelium materials is prolific, but its

use as a biopatterning process for textiles is an underresearched area. Results

include the production of the self-patterning mycelium rubber, the production

FIGURE 8.8

Textile samples dyed with engineered microorganisms. r Colorifix.



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FIGURE 8.9

Tie-Grow on cotton. r Carole Collet, Design & Living Systems Lab, Central Saint Martins UAL.

of a permanent pleating process at ambient temperature for cotton, a “tie-grow”

mycelium on cotton ([Fig. 8.9](#)), the development of an embroidery-like patterning effect on cotton, and the use of mycelium as a binding agent to assemble

mixed textile materials to create a lace-like textile technique.

Cooperating and collaborating with living systems to develop alternative tex-

tile finishing processes is still a niche area but a crucial one. Current finishing

processes that include dying, printing, and coating require a large amount of water and the fashion industry with a water usage set to double by 2030 is recognized as the third largest user of water globally ([Common Objectives, 2018c](#)). Biocompatible, low energy, low water usage, and biodegradable processes informed by laws of nature can make a real impact and further research is needed in this area.

8.4.3

Textile fibers and materials made by reprogrammed

organisms: (does it use only the energy it needs?)

As discussed in [Section 8.2.2](#), synthetic biology research disrupted textile material innovation with the introduction of a new type of fibers and materials brewed by proteins and grown in a lab. Spiber, Amsilk, Bolt Threads, and

Modern Meadow opened the door to a new programmable textile materiality, sourcing DNA codes, and cellular protocols evolved over 3.8 billion years

to produce new kinds of natural fibers using genetically engineered microorganisms as microfactories. If the output material is “natural,” the “microfactory” is genetically engineered. Beyond the scientific exploit, we need to

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examine the relevance of this radical innovation. One key tenet of the laws of nature is that the natural system uses less energy than human-made technological systems. “In technology about 75% of problems are solved by manipulating energy, whereas the equivalent figure for biological systems is 5%” ([Vincent, 2014](#), p. 241). So, relying on biologically active microorganisms to grow textile materials is in theory a more energy-efficient system.

However, the production of these new biofibers and materials has not yet been scaled up to large-scale manufacturing and their full life cycle analysis is incomplete. They require sugars to grow, so the production cycle of these sugars needs to be carbon negative if we are to offer a genuine alternative to shape a future regenerative textile and fashion industry and it is still too early to balance the pros and cons of genetically engineered brewed fibers compared to conventional textile fibers in terms of full environmental impact. This is also an area where further research is needed.

8.4.4

Textiles made by and for emission capture:

(does it curb excess from within?)

Here, we will discuss a series of cutting-edge biotextile innovations that rely on biocapture to biofabricate materials. Mango Materials, for instance, uses a

bacterium that feeds on waste methane gas to produce a biodegradable biopo-

lyester. Wearpure has developed a biopolymer suitable for three-dimensional printing textiles, which can mineralize primary greenhouse gases (CO₂ and NO_x) and reduce volatile organic compounds. DyeCoo has patented a water-free dyeing process using reclaimed CO₂ as the dyeing medium in a closed-loop process. The startup Post Carbon Lab is working on developing a Photosynthesis Coating that transforms textiles into carbon-capture surfaces. Designer Roya Aghighi collaborated with the University of British Columbia and Emily Carr University, to create Biogarmentry, a textile research project that uses *Chlamydomonas reinhardtii*, a type of single-cell green algae, which when activated by sunlight can photosynthesize and turn CO₂ into oxygen.

While this is a rich context for research, some of these biotextiles are still at the proof-of-concept stage. We are far away from a widespread use of carbon-

capture textile materials, which by default would only make a real difference to the fashion carbon footprint when scaled up. However, exploring nature-inspired strategies to use textiles as carbon sink and carbon-capture material is

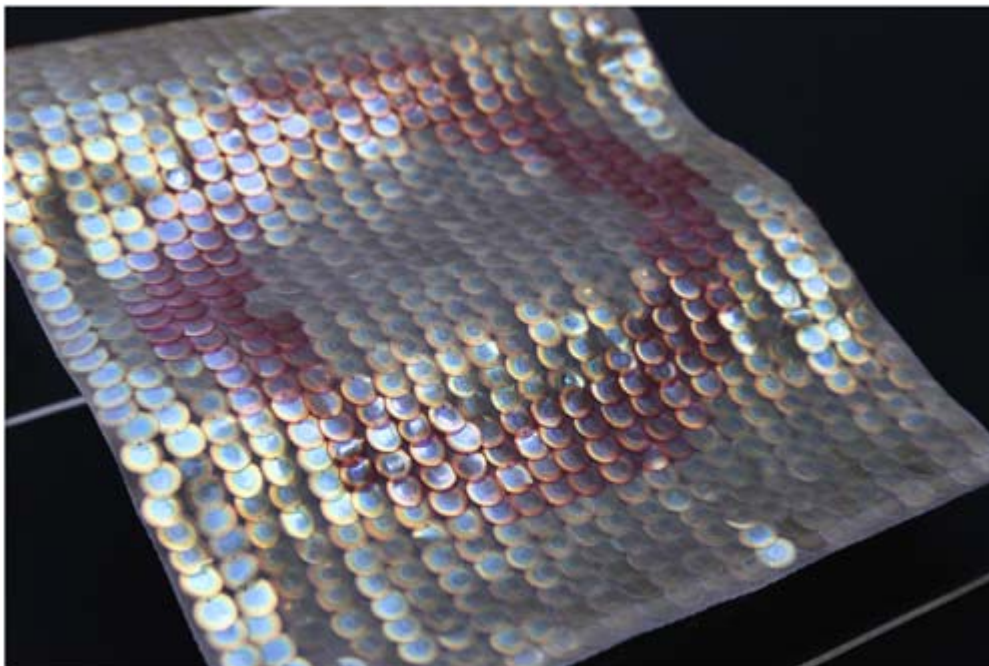
a relevant path. The question is when will these biotextile innovations be ready for large-scale adoption?

8.4.5

Textiles made with abundant material flows:

(does it support biodiversity?)

We will conclude this section by exploring new biomaterials made from some of the most abundant materials found in nature. The most common



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chain molecules in the world are cellulose and chitin ([Fratzl, 2016](#), p. 173).

Elissa Brunato works with cellulose and has created the first bio-iridescent sequins that produce shimmering structural colors for a graduate project on MA Material Futures at Central Saint Martins UAL in 2019. Collaborating with material scientists Hjalmar Granberg and Tiffany Abitbol from the RISE

Research Institutes of Sweden, her key objective was to develop an alternative

to plastic sequins commonly used in the fashion industry. Sequins are detrimental to ocean life and contribute to microplastic pollution. The bio-iridescent sequins offer a biodegradable and compostable alternative ([Fig. 8.10](#)).

Algae also occur in large quantities on Earth, even more so with algal blooms triggered by the use of fertilizers in agriculture. Creating materials derived from algae offer a new perspective for fashion. Algiknit, for instance, integrates biotechnology and design to develop algae-derived yarns that are biodegradable and compostable while Algix makes shoe insole out of algae.

By capitalizing on the use of naturally abundant materials instead of investing in oil-based technologies, these examples showcase that we can shift the textile and fashion system and develop biodiversity-positive new material propositions. Here, biodiversity is enhanced by two strategies: the replacement of plastic with biodegradable alternatives and the use of excess living materials such as algal blooms (the result of intensive agricultural practice) to replace synthetic polymers.

FIGURE 8.10

A hand-embroidered sample using bio-iridescent sequins, showing the sequins natural shimmering colors. r Elissa Brunato.

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8.5

Conclusion

This chapter posits that we are at a crossroad between an oil-centric and a post-petrol textile industry. By first asserting the damaging effects of the textile and fashion industry on land, water, biodiversity, and climate change, we have also established that despite valid positive initiatives and new frameworks, the industry is not changing fast enough to meet the recommendations of the International Panel for Climate Change in terms of carbon emission. Incremental change, cleaner, and more efficient technologies are not enough. Looking more closely at textile material innovation mapped against human population, we recognized the urgency to explore radical new systems that can disrupt the current textile production paradigm. Recent scientific advances, especially in the field of synthetic biology and the eagerness

of a new generation of designers to search for and create new materials, have contributed to the emergence of biodesign. A fast-evolving discipline, biode-

sign research has been prolific in developing biotextile material innovations in the past 10 years, often in response to environmental concerns. While it is still too early to fully analyze their environmental benefits, we can examine their credibility against living systems principles derived from biomimicry. As

such this chapter provides a new insight into biotextile strategies driven not by their material origin, but by their ability to reward cooperation, their actions onto the environment (such as carbon capture), or their ability to enhance and support biodiversity.

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CHAPTER 9

Defining the DIY-Materials approach

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The practices that shape the do-it-yourself (DIY) approach have always considered

different sectors of knowledge and experience ([Lukens, 2013](#)). The DIY movement is expanding beyond artifacts to include materials from which products are made;

namely, DIY-Materials. Designers from all over the world are engaged in various

experimental journeys in the field of materials development, and they consider

these experiments as the starting point of their design process, which will lead

them to the creation of new artifacts. The possibility to self-produce their own

materials provides designers with a unique tool to combine unusual languages and

innovative design solutions with authentic and meaningful materials experiences.

As this phenomenon of self-production of materials has spread widely in recent years and is starting to be considered as an essential phase of the design process ([Bak-Andersen, 2018](#); [Karana et al., 2015](#); [Parisi et al., 2016](#)), it is necessary to investigate and understand it accurately. This chapter aims

to provide an updated and comprehensive definition of the DIY-Materials phenomenon, as one of the emerging experiences in the field of design.

Nowadays, and for at least centuries beforehand, the artifacts of daily human life originate mainly from industrial materials, that is, materials developed to meet the requirements and constraints of mass production. Human beings are aware that this model of creation and consumption has led to a problematic situation from an environmental perspective, putting the climate in crisis, depleting nonrenewable resources, creating hazardous waste, and perpetuating an inefficient use of energy resources ([Ulluwishewa, 2014](#)).

However, over the last few years, another interesting phenomenon has

emerged, bringing the relationship between design, science, technology, production processes, sources, and materials to a new dimension. The phenomenon refers to the rise and use of DIY-Materials, a “new class” of materials, which are conceived by the designer and are characterized by a tinkering

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00010-7>

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approach and self-production processes ([Ayala-Garcia, 2019](#); [Ayala-Garcia et al., 2017](#); [Parisi & Rognoli, 2017](#); [Parisi et al., 2017](#); [Rognoli et al., 2015](#); [Rognoli & Parisi, 2021](#)). This new approach to materials development is enhanced by the renaissance of craftsmanship, by the democratization of technologies, and by combining making, crafting, and personal fabrication practices ([Bettioli & Micelli, 2014](#); [Tanenbaum et al., 2013](#)).

9.1

The DIY-Materials phenomenon

Scholars already framed and defined the emerging phenomenon of self-produced materials with a first definition of DIY-Materials in 2015 ([Rognoli](#)

[et al., 2015](#)). The definition describes the materials as self-produced by designers, who follow their own design inspiration while looking for original

and unusual sources and adopting a low-cost approach and processes. In short, based on tinkering, this practice guarantees to obtain some material drafts or material demonstrators ([Rognoli & Parisi, 2021](#)) with which it is possible to discover and explore the design space of materials.

The phenomenon of DIY-Materials is ubiquitous today, and there are many examples of materials self-produced by designers after intense exploration and

tinkering activity. ¹ Around 10 years ago, designers began in earnest to create and self-produce materials as if finding immediately ready ones in material libraries

was no longer sufficient. For over 20 years, material libraries had been fulfilling

their function of bringing closer together designers and the world of materials

which, in this case, were industrial materials. Industrial materials are the result

of mass production, that is of workmanship of certainty ([Pye, 1968](#)), to be chosen considering their expressive-sensorial aspect or to be selected considering

their engineering capabilities. The materials included in material libraries' collec-

tions are usually materials already developed, marketed, and branded: in other

words, ready to be processed and incorporated into a product.

Some designers who embark on a path of development and self-production of materials want to demonstrate their dissatisfaction with the monotonous uniformity of the industrial material landscape, and therefore they try to generate original material experiences, even transforming themselves into real activists² (Ribul, 2013) against the mass-production system. They want to take a risk, the workmanship of risk, in which the quality of the result is not predetermined (Pye, 1968). It seems that designers enjoy a renewed synergy between ideation and production processes, getting their hands dirty by

1 Looking at Dezeen's blog where there are many examples of DIY-Materials developed by professional designers and above all, the DIY-Materials research group's web page: <https://www.diy-materials.com/>.

2 <http://www.materialactivism.com>.

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experimenting with colors, textures, consistencies, mixing various ingredients,

and having fun looking for alternative and unconventional sources as raw materials.

With DIY-Materials, designers decide not to look at materials that someone has already designed and developed, but instead they inquire/challenge themselves by experimenting and thinking about their own design of materials. This phenomenon does not represent the first time designers have

wanted to challenge themselves with the design of matter. In Italy in the 1980s and 1990s, research relating to “The Material of Invention” ([Manzini, 1986](#)) and “Neolite” ([Manzini & Petrillo, 1991](#)) opened the material creation path, where designers started to include materials as a crucial and decisive moment within the wider design process. DIY-Materials have also strongly influenced research in the domain of materials for design, which today looks with interest at the experimental field of material development. A significant example of this is the recently concluded MaDe (Material Designers) project (2018-20). MaDe was cofunded by the Creative Europe Programme of The European Union and coordinated by Elisaviva, [3](#) Politecnico di Milano, [4](#) and [Matter, 5](#) with the aim to boost talents toward circular economies across Europe. The project focused on the organization of competitions, workshops, an event series, and a web platform, devoted to demonstrating the positive impact material designers can have across all creative [sectors.6](#)

Another valuable example in this renewed line of research on design materials is the Chemarts project, developed by the School of Arts of Aalto University, Finland. This aimed at innovatively researching bio-based materials while trying to create new material concepts with the help and support of the School of Chemical Engineering of the same University ([Kaariainen et al., 2020](#)). A great wealth of studies and research on material design is ongoing, [7](#) including not only DIY-Materials but also the development of

living or growing materials ([Ginsberg et al., 2017](#); [Karana et al., 2018](#); [Oxman,](#)

3 <http://www.elisava.net/en/research/know-us>.

4 <http://www.dipartimentodesign.polimi.it/en/>.

5 <https://ma-tt-er.org/>.

6 “Material Designers are agents of change. They can design, redesign, reform, reuse, and redefine materials giving them an entirely new purpose. Increasing the potential of materials, they can go on to research, advise, educate, and communicate what materials are and can be in the immediate, near, and far future, implementing positive social, economical, political, and environmental change across all sectors toward a responsibly designed future.” <http://www.materialdesigners.org>.

7 Among others are the following: The research group on DIY-Materials based at the Design Department, Politecnico di Milano and the University of Los Andes, Bogotá, Colombia; Professor Carlo Santulli of the University of Camerino, Italy; Professor Carla Langella of the Vanvitelli University of Naples, in collaboration with Professor Mario Malinconico of the CNR of Naples, Italy ([\[ipcb.cnr.it/index.php/it/personale/strutturato/117-mario-malinconico\]\(http://www.ipcb.cnr.it/index.php/it/personale/strutturato/117-mario-malinconico\)\); and The Royal College of Art’s Materials Science Research Center, led by Professor Sharon Baurley.](http://www.</p></div><div data-bbox=)

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[2020](#); [Zhou et al., 2021](#)), where the designer codesigns together with organisms. Experiments on materials in close collaboration with biologists and

scientists are counted among DIY-Materials and expand their definition as

they are based on the same process of experimentation and tinkering and on the creation of drafts and demonstrators. Many case studies⁸ ([Franklin & Till](#),

[2018](#); [Karana, 2020](#)) can be found and substantial research is ongoing in different international universities. ⁹ Moreover, tinkering and material experimentation are also used frequently in design for interaction, using the

hybridization of DIY-Materials with technology and designing and self-producing interactive, connected, and smart materials. ¹⁰

Finally the emergence of the DIY approach to materials is closely intertwined

with materials education in the field of design. In many universities and

design schools¹¹ materials are again at the center of the organization's didactic activities, as it was in the first design school, the Bauhaus ([Wick, 2000](#)).

As Albers stated ([1928](#)): “We do not always create ‘works of art,’ but rather experiments; it is not our ambition to fill museums: we are gathering ‘experience’.” The emerging new design courses combine the fundamental ingredi-

ents of experimentation, a transdisciplinary approach and speculative design,

aiming to give the design student tools to approach the world of matter not

as a mere observer, but as a participant who can precisely design and self-

produce their own materials.

9.2

DIY-Materials: theoretical foundations

As previously mentioned, the concept of DIY-Materials was born following the observation of what was happening in the context of materials for design.

This was done using the lens of materials experience, which defines the

“experience that people have with and through the materials of a product”

([Karana et al., 2014, 2015](#)). DIY-Materials, in fact, lead to a completely different material experience compared to other materials, with regard to the

8 Mogu, <https://mogu.bio/>; Solaga, <http://www.solaga.de/en/>; Other cases can be found at <http://www.futurematerialsbank.com/>.

[futurematerialsbank.com/](http://www.futurematerialsbank.com/).

9 Among others, there are Professor Elvin Karana, Materials Incubator, TUDelft and Avans Hogeschool,

<http://www.materialincubator.com/about>; Professor Carole Collet, Design and Living Systems Lab, UAL, <http://www.designandlivingsystems.com>; Professor Carla Langella, Hybrid Design Lab, Università Vanvitelli Napoli, <http://www.hybriddesignlab.org/designers-in-lab>.

10 Among others, there are ICS Materials research, Design Department Polimi, <http://www.icsmaterials>.

polimi.it; Institute for Material Design (IMD) and Professor Markus Holzbach, [https://www.hfg-](https://www.hfg-offenbach.de/en/pages/institute-for-materialdesign-imd#about)

[offenbach.de/en/pages/institute-for-materialdesign-imd#about](https://www.hfg-offenbach.de/en/pages/institute-for-materialdesign-imd#about); and Materiability, Professor Manuel Kretzer, Materiability Lab at the University Campus Dessau, <http://materiability.com/>.

11 Charlotte Asbjørn Sørensen at School of Art and Communication, Malmö University; Ziyu Zhou at Design Department, Politecnico di Milano; Professor Camilo Ayala-Garcia at Universidad de Los Andes; and Professor Jimena Alarcon at Bío-Bío University.

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user who will interact with original materials mainly for their expressive-sensorial component, as well as for the designer themselves. Concerning the designer's role, the main change concerns her/his involvement, as she/he now operates at the forefront of material creation, defining qualities that determine the sensoriality, meaning, and emotional dimension, and the performance of the material ([Giaccardi & Karana, 2015](#)).

Compared to what happened in the past, today, designers find a favorable context for their experimental approach to materials because other phenomena have emerged and developed. The first promoting factor is undoubtedly the spread of Fab-labs and maker culture. Following this drive, designers decided to reject the "sit back and be told" school culture ([Gauntlett, 2011](#)) and embraced instead making and creating, the idea of continuous works-in-progress, continual experiments with a practical approach to materials, and a curious mind oriented to autonomous research. In addition to maker culture, approaches to frugal innovation were also reevaluated. In specific parts of the world these are called Jugaad ([Radjou et al., 2012](#)) or Technological Disobedience ([Oroza, 2012](#); [Oroza & de Bozzi, 2002](#); [Rognoli & Oroza, 2015](#)).

The explicit combination of frugality and innovation is relatively new

([Albert, 2019](#)). In this way, it is possible to highlight the flexible mentality of those who want to question the status quo, opposing structured approaches, and responding quickly to requests to change the context. Not only it is useful to “think outside the box,” but it becomes inevitable to establish new ones.

Designers interested in the material dimension can thus be called Lay

Materials Designers following the logic with which Angus Donald Campbell coined the term lay designer ([Campbell, 2017](#)). The enhancement of these approaches to innovation is made possible thanks to changes that are taking place in the general esthetic language. In fact, today, more than ever, consumers are aware and sometimes require something that is not the result of industrial production, which appears increasingly cold and flat. Everything Standard looks outdated ([Friedman, 2010](#)), while imperfection offers an escape ([Karana et al., 2017](#); [Ostuzzi et al., 2011a, 2011b](#); [Pedgley et al., 2018](#); [Rognoli & Karana, 2014](#)).

More than in standard industrial production, the designer begins to look with renewed interest into craftsmanship, reevaluating and rediscovering a more intense relationship between the individual and her/his practice. The craftsperson’s making places emphasis on visual, tactile, and emotional qualities and represents the ability to convey meaning through form and

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sensitivity to materials ([Yair et al., 1999](#)). Compared to designing on paper and then producing industrially or choosing a material from a library or modeling it on the computer, reevaluating craftsmanship means reevaluating the bodily experience and the relationship that the designer establishes with the material during the making process. As argued by [Aktas & Mäkelä, \(2019\)](#), as a material becomes a medium to reflect the embodied knowledge, it actively informs the making and conveys information. So the material represents an active nonhuman participant that is no longer passive during ideation. In this way an artifact comes into being through a negotiation process in which both the material designer and the material itself have essential roles. The designer who embraces craftsmanship can become an active maker of materials ([Barati & Karana, 2019](#)), capable of exploiting her/his own body to comprehensively explore the potential of materials. The most important tool she/he has at her/his disposal is the hands. As argued by [Semett \(2008\)](#), [Focillon \(1939\)](#), and [Pallasmaa \(2009\)](#), a design that excludes the hands also disables a specific type of relational intelligence because “making is thinking.” When the mind and the hands are divorced, it is the mind that

suffers. The hand is the outlet of human will, choice, and action; it characterizes the human being, and it is through the hand that the designer carries out her/his own creative process.

Undoubtedly, craft as a way of thinking through materials ([Nimkulrat, 2012](#)) is already included in the context of design research as a way to regain possession of the material culture that surrounds people's daily life.

Everything,

from furniture to clothes, from food to material tools, can become a field of experimentation because the continuous commitment to make, transform, and modify things and materials can lead to greater awareness and increased autonomy and individual choice ([Micelli, 2011](#)). Doing things and making materials—the essential activities of DIY-Materials—make designers more aware of potentials and more able to think radically and unconventionally.

The underlying mindset facilitates and embraces interpretation of the incomplete as a positive event of intellectual activity. It is a concrete yet malleable stimulus that cannot be substituted by the simulation and facilitated manipulation of already complete and resolved objects.

For this reason, research on Open-ended Design (OeD) is being developed ([Ostuzzi, 2017](#); [Ostuzzi et al., 2017](#); [Ostuzzi & Rognoli, 2019](#)). OeD is the approach by which a result of a product design can change in response to a changed or evolved context. It is defined as suboptimal, error-friendly, unfinished, and contextual, embracing context-dependent errors and is character-

ized by its internal flexibility, incomplete voluntary definition of its characteristics, and significant imperfection. Making things and self-producing materials, therefore, means reappropriating the delegation that more or less consciously a century ago was granted to large manufacturing companies,

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separating having ideas from making, and distancing the craftsperson/designer

from the pleasure and satisfaction inherent in making ([Gauntlett, 2011](#)).

The principle that DIY-Materials practices promote a form of knowing in action ([Schön, 1984](#)), that is, experiential knowledge with and through materials, must be incorporated into a broader examination. The outcome of this

process is often a self-produced material as a result of making by hand, but

this also reflects a dialog and underlying thinking that is induced through the

manipulated materials ([Nimkulrat, 2012](#)). Thus the process of creating materials by hand can be identified as a way of thinking intellectually ([Sennett,](#)

[2008](#)) and a way of tinkering manually ([Parisi et al., 2017](#)). Furthermore, it satisfies designers' needs for a dynamic process of learning and understanding

through material and sensory experience ([Gray & Burnett, 2009](#)).

Other significant aspects that distinguish and define today's DIY-Materials

and material designers compared to what has been done in the past are undoubtedly the possibility of sharing experiences, the ease of information retrieval, and the democratization of technological practices. Importantly, material research is not limited to self-exploration, as multidisciplinary knowledge sharing platforms are also contributing to the dissemination of materials knowledge to the public ([Fadzli et al., 2017](#)). The DIY-Materials approach is configured as a creative activity that implies creation, sharing, and collaboration. As [Gauntlett \(2011\)](#) stated, making is connecting.

Nowadays, product design can be practiced at home or as a hobby, supported by the democratization of technological practices ([Tanenbaum et al., 2013](#)) that make available commonly used production labs and low-cost equipment and facilities for fabrication.

The last important aspect that must be emphasized about the practice of DIY-Materials is the relationship with sustainability. Today, sustainability is a matter of great importance for society and for the future of Earth and all its inhabitants. For this reason, sustainability is an essential issue within design activity and for designers who have responsibility for shaping our futures. It is stated that more than 80% of the environmental impact of any artifact is determined in the design [phase13 \(Thackara, 2006\)](#) because during design, decisions are made in relation to production, material usage, and acceptable longevity. A major motivation for designers undertaking DIY-

Materials is to find more sustainable and eco-friendly material solutions.

However, using a DIY-Materials approach does not guarantee a sustainable material outcome at the end of experimentation. Instead, it is necessary to

13 “Eighty percent of the environmental impact of the products, services, and infrastructures around us is determined at the design stage. Design decisions shape the processes behind the products we use, the materials and energy required to make them, the ways we operate them on a daily basis, and what happens to them when we no longer need them” (Thackara, 2006, p. 1).

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consider that this type of approach leads the designer to make reasonings and choices to acquire a sensitivity toward sustainability challenges since she/he becomes increasingly aware of her/his role as a facilitator and pursuer

of sustainable solutions.

The environmental impact of DIY-Materials has not yet been studied in-depth,

much less demonstrated. What can be said here is that positive connections can be glimpsed between DIY-Materials and environmental sustainability.

Thinking of an alternative approach to the development of design materials can contribute to a more sustainable world and contribute to the three pillars of environmental, social, and economic sustainability ([Purvis et al., 2019](#)).

Scholars describe a positive relationship between DIY-Materials and sustainability and identify the potential of the DIY-Materials approach for finding more sustainable material solutions ([Alarcón & Llorens, 2018](#); [Fadzli et al., 2017](#); [Karana et al., 2017](#); [Rognoli et al., 2017, 2021](#); [Santulli et al., 2019](#)).

Following the reasoning that Martin [Albert \(2019\)](#) makes regarding the relationship between sustainability and frugal innovation, it is possible to elaborate some similar considerations concerning the relationship between sustainability and DIY-Materials.

9.2.1

Environmental sustainability pillar

Developing materials following the DIY-Materials approach is consistent with

improving potential ideal models to create green materials, that is, materials that

are eco-friendly and useful for concretizing ecological ideas. A DIY-Material is

usually developed from the perspective of employing fewer resources, reusing

resources, and/or being economically frugal. Habitually, resources are conserved,

saved, reduced, and consumed less, while overall more sustainable, renewable,

and local resources and processes are preferred. In general the designer who undertakes self-produced materials seeks to improve/maximize energy and material efficiency. Furthermore, sufficiency is an essential part of the environmental sustainability of DIY-Materials. Moreover, the self-produced materials approach creates value from waste (waste as a resource), where existing components and materials are reused, and recycling is performed instead of new material sourcing.

The material designer tries to minimize environmental impact by reducing complexity and creating simple, implementable, and repeatable materials and/or material recipes.

9.2.2

Social sustainability pillar

The potential of self-production of materials also consists of realizing social sustainability ([Rognoli et al., 2017](#)). The utilization of local resources and local processes could alleviate and reduce global poverty by creating and

9.3 DIY-Materials cases: collection and classification

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offering jobs, enabling new entrepreneurship linked to sustainable materials

production. Through the development of DIY-Materials, agricultural waste markets are created and valorized as a resource and raw material. As mentioned above, another essential issue concerns better access to information, global knowledge, shared knowledge networks, education and training through DIY-Materials and self-production practices. The DIY-Materials approach promotes the development of social awareness because such materials need to be narrated and described within local contexts and among various stakeholders.

9.2.3

Economic sustainability pillar

Concerning economic sustainability, DIY-Materials appear in general as an opportunity to investigate alternative routes for economic growth that may be used for competitive advantage or to survive material crises in a commercial context. As far as developing countries are concerned, adopting more eco-friendly material development approaches can deliver economic growth according to more sustainable models. The material designer is aware that generating ideas for more sustainable materials can present customers with unique value propositions, potentially increasing competitiveness, improving sustainability performance, and leading to greater productivity and reduced cost

per unit related to procurement, production, and distribution. The reason for

the positive correlation between economic sustainability and DIY-Materials is

intrinsic innovation. Innovation can be exploited commercially and produce, when possible, positive economic effects.

All these introductory observations are necessary for a complete comprehension of DIY-Materials and must be taken into account during the material development.

9.3

DIY-Materials cases: collection and classification

In the last 5 years, DIY-Materials creation has accelerated. More than 100 examples have been collected and examined by the researchers. The collection

includes materials created through individual or collaborative self-production

experiences, often by techniques and processes of the designer's own invention. Most of these materials are the result of a process of tinkering with materials.

The DIY-Materials considered for inclusion in the collection met the criterion of being complete in every part. In particular, great importance was given to the demonstration and video, or photographic documentation, of the experimentation process to create the material.

A fundamental aspect in the definition of self-produced materials concerns

precisely the need that the material designer feels to tell the story and she/he



(A)



(B)



(A)



(B)

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Defining the DIY-Materials approach

does it employing different techniques (storyboard, photos, videos, storytelling, sketches) ([Figs. 9.1](#) and [9.2](#)). The scientist's traditional laboratory notebook is flanked by all kinds of graphic drawings that enrich the idea's communication, allow the sharing and replication of the experimentation

and support the acceptability by future users who, through history, can understand precisely the background of the development of the material. As [Lambert and Speed \(2017\)](#) state, even if sharing and distributing processes are commonplace today, the use of narrative brings an additional dimension

FIGURE 9.1

Typical layout of DIY-Materials development. Photo by Jonas Edvard.

FIGURE 9.2

Videos and photography to elaborate the DIY-Materials narrative. Photo by Jonas Edvard and Sanne Visser.

9.3 DIY-Materials cases: collection and classification

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to the outcome—the final material or materialized artifact—while increasing the currency in the process itself. It brings people who encounter the material closer to its making, by providing further insight into, and reflection on, our material world. In the DIY-Materials narrative the making is inextricable from the resulting artifact.

Initially the collected DIY-Materials case studies were divided between “DIY new

materials” and “DIY new identities for conventional materials.” For “DIY new

materials,” the materials had to be developed starting from the creative use of

various substances as material ingredients (e.g., a material made of dried, blended waste citrus peel combined with natural binders). The “DIY new identities for conventional materials” were focused on new production techniques, which rose to new identities for existing materials (they do not necessarily contain new ingredients, e.g., 3D-printed metal and recycled thermoplastics). However, this splitting into two elementary groups was no longer sufficient, given the large number of DIY-Materials examples subsequently found and analyzed from blogs, magazines, books, or created through dedicated workshops. A need to classify DIY-Materials more accurately and more comprehensively has emerged.

As [Ashby & Johnson \(2002\)](#) explained, classification is the first step in bringing order to any scientific endeavor. A classification divides an initially disordered population into groups that have significant similarities, presenting an order. This happened originally in scientific disciplines such as biology, zoology, and geology, contributing to the creation of traditional and still-used classification systems. Materials are classified based on ISO (International Organization of

Standardization) descriptors. They are divided into classes (metals, polymers, ceramics, etc.) reflecting similar atomic structures that affect various properties (especially mechanical) and behavior. A correct definition of DIY-Materials must also include the positioning of the materials in a class recognizable by scientific communities. However, given the experimental nature of DIY-Materials and their sometimes mixed ingredients, the ISO classifications of materials are rarely sufficient or relevant.

Furthermore, scholars have already highlighted how, for artistic disciplines, standard classifications of materials are inadequate or unsatisfactory for communicating material qualities and information useful for design ([Ashby, 2011](#); [Marschallek & Jacobsen, 2020](#)). In particular, [Marschallek & Jacobsen \(2020\)](#) elaborated an alternative and systematic way of defining and classifying what is meant by the term “material substances.”

Given these premises, the activity of collecting DIY-Materials case studies focused on finding what could be described as the distinctive feature of the materials. This was identified as the sources from which the whole creative

process starts. Sources are defined as “a place, person, or thing from which

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something originates or can be obtained.” [14](#) In this context the term “source”

indicates the origin and is different from the word “resource,” which means

“source of supply or support” ;[15](#) in short, something that serves as an aid, especially one that can be readily drawn upon when needed. From careful

observation and analysis of the material stories created by designers to report

and document their tinkering and experimentation activities, it was deduced

that the sources were a fundamental element capturing the material

designer’s great attention. The material storytelling always starts from the

description of the source and the reasons that prompted the designer to con-

sider it.

DIY-Materials are developed using different material substances as ingredi-

ents, for which the “main” ingredient constitutes the source that determines

the origin of that particular material. All the collected DIY-Materials case

studies were then grouped according to the source used to start the creative

process, and families of individual materials with similar origins were cre-

ated. The taxonomic categories used for DIY-Materials are called “Kingdoms”

and are distinguished based on the source used by the material designer to start the design process focused on materials ([Ayala-Garcia, 2019](#); [Ayala-Garcia et al., 2017](#)).

9.4

DIY-Materials classification: the five kingdoms

The categorization phase involved analyzing the 100 DIY-Materials case studies based on their material source. As has already been said, the source is an essential element in the DIY-Materials approach. Based on the sources of the 100 case studies, five principal families (kingdoms) were deemed necessary.

As the first three families shared an exact analogy with the biological classification of natural elements conceived by the Swedish botanist, zoologist, and physician Carolus Linnaeus called *Systema Naturae*, [16](#) it was decided to proceed to develop the biological metaphor by completing the *Systema* with missing families.

The *Systema Naturae* was for several years the standard biological classification of the elements of the Earth. Known as Linnaeus’ taxonomy, [17](#) this

<https://dictionary.cambridge.org/dictionary/english/source>.

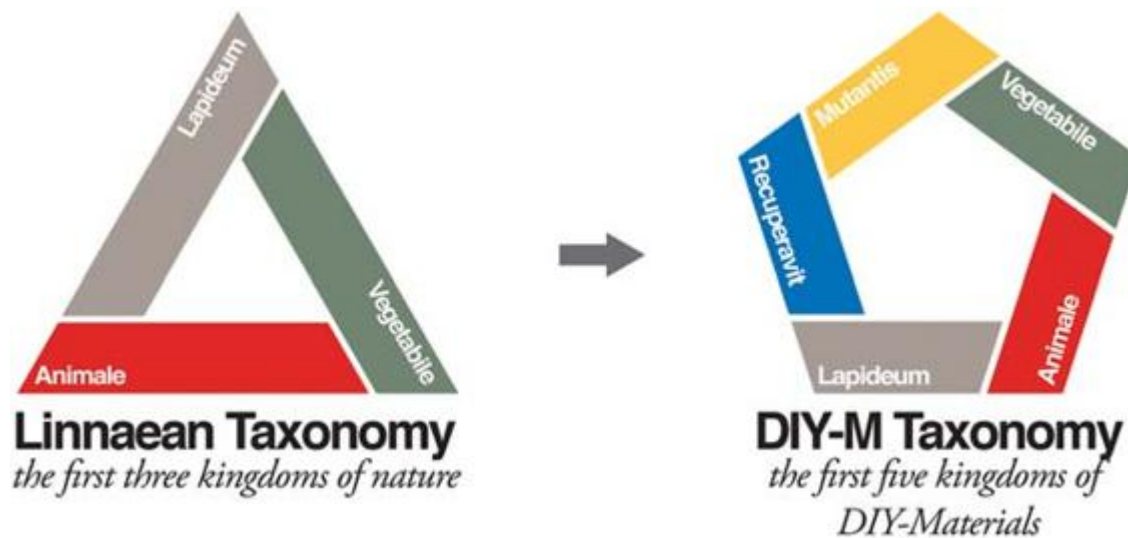
<https://www.dictionary.com/browse/resource>.

<https://www.dictionary.com/browse/resource>.

<https://www.dictionary.com/browse/resource>.

16 https://en.wikipedia.org/wiki/Systema_Naturae.

17 Carl Linnaeus (1707-78) laid the foundations for modern biological nomenclature, now regulated by the Nomenclature Codes, in 1735. He distinguished two kingdoms of living things: Regnum Animale (“animal kingdom”) and Regnum Vegetabile (“vegetable kingdom,” for plants). Linnaeus also included minerals in his classification system, placing them in a third kingdom (not living), Regnum Lapidum.



9.4 DIY-Materials classification: the five kingdoms

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FIGURE 9.3

New kingdoms emerged for DIY-Materials classification as a result of contemporary human impact.

historical publication established a hierarchical classification of the world’s natural elements, dividing it into three main kingdoms: animal, plant, and mineral.

Although modern biological terminology has evolved into many deeper divi-

sions than the taxonomy of nature, Linnaeus's original approach provided an excellent and engaging basis for naming the DIY-Materials kingdoms.

To the three original kingdoms: animals, plants, minerals (kingdoms Vegetabile, Animale, and Lapideum), two others have been added. The first concerns sources deriving from waste and scraps (kingdom Recuperavit) and the second relates to information technologies and interaction (kingdom Mutantis) ([Fig. 9.3](#)). Hence the kingdoms mainly obey the source of the material substance, which becomes the main ingredient for developing the self-produced material. Classes, as subcategories, were then generated for each kingdom based on further similarities identified between the sources within each kingdom ([Fig. 9.4](#)).

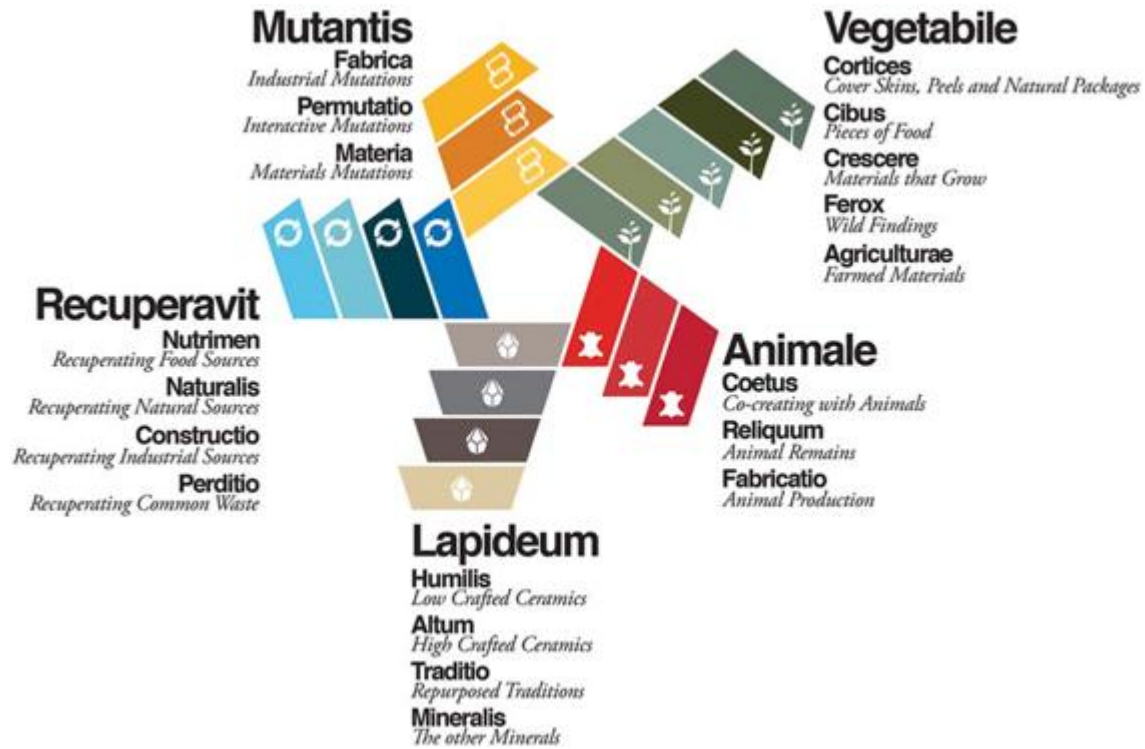
9.4.1

Kingdom Vegetabile

The first kingdom is the “kingdom Vegetabile.” It refers to every material development where the primary source derives from plants and fungi.¹⁸

DIY-Materials developed under this kingdom differ from the others, mainly because they can be originated from growing or farming techniques.

¹⁸ In Linnaean taxonomy, the classes and orders of plants, according to his *Systema Sexuale*, were never intended to represent natural groups. Classis XXIV. Cryptogamia included the “flowerless” plants such as ferns, fungi, algae, and bryophytes.



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FIGURE 9.4

The DIY-Materials kingdoms with their classes.

Designers who create materials under this category collaborate with, for example, farmers and biologists. Kingdom Vegetabile is subdivided into

([Fig. 9.5](#)) Farmed Materials; Wild Findings; Materials that Grow; Pieces of Food; Cover Skins, Peels, and Natural Packages.

9.4.1.1

Farmed materials (Agriculturae)

This class includes all the different materials obtained using a growing crop or a

domesticated plant as a source. It covers all the DIY-Materials created as alterna-

tives to industrial production with traditional means of agriculture, respecting

the timing and seasons and maintaining a biological cycle that allows each application to be compostable or degradable in the medium/short term.

9.4.1.2

Wild findings (Ferox)

Since some DIY-Materials are obtained from agricultural systems,

others can be created by picking wild sources. Therefore the source is

Vegetabile

Agriculturae *Farmed Materials*



GreenNet* By Aversa, Ertin, Wang, Bettoni.
A material developed using celery fibers. By twisting filament, the celery can be knitted.



Leek Paper*
by Erdogan Fumagalli Paillicux, Hasegawa.
obtained by peeling the surface layers of the leek and inked when dry.

Ferox *Wild Findings*



Story of a Pinetree by Sarmite Polakova.
From the inner bark of the Pine, leather-like material with natural color, elegant and robust character.



Catching Autumn*
by Bektaş Kettl, Aydin & Milly.
Different types of leaves in different colors with wax finishing.

Crescere *Materials that Grow*



A Matter of Time* by Stefano Parisi.
Mycelium, the fast-growing, vegetative part of fungi with flax seeds.



EC Grass*
by Milanese, Kagaine, Park & Jimenez.
Made of pure grass. Light structures combining length of fibers.

Cibus *Pieces of Food*



Sugar Glass by Fernando Laposse.
Glazing, an old tradition in the patisserie industry replicable to produce rotational molding shapes.



Rice* by Xu Mengdi.
Material made out of rice, one of the biggest food leftovers in the world. Mixed different kinds of rice is possible to obtain various colors and textures.

Cortices *Skins, Peels, Natural Package*



Piñatex by Carmen Hijosa.
leaf pineapple fibers to produce a non-woven mesh with a similar leather-like appearance.



Artichair by Spyros Kizis.
Artichoke thistle mixed with a bio-resin to produce sort of plant fiber reinforced polymer.

9.4 DIY-Materials classification: the five kingdoms

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FIGURE 9.5

Examples of DIY-Materials belonging to kingdom Vegetabile.

characterized by the geographical area from which it is collected, such as

the rainforest, tropical environment, grasslands, or coniferous forests.

Designers collect sources that are not considered necessary by industrial counterparts because they are not reliable as a supply, difficult to obtain, or hard to scale. However, they remain excellent sources for the realization of local DIY-Materials, favoring zero-kilometer economies and circular approaches.

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9.4.1.3

Materials that grow (Crescere)

Growth is a natural phenomenon characterized by a living organism's ability, or part of it, to develop and increase its volume over time. Materials in this subcategory are recognizable as the designer often, with the aid of scientists, grows some of these organisms in controlled environments. This class includes fungi, algae, and plants. The vast majority of these organisms pose no real threat to humans, plants, or animals; therefore they are studied as an opportunity or alternative source to be used as substitutes to produce more sustainable materials.

9.4.1.4

Pieces of food (Cibus)

The development of materials from sources that help the sustenance of communities is a very sensitive issue. However, some substances suitable for feed-

ing humans can be contraindicated if consumed in large quantities, in which case they can be used for other purposes, such as DIY-Materials development.

In this subcategory, finding materials in which the primary source is an edible or recognizable nutrient is possible.

9.4.1.5

Cover skins, peels, and natural packages (Cortices)

The materials that belong to this subcategory are developed starting from natural skins, peels, or nutshells in which fruits and vegetables are biologically protected. When these items are removed and thrown away, they could be used as a source to self-produce materials employed for short-life applica-

tions before being discarded.

9.4.2

Kingdom Animale

The “Animal Kingdom” refers to all material sources derived from animals.

Bacteria have also been included as a possible source in this kingdom,

although they are not considered to belong to the animal kingdom in mod-

ern biological classifications ([Schleifer, 2009](#)). DIY-Materials of this kingdom can be developed using parts (hair, skin, bones, etc.) of animals or through

the collaboration of animals or microorganisms such as bacteria. Kingdom

Animale is classified into ([Fig. 9.6](#)) Cocreating with Animals, Animal Remains, and Animal Production.

9.4.2.1

Cocreating with animals (Coetus)

In addition to getting daily sustenance, some animals work to create artifacts useful to guaranteeing their own life as much as sourcing or protecting food.

There are many examples in the world of insects (e.g., bees, ants, worms, ter-

mites, and spiders), but other species can also build and process materials to create, for example, a nest, a dam, or a coral reef. In the history of human-kind, nature has always been an essential reference for conceiving innovative



9.4 DIY-Materials classification: the five kingdoms

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FIGURE 9.6

Examples of DIY-Materials belonging to kingdom Animale.

artifacts. Numerous advances in technology, design, and art have arisen in the broad basin of biological inspiration. In recent years the bioinspired approach has become very popular ([Benyus, 1997](#)), and in addition to specific projects, a large body of research is developing. ¹⁹ Regarding DIYMaterials, animals' behaviors and abilities can be considered sources for

cocreating materials and even artifacts.

Some designers analyze animal behaviors and, without interfering with the biological means that such actions represent for the sustenance of a particular

species, have initiated a process of cocreation. In this class of DIY-Materials,

it is possible to find materials in which animals address the primary source through the guidance of an artificial structure or a material manipulated by a designer after being processed by another organism. In this class, much more is experienced in the process, sharing it with the animal, rather than material sources.

9.4.2.2

Animal remains (Reliquum)

Life and death are, in general, a delicate subject to be addressed and themes quite far from the context of design materials. Problems related to overpopulation of the planet and access to food derived from intensive farming are

19 <https://biomimicry.org/>.

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putting pressure on the environment and compromising human beings' future. The call to action is necessary. This class of DIY-Materials belonging to the animal kingdom considers as a source the enormous quantity of carcasses and shells of animals that are discarded after extracting their nutrients for human sustenance. This mass begins to weigh negatively on public

health. Many different solutions are under discussion, starting from consuming less meat to the diversification of the human diet. Nevertheless, a challenge that can be faced by designers is how to use the remaining parts of the animals usefully and creatively. The materials in this class are recognizable as

the designer creatively uses leftovers from organic animals to compose structures, sheets, or volumes.

9.4.2.3

Animal production (Fabricatio)

Compared to other animal species, human beings can project and therefore can

see design opportunities in the natural phenomena they are surrounded by. For

example, humans have always bred animals for their own sustenance, taking advantage of everything that could be used and grown back (e.g., sheep's wool).

Many organic elements capable of regeneration can be used as material sources.

The materials in this class include everything provided and created by animals,

including humans, which grow, can be cut, cleaned, and creatively processed.

9.4.3

Kingdom Lapideum

The kingdom of the minerals was the third kingdom recognized by Linnaeus and related to the first two (plants and animals), it was the only kingdom encompassing nonliving elements. The kingdom Lapideum includes all the DIY-Materials from minerals such as stones, sand, pottery, and clay. In some cases, sources belonging to other kingdoms, such as wool or cotton fabrics, were combined with sources from kingdom Lapideum (but in a lower percentage than the primary material substance).

Kingdom Lapideum is divided into [\(Fig. 9.7\)](#) Low Crafted Ceramics, High Crafted Ceramics, Repurposed Traditions, and Other Minerals.

9.4.3.1

Low crafted ceramics (Humilis)

By definition, craftsmanship deals with details and does not allow itself to be dis-

tracted from them to consider mass production needs. The craftsperson focuses

on transforming materials and creating unique pieces, enhancing, for example,

characteristic and unique imperfections or defects, such as a knot in wood or a

strip in stone. The DIY-Materials developed and belonging to this class are recog-

nizable by the designer's intention to enhance traditional craftsmanship,
mainly

with ceramics as a source. Other stones and terracotta may be included, as
long

as the designer maintains conventional ways of working with the material. In
this

class, much more is experienced in the process rather than on material
sources.

Lapideum

Humilis

Low crafted ceramics



Balloon Bowls by Maarten De Ceulaer.
Clay with a polymeric hardener inside two air-inflated balloons.



Improvisation Machine by Annika Frye.
A DIY rotational molding process in which polyper plaster is poured.

Altum

High Crafted Ceramics



Marwoolus® by Marco Guazzini.
A combination of marble dust with pieces of wool and resin obtaining a colored marble material.



Ceramic wood by IMD Offenbach.
A ceramic made out of wood pieces. The obtained shape retains the natural form of the plant.

Traditio

Repurposed Traditions



Blueware Vases by Studio Glithero.
Ceramic finish by exposing elements to ultraviolet light using the early principles of photography.



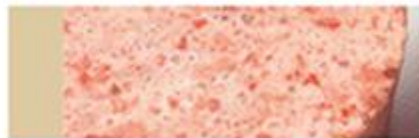
Kivi by Erin Turkoglu.
Hammering clay of different colors into a mold.

Mineralis

The Other Minerals



Melach*
by Grubisič, Nikaein, Zhou & Shabani.
Material made from different types of salt.



Nabatea* by Talithashani, Cui, Chanalithichai & Chen.
Pink Himalayan salt with a colored concrete appearance.

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FIGURE 9.7

Examples of DIY-Materials belonging to kingdom Lapideum.

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9.4.3.2

High crafted ceramics (Alum)

New craftsmanship and modern artisans with an industrial backend can achieve exciting results, thanks to the democratization of technology. While the means of modern production is moving toward automation and data exchange in manufacturing, through what is known as Industry 4.0, the traditional machines for industrial production that have become the mainstream of engineering development over the past century are more accessible than ever. A new army of tech artisans is starting to produce materials by gaining access to industrial infrastructure or hacking machines and controlling their behavior with mere coding knowledge. In this class, it is possible to find ceramic and composite materials that can be configured with a particular automated technology aid. The peculiarity of the DIY-Materials in this class lies in the process rather than in the recipes.

9.4.3.3

Repurposed traditions (Traditio)

Contemporary society's technological advances improve the way something is done by changing the manufacturing technique or introducing a different approach to achieve a similar result. It happens to many other objects and products made in a particular way such as shoes, bags, glass vases, or lamps. For many years, skilled artisans built those elements, but due to the inevitable need to increase production, either the tradition was abandoned or replaced by a new efficient technique.

The materials in this class are recognizable as the designer repropose old or traditional methods to create a particular element. Photography, engraving, illustration, or other techniques are often used to provide a particular finish to the skin of the ceramic material. It is an essential strategy as it provides the designer with rich tools and techniques to achieve unexpected results.

9.4.3.4

The other minerals (Mineralis)

In this class are grouped some impressive developments of stone materials that are not related to traditional minerals. Curiosity and fearless experimentation, decisive components of the designer's mentality, reveal other material development sources that are sometimes not so evident. This class of material sources spans unexpected substances such as dust, salt, or crystals that

create unique compositions of materials.

9.4.4

Kingdom Recuperavit

The kingdom Recuperavit is the first that was introduced specifically for the classification of DIY-Materials. This kingdom includes all materials self-produced from sources that the external context considers as a waste, but which have potential to be transformed into precious resources. In the words of Michael [Ashby \(2013\)](#), “Waste is waste only if nothing can be done to

9.4 DIY-Materials classification: the five kingdoms

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make it useful.” DIY-Materials under this kingdom often come from plastic, metal, or organic waste, sometimes as a by-product of industrial production or sometimes due to the throw-away society. At present, this is the most powerful kingdom, considering the number of cases observed. Within this realm the designer’s intention toward a more conscious and sustainable future is explicit. Kingdom Recuperavit has the following classification

([Fig. 9.8](#)): Recuperating Food Sources, Recuperating Natural Sources, Recuperating Industrial Sources, and Recuperating Common Waste.

9.4.4.1

Recuperating food sources (Nutrimen)

Tackling food “waste” is primarily an ethical question. Therefore definite crit-

ical issues emerge about the overproduction of food, its industrial production and transformation, as well as the impact of its packaging and transport.

In this class, it is possible to find different materials originated using organic waste and leftovers as sources that designers creatively transform by convert-

ing them into resources. The waste/sources considered here concern both the domestic sector, those of shared consumption of commercial establishments, and large-scale distribution up to and including the level of industrial waste.

9.4.4.2

Recuperating natural sources (Naturalis)

Natural sources are not necessarily a problem. Unlike food overproduction, various material self-development opportunities can be found by recovering materials from a wide range of sources. Once again the designer’s trained eye

is what plays a crucial role in identifying resources that can transform into something significant before returning to the ground and could replace inorganic materials in a wide range of critical applications. In the book *Cradle to Cradle* ([McDonough & Braungart, 2002](#)) the authors criticize the common desire for perfection and geometric management of natural resources such as grass or garden bushes. The authors criticize modern society’s unnatural

behavior: everything should look fantastic, pointing out how much time and energy it takes to remove every inch of grass and bushes, fighting against natural plant growth. The materials in this class are recognizable as the designer is making innovative use of different biological sources which are often considered useless by society. For instance, elements like corn stalk and leaves sometimes are discarded during the process of collecting corn to feed humans and animals. Such sources, when creatively used by designers, can become an important source to replace common industrial materials and foster social innovation ([Rodriguez, 2017](#)).

9.4.4.3

Recuperating industrial sources (Constructio)

As discussed above, industry produces enormous leftovers, which are unsuitable for feeding animals and organisms, or not put to use in any meaningful way for consumption. They should be kept away from any

Recuperavit

Nutrimen

Recuperating Food Sources



Fruit Leather Rotterdam.
Semi-translucent leather like material made out of rotten fruits from local markets.



Decafé by Raúl Laurí.
Coffee grounds mixed with a natural binder, pressed and heated to obtain a solid material.

Naturalis

Recuperating Natural Sources



Funco* by Catalani, Chen, Panza & Yang.
Cotton pads used to remove makeup from the skin. It is colored in different ways depending on the makeup color.



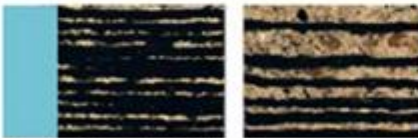
Cornstark DIY-M by Karen Rodriguez.
Discarded Cornstalk and leaves from the agricultural production of corn.

Constructio

Recuperating Industrial Sources



Structural Skin by Jorge Penadés.
Scraps from leather production with bone glue. A solid structural material with good isolation properties.



Re-Surface* by Helga Aversa.
Recuperated fiberglass from abandoned boats and yachts. The material can be developed with different patterns and colors.

Perditio

Recuperating Common Waste



Fluff* by Koski, Munda, Kruger & Salehi.
An elastic and semi-transparent material made out of the remaining particles inside the drying machine's filter.



Butts Bunny* by Studio Swine.
A semi-translucent material with a certain degree of flexibility made out of discarded cigarette butts.

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FIGURE 9.8

Examples of DIY-Materials belonging to kingdom Recuperavit.

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natural ecosystems to avoid damage. Many industries reuse their scraps and have an industrial closed metabolism system ([McDonough & Braungart, 2002](#)), but many others do not. In several countries where regulations and legislation are not as strict as they should be, even large companies avoid investing in waste management as it is not mandatory. Fortunately, designers are more aware of becoming material hunters in such urban settings.

Materials in this class are recognizable as the designer identifies a useful source from an industrial leftover, unused components, or a product entering a final stage of its life cycle.

9.4.4.4

Recuperating common waste (Perditio)

Throughout the kingdom Recuperavit, different sources are classified according to their natural or industrial origin. However, there are some elements of unselected provenance, which may belong to another class.

Common waste is a term used to describe all unsorted daily discarded waste.

It comes in such quantities in different places that it can become almost

invisible ([Freinkel, 2011](#)). For example, buying food packaged in plastic is so common that people do not calculate the package's shelf life. Plastic does not hurt, and it is not worth waging open warfare like has been happening in recent years. The plastic is not at fault; it is humans' failure to deal with plastic sensibly and sensitively that is the matter. As designers, consumers, or industrialists, plastic is relied upon as a commodity, the implications of which on a large scale, regarding disposal, are severe. Many such sources are problematic as they can include different material substances in a single composition, making them difficult to separate at the end of their life cycle. In this class it is possible to find several alternatives to treat this unselected material from untraceable sources of origin.

9.4.5

Kingdom Mutantis

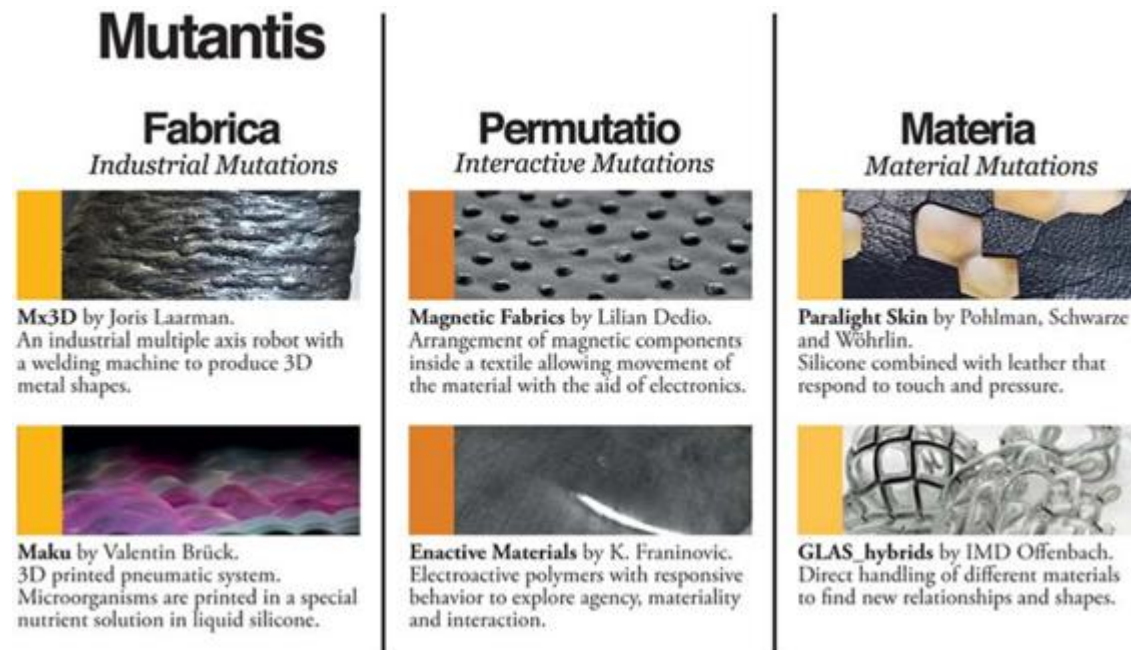
The kingdom Mutantis is the second newly added kingdom, to fully define the DIY-Materials phenomenon. This realm includes DIY-Materials created from different technological mixes and the hybridization of industrial, interactive, or intelligent sources ([Ritter, 2007](#)). In this category it is possible to see combinations of different material sources that come from another realm but evolve into something particular with the aid of technology. This trans-

formation represents a significant change in the nature and behavior of the material compared to other kingdoms. Kingdom Mutantis is divided into (Fig. 9.9) Industrial Mutations, Interactive Mutations, and Material Mutations.

9.4.5.1

Industrial mutations (Fabrica)

“Hacking” is a word with its origins in the German term “Hacken.” It is an adequate definition to explain how to intervene, disassemble, or form a



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FIGURE 9.9

Examples of DIY-Materials belonging to Kingdom Mutantis.

particular structure or system into pieces. In the domain of materials, hackers are the same artisans and bricoleurs, who learn by taking apart and transforming, changing the principal behavior of a material, machine, or a particular tool, to obtain a result. Designers who have access to different tools and machinery can create improvements and change the devices' behavior by introducing new techniques. This process leads to the creation of new materi-

als and subsequently to new products with original languages. The materials in this class are recognizable as the designer creates a material by intervening

on a particular type of machinery or transforming and hacking a specific process. For this specific class the source is the process.

9.4.5.2

Interactive mutations (Permutatio)

The field of interaction design has provided essential tools for intervening on the behavior of materials through programming and controlling properties and qualities. Interaction has become relevant in design as it has highlighted the importance of focusing on behaviors of things and people ([Cooper et al., 2007](#); [Moggridge, 2007](#)). The advent of open-source printed circuit boards, which began with Arduino, Wiring, or Raspberry several years ago, allowed

designers to control a material's behavior and activate interactions between people and the material. It is still an approach to material design that is in an embryonic stage. Some technological advances may be necessary before

9.5 Interrelationships between kingdoms and their updated definition

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electronic circuits and computing capabilities can be incorporated into a material, and they are considered the real sources in this [case.20](#) However, several designers are manipulating material properties with the help of these tools and envisioning alternative futures. Materials in this class are recognizable as the designer fuses any standard material with a computational layer that exhibits a desirable property that can be controlled and produce a specific performance.

9.4.5.3

Material mutations (Materia Mutantur)

Material hybrids and composites are one of the four categories of the so-called engineering materials. Inside this category it is possible to find a whole

universe of materials composed of two principal elements with specific prop-

erties or characteristics to add to the composite: the matrix and the reinforcements. Sometimes they can include a third element called the core. A

material composite aims to obtain an improved system with augmented properties compared with the original matrix material. Recently, designers have embarked on similar quests for hybridization and compositions of two or more elements. The aim is usually a mix of seeking superior performance and sensorial improvements. Materials in this subcategory are recognizable as the designer mixes two or more base materials, different from composites, creating new material languages embodying future applications that challenge the current state-of-the-art.

9.5

Interrelationships between kingdoms and their updated definition

The purpose of this chapter was to provide an updated and comprehensive definition of the DIY-Materials phenomenon, as one of the emerging experiences in the field of design. Categorization of DIY-Materials has been approached from the perspective of identifying the various sources that form the origin for DIY-Materials development. The categorization is made accord-

ing to “kingdoms,” through which the numerous development potentials of DIY-Materials can be conveniently highlighted. Furthermore, the kingdoms help indicate the designers of materials the many material substances that can be used as a source. However, it should be emphasized that, despite the

classification introduced here, the sources and consequent DIY-Materials can belong to several kingdoms at the same time. In other words the boundaries between categorizations can be quite flexible when developing DIY-

20 In these circumstances, we should mention the concepts of Computational Composites ([Valgarda &](#)

[Redstrom, 2007](#)), Smart Materials Composites ([Barati et al., 2019](#)), ICS Materials ([Parisi et al., 2018](#)), and Open Materials (by Catarina Mota, <http://openmaterials.org/>).

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Materials. Furthermore, the classification is of great help to identify the different types of DIY-Materials produced and to guide their design and development.

Through the classification, it is possible to understand how any given material in hand can belong to two kingdoms, build a bridge between categories, and enrich the definition of a material that shows advantages, characteristics, and properties from each side of the categorization. Projects such as Fruit

[Leather21](#) or [Marwoolus22](#) demonstrate this principle well. The first of these materials belongs to the kingdom Recuperavit based on its foundations to

recover food sources that are thrown away daily in various urban markets.

However, given its condition as a natural plant source, it could also be considered a breeding material from the kingdom Vegetabile. The second material is part of the family of high craftsmanship ceramics within the kingdom Lapideum since the material emerges by setting the industrial machinery to achieve the designer's will. Simultaneously, it is a material produced by intel-

ligently recovering the leftovers of two industries from the same region by mixing them into a new material, also inscribing the kingdom Recuperavit.

In light of what has been said and explained, it is now possible to generate a more complete and updated definition of DIY-Materials to conclude the discussions presented in this chapter.

The original definition of DIY-Materials ([Rognoli et al., 2015](#)) highlighted a new practice whereby designers create materials using DIY methods, providing an opportunity to reconsider the characteristics of existing production processes alongside the properties of industrialized materials, for the purpose of developing new unique experiential qualities. In the original definition the practice of material-making was understood to be an individual or collective endeavor, requiring the designer to work with suitable tools for experimentation and the production of the material. In recent years the DIY-Materials phenomenon has expanded strongly, requiring more refined ways of describing the material-making processes and

classifying the created materials. After having carried out in-depth research on the phenomenon, formulating a theoretical basis to collect, analyze, and classify the different cases, the following extension to the original definition is proposed.

DIY-Materials are defined by sources of matter that may be located in one of five material kingdoms. DIY-Materials differ from other materials when the transformation of an unconventional source is evident (e.g., cultivated vegetables, animal constituents, raw minerals, and recovered waste). The

21 <https://fruitleather.nl/>.

22 <http://marcoguazzini.com/marwoolus/>.

9.5 Interrelationships between kingdoms and their updated definition

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motivations behind the development of DIY-Materials are powerful and mainly concern the designer's desire to look for alternatives to the world of standardized industrial materials. Furthermore, the designer's will is also to experiment and to undertake research so that their design path concentrates on the material itself and not only on its application. DIY-Materials designers have a desire to go back to handling and designing materials and to have influence right at the start of the process.

To develop these materials, designers embrace available technologies and

work within material creation studios, spaces, and labs. The DIY-Materials approach is transdisciplinary and interdisciplinary. In other words, it is an approach that at the same time goes beyond and intertwines different disciplines, essentially rejecting the fragmentation of knowledge, aiming instead at an integrated and unitary understanding of the phenomenon. To this end, the DIY-Materials development practice often involves biologists, materials scientists, environmental engineers, and other specialists outside the core of “design.” DIY-Materials are born from experimentation with an unconventional source. In the earliest phases of development the designer typically experiments with low-tech tools and equipment, often conceiving and producing these tools directly. Such experimentation is essential to learning material possibilities and is called tinkering.

The initial phase of DIY-Materials creation is therefore called “Tinkering with

Materials” ([Rognoli & Parisi, 2021](#)), supporting the acquisition of knowledge on the sources and developing procedural understanding. Here the designer

aims to obtain information and understand the qualities of sources and their empirical properties, recognizing their constraints and identifying their potential. Tinkering promotes sensory awareness of material attributes and can reveal unpredictable and unique results. Tinkering with materials means

working with the hands and the direct involvement of all human senses.

Through this practice, the possibilities of how materials can look, feel, sound,

and smell are discovered, and it is possible to manipulate the sources to cre-

ate “material drafts.” The second phase of DIY-Materials development is

called “Tinkering for Materials,” focusing on the creation of “material

demonstrators.” The material demonstrators are designed and delivered as

the outcome of an experimentation process. The most common material

demonstrators are those aiming to explore and represent quality variants for

DIY-Materials such as color, thickness, and texture. There are also demonstra-

tors of processes, that is, showing variations around the creation of forms.

Demonstrators emerging from “Tinkering for Materials” become a valuable

resource for design activity. In fact, by tinkering for materials without a

design application in mind, the designer adopts exploratory research to create

and nurture a vision that may further develop the material or its meaningful

application.

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Both the proofs and the demonstrators are, however, potential materials, which cannot be considered as finalized but rather a work-in-progress. Their general qualities of being affordable and competitive, and crucially still open to modification and development, make them attractive as tools for speculation and reasoning about possibility and potential. DIY-Materials can help solve a specific problem, by creating and embodying material visions to understand and evaluate which path to take.

An essential aspect in the definition of DIY-Materials is the creative narrative

([Lambert & Speed, 2017](#)). The material ideation and development must be communicated. This is frequently achieved by accompanying the material creation pro-

cess with the main tools of storytelling, such as videos, storyboards, and diaries.

This narrative component is an integral part of the DIY-Materials phenomenon

and is fundamental for communicating the perception and vision of the new pro-

posed material, as well as defining the material identity and its future acceptance

in the lives of people who may come in contact with or use the material.

In closing a quick final consideration needs to be made on the issue of scaling-

up DIY-Materials creation. Material demonstrators have the potential to be taken

as a model for companies to replicate and refine the materials from the perspective-

tive of commercial application, especially locally as an alternative to mass production and supply of industrial materials. At the academic level, it is exciting to

show how this type of approach is relevant for the training and professional practice of the designer who becomes a material designer, possessing the sensitivity and propensity to design not only forms but also material qualities. It is

also crucial to highlight how this approach can become an opportunity for companies interested in more sustainable material alternatives and attentive to their local economies because, in fact, it would allow the improvement of alternative

and more flexible production systems even at an industrial scale.

Acknowledgments

All cases presented in this chapter marked with an asterisk (*) in the images, were developed under the made@polimi workshops or Master's thesis at Politecnico di Milano and are available at <https://www.diy-materials.com/>.

The authors are grateful to Owain Pedgley for his feedback in the preparation of this chapter.

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CHAPTER 10

Design and science: a pathway for material

design

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10.1

Intersections between design and science

The relationship between design and materials science can be placed within the wider framework of the scenario built on the intersection of design culture and the sciences. In recent years, more and more designers have chosen to weave their paths with scientific disciplines, offering themselves as an ele-

ment of connection between scientific knowledge and society. The strengthening of the relationship between design and science is now a widespread phenomenon, a media success, which has acquired multiple forms generated by the combination of infinite design variants and multiple scientific areas ([Langella, 2019](#)).

Many of the science and technology achievements have produced revolutions that profoundly affect not only people's way of life but also their opinions and choices. The design of the Anthropocene ([Seidl et al., 2013](#)) plays an important role in the processes of decoding and adapting to change since it is capable of giving shape and meaning ([Verganti, 2018](#)) to the changes induced by science and technology, along with new knowledge, transmitting them to society through objects, communication devices, services, critical interpretations, and material experiences ([Hekkert & Karana, 2014](#)) elaborated with accessible languages, which can allow as many people as possible

to know, metabolize and use the results of the techno-scientific evolution in

a conscious way ([Olson, 2000](#)). For these reasons, in recent decades design — intended both as practice and as thought—has increasingly intersected its paths with the so-called “hard” sciences such as physics, chemistry, mathematics, biology, as well as with the most fluid and interdisciplinary contemporary sciences: synthetic biology ([Agapakis, 2013](#)), neuroscience ([Zuanon, 2014](#)), bioengineering ([Kutz, 2003](#); [Ramsden et al., 2007](#)), and nanotechnology ([Kemp, 2017](#)).

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00001-6>

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The designer who collaborates with science, induced by the intention of enhancing the results for the benefit of society, summarizes the modern narrative vision of science as a vector of development, improvement, growth, and emancipation: placing in it a trust very similar to the cultural modernity approach evoked by Habermas in *Der philosophische Diskurs der Moderne* ([Habermas, 1986](#)). However, these current phenomena, like those of the past, occur according to nonlinear development paths, through leaps and

round trips, consistent with the flows of contemporary science, which proceeds in the new directions of sustainability, equity, social well-being, and regeneration of the body and mind—building a bridge of continuity with the optimistic-scientific visions of modernity.

An important contribution to the focus on the new forms of relationship between design and science was the exhibition curated by Paola Antonelli

Design and Elastic Mind held at the MoMA in 2008, the year of the beginning

of the large-scale diffusion of this cultural phenomenon. According to

Antonelli, designers and scientists should collaborate by making mutual contributions

to

their

paths,

establishing

biunivocal

relationships

to

prefigure possible futures together ([Antonelli, 2008](#)). As Joichi Ito writes, this connection includes both the science of design and the design of science, as

well as the dynamic relationship between these two activities ([Ito, 2016](#)).

Designers can create connections between new scientific knowledge and peo-

ple's lives. Their ability to grasp epochal changes in technology, science, and society by transforming them into objects and behaviors that people adopt,

more or less consciously, makes it possible to translate the results of contemporary science into new expressive and productive trajectories. At the same

time, designers are able to provide science with indications on new directions

and research themes to be undertaken that respond to the needs of society

and the market as well as any cultural changes or to stimulate the creative capacity of science with points of view and design matrix approaches.

The collaboration between design and science is increasingly frequent both in design schools and in the professional work of designers, especially for

younger generations. The diffusion of these phenomena, along with the need to fully define and understand them, resulted in the founding of a journal in

2016: the Journal of Design and Science (JoDS), a joint venture between the

MIT Media Lab and MIT Press, which aims to investigate the new connec-

tions between design and science by breaking down the barriers between traditional academic disciplines, while exploring current and controversial

scientific, design, and social issues, with particular attention to mutual inter-

actions. Overcoming the barriers must not be intended as a symptom of homogenization or loss of complexity, but rather as a paradigm within which new forms of connection and intersection between design and science

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are generated, aimed at developing hybrid products in which different points of view and skills coexist and collaborate ([Oxman, 2016](#)). In other words, a paradigm shift profoundly revises project and design culture.

10.2

Divergences and convergences

In the field of material design, there are several reasons that push designers toward science: at times less utilitarian and at times rational reasons.

Science

can offer inspiration for innovative material solutions, from both a performance and experiential point of view, in a time when stylistic innovation is increasingly difficult and technological innovation is harnessed by homologation. The designer who collaborates with the science of materials can be motivated by the ethical choice to help bring scientific knowledge closer to society, but often also by a desire to legitimize their work through the attribution of the values of utility and indispensability recognized to science.

These reasons can be traced back to the tendency of design to look to science

for new material solutions to problems related to the protection of the environment and the well-being of people. In some cases, it seems that designers are looking for an ethical or cultural justification in the science of materials for choosing to propose new products in a market that is now saturated.

Assisting science, a vector of innovation and advancement for contemporary society, through the project, to improve the quality of life, can be perceived as a noble intent, capable of rehabilitating the cultural and social image of the design discipline.

In opening *The emergence of a scientific culture: Science and the shaping of moder-*

nity Stephen [Gaukroger \(2006, p. 11\)](#) uses a quote by Nietzsche from *Die Geburt der Tragödie* which states “What is the significance of science viewed as

a symptom of life? (. . .) Is the resolve to be so scientific about everything perhaps a kind of fear of, and escape from, pessimism? A subtle last resort against-truth? and, morally speaking, a sort of cowardice and falseness?”

([1872, p. 18](#)). Even if design, interested in making a contribution to the evolution of materials, looks toward the sciences, it does not always act fully aware of the scientific process.

The attempt to use science as a sort of guarantor of meaning does not always correspond, on the part of the designers, to a rigorous knowledge of the scientific issues that characterize the materials with which it approaches and,

therefore, the actual implementation potential in product design. For example, it is quite rare (and probably unreasonable to expect) that a designer can design materials at a molecular level like a chemist or to personally carry out assessments related to process parameters. The objective of the intersection with materials science for designers must not be to replace scientists, but

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rather to propose new points of view, interpretations, strategies, and applications, related to research and scientific discoveries, using the tools of the design culture, linked to the perceptual and experiential aspects, which can even go so far as to contribute to the advancement of scientific culture in the sectors in which they are inserted.

In order for this to happen, the limits and obstacles that resist the cooperation between design and the sciences, which is linked first of all to a distance of the languages and objectives of the research, must be made explicit. One of the main obstacles to a biunivocal relationship is the difficulty of synchronization. Scientific research takes a very long time, based on the experimental

method which includes attempts, errors, intuitions, and verifications. For this reason, scientists working in the field of new materials tend to set precise

and short-term goals, while trying to optimize their work as much as possible. The main aim is to reach the results before anyone else in order to publish them in the most prestigious magazines as original data, avoiding any deviations and slowdowns.

Design, on the other hand, thanks to new digital modeling and production technologies, is able to shorten, compared to the past, the time required from conception of the project to the verification of the prototypes and production. If the design process does not involve particularly complex processes, it can take a relatively short time, even a few months—unimaginable compared to scientific research, which generally takes years to obtain ascertained and publishable data. For these reasons, designers must be aware of the need to plan short and effective meetings, avoiding digress so as to respect the needs of scientists. In addition, it is useful to quickly identify the needs and effectiveness of the technology transfer of scientists to envisage possible applications from the beginning of the collaboration. The target audience is also very different. Scientists come to new knowledge through original but repeatable protocols, which they communicate to a scientific community in the sector, generally international but very specific and limited. These needs can contrast with the attitude of design to solve design problems by designing characteristic products that can be understood and

appreciated by the largest possible market. Unlike the sciences, the scale of intervention of design is much wider and can also address different types of targets since there is no form of selective ranking.

The use of language in materials science is also very precise and specialized,

based on strictly binding conventions and rules. Terminological translations, inaccuracies, or personal interpretations are not allowed since they would change the meaning and scientific value of a statement. Terms such as hardness, rheological characteristics, elasticity, and plasticity have very precise meanings linked to the measurable and testable technical properties of the

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materials. Design, on the other hand, plays with languages in a more flexible and creative way, also using rhetorical tools such as analogies, metaphors, allegories, translations, antitheses, and similarities. Through these modes, it is able to generate original, innovative expressions and syntactic devices, which often deviate from the conventional use of terminologies. When discussing materials, designers refer to perceptual and experiential properties that are difficult to define in an absolute and precise way, but inevitably require nuanced, hybrid, allusive, and evocative languages. This distance must be bridged by designers who must strive to be respectful of the termi-

nological and precise conventions when dealing with scientific topics. At the same time, they must try to transfer their criteria for defining materials in the most shareable way possible, also by expressing them through schemes, infographics, or prototypes that allow them to directly experience the different forms of quality related to experiences.

Furthermore, to reach the production target, the design must necessarily use available and applicable knowledge, materials, and technologies, while adhering to specific economic and regulatory constraints. Science, however, to be considered original, aims to define experimental procedures that must be as new and unexplored as possible. This difference can induce the world of design and production to go beyond the usual boundaries to outline innovative production processes that only with the help of science is it able to catch a glimpse of.

In addition to distances, there are also many affinities that bring design and science closer together. First of all is the common attitude to make research projections converge toward distant but possible and feasible futures. An important prerequisite for any successful collaboration is that common goals are established. To do this, it is important to mediate between the priority objectives of scientists and designers. Scientists are interested in publishing in high-impact journals, as well as obtaining funding. For this reason, it is

important to demonstrate the technological transferability of the research results through the Technology Readiness Level (TRL), that is, the maturity and implementability index of new materials or transformation processes developed in a potential production context ([Peters, 2014](#)). Design can assist science in prefiguring the best opportunities to translate scientific knowledge on specific materials into production results by increasing the TRL index and, consequently, the opportunities to attract public or private funding.

Designers are also interested in realizing and bringing their own projects to the market and people's lives. It is important when starting new collaborations between design and science to highlight this affinity and immediately begin to focus on research and experimentation paths that can facilitate the technological transfer of scientific and design research, with the conversion of material inventions into products and services aimed at end users.

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Finally, collaboration with scientists can help design researchers be involved

in scientific publications with a higher impact than those of their own sector, while for scientists the possibility of producing patents and technology trans-

fer and third mission operations increases. The awareness of the main differentiating factors and affinity between design and science serves both designers and scientists to make them aware of the individual specificities to induce them to relate, respecting these specificities with a propensity for dialog and the achievement of common objectives. It is important that, from the first moments of the interaction, mutual curiosities, common interests, common testing, and simulation platforms arise that allow to simultaneously verify the technical properties and experiential qualities up to obtaining a shared intent and joint prefigurations of new scenarios and products.

Compared to the past, there are now cultural and instrumental prerequisites to

facilitate scientists and designers when collaborating. Multidisciplinarity, interdis-

ciplinarity, and transdisciplinarity are now required by most public funding calls

for research, and the concepts of sharing and hybridization of skills are now

acquired in the common lexicon of researchers from both the scientific and

design fields ([Bellotti et al., 2016](#)). For the distances identified to be reduced so as to generate advancements, it is therefore important that the dimension of

learning, in the field of both design and science, adapt to these evolutionary pro-

cesses by offering students the tools and skills necessary to tackle innovation

based on scientific research, oriented, and mediated by design.

10.3

The evolution of the relationship between design and materials science

The history of the role of design in the design of materials must be read in the light of the evolutionary scenario of the relationship between design and science. The relationship between designers and traditional materials has been characterized since the Industrial Revolution by an experimental approach that led designers to adapt to the characteristics of the materials that were limited to the available technologies, sometimes trying to push the limits of their properties in an empirical and experimental way, perhaps in collaboration with the manufacturing companies. In the last century, new materials were developed primarily in chemical laboratories, on the basis of many discoveries, such as those made in the macromolecular field that led to the progressive increase in polymeric materials.

In the last few decades of the 20th century, the rapid proliferation of new hyperperforming materials such as technopolymers, superconductors, smart materials, superalloys, and nanomaterials based on the discoveries and scien-

tific inventions of chemists, physicists, and engineers led designers to

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gradually lose confidence in their ability to manage such materials and control their increasingly complex properties. This marked a departure from the integrated relationship between design and materials that had characterized the design culture of the 1950s.

The creation and diffusion of physical and digital material libraries was supposed to help designers keep up to date and access the information needed to make an informed selection of new materials for their projects. However, the exponential speed with which the number of materials was collected probably increased their feeling of vertigo and inadequacy. The subsequent phenomena related to the Maker and Do It Yourself (DIY) movements

([Anderson, 2012](#)) had the merit of bringing designers closer to experimentation on materials, inducing them to enter into an interspace between research

on materials and their application, in a position closer to that of the craft workshop than to that of the scientific laboratory.

Human value is a dimension in materials design that has been recovered.

Values related to both the sensory experience and the evocative and imaginative dimensions have acted as an antidote to the anxiety of performance generated by a pressing technological-scientific progress. Among the designers

who deal with materials, the category that adopts an empirical approach is the most active and widespread. They are mainly young designers who act in first person on the material compositions through attempts, tests, and experiments—mainly consisting in the original combination of available materials and formulations, which often include waste or natural elements. With this approach, designers sometimes experiment instinctively, others according to a more rigorous plan that approaches a scientific method, resulting in a solution that best approximates their design vision. It is a modality that does not necessarily require the participation of scientists, but which certainly benefits

from a basic knowledge of the fundamentals of chemistry as well as the ability to search and study similar experiments in the scientific literature.

Driven by the spread of the Maker phenomenon, these experiments are often very close to the open-source culture which leads to confront, in a mainly informal way, with the dimension of self-production. The materials developed in this context are called Do-It-Yourself materials ([Rognoli et al., 2015](#)).

because they are the result of self-production, and Open Materials, when the procedures used to make the materials are shared in open source through communities, generally digital. The maker, open-source and open innovation approaches, based on the principles of cooperation and the innovation

potential of communities, makes it possible to disseminate and share experiences with a strong experimental content, making the procedures repeatable and updatable through sharing vehicles such as recipes and tutorials often diffused via the internet.

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Designers enter the production process in a new way, albeit mainly at a reduced scale in terms of the quantity of pieces produced, with the production of limited series or single prototype pieces. The interest in the processes leads to the research for a new and deeper relationship with the material and its workability. A relationship becomes a dense experience due to its senso-

rial, perceptual, and anthropological value. The concept of material experience ([Karana et al., 2008](#)) extends beyond the user experience of the final product to also include that of the designers in the phases of conception and manipulation of the new materials. The choice to manipulate the material autonomously and spontaneously becomes an opportunity to investigate the relationship between nature and artifice, along with the issues of sustainability, through the use of materiality rather than dematerialization. Designers are moving toward new renewable, recyclable, recovered, and ennobled materials. For example, they are experimenting with new forms of upcycling of waste products or repropounding vegetable resins and fibers which, for technical-economic reasons, had been supplanted by petrochemical materials in the last century. Along with the contemporary recovery of the materials of the past, designers are also reinterpreting the techniques, procedures, and tools found in ancient ethnographic memories, but implementing them with innovative digital tools.

For several years, the self-production approach has been strongly driven both

from below through the Maker movement and from above through universities, schools, and design academies, mainly Central European, which have focused on processes, the modification of machinery, the reuse of waste, and the transformation of easily accessible materials, which also includes food

ingredients. This has achieved an important paradigm shift carrying a significant value, not so much for the results achieved in terms of newly designed materials but, above all, for the culture of design that regains confidence in its ability to intervene on the material.

The implementation of DIY-materials in design teaching ([Parisi et al., 2017](#)) allows young students to become familiar with the physical and concrete

component of the project—with the material experience. From empirical experiences, design students learn to experiment with processes and composi-

tions, refining their ability to intuit and prefigure new material scenarios.

They approach scientific method acquiring, directly in the field, the awareness of the need to carry out experiments with the rigor of protocols. A rigor leads them to gain experience in the integration of raw materials, processes, material properties, and applications.

It is infrequent that self-produced materials, developed by designers in contexts other than scientific laboratories, translate into the industrial dimension. It is more likely that they can remain in a sphere of limited



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reproducibility such as that which characterizes some specific applications strongly linked to customization such as orthopedic supports (prostheses, braces, orthoses), which must often be made to measure as in the Thumbio project shown in [Fig. 10.1 \(Caliendo et al., 2018\)](#). In an empirical approach to materials, the design is based on aspects related to intuition, synesthetic perception ([Schifferstein & Wastiels, 2014](#)), as well as the instinctive and emotional prefiguration of the fruitful experience that constitutes the genetic heritage of the design discipline.

In both research and the profession, the DIY approach is not enough for

designers to concretely impact the innovation of materials. Once they have gained greater confidence with formulations, processes, compositions, and an experimental approach, designers must take a further step toward materials science, which is increasingly open to the possibility of cross-fertilization

and collaboration with design contexts. What has changed in recent decades is that, while in the past centuries, the development of new materials was based on a discovery approach that strongly limited the participation to chemists, physicists, and engineers; today the research on materials is based on

FIGURE 10.1

Thumbio, bioplastic immobilization brace made with starch-based biomaterial, waste liquid from mozzarella production, and hemp fibers.

Designed for the rhizarthrosis pathology by Clarita Caliendo with the collaboration of material engineer Carlo Santulli and the orthopedic doctor Antonio Bove.

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the integration of knowledge by opening-up to a much wider range of actors that also includes designers. This openness must, however, correspond to an adequate orientation on the part of designers who often do not have the skills or self-confidence necessary to exercise an active role.

10.4

The new material experience generated by the

intersection between design and science

To participate in the innovation of materials, designers must necessarily immerse

themselves in the techno-scientific dimension of materials, inoculating the reasons

for the project, the human values of the sensory and emotional experience, and

the visions of a more sustainable future in which materials can adaptively adhere

to the new complex needs of contemporary living. The increasing proximity

between design and science, along with the openness offered to designers by the

integration paradigm to participate in the processes of development and innova-

tion of materials, increases the number of designers who choose to concretize

their visions by penetrating into the material dimension with different gradients

of awareness and interrelation with scientists.

Since the second decade of the 2000s, driven by a greater awareness of the

need to be assisted in their experiments by chemists or materials engineers,

along with a greater openness and practice in the interdisciplinary dialog,

some designers have intervened on materials in an increasingly more incisive and integrated way with science ([Wilkes et al., 2016](#)). These designers no longer simply offer compositions indirectly based on instinct and intuition, but

personally experience a direct relationship with the designing of materials from the point of view of science, conducting their activities in scientific laboratories outside of the specific context of their design projects. They discover

scientific method, the rigor of experiments, protocols, and rational criteria ([Langella, 2019](#)). The commitment to the experimental scientific process becomes the moment in which the designer transfers his visions, but also the most pressing needs of society, to the world of materials.

The critical and operational tools of design allow to enhance the research results by recovering and elevating what can be defined as innovation waste, that is, new materials developed in the laboratory that have yet to find an application. Material scientists, although inclined to develop products and services that enhance their research, often fail to do so due to the lack of time or approach and, for this reason, their experiment risk remaining as such, rather than passing from the scientific research stage to that of innovation and then product. It is in the scientist's own attitude not to stop at the result achieved, but to project himself toward the next one so as not to risk that other researchers get there first. It is this race against time that, in many

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cases, leaves no room for technology transfer ([Kotha et al., 2013](#)). This scenario opens a new gateway to design which, by integrating the results of sci-

ence with market trends, and with the evolution of contemporary languages, needs, and lifestyles, manages to implement the new materials developed by researchers, but not yet enhanced into concrete forms of innovation, through methods of application and interpretation that respond to unresolved needs set out in the contemporary context. Design research can guide and modulate the relationships between experimental and industrial dimensions, helping to increase the TRL, the degree of maturity of the materials developed in engineering and chemical fields, in industrial production and favoring the creation of innovative start-ups ([Peters, 2014](#)). In this case, designers manage to understand the opportunities as well as the limits of the new materials so

as to use them in contexts in which the identity and potentialities can be best expressed and acquire value.

Design is able to build a bridge between the scientific research of materials and production contexts through the prediction, realization, and prototyping of research results in the form of applications and products, which amplify the possibility of persuading companies to implement them in their produc-

tions ([Luo, 2015](#); [Na et al., 2017](#)). Going even further into the intimacy of the development process, some designers manage to push themselves into an almost equal cooperation by making a substantial contribution to the development processes of new materials, proposing changes, and identifying correlations between the parameters that scientists would have missed. They therefore create grafts of unusual components for researchers, which lead to leaps of innovation that only the intervention from outside of an unusual variable such as design can induce.

In proposing these deviations, designers often consider the needs of the market

and the user affordances or try to transfer their experience-driven visions of innovative products by including the development phase of the materials into a single organic path ([Barati & Karana, 2019](#)). The design of materials, in these cases, should be based on a mutual cooperation between designers and scientists based on the scientific method, rigorous protocols, as well as interdisciplin-

ary cooperation methods that allow to conceive a composite and multifaceted material experience in which both the technical performances flow and the per-

ceptive, emotional, and evocative qualities that designers care about are involved. The concept of material experience extends to the conception phase

of materials, which becomes an experience of collaboration and contamination

between designers and scientists, made of comparisons, exchanges, references,

divergences, and convergences.

The advantages of a mutual relationship between design and materials science can be found in the possibility for scientists to take advantage of the

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predictive and interpretative ability of the designer, who is used to moving in areas of application that connect science and society. At the same time, designers can, through the scientific approach, undertake feasible and concrete experimentation and innovation paths, balancing their innate tendency to imagine material solutions that are impossible to achieve or to delegate most of the product innovation to materials without however fully knowing their properties and potential. This constructive and revolutionary form of collaboration can only take place with work opportunities in close contact, in the practice of the scientific laboratory, and exchanging information necessary to integrate the two different approaches and knowledge, thus generating new cultural tools.

Through mutual collaboration, designers and scientists compare and share

their different points of view on materials. While chemists and engineers perceive materials in an instrumental way, through the investigation and production devices that are mostly based on two-dimensional images, numerical data, and formulas, designers appreciate materials as the body, sensual, and multisensory components, and therefore as a provider of experiences. The awareness of scientists about the experience dimension of materials is one of the most important revolutions induced by this phenomenon of approach between design and science that will lead to materials of the future that are not only technically more advanced but also much denser from a psychoperceptive and neurocognitive point of view.

The world of materials for designers is very different from how it is observed

by scientists and technologists because it constitutes a universe of expressive opportunities through which to express ideas and concretize any relative visions. In the imagination of designers, the maps and technical classifications based on the chemical, physical, and mechanical properties of the different types of materials are superimposed on the interpretations of designers and users who graft references to the cultural, symbolic, experiential, imaginative, iconic, and sensorial aspects which outline what Bachelard called the “poetry of materials.” Along with the constellations of the technical proper-

ties of materials, the culture of design juxtaposes a “connectomics” that unites materials with objects, design thoughts, intentions, and attitudes of the designers who have interpreted the different materials through those objects. A system of profound traces is engraved in the history of the anthropological relationship between man and material.

The new materials experience generated by the collaboration between design and science is highly enhanced, intense, and profound since the intents of the designers in relation to the gradients and perceptive, evocative, and emotional nuances are translated through the tools of science. They are translated not only through detailed control but also the specific chemical-physical

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characteristics of the materials that modulate perceptions and sensations. The realization of the materials experience is therefore based on parameters elaborated with instrumental tests, chemical-physical manipulations at the molecular scale, digital simulations, or very precise and exact digital manufacturing. The quantitative and qualitative management of the designing of the materials experience also facilitates collaboration with the neurosciences that can study the neurological feedback linked to the metrics of various parameters through tools such as electroencephalogram, providing

useful information for coding the experiences, while decoding user reactions.

With this approach, users have the opportunity to live even very unusual and original experiences since qualities such as softness, lightness, layering, grain,

and texture are the result of the encounter between different points of view

can be calibrated according to a hybrid qualitative and quantitative approach, which leads to completely new and unexpected results.

Through the collaboration between design and science, it is possible to obtain materials that surprise because the experience that characterizes them is different from what would be expected, making it possible to see equally unusual applications. The traditional categories of materials experience are no longer viable. Very lightweight and layered metals used for wearable accessories, transparent woods used for separating walls, soft and perfumed stones to sit on, and elastic ceramics to hold food are just some of the experimental combinations of materials and functions that the mutual collaboration between design and science can produce.

The results of the cooperation between designers and material scientists carried

out in laboratories are often unusual and original. These include materials such as bioplastics from the sea made with a bio-inspired approach from raw materials of marine origin including mussel valves, algae, and prawn shells,

developed by the designers Clarita Caliendo and Francesco Amato, with the chemistry research group coordinated by Mario Malinconico. They were put on display at the itinerant exhibition Italy: The Beauty of Knowledge promoted

by the science center Città della Scienza and the National Research Council (CNR). The characteristics generally conferred by materials chemists are sub-

verted in these materials from the point of view of the designers: discontinuity

instead of continuity, inhomogeneity instead of homogeneity, color nuances

and opacity gradients instead of chromatic and optical uniformity, while still

ensuring the resistance and adaptability of the structural responses to mechanical stresses.

The samples of these materials are shown in [Fig. 10.2](#).

Designers and scientists can conceive the material experience together, from the micro- to the macro-scale as in the FARE LUCE project, which was based

on a productive and essential collaboration between material chemists and

designers. The project focused on ETE technology (Emulsified Thermoplastics



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FIGURE 10.2

Material samples of bioplastic from the sea developed by the designers Clarita Caliendo and Francesco Amato, with the chemistry research group coordinated by Mario Malinconico.

Engineering), which was patented by the research Institute of Polymers, Composites and Biomaterials (IPCB) of the CNR with the companies Airpol and Res Nova Die ([Aversa et al., 2019](#); [Corvino et al., 2016](#)). The technology uses a polymer (polystyrene, acrylonitrile butadiene styrene, and polycarbonate), sourced from packaging waste or e-waste, loaded with postconsumption

waste, in particular, resulting from the grinding of composites, fiberglass,

and polystyrene derived from the demolition of multimaterial products such as boats or buildings, to produce a thermoplastic technopolymer through a cold process. The samples of ETE materials developed by the collaboration between designers and chemical scientists are shown in [Fig. 10.3](#).

The designers interpreted this project guiding it in relation to the material experience expected for the final objects. Marzia Micelisopo's intervention in

the design of the material developed to make the translucent diffuser panels of the relational lamp called Eve from the recycling of buildings led, for example, to making explicit through a metal grain the multimaterial origin to visually communicate the ability of the ETE process to recycle complex





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FIGURE 10.3

Material samples developed by the ETE process exhibited in the Airpol Res Nova Die material library. ETE, Emulsified Thermoplastics Engineering.

FIGURE 10.4

EVE, relational lamp designed and realized by the designer Marzia Micelisopo in collaboration with the chemists of the IPCB of CNR.

products without separating materials. The chemists on their own would

have mixed the different materials making them unrecognizable or hidden,

whereas through a metal the origin of the recycled material is communicated

([Fig. 10.4](#)). The designer also proposed an analogy between the regeneration of human relationships and materials. The degree of transparency, opacity,

and colors has also been carefully and strategically studied to obtain an effect

similar to a hearth evoked by the lamp as illustrated in [Fig. 10.5](#).

In the Fold lamp, however, the designer Martina Marchi, the chemists of the CNR and the engineers of Airpol and Res Nova Die, dosed together the layers of

material and the way of juxtaposing them to obtain different light intensities in

different directions to obtain a directionally differentiated light ([Fig. 10.6](#)). The lamp was developed to represent, through the object and the material experience, lights and shadows of the local industrial context and the importance of

combination and stratification between production history and innovation.



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FIGURE 10.5

Detail of the material specifically developed for EVE lamp, from the upcycling of building wastes. Realized by the designer Marzia Micelisopo in collaboration with the chemists of the IPCB and Gabriele Pontillo.

FIGURE 10.6

Detail of the material specifically developed for the Fold lamp, made with expanded polystyrene waste structured in overlapping layers.

Realized by Martina Marchi in collaboration with the chemists of the IPCB and the companies Airpol and Res Nova Die.

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10.5

Conclusion

Design that manipulates materials by collaborating with science can enrich the

materials experience with a significant expressive, narrative, and experiential

potential that is rooted in the instinctive, sensorial, ancestral, and involuntary memory of humans. Through a scientifically competent approach, it acquires the opportunity to explore and define new material relationships, combining

the technical and sensorial aspects of the materials, to create richer product experiences, based on the observation and knowledge of biological, chemical,

and physical principles ([Thompson & Ling, 2014](#)). The contribution of neuroscience to this type of intervention can be very valuable. Many of these topics

are studied in the context defined as “embodiment” based on interdisciplinary

research that integrates studies on the phenomenology of the living body with neurosciences and cognitive sciences, to understand the complex relationships

between body factors, such as physical and motor perception and cognitive processes ([Van Rompay & Ludden, 2015](#)).

The digitization, virtualization, and dematerialization of experiences are allowing

people to evade physical contact with others and things, with this probably lead-

ing, through an opposite reaction, to making people more sensitive and perme-

able to material experiences. This must provide designers with a greater awareness

of having new possibilities available to affect the emotions, the appeal of the unconscious, and the induced thought of users through materials experience. The

design of the materials experience can become a very powerful tool if based on

the knowledge of chemical and neuropsychological mechanisms, on the study of

pheromones and sensory perceptions, which can also prove useful in balancing

the evanescence of the digital, through the body component to safeguard the size

of physical things and thus to ensure the psychophysical balance of people.

In all these forms of designing materials and material experiences, the vision-

ary nature of design emerges. Through it, unconventional creative strategies manage to facilitate the dissolution of barriers and the building of paths, in which design and science come closer, to fertilize and eventually hybridize, ultimately helping each other out in a coevolution. Design becomes a tool to bring people closer to the progress of science that affects the quality of life, through experiences rather than products, which involve aspects such as curiosity, fun, and emotion, not remaining on the surface, but rather to impress more profoundly the planning thought in the materials of things.

Acknowledgments

The FARE LUCE project multidisciplinary research team involved material chemists: Mario Malinconico, Salvatore Mallardo, and Maurizio Avella of the IPCB of the CNR; designers: Marzia

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Micelisopo, Martina Marchi, Alfredo Buccino, Carla Langella, and Gabriele Pontillo; a design historian: Francesca Castanò; an expert of cognitive sciences: Maria D'Ambrosio; and experts of lighting technology: Sergio Sibilio and Roberta Laffi. The involved companies are Airpol and Res Nova Die.

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CHAPTER 11

Materialdesign: design with designed

materials

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11.1

Introduction

Since its beginnings in the industrial age of the 19th century, industrial design has developed into an expanded concept of design that today affects many areas of life. The increasing digitalization of our living environment reinforces the approach of thinking in interdisciplinary processes and seeing different areas of society and knowledge as a unity or at least linking them. This offers great opportunities, especially for the design disciplines. Today, design can no longer be classified as a core discipline only in its classical ter-

rain—as Mateo Kries, Director of the Vitra Design Museum, sees design today

“as a cross-sectional discipline between art, science and technology” ([Kries, 2013](#), p. 136; quote translated by the author). Today, more than ever before, design and creation can be understood—in addition to its contribution to industrial value creation—as a cultural task.

Materials are indicators of a strengthening or changing will to design. They act

as impulse generators for new forms of design and also as incubators of cultural-historical developments. These are significantly accelerated by the use of

new artificial materials and processes. The progressive approach of thinking in

interdisciplinary processes and seeing material, construction, and design as a unity represents a connecting factor for modeling for many disciplines in our digitized world. Digitization is predestined to bundle such diverse, but mostly

different and heterogeneous processes. Only through their visualization and materialization, our ideas and design intentions become visible and tangible

—
and it is the materials that transfer our ideas into the real world and increasingly

take over the role of the actual object. Through the materialization of our ideas

and design concepts, they become tangible. Today, design concepts are funda-

mentally influenced not only by digital design and production tools but also by

their materiality in a blending of digital and real.

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Materials Experience 2. DOI: <https://doi.org/10.1016/B978-0-12-819244-3.00013-2>

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Materials thus become carriers of a wide variety of information and enter into a dialog with their environment. They become informative and intuitive. The design with material becomes a design of material and in the consequent continuation, “Design with Designed Materials” ([Holzbach, 2015](#)).

11.2

Design with designed materials

In contrast to classical product and industrial design, in material design the processes and also the basic principles of materials, structures, and systems play a decisive role. The aim is to provoke results with a usually high degree of experimental freedom. It is the material that transfers our ideas into the real world and increasingly take over the role of the actual object. The traditional thought pattern of “material-authentic design” seems to have been overcome by the combination of digitalization and materialization. Speculative design processes link the material with various research and creation methods in order to design and inform the materials before they are themselves integrated as part of the design process in a larger context. Simultaneously, or interacting with the previous more rational and analytical—and mostly technological or

scientific—methods, creative and design methods are also introduced into the

design-oriented development of materials. In contrast, essential partial aspects

of the design process, which up to then had mostly been predetermined, now

take place on the material level from the very beginning. Functions of the

object to be designed are anticipated and transferred to the material. The ques-

tion of materiality is asked at the very beginning of the design task and not, as

usual, as a selection of existing materials at the end of a traditional design pro-

cess. But it is less about the traditional choice of materials in the sense of

wood, ceramic, metal, etc. Rather, the question of the characteristics, sensitive

properties, and nature of the material to be used arises. The selection and

description of the material profile already includes and subsumes the hybrid

properties of the object to be designed. Design takes place with designed

materials—it is “Design with Designed Materials.”

Despite digital charging or information, the material can still be experienced

—

instead of pure digitalization, there is an increased “reanalogization.” Even in

the digital world, material has not—as predicted—lost its importance.

Despite

progressive digitization, it remains the digitization of our world—a physical world. Rather, an increasing overlapping of the digital with the real, that is, our

living world, can be observed. The digital infiltrates the “real” and the physical

and material world surrounding us. From the symbiosis of the material and designed objects with the digital and material-technical charges, hybrid concep-

tions result, which open up new ways of formal and functional design. The path from static to dynamic and process-oriented properties is thus smoothed.

11.3 Sensitive properties

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11.3

Sensitive properties

The recognition of the specific sensitive material qualities—beyond given material parameters such as tensile strength or modulus of elasticity—is the great potential for designers. These are qualities in the material that are difficult to describe theoretically. This logic of the material is interesting for designers. The interpretation of material design is also about the integration of material research. Especially the integration of material parameters in digital models, as it is possible to see them more and more in

design disciplines, originates from the natural sciences and technically motivated disciplines. Of central importance are not only functional but also esthetic qualities. Therefore in addition to the material as such, as well as the manufacturing processes and construction, “soft” factors such as emotions or sensitive properties are of decisive importance. What does the texture, the aggregate state, elasticity, or viscosity of a material tell us? ([Holzbach et al., 2014](#)).

By placing the materials in completely new contexts or by digitally and procedurally charging and developing hybrid material combinations, the materials are given new information. Today, generative methods can be seamlessly integrated. In the design process, digital design and manufacturing tools can be used in continuous process chains, not least because of the appropriate scaling. Nevertheless, there is still the physical handling of the material, the constant questioning of the concept as well as the matching and interaction between digital and analog. Historical production techniques are combined with new digital methods, or even lost knowledge is transferred with new contemporary digital tools into a new context and thus also newly informed.

The essence of the material itself becomes increasingly—and then also often intensified—sensually perceptible again. Otl Aicher spoke in [1987](#) in his essay “greifen und begreifen” about the grasping and understanding of things

(Aicher in Braun, 2005). The reinterpreted material worlds open up a variety of ways to shape our environment. In addition to the principle of the minimal, the experimental methods for finding forms and the observation of natural and technical structures, the self-organizing processes and the finding of forms, the focus is on actively shaping the processes taking place. These seem

to contradict each other, as Frei Otto already described in [1972](#): “The will to emphasize design is in contrast to the search for the still unknown form which is subject to the laws of nature” (Otto in Burkhardt, 1984; quote translated by the author). Here there is an important superimposition on the current development, in which an intentional will to design takes place through minimalization, but which is inherent in the materials and the material world as hidden information due to its microscaling.

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11.4

Informed materials

In a complex setting of highly different, often simultaneous and sometimes even contradictory levels of action, hybrid design processes are initiated, which in their consequence also lead to hybrid design forms with interac-

tive, connective, smart, or gradually varying properties. The new logic of the material often no longer has anything to do with originally “inherent” or even “authentic” qualities. This fundamentally changes the nature of design concepts. The observed linking of the digital with the real or the digital with the material was followed by hybrid structures with their own hybrid property profiles. This results in a formal and functional charging of the existing materials. Classical categories of material are increasingly dissolving. Thus Sabine Kraft writes in her article “Werkstoffe. Eigenschaften als Variablen”: “The relationship between form and material has become as diverse as it is ambiguous. A recourse to clear specifications as to what can be conceived and constructed in which material and how, and what esthetic message would be transported by this, is hardly possible anymore—if it ever existed” ([Kraft, 2004](#), p. 24; quote translated by the author). [Schäffner \(2016\)](#) raises an important related point.

If this quite different, far more active role of materials that function like automatons and represent their own operative systems is currently emerging in the context of material sciences, then it is something that will change our entire understanding of materiality and design, of technology and nature. Material and matter will no longer be regarded as passive masses that become the carriers of technical or symbolic operations.

Rather, it reveals itself as an active operative system. ([Schäffner, 2016](#), p. 29; quote translated by the author)

Through digital or process-related information of materials, their formerly material-specific or “authentic” properties are supplemented, overwritten, or completely replaced. This fundamentally changes the nature of design concepts and leads to completely new links of knowledge. “Informed” or “charged” materials with sensitive or smart properties lead to an increasing blending of different contexts. This results in hybrid forms which no longer allow separation. The increasing microscaling has already been described by Nicholas Negroponte in “Beyond Digital” as computers “. . . that disappear into things that are first and foremost something else. . . . Computers will be an important but invisible part of our everyday life” ([Negroponte, 1998](#); quote translated by the author).

New qualities result solely from the microscaling of the individual components and their hidden present—and operating properties. The contemporary and newer generation of digital and also postdigital material hybrids show

11.5 Institute for Materialdesign IMD case studies

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the reactive properties of the animated world, but suggest the properties of the “intrinsic.” In their 1977 film “Powers of Ten,” Charles and Ray Eames in

a certain way anticipate the question of scaling and the microscaling which is associated with digitization and postdigitization. At the interface between design and science, they, as designers, take a short journey to present the different dimensions of the most distant and largest, as well as the very near and smallest, structures. As Ray Eames writes “Charles learned from Eero Saarinen how important it is to look at things from the next largest or next smallest scale” ([König, 2005](#), p. 85; quote translated by the author).

11.5

Institute for Materialdesign IMD case studies

The Institute for Materialdesign IMD at the University of Art and Design Offenbach works in an experimental and interdisciplinary dialog on the analog and digital intersection of visualization and materialization. In teaching and research, works that in their core deal with the role of material in the design process are conceived in different scales. Many works are the result of

experimental, interdisciplinary, and unconventional processes. The different qualities, possibilities, and even impossibilities of materials and their role in the design process are explored. In addition to the digital and analog processes, the special attraction lies in interdisciplinary, material-unspecific combinations and in the experimental transfer from familiar to unfamiliar

contexts. Increasingly systems that are inspired by physics, chemistry, or biology are getting developed. A new nomenclature is emerging—materials or hybrid materials receive their information or determination through the manufacturing and forming process or through their compositional joining with other components. The newly interpreted material worlds hence open up a wide range of possibilities for shaping our environment.

Andreas [Reckwitz \(2010\)](#) writes about the “proceduralization of creativity.” Since the avant-garde movements [. . .] a special interest has been in the techniques, the procedures of the creative process. These now essentially appear as those of coincidence management [. . .]. It is not the subject that appears as the original instance of a production process, but it is the process itself that produces something new in its own dynamic. This production of something new can be promoted by certain techniques [. . .]. For these creativity techniques, the promotion of chance is central—whether in dealing with the material or in the mental sequence of the association. The point is to allow a momentum of processes in which something new is produced [. . .]. Creativity is then no longer to be identified with a subjective creative power, but amounts to a promotion of unpredictability in dealing with things and ideas.

([Reckwitz, 2010](#), p. 111; quote translated by the author)

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The integration of new digital or even material-technical components creates completely new formal and functional contexts—they are informed or overwritten. The boundaries of design, architecture, art, technology, or science are

often no longer recognizable. Many of the works created in this way move at the interface between human and material or nature and artifact. Emerging hybrid forms no longer allow a clear separation or even classification. Partly different and also contradictory materialities and functionalities coexist alongside and with each other. High-tech is linked with low-tech strategies and nonlinear storylines are implemented. Materials increasingly have properties that seem to be “alive.” At the same time, natural materials are linked with synthetic materials and digital interfaces and thus transformed into the artificial world. Materials or hybrid composites with sensitive, smart, or grad-

ually varying properties lead to new and complex design concepts. The aim is

not a dogmatic reduction but a conceptual materialization based on a variety of analog and digital methods and their combination. New “highly charged”

materials increasingly take over the role of the actual object. The observable linking of the digital with the real or the digital with the material leads directly to hybrid structures with their own hybrid property profiles. The following case studies were developed in research and teaching at the Institute for Materialdesign IMD at the University of Art and Design Offenbach.

11.5.1

Parametric Skin

Parametric Skin is a structure that enables us to experience leather in a new way.

The design superimposes a graphic, computer-generated honeycomb structure on

the natural microstructure of leather. This artificial structural pattern changes the

natural appearance of leather by exaggerating it, in particular, in the transition

from two- to three-dimensional. The digital net structure that Parametric Skin is

based on is made by parametric programming of the organic leather grain. This

is why it adapts to any surface shape. The distortion of the structure emphasizes

the edges and specific areas of an object. Using several such “informed” leather

areas, complex spatial objects without seams can be made. The leather gives objects such as the inherent stability though they remain flexible ([Fig. 11.1](#)).

11.5.2

Magnetic Fabric

The work Magnetic Fabric explores the properties of a textile such as mobility

and flexibility. Integrated, magnetically effective components are used according

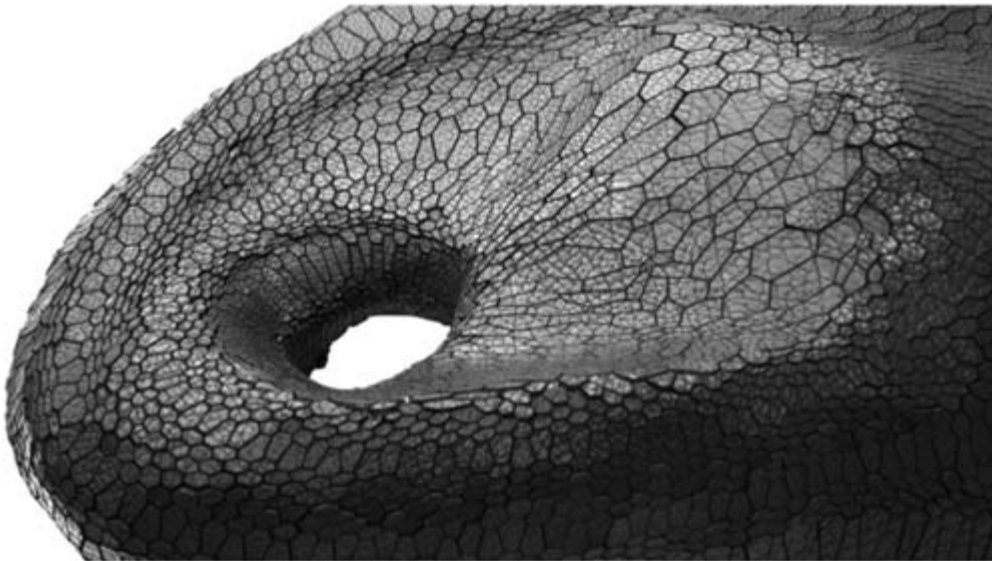
to various parameters and depending on the arrangement of the elements and

the nature of the textile and set the textile surface in motion. The interaction of

active and passive units, methodically arranged inside the textile envelope struc-

ture and the surface, causes a mechanical attachment of the components and

thus a dynamic rearrangement of the entire medium. The behavior of the





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FIGURE 11.1

Parametric Skin. Johannes Wöhrlin at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BASF designfabrik and Hyundai Motor Deutschland GmbH.

FIGURE 11.2

Magnetic Fabrics. Lilian Dedio at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BMW AG “Intuitive Brain”.

textile and the permanent transformation of its shape are initiated by a hidden digital interface, thus suggesting a moving life of the textile itself ([Fig. 11.2](#)).

11.5.3

Interactive Wood

Wood as a high-quality and natural material has anisotropic properties and often very individual grains. Each piece of wood is individual and unique. Through touching the surface, the light is activated on-spot, creating a



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FIGURE 11.3

Interactive Wood stages 1 3. Johannes Wöhrlin at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BMW AG “Intuitive Brain”.

gesturally controlled functionality. After activation the light is dimmed over time and the grain emits a soft light for a further while. The esthetics of the high-quality wooden surface is visible even in the dark. The wood grain spreads a faint shimmer that offers light for orientation ([Fig. 11.3](#)).

11.5.4

Light Skin

Light Skin is the vision of an interactive “skin” in an automotive context.

Stimuli such as touch, pressure, and vibrations are received via embedded silicone lenses and released as spots of light: touch becomes visible and provides an optical feedback. The display becomes an analogous interface between object and space. Along with its tactile qualities, in an automotive context Light Skin makes it possible to control the car body and use it as an information and warning display in traffic by visualizing physical forces.

Centrifugal and inertial forces would then make the vehicle light up in different ways. Light Skin strives to overcome the existing notion of an automobile and reinterpret its function and appearance ([Fig. 11.4](#)).

11.5.5

Hydro Lighting Surface

Hydro Lighting Surface stands for a membrane construction with local function allocation. A resin coating, which is applied to a textile by means of the screen-printing process, enables the opposites solid/flexible and hydrophilic/hydrophobic to be inscribed in a textile fabric. The adhesive



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FIGURE 11.4

Light Skin. Julian Schwarze, Martin Pohlmann at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BMW AG “Intuitive Brain”.

property of the textile is changed in such a way that water adheres to the printed structures like pearls. Thus the water acts as a control and triggers further functions, such as hydrochromic or thermochromic effects. In this way, the coating reacts to the chemical composition of the water or its temperature and makes hidden things visible. Fluorescent pigments contained in the liquid give the textile a luminosity in the dark, which is further enhanced by the prismatic effect of the drop of water. The luminous textile

is always active when water interacts with the textile. The water drops act as a local conductor of electricity. Where the water can accumulate, the electric circuit closes and an LED starts to light up ([Fig. 11.5](#)).

11.5.6

Transformative Paper

Technical or engineering material parameters are often included in digital models. Today, the materials often undergo digital programming themselves. Swelling behavior and the anisotropic nature of machine-made and wood-based paper are often a disadvantage, as they do not guarantee uniform properties in different directions. However, if one takes advantage of this, materials can be completely defined and activated individually depending on their preferred direction. In this example, the paper as starting material was combined with another material to form a hybrid structure that leads to new combined qualities. The adaptive structure reacts automatically and continuously to environmental influences and is fed solely by the “intelligent” behavior of the used starting materials. The postdigital approach—in contrast to the previously presented example of Magnetic Fabrics—no longer has a



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FIGURE 11.5

Hydro Lighting Surface. Alix Huschka at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BASF designfabrik and Hyundai Motor Deutschland GmbH.

digital interface. The result is a reactive—lifelike—skin that is able to close automatically when it starts to rain. Depending on the humidity of the air, the paper structure transforms into different states—subtly or very clearly. At high humidity, the reactive skin closes completely and begins to glow intrinsically via a further material and not digitally motivated charge. All reactions take place in real time and are reversible. In the case of high dryness, the

individual segments return to their original position ([Fig. 11.6](#)).

11.5.7

LEM—Intelligent Skin

Mobility between digitality and exploration. Mobility is one of the central achievements and an important feature of our civilization and society. In the age of limited resources, new mobility concepts have become a relevant subject

of debate. Especially acquisitions in the era of information technology shape future forms of mobility to pave the way for unprecedented connectivity. The project “LEM—Intelligent Skin” implies eminent potential for the integration of

innovative techniques. The surface is a dynamic communication interface between the automobile, its users, and the spatial context. The passive, support-

ive surface thus develops into an emancipatory, intelligent skin ([Fig. 11.7](#)).

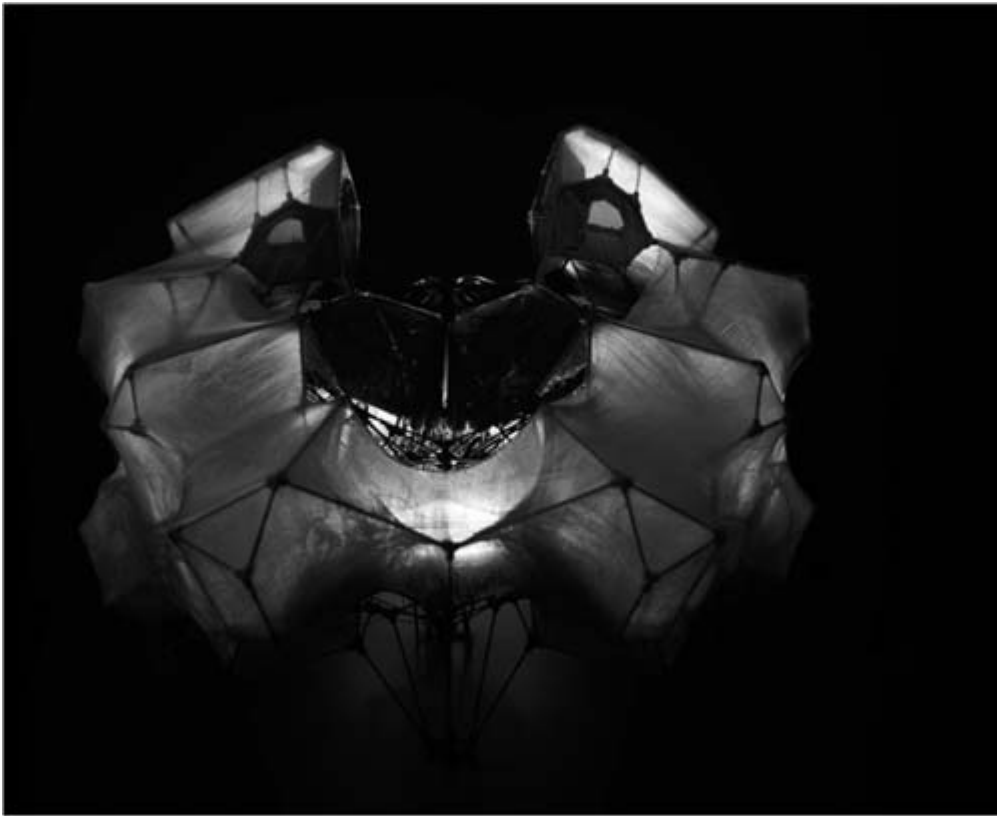
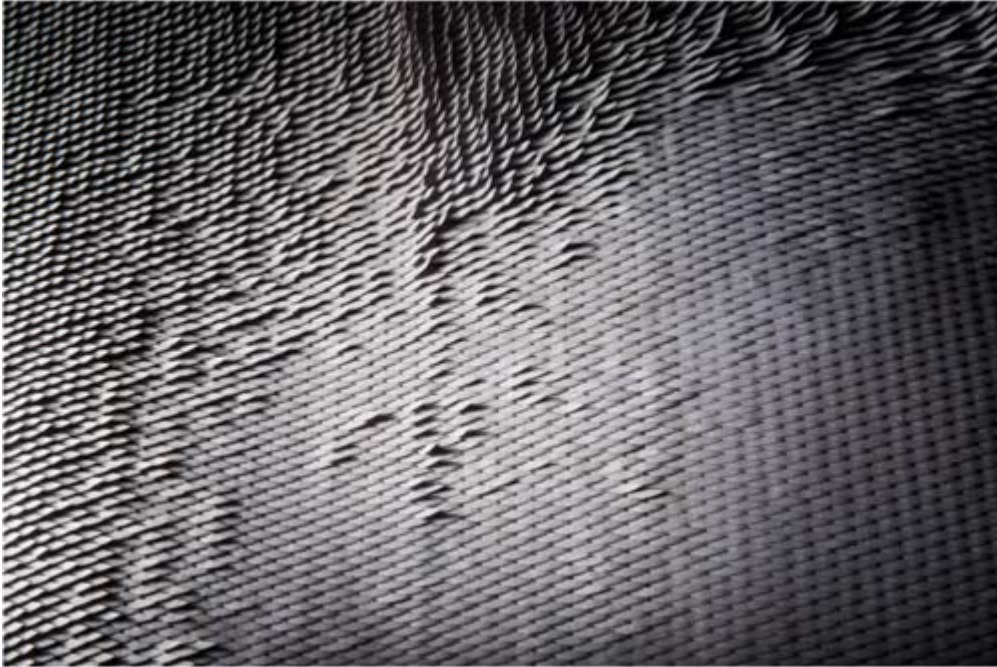
11.5.8

plant b

The project “plant b” deals with alternative manufacturing methods in design.

The responsible use of resources (“circularity”) is an important topic in mate-

rial design. Therefore sustainable alternatives for the production of digitally



11.5 Institute for Materialdesign IMD case studies

FIGURE 11.6

Transformative Paper. Florian Hundt at Institute for Materialdesign IMD, University of Art and Design Offenbach. IMD in collaboration with BMW AG “Intuitive Brain”.

FIGURE 11.7

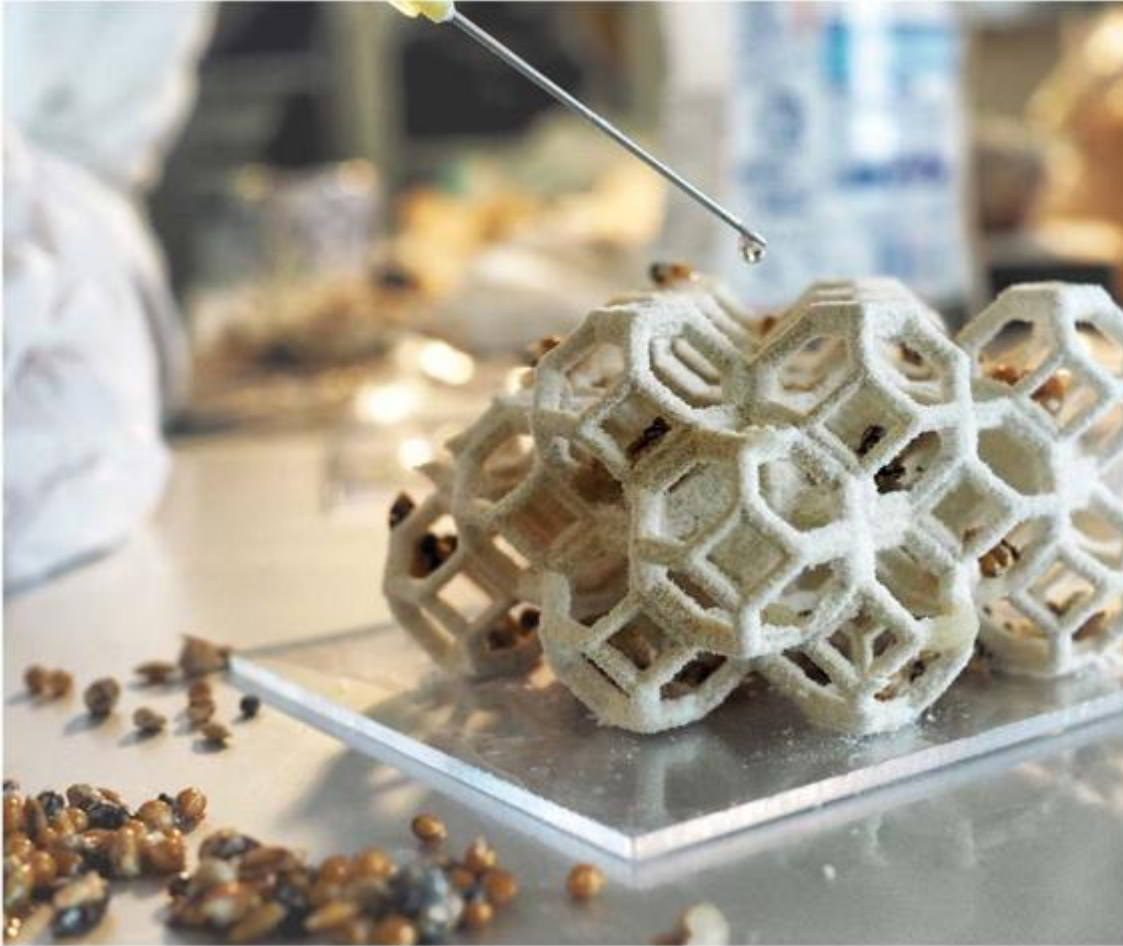
LEM—Intel igent Skin. IMD: Huschka, A., Grimm, A., Maurer, D., Burfeind, E., Hundt, F., Kovacevic, I., Huisken, J., Wilde, L., Chiera, L., Porstner, L., Mau, M., Riegler, M., Ponce, R, Brück, V., Maskow, V. IMD in collaboration with BASF designfabrik and Hyundai Motor Deutschland GmbH.

designed structures were developed. The 3D-printing process creates complex

spatial structures from cellulose that can be combined with growing organisms

(wheatgrass and mycelium) and various waxes. The resulting composite is bio-

degradable and can be returned to the production process ([Fig. 11.8](#)).



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FIGURE 11.8

plant b. Emilie Burfeind and Andreas Grimm at Institute for Materialdesign
IMD, University of Art and Design Offenbach.

11.5.9

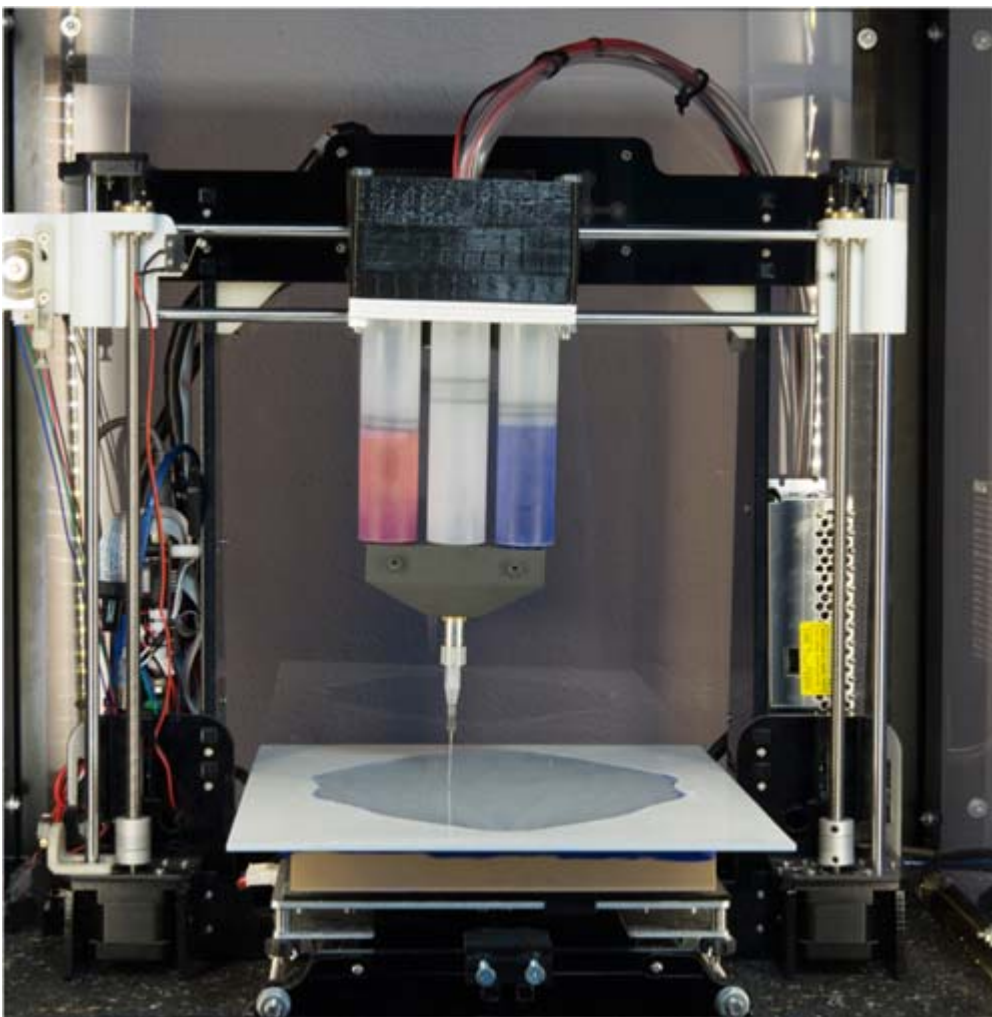
MAKU—microorganisms

MAKU is a 3D-printed pneumatic system. In a specially developed printing

process, microorganisms are printed in liquid silicone in a special nutrient solution. The symbiotic life cycles of the microorganisms drive the pneumatic system. Different functional and design levels are produced in a continuous printing process. The organisms become more active with increasing temperature and thus drive the pneumatics.

The system functions autonomously and does not require any further aids. Only the ambient temperature must be adapted to the process

([Fig. 11.9](#)).



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FIGURE 11.9

MAKU Microorganisms. Valentin Brück, diploma thesis at Institute for Materialdesign IMD, University of Art and Design Offenbach.

11.5.10

CeramicWood

Through a thermal process or multistage sintering process, evolutionary wood

structures are transformed into biomorphic ceramics. The biomorphic ceramics

show the shape of the wood and yet have completely ceramic properties. The transformed wood is cold, very hard, and brittle. Through the transformation process, the warm, rather soft, and ductile characteristic properties of the wood

are completely exchanged. Examination with the scanning electron microscope

(SEM) shows a ceramic with a completely intact anisotropic wood structure—a

hybrid material with a hybrid shape is created. The shape of the wood remains

intact at the macro level—likewise, the images taken with the SEM show that the anisotropic structure of the wood remains intact at the microlevel as well.

The shape and structural characteristics of one material are combined with the

materiality and specific material properties of the other.

The superposition of shape, materiality, and structure from different material areas and the combination of ceramic properties with the special structural con-

ditions of the anisotropic wood structure opens a dialog in which nature with its evolutionary strategies and structures is linked with that of the artificial,





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perhaps cold efficiency of a material. The resulting image is no longer congruent

with the expected and experience-based properties ([Figs. 11.10](#) and [11.11](#)).

11.5.11

Engelstrompete

Presented in the Palmengarten Frankfurt the “Engelstrompete” combines low-tech

with high-tech strategies. Natural and artificial components combine to form a

light, flat supporting structure made of renewable regional hazel and willow

woods and a translucent membrane. The interactive installation interprets the

FIGURE 11.10

CeramicWood Micro. Research at Institute for Materialdesign IMD, University of Art and Design Offenbach, Markus Holzbach/Werner Lorke Mikro_Surface biomorph SiC-Ceramic.

FIGURE 11.11

CeramicWood Macro. Research at Institute for Materialdesign IMD, University of Art and Design Offenbach, Markus Holzbach/Werner Lorke Makro_biomorph SiC-Ceramic.



11.6 Hybrid—material, properties, . . . , communication

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idea of sustainability: all materials can be easily separated, while no environmen-

tally harmful compounds are used or produced. The pavilion shows analogies to

an organism that reacts to its environment and communicates with it—
visually

and acoustically. The very light translucent membrane forms the skin between
the

wooden leaf ribs and at the same time serves as a reflection surface or space
for

different projections. Moving forms and changing colors underline the
analogy to

a living organism. The visual level interacts with the visual sound space,
which

was specially designed for the project. Sounds of nature, the twittering of
birds

from the surroundings, but also urban sounds, for example, from the
neighboring

underground railway, are the raw material for the acoustic superimposition
and

are reproduced in an alienated way. The video projection, which is adjusted
to

the sound situation, interacts with the metallic shimmering inflorescences that
are

moving in the wind and changing color and shape progressions ([Fig. 11.12](#)).

11.6

Hybrid—material, properties, . . . , communication

“Hybrid” material solutions integrate digital and material-specific technolo-
gies at a scale and complexity that no longer allows conclusions to be drawn

about the performance or function of the existing material systems. Materials become informative or even intuitive, enter into a dialog with their environment and thus possess new functions of meaning. Many of today's object and material hybrids follow the approach of sustainability and focus on an intelligence that is not always inscribed in the material itself, but in the way it is constructed, joined, and used. The digital, in particular, is predestined to

FIGURE 11.12

Engelstrompete. IMD-Project for Luminale Palmengarten Frankfurt am Main
IMD: Freund, A.; Kliem, P.; Wildung, B.; Wirkner, B.; Bagdulin, N.; König, P.; Lilienthal, S.; Pohlmann, M.; Reinhardt, N.; Sound: Eulberg, Dominik;
Foto: Wabitsch, Emily.

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connect different sensory levels. In the digitalized world surrounding us, concepts are increasingly developing in the intermediate area between Art and Science or Design and Technology.

Real materials are digitally or procedurally charged, programmed, and informed

and increasingly possess dynamic and “smart” properties. How much do nature

and material interact with the artificially created? The real and the virtual combine

in new hybrid forms with their very own hybrid characteristics. How and with

which tools can these be described? Materials are reprogrammed by placing them

in completely new contexts, digitally changing, and developing hybrid concepts.

Through this information, materials acquire new properties and attributes of “living” or “intelligent.” They become interactive, connective, or even smart—they

seem to react automatically to their environment. Microscaling thus leads to the

suggestion of apparently existing formal and functional properties in the material.

The resulting static, dynamic, and process-oriented properties, some of them exis-

tent together, give rise to new design concepts and, at the same time, important

questions. How do different and sometimes contradictory characteristics act and

interact in hybrid overall concepts? This is also the ambivalence of the presented

material solutions. Shape and properties are no longer congruent.

Articulation of the new material solutions and hybrids will be an important task

of material design and creation ([Parisi et al., 2020](#)). In classical product design, the instructions for use are clearly communicated through the specific

formal

training of the sign function. This understanding is essentially based on the pre-

vious experience, but also—and here it becomes more speculative—on expecta-

tions. Are these clear assignments of function still given in the newly coded and

informed hybrids? The role of the sign function as a mediator has to be renego-

tiated especially in the area of “intelligent,” smart, and connective material

hybrids. The basis of the knowledge mediating dialog between human and

object or also human and hybrid materials lies in experience and recognition.

The hybrid material systems no longer convey these distinct characteristics

clearly and the idea becomes ambiguous. What are the signs of the designed?

What does it represent? How can it be used? How can hybrids, which are simul-

taneously located in the real and virtual world, be described with previous

tools? Particularly in completely new functional and technological contexts, spe-

cific sign functions are often not recognizable, especially at the beginning.

There

is just as much potential for new solutions in their redefinition as in their

trans-

fer from other contexts. They are not necessarily based on stored experiences

and the resulting recognition. This has a great impact on communication and the perception of the world around us, characterized by a communication that is no longer based on the necessary recognition and mediation, but that may not take place at all—intuition takes the place of instruction.

11.7 Nomenclature _ Interdependence and In-Between

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11.7

Nomenclature _ Interdependence and In-Between

The resulting works often move at the interface of nature and artifact, analog and digital. What is real or fake, natural or artificial? Material simultaneously

takes on another role—the role of the actual object. Materials and objects of the material world surrounding us are more and more informed. Through this new “charging level,” materials and things are given a new and unique nomenclature—in other words, a hybrid nomenclature.

Hybrid material systems and objects suggest the properties of intrinsic intelli-

gence or the intuitive. The object or hybrid system decides whether it communicates itself to us. This means that it can no longer be a human object or human material relationship but conversely an object human or material human relationship. Essential factors for the additional arrival of a dia-

log, such as recognition, now start from the object. This recognition is conveyed by different connectivities and data acquisition on the side of the object—with important user data, user recognition, etc., in order to gain knowledge by creating a user profile and to form the basis for an allegedly “optimal” communication through that. Many of the informed objects and materials are increasingly complex, contradictory, and hybrid. They unite different worlds of the virtual and the real, the physical and the nonphysical. Just as hybrid materials, objects and materials are characterized by hybrid properties, the tools that describe them individually will also have to carry this hybrid nature within them. The dynamic digitization of our real environment world demands a holistic theoretical approach that takes into account the different pluralities and realms of the virtual and the real with the interdependence areas operating in between. Due to the increasing developments in science and technology and the growing interconnection of different fields of knowledge in the digital world, the number of indeterminate interdependencies is simultaneously growing. It is necessary to develop a nomenclature for the in-between. This is linked to the task of expanding and further developing the creative and artistic experiment and interdisciplinary permeability and deriving from these decidedly inductive and hybrid theories. How can processes be described in which microorganisms become active? Bruno

Latour writes about nonhuman actors and in this context refutes the subject/object dichotomy. Latour describes this using Pasteur's nutrient solution for yeast cultures as an example:

Do these belong to subjectivity or to objectivity or to both? None of the above, obviously, and yet each of these little mediations is indispensable for the emergence of the independent actor that is nevertheless the result of the scientists' work. ([Latour, 2000](#), p. 148)

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CHAPTER 11 :

Material design: design with designed materials

11.8

Outlook

The opening up to other fields of knowledge and science defines a new scientific claim, according to which design is also to be understood essentially as a

cultural task and as a cross-sectional discipline in interdisciplinary exchange that has an active role as an impulse generator and designer of our environment. Despite all the desire for determination, the degree of variables, discrepancies, and transitions is growing—the world is becoming more complex and

indeterminate. These uncertainties, however, are also a source of great inspira-

tion and ultimately of great essence for many disciplines and also for design.

Digitization is forcing a stronger interaction with different fields of knowl-

edge. This represents a great opportunity, especially for design as a complex

image of an even more complex living world. The simulability of intuitive

and systemic design processes resembles a multitude of different vectors in

space, which take on a variety of—even contradictory—directions. It is

important to understand this as an essential quality of a discipline and to

allow for individual, independent, or more autonomous interpretations as

part of a whole. Design can very well continue to act in the sense of a core

discipline and/or a cross-sectional discipline. Linear, solution-oriented, even

efficiency-determined, clear industrial design is just as possible here as non-

linear studies and experiments—or even contradictory hybrids of these differ-

ent systems. Intuitive and systemic design processes can take place equally,

sometimes autonomously, sometimes interacting. Regular and linear systems

that integrate chance or non-linear and disruptive moments and confront the

existing system with the question of cause and effect.

From the manifold links and tasks, an increasingly heterogeneous overall profile

of the design discipline is derived, based on simultaneity. Design as a discipline

that sees itself as the designer of our environment, which, in addition to fulfill-

ing its function and the interest in results, is open to processes, experiments and

innovations, nonlinearities, imponderables, contradictions, coincidence, and disruptive moments as well. In the spirit of Ludwig Wittgenstein, this is where

new questions arise. Essential aspects concern the questions of material and energy consumption, the digital and procedural charging and information of materiality and things, or digital and postdigital interactive materials, lightweight construction, as well as natural constructions or building with or accord-

ing to nature and sustainability. Last but not least, all this leads to the central questions of how the human beings will live in the future or what forms of mobility they will have. Thinking in terms of natural processes is very topical.

In times of dwindling resources, the minimization of material and energy consumption is more urgent than ever.

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Materials Experience 2: Expanding Territories of Materials and Design is the follow-up companion to *Materials Experience* published in 2014. Materials experience as a concept has evolved substantially and is now mobilized to incorporate new ways of thinking and designing. Through all-new peer-reviewed chapters and project write-ups, the book presents critical perspectives on new and emerging relationships between designers, materials, and artifacts. Subtitled *Expanding Territories of Materials and Design*, the book examines in depth the increased prevalence of material-driven design practices, as well as the changing role of materials themselves, toward active and influential agents within and outside design processes. The book is essential reading for anyone involved in materials and design, containing 11 authoritative chapters and 18 illustrated accounts of contemporary research projects and practices.

"We have reached a point where products and materials are synergistically designed. This book sets out the material responsibilities and privileges of today's designers."

Ezio Manzini

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Materials Experience 2
Expanding Territories of Materials and Design
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Butterworth-Heinemann
An imprint of Elsevier
elsevier.com/books-and-journals

ISBN 978-0-12-819244-3



9 780128 192443

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