

Research for Development

Venere Ferraro
Pirjo Kääriäinen
Paz Morer-Camo
Anke Pasold *Editors*

Materialising the Future

A Learning Path to Understand, Develop
and Apply Emerging Materials and
Technologies



Fondazione
Politecnico
di Milano

OPEN ACCESS



Springer

Research for Development

Series Editors

Emilio Bartezzaghi, Milan, Italy

Giampio Bracchi, Milan, Italy

Adalberto Del Bo, Politecnico di Milano, Milan, Italy

Ferran Sagarra Trias, Department of Urbanism and Regional Planning, Universitat Politècnica de Catalunya, Barcelona, Barcelona, Spain

Francesco Stellacci, Supramolecular NanoMaterials and Interfaces Laboratory (SuNMiL), Institute of Materials, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Vaud, Switzerland

Enrico Zio, Politecnico di Milano, Milan, Italy
Ecole Centrale Paris, Paris, France

The series Research for Development serves as a vehicle for the presentation and dissemination of complex research and multidisciplinary projects. The published work is dedicated to fostering a high degree of innovation and to the sophisticated demonstration of new techniques or methods.

The aim of the Research for Development series is to promote well-balanced sustainable growth. This might take the form of measurable social and economic outcomes, in addition to environmental benefits, or improved efficiency in the use of resources; it might also involve an original mix of intervention schemes.

Research for Development focuses on the following topics and disciplines:

Urban regeneration and infrastructure, Info-mobility, transport, and logistics, Environment and the land, Cultural heritage and landscape, Energy, Innovation in processes and technologies, Applications of chemistry, materials, and nanotechnologies, Material science and biotechnology solutions, Physics results and related applications and aerospace, Ongoing training and continuing education.

Fondazione Politecnico di Milano collaborates as a special co-partner in this series by suggesting themes and evaluating proposals for new volumes. Research for Development addresses researchers, advanced graduate students, and policy and decision-makers around the world in government, industry, and civil society.

THE SERIES IS INDEXED IN SCOPUS

Venere Ferraro · Pirjo Kääriäinen ·
Paz Morer-Camo · Anke Pasold
Editors

Materialising the Future

A Learning Path to Understand, Develop
and Apply Emerging Materials
and Technologies

 Springer

Editors

Venere Ferraro 
Department of Design
Politecnico di Milano
Milan, Italy

Pirjo Kääriäinen
Department of Design
Aalto University
Espoo, Finland

Paz Morer-Camo 
Department of Mechanical Engineering
and Materials
University of Navarra
Donostia-San Sebastián, Spain

Anke Pasold
Copenhagen School of Design
and Technology
Copenhagen, Denmark



ISSN 2198-7300

ISSN 2198-7319 (electronic)

Research for Development

ISBN 978-3-031-25206-8

ISBN 978-3-031-25207-5 (eBook)

<https://doi.org/10.1007/978-3-031-25207-5>

© The Editor(s) (if applicable) and The Author(s) 2023. This book is an open access publication.

Open Access This book is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this book are included in the book's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the book's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Disclaimer

DATEMATS project (Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach Agreement Number: 600777-EPP-1-2018-1-IT-EPPKA2-KA) is co-funded by the Erasmus+ programme of the European Union. The European Commission's support for the production of this book does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

About This Book

The book contains the theoretical knowledge at the base of new Emerging Materials and Technologies (EM&Ts), namely: Interactive Connected Smart Materials, wearable-based (ICS), Nanomaterials, Advanced Growing Materials, and Experimental Wood Based Materials. It will describe the unique design teaching method developed within the context of the European Project DATEMATS, the results of the creative workshops executed in the four HEIs partners of the project, stressing the pros and the cons of the method and, the improvement for further development.

It provides a framework to design with and for the new materials and to educate designers and give them the right experience on taking advantages of the opportunities offered by EM&Ts. Contemporary it explains the developed method intended to transmit to companies the knowledge generated in research centres and universities.

The Book is divided into two main parts:

The first section is dedicated to the main findings generated by the Project DATEMATS: the new unique teaching and design method to design with and for EM&Ts (Chap. “[Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design Method](#)”); a new tool to support the design process in the domain of the EM&Ts (Chap. “[How Do We Approach and Involve Companies in Design Fields? Lessons Learned from Surveys and Participative Workshops](#)”); the main issues met by companies while collaborating with the academia from outside and the academia perspective from the other (Chap. “[A Supporting Tool to Design with and for EM&Ts: The Materials Toolkit](#)”); the new method useful to be used by academia to transfer the generated knowledge to the companies (Chap. “[Transferring Knowledge from Academia to the Companies: A New Method](#)”).

The second part is instead dedicated to the field studies that is the application of the design method and tools to the four design challenges launched by companies and applied to the four EM&Ts (Chaps. “[Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design method](#)”–“[Transferring Knowledge from Academia to the Companies: A New Method](#)”); the reflection related to the way through which academia can/should establish a long-lasting collaboration with companies.

The two main sections are preceded by an introduction to the main context of the book, and it is followed by a critical reflection on the learning process and a glossary composed of the vocabulary set by the researchers. An appendix with the projects explored into the section two completes the book.

Introducing Emerging Materials and technologies (EM&Ts) areas and their theoretical framework

The present text introduces the main objective, framework, and areas of investigation of the DATEMATS project (Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach Agreement Number: 600777-EPP-1-2018-1-IT-EPPKA2-KA) co-funded by the Erasmus+ programme of the European Union. The research carried out in three years aimed to transfer and implement a design-led teaching method for students with a background in design and engineering in Emerging Materials and Technologies (EM&Ts) and boost knowledge and technology transfers from Academia and research centres to industry. This investigation started from the evidence that the landscape of EM&Ts, through which industries stimulate innovation processes and foster creativity, requires new interdisciplinary and transdisciplinary approaches in education, industry, and business. Specifically, researchers from four high-ranked universities (School of Design of Politecnico di Milano, Chemarts, Aalto University, Copenhagen School of Design and Technology, University of Navarra) explored such an issue concerning four areas of EM&Ts: (1) *ICS Materials*, Interactive, Connected, Smart solutions able to communicate and respond to external stimuli, linked to another entity or to an external source, and programmable not only through software; (2) *Nanomaterials*, Nano-scaled structures, or composite blends whose properties are altered by surface and/or substrate doping thereof. Matter controlled at a molecular level, on a scale of 1 to 100 nanometres; (3) *Experimental Wood-based Materials*, materials that are processed either chemically or mechanically from trees or other plants for innovative applications. The materials include cellulose fibres, fibrils (micro- or nano-structured), and derivatives; (4) *Advanced growing Materials*, materials from controlled cultivation of organisms (bacteria, yeast, algae, mycelium, etc.) that are directly grown and/or manufactured into their subsequent form (bio-fabrication).

During the three years project, several research activities were executed to identify, and perimeter the theoretical and practical knowledge related to the four areas of EM&Ts on the one hand and generate new methods and tools on the other. (Part I of the Book)

Firstly, an in-depth literature review helped map the state of the art of the EM&Ts' themes framing the core competencies, expertise, facilities, role of different involved

actors (designers, engineers, material scientists), and methodological approach used in the design process.

This literature review was conducted through Mendeley platform using five lenses: materials selection, context-specific approach, materials' behaviours and perception, and innovative applications, considering a period from 2015 to 2020.

One hundred forty-one articles delineated a rich panorama within the four EM&Ts stressing an overall agreement on the cross-disciplinarity being the most significant innovation potential and the lack of systematised methods and approaches to sustain the complexity and the intersection of diversified disciplines.

The analysis made evident the necessity of a new method to support the designer in dealing with EM&Ts, considering the cultural and social aspects of the design process aimed at developing demonstrators/products able to inspire new business.

Therefore, a shared ground document was elaborated to describe the common issues and aspects of the four EM&Ts.

The findings were formalised in a logical framework for an original design method, and it was used as a blueprint for the setting of the unique method in the four EM&Ts area.

In this regard, the Chapter 1 will illustrate and describe the results of the literature review, the re-elaboration of the contents into the unique method articulated in three phases (understanding, shaping, and applying) useful to both design and teach how to shape the four EM&Ts and a new tool called 'integration card' to support the creative process.

While understanding and setting the theoretical knowledge in the academic field, a survey submitted to more than one hundred companies in five different countries (Italy, Spain, Sweden, Finland, and Denmark) was elaborated.

This analysis lays into one of the other primary purposes of the project: to strengthen Academia's third mission to transfer knowledge outside researchers' borders and help companies to embrace innovation.

Indeed, in response to the economic and societal challenges we face today, companies are increasingly looking to new methodologies linking together consumers, designers, technologists, and other stakeholders in new ways to enhance and accelerate their investment to create a competitive advantage.

The survey was then set to understand how to effectively transfer the knowledge from Academia to companies by supporting them to exploit the results achieved in Academia and generate new innovative products and services.

The questions were framed to collect information regarding companies' specific interests and needs related to EM&T, internal methods to manage knowledge related to them, and the channels and tools they would prefer to use.

To better grasp such a complex issue, we also conducted a qualitative analysis done with the Academia to identify the preferred channels to transfer knowledge.

Chapter 2 will illustrate the quantitative and qualitative analysis results, highlighting the barriers experienced by Academia and companies by suggesting alternative ways to promote better collaborations.

One of the main relevant findings is the willingness of the companies to touch with hand the results, likewise, having product samples, prototypes, and technical

briefs to be able to envision how to use them to improve their products, services, and processes.

For this reason, the consortium decided to elaborate a material toolkit called ‘EM&Ts transfer toolkit’ to facilitate the understanding and application potentials of Emerging Materials and Technologies (EM&Ts).

The EM&Ts toolkit is a collection of tangible samples displaying five case studies for each of the four EM&Ts areas approached in the project: Advanced Growing EM&Ts; Experimental Wood-based EM&Ts; Interactive Connected Smarts (ICS) Wearable-based EM&Ts; Nanomaterial EM&Ts. The collection of materials samples, a total of twenty (20), is not exhaustive but of illustrative nature to trigger interest in emerging materials or reconsider known physical matter under a new perspective.

The Toolkit is the object of Chapter 3, and it is framed by following the same logic of the design process that is understanding, shaping, and applying. The text will illustrate and describe how the Toolkit is composed, in which section is divided, and describe the continuous iterative process through which the Toolkit was created and evaluated.

Finally, Part I of the book will close with Chapter 4, covering another method developed within the project lifespan: the ‘knowledge transfer method’, a guide to facilitate the unidirectional transfer of EM&T from Academia to Industry. This method combines a Learning stage -to explain the fundamentals of the EM&T- and an Applying phase to explain specific strategies for coming up with ideas to find new opportunities that link the emerging EM&T and the company’s product strategy.

This chapter contains a review of articles reflecting the different practices carried out for the transfer of knowledge between Academia and Industry in order, the main channels used, and the barriers identified. It describes the new method and its validation during four half-day workshops involving 94 companies.

The Part II of the book is dedicated to the validation of the main results of the research project within academia context namely: the new design (teaching) method, the integration card tool, and the EM&Ts toolkit.

The evaluation and application were performed during four interdisciplinary challenges, international learning experience involving students and teaching staff from the universities involved in the project. The interdisciplinary EM&Ts challenge was in the format of a workshop made of a combination of hands-on experimentation, design activities, and lectures and presentations by the teaching staff of the four universities and by partnering companies. About thirty students worked together in multidisciplinary teams to find solutions for a challenge launched by a real brief set by companies to produce product concepts, prototypes.

The Chapters 5, 6, 7, and 8 will explain in detail how the methods and tools were used and applied in each of the five days of workshops, the concepts generated, the results of a questionnaire submitted to both students and involved companies to verify if and how the methods and tools were effective or not to train the professionals of the future and generate innovative solutions.

Contents

The DATEMATS Project: Methods, Tools and Frames	
Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design Method	3
Venere Ferraro	
How Do We Approach and Involve Companies in Design Fields? Lessons Learned from Surveys and Participative Workshops	27
Alba Obiols	
A Supporting Tool to Design with and for EM&Ts: The Materials Toolkit	41
Gemma Esteban, Geraldine Kann, Veronica Sarbach, and Daniela Amandolese	
Transferring Knowledge from Academia to the Companies: A New Method	65
Aitor Cazón-Martin	
Field Studies: From Ideation to Applications	
Applying DATEMATS Methods and Tools to Nanomaterials: A Design Challenge by the Company Antolin	83
Robert D. Thompson Casas	
Applying the DATEMATS Method and Tools to Wearable ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies for Caring and Well-Being	103
Stefano Parisi	
Applying DATEMATS Methods and Tools to Advanced Growing Materials: Ideating Material Value Streams Through Symbiotic Growth of Production Residues and Microbes	133
Anke Pasold	

Applying DATEMATS Methods and Tools to Experimental Wood-Based Materials: Materiality in an Ideation Process 161
Tarja-Kaarina Laamanen and Pirjo Kääriäinen

Critical Reflection on the Learning Process: Envisioning Future Development 185

Glossary 195

Appendix: Workshop Posters 207

Editors and Contributors

About the Editors

Venere Ferraro, Ph.D. in Industrial Design, is an Associate Professor at the Design Department of Politecnico di Milano. She has been Visiting Researcher at the University of New South Wales of Sydney (2006) and at the Media Lab of Massachusetts Institute of Technology (2009) where she runs research on Wearable Systems with the lens on design-driven and user-oriented approaches. She is a Member of the Experience and Interaction Design Research Lab; She participated in several International and National research, and she has been the principal Investigator of the research project POD: Plurisensorial (SAF€RA 2014 joint call). Venere is currently the Coordinator of the European Project 'DATEMATS' (KA2-2018). Her main research activity is focused on the role of interaction design in the use of disruptive technology (Wearable and smart textile). In particular, on how to exploit the potential of digital technologies to design experiential systems in both the private and public sectors. What characterises her research is human-centred design. The research interests lie in the field of wearable devices, smart interactive systems for well-being with particular attention to tools and methods for changing user behaviour. She's the author of several international publications, and she holds International, National Patents and models.

Pirjo Kääriäinen is Associate Professor of Design and Materialities at Aalto University's School of Arts, Design, and Architecture. Her background is in textile design and manufacturing. Together with professor Tapani Vuorinen she has facilitated the interdisciplinary CHEMARTS collaboration between the School of Arts, Design, and Architecture (ARTS) and the School of Chemical Engineering (CHEM) since 2011. CHEMARTS aims to inspire students and researchers to explore design-driven approaches in materials research and to create future-oriented concepts, applications, and business seeds for a more sustainable world of materials.

Anke Pasold is an Associate professor at the Material Design Lab at the Copenhagen School of Design and Technology, where she is developing the methodological and technological side of the lab and is structuring new material-educational programmes. With a background in Architecture and Cross-disciplinary design, her research focus is on material practice, in particular on advanced design methodologies, material formation, and fabrication processes, which she explores by means of experimental prototypes—making things tangible between the digital and the physical towards integrated, applied solutions.

Paz Morer-Camo is a Professor at the University of Navarra—Tecnun (Spain). She holds a Ph.D. (1991) in Architecture from the University of Navarra. Specialised in Computer Design, her doctoral thesis focused on the realistic representation of 3D models and simulation of virtual environments using computational techniques. She is currently the coordinator of the Industrial Design Engineering degree and is responsible for the Industrial Design area. Currently, she lectures on ‘Artistic Drawing’, ‘Technical Drawing’, ‘Sustainable Engineering’ and ‘Design Methodology’ to Bachelor students and coordinator of the subject ‘Ethical challenges in Artificial Intelligence’ to Master students. She has participated in more than 25 research projects subsidised by different government entities. She has participated in more than 35 international conferences, and she was chairman on 5 international conferences. She is the editor of 3 books. She spent three months as a researcher at MIT (Cambridge-USA) in 2007 and a second one-month stay at CalPoly (California) in 2019. She has obtained three six-year research from the national committee for the assessment of the research action. She has supervised six PhD Theses and more than 100-bachelor thesis projects. She belongs to the Board of the Ingegraf Association since 2013. She was President of this association for 4 years. She is a reviewer of several scientific journals: Sensors, DYNA, and Applied Sciences between others.

Contributors

Daniela Amandolese Materially S.r.l. Impresa Sociale, Milano, Italy

Robert D. Thompson Casas Materfad, Barcelona, Spain

Aitor Cazón-Martin Tecnun, University of Navarra, Pamplona, Spain

Gemma Esteban Materfad, Barcelona, Spain

Venere Ferraro Department of Design, Politecnico Di Milano, Milan, Italy

Geraldine Kann Materfad, Barcelona, Spain

Pirjo Kääriäinen University of Helsinki, Espoo, Finland

Tarja-Kaarina Laamanen Department of Design, Aalto University, Espoo, Finland

Alba Obiols Barcelona Design Centre, Barcelona, Spain

Stefano Parisi Delft University of Technology (TU Delft), Delft, Netherlands

Anke Pasold Copenhagen School of Design and Technology, Copenhagen, Denmark

Veronica Sarbach Materially S.r.l. Impresa Sociale, Milano, Italy

The DATEMATS Project: Methods, Tools and Frames

Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design Method



Venere Ferraro

Abstract The present chapter describes the unique design (teaching) method developed within the European Project DATEMATS by providing a framework to design with and for new materials, educate future designers, and give them the right knowledge to take advantage of the whole spectrum of opportunities (i.e., meaning and performance) offered by EM&Ts. It firstly depicts the core knowledge at the base of new Emerging Materials and Technologies (EM&Ts), namely: Interactive Connected Smart Materials, wearable based (ICS), Nanomaterials, Advanced Growing Materials, and Experimental Wood-Based Materials. It then provides the theoretical findings of a literature review carried out to perimeter the peculiarities of the four areas, the used approaches, and methodologies; the results of a collaborative workshop aimed at re-elaborating the findings of the literature review and setting the ground for the contents of the original framework for designing and teaching EM&Ts. It finally displays the result of both the literature review and the collaborative workshop in the form of the unique method divided into three phases (understanding, shaping, and applying). It will also include a section dedicated to the tools elaborated to support the method, such as a material toolkit and integration cards. A discussion closes the text by showing the pro and cons of the new method and its further development.

1 Introduction

The topic of emerging materials and or materials, in general, has been one of the key investigating factors both in academia and in industry.

Materials are often thought of as mainly related to material science and engineering; in this perspective, the material is seen for its physical and mechanical properties such as stiffness, hardness, transparency, and in general, for the performance, it can give a final product. In a traditional design process, dealing with materials for a designer mainly means selecting the materials and choosing the right one for technical purposes (Ashby and Cebon 1993; Ashby and Johnson 2013).

V. Ferraro (✉)
Department of Design, Politecnico Di Milano, Milan, Italy
e-mail: venere.ferraro@polimi.it

© The Author(s) 2023
V. Ferraro et al. (eds.), *Materialising the Future*, Research for Development,
https://doi.org/10.1007/978-3-031-25207-5_1

Most of the scholars' experts in materials matter, refer to the so-called 'material-driven' approach: exploring materials' technical/engineering properties to embody a product (Dietza et al. 2006; Jahan et al. 2010; Knauer 2014).

Conventionally, materials have been based on the 'hard' profile of materials, i.e., their technical characteristics, complying with a 'Science-led' approach (Ashby et al. 2007), and 'Top-down' approach, i.e., from the understanding of the fundamentals.

Nevertheless, materials represent a value not only to obtain better performances but also to give meaning to an artefact by enhancing its aesthetic and its expressive-sensorial dimensions (Rognoli 2004, 2010; Karana et al. 2008). Materials can revitalise design, create new business opportunities, transform industrial activities, and conceive innovative solutions.

In the last two decades several attempts have been done by scholars in design discipline towards the formalisation of methods embracing design approaches rather than the mere chemical and engineering ones. The material selection is therefore not a starting point for possible applications (Pedgley 2013) but rather a process where an idea, its form and application, is generated through material understanding, mapping and selection.

From this perspective the material can drive the creative finding process by evoking ideas and opening the path to discovering opportunities of a given or new material.

Indeed, new approaches in materials for design have been emerging, since the 'soft' profile of materials have been brought to light and embodied in research and practice by a whole body of research (Rognoli and Levi 2004; Rognoli 2010; Karana et al. 2018; Van Kesteren 2010; Pedgley et al. 2016), basing on notions from prior works by Manzini (1986), Cornish (1987), and Ashby and Johnson (2002).

Many recently developed methods, tools, and procedures applied to design with and for materials are based on this (Karana et al. 2015; Ferrara and Lecce 2016).

On the other side, nowadays, the panorama of the materials is getting rich, offering new advanced and emerging materials as alternatives to traditional ones, such as smart materials, bio-based and growing materials, nanomaterials, recycled materials from organic resources, etc.

These multifaced souls of materials trigger the tension to envision new methods and approaches to fully cover the matter of designing with new emerging materials characterised by a higher level of complexity than the traditional ones.

More in detail, four areas of emerging materials (EM&Ts) are spreading and impacting the material domain recently: Interactive Connected Smart Materials, wearable based (ICS), Nanomaterials, Advanced Growing Materials, and Experimental Wood-Based Materials. Hereafter a brief description of each area follows.

Interactive Connected Smart Materials (ICS) are material systems able to establish a two-way exchange of information to respond to external stimuli, linked to another entity or to an external source and programmable not only through software (Parisi et al. 2018). They are mainly applied in the context of wearables that are smart electronic devices with microcontrollers embedded into clothing (i.e., e-textiles) or worn on the body as implants or accessories (Ferraro 2020).

ICS Materials peculiarity lies in its interconnected layouts made up of Inactive components, Reactive components, Active components, Interconnection, Alternative source of energy (see Fig. 1).

Nanomaterials are the sector of materials research and applications industry involving materials at nanoscopic scale and are of small matter.

They have nano-scaled structures, or composite blends whose properties are altered by surface and/or substrate doping thereof. The matter controlled at a molecular level, on a scale of 1–100 nm (see Fig. 2). Nanomaterials are the invisible materials able to generate extra performance to an artefact such as self-healing properties and or robustness (Morer et al. 2020).

Experimental wood-based materials refer to materials that are processed either chemically or mechanically from trees for innovative applications (see Fig. 3). The materials include cellulose fibres, fibrils (micro- or nano-structured) and derivatives, lignin, bark extractives, and novel combinations of these (Kääriäinen et al. 2020).



Fig. 1 Overview of ICS materials



Fig. 2 Nanotex: an example of nanomaterials

They are considered among the best options to replace dominating fossil-based materials since they come from renewable sources; they can be modified on the chemical level and can be used for recyclable and/or biodegradable products.

Advanced-growing materials are materials from a controlled cultivation of organisms (bacteria, yeast, algae, mycelium, etc.) that are directly grown and/or manufactured into their subsequent form (bio-fabrication) (see Fig. 4). They play a significant role in the current search for sustainable substitutes and can be envisioned as surrogates for harmful, conventional materials in the context of packaging, building and insulation materials, alternatives for leather, and active agents for fabric dyeing (Pasold 2020).

The overview of those four EM&Ts reveals their complex nature and their strong connection with disciplines other than materials science, engineering, and design likewise, computer sciences, biology, chemistry, and physics.

The new EM&Ts expose new and unique characteristics, qualities, behaviours, and processes, channelling a shift in paradigm and requiring new approaches to learning and teaching techniques. Design practitioners and students continuously need to gain updated materials knowledge, skills, and competences, not only to deliver designs that exploit available material possibilities but also to contribute to new materials innovation and development (Haug 2019).

This primary consideration poses relevant questions: what is the expertise needed to deal with these EM&Ts? How can we approach EM&Ts as designers? And as scholars/educators how can we educate designers of the future to design with and for always new and emerging materials?



Fig. 3 Examples of wood-based materials and applications

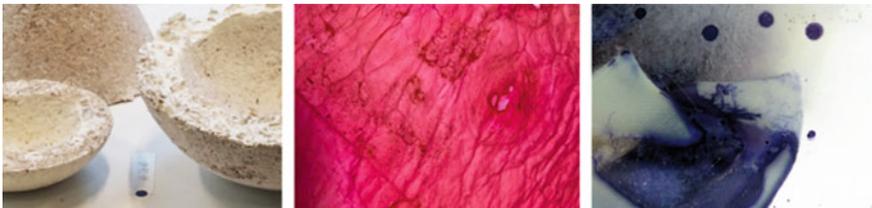


Fig. 4 Mycelium shapes, SCOBY leather, controlled fabric dyeing with *Janthinobacterium lividum*. Left image by Anke Pasold from KEA, centre, and right image by Alkymi

To this end, this contribution aims to answer these questions on the described areas by proposing a new design method able to support the designers in dealing with EM&Ts, considering the knowledge at the core of the EM&Ts, and the multilayer skills required within the design process to develop demonstrators and products able to inspire new business.

The text is divided into four main parts. Following, the methodology part presents and examines: (i) the process of literature review in detail, illustrating the results and the main theoretical findings, (ii) the results of a collaborative workshops to generate the framework of the design (teaching) method. As third part, the new design (teaching method) is described followed by the exploration of new tools to be integrated into the new method. A discussion part follows and ends the contribution.

2 Methodology

From a methodological point of view, we established two main approaches, put in temporal sequence:

- A literature review to provide an overview of current knowledge allowing to identify relevant theories, methods, and gaps in the research intersecting the four areas of EM&Ts.
- A collaborative workshop among researchers and professionals with strong expertise in the four EM&Ts to build the new knowledge starting by the findings of the literature review.

2.1 Literature Review

The literature review process started with questions: how much literature on each specific area ICS, Nano, Advanced Growing, and Wood-Based materials (general keyword 1)? Which are the innovative methods related to: application context (general keyword 2), behaviour (general keyword 3), perception (general keyword 4), and selection of the materials (general keyword 5)? Are there any innovative applications (general keyword 6)?

The research was focused on understanding the main related contents inside design disciplines in the period between 2015 and 2019. The choice to perimeter the article's research within the design field was done because of the already exhaustive and existing literature in materials science and engineering. The review was conducted using academic electronic databases such as Scopus, Web of Science, and relevant journals to better understand the subject. The analysis was conducted by inserting the name of the specific material plus the keywords mentioned above and verifying their presence in the title or abstract. We performed four literature reviews in parallel and we organised them using the platform Mendeley.

Table 1 Sources identified for each keyword

Specific area	Application context	Behaviour	Perception	Selection	Innovative applications
19	24	34	32	14	18

A preliminary list was extracted by taking per each query, the first 50 results for relevance and citations up to 15. Afterwards, the database was refined, considering the relevant results after reading the abstracts and selecting just the most appropriate for the objectives of the investigation. The extracted list was further refined by avoiding repetition. A reduced list of 141 sources to be analysed for the review was obtained from this process.

Table 1 summarises the number of sources that were associated with the six identified keywords during the review process conducted on abstracts.

The literature review helped to map the state of the art of the EM&Ts' the core competencies, expertise, facilities, role of different involved actors (designers, engineers, material scientists), and methodological approach used in the design process. The hundred forty-one articles delineated a multifaced panorama within the four EM&Ts stressing an overall agreement on the cross-disciplinarity and the lack of systematised methods and approaches to sustain the complexity and the intersection of diversified disciplines. In the next section the theoretical findings are presented.

3 Theoretical Findings

The main results of the literature review as Pasold (2020) reported can be summarised as follow.

General keyword 1: Knowledge at the core of each of the four EM&Ts:

ICS Materials wearable based are concrete, product-related, and with a strong potential access to the market.

Advanced Growing and Experimental wood-based are material-property focused EM&Ts focusing on exploring materials and their respective potentials within products or substituting existing harmful materials.

Nanomaterials are instead application-ideation focused EM&Ts where the designers are part of shaping the capabilities of the respective applications.

ICS is the closest to a traditional design process while Advanced Growing and Nanomaterials require the need to move to the microscale and experimental wood-based require an understanding of the material on a chemical level to create possible areas of application.

They all share, and *high level of complexity* placed at the intersection of Design with other disciplines: Material research, Chemistry (Experimental wood-based) Material science, Biology, Chemistry and Engineering (Advanced Growing), Material science, Chemistry (Nanomaterials), and Design and Technology (ICS).

They also share four main recurrent approaches: *open access learning* such as a forum and platform to freely access the knowledge (BioHack Academy 2019; Materiability 2017; Materiom 2018; <http://openmaterials.org>); *Hands-on learning* to familiarise with specific characteristics, properties, and processes (Groth 2017; BioHack Academy 2019; Kääriäinen et al. 2017; NANOLAB 2019; BioHack Academy 2019); *Facilitation of expert integral courses* to merge the competencies (Chemarts 2019); *Facilitation of co-labs* (Itälä 2014; Kääriäinen et al. 2017; Karana et al. 2010).

Finally, a new evolving role of the designer arose: mediator and communicator.

Specifically, within the four areas a designer can be a scenario and application generator for Nanomaterials technology shapers, human physiology explorers, and user experience and scenario experts of ICS and material designers in the frame of Advanced Growing and Experimental wood-based materials.

General keywords 2–6: Methods related to Behaviours, perception, selection application of the EM&Ts.

Grouping the keywords from two to six we obtained four overall methods namely: *Contextualisation; Material-centred; User-centred; Case-centred.*

Table 2 the four approaches are synthesized through the most relevant articles.

The above-mentioned methods might be applied to all four EM&Ts explored in this text, nevertheless, they don't seem to cover their complexity (cross-disciplinarity) their newness, the communication between different professionals, the lack of samples, lack of standardised documentation and procedure making difficult to understand how to design with and for these new EM&Ts by embracing the full spectrum of their peculiarities.

4 Collaborative Workshop

The findings of the literature review have been elaborated in a graphical way to be used as input for half a day collaborative workshop involving researchers from Politecnico di Milano, Aalto University, Copenhagen School of Design and Technology (KEA), Tecnun University, and experts in the material field for the setting of the framework of the unique design (teaching) method in the four EM&Ts area.

We elaborated a shared ground poster summarising the literature review through common Gaps & Issues, and Methodological approaches, shared among the EM&Ts (see Fig. 5).

Moreover, for more advanced visualisation of the literature review, we elaborated four canvases per each EM&Ts: (1) The Sum up Canvas (single synthesis of the literature review per area), the EM&T Canvas (description of the area), The role of Designer Canvas and the Cross-disciplinarity Canvas (see Fig. 6).

Sixteen participants took part in the collaborative workshop; we created four groups of four participants. We assigned specific EM&T to every table where four copies (1 per group) of all the four canvases regarding each EM&T were placed (see Fig. 7). The room was organised, exhibiting a set of samples of materials from each EM&T on four different tables.

Table 2 The four methods identified in the literature

Contextualisation	Material-centred	User-centred	Case-centred
Create a relevant context to tackle the abstract nature of the material	Direct access to the material knowledge through	Ideate ideas around a specific user and the connected scenario	Connection to the industrial application and manufacturing processes
The Design-Driven Material Innovation Methodology Analogies (Abersek 2016) Metaphors (Piselli et al. 2015)	Tinkering activities (Garcia et al. 2017) Physical probes (Garcia et al. 2017; Parisi et al. 2017; Rognoli et al. 2016; Rognoli and Parisi 2018) Material samples that support experimental processes (Ferrara and Lucibello 2012) Material samples for experiments material mappings of performative, behavioural and sensorial parameters, of properties (Barati et al. 2015) Properties and applications (Pedgley 2013; Barati et al. 2015) Sensorial mapping (Rognoli 2011; Asbjorn Sorensen 2017; Parisi et al. 2017) Material experience (Barati et al. 2015), Material concepts, Affordance making (Barati et al. 2018) Prototypes, simulation of material behaviours through small tangible library (Barati et al. 2015)	Sense making human pleasures and consumer needs (Lecce and Ferrara 2016) ICES Design for Wearabilities, Human body in motion, Unobtrusivity (Gemperle), MDD (Karana et al. 2010)	Material property exploration (Piselli et al. 2018) Specific environment (Parisi et al. 2019) Specific application in the context of Tangible interfaces (Ferrara and Russo 2019)

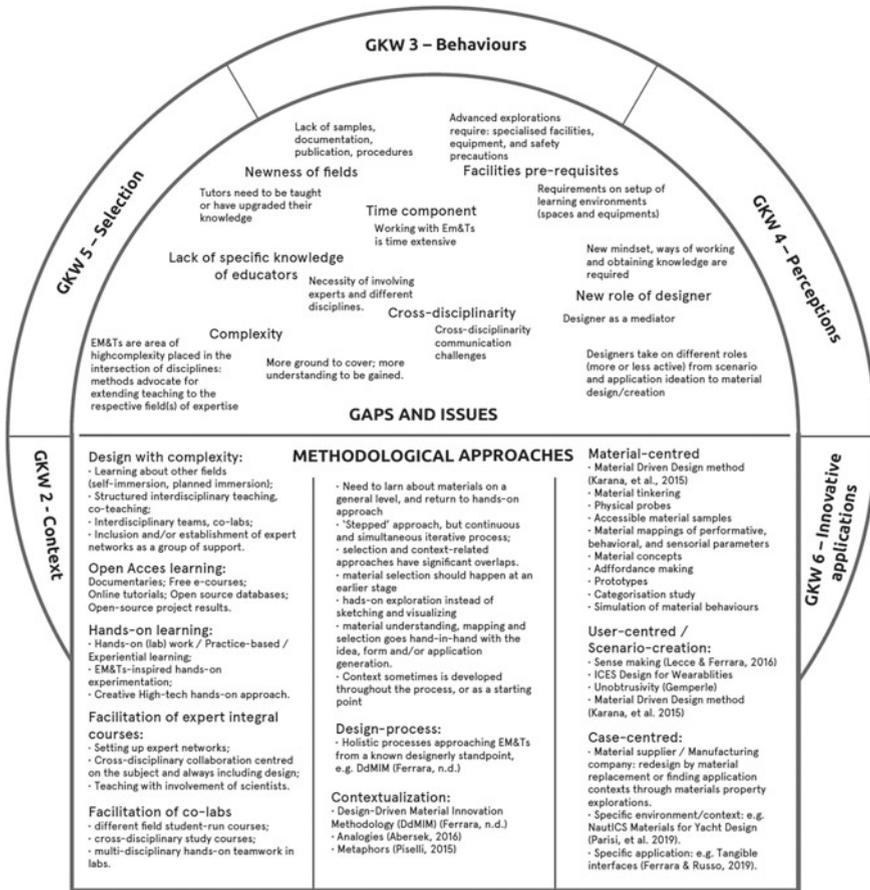


Fig. 5 Graphical result of the literature review

The session was organised in three steps:

- Discuss and fill empty canvases on 25 min turn.
- Leave the filled canvases on the table and move to the next one.
- Verbalise the insights and opinions by presenting the results for each EM&Ts in 6 min.

A 15-min collective discussion followed. A facilitator used a whiteboard to keep records and systematically organise the most relevant points of the debate. The whole activity was audio recorded.

All the data generated during the collaborative workshops were consequently re-elaborated and created, together with the findings of the literature, the basic knowledge for the framework of the new design (teaching) Method. The resulted body of knowledge can be summarised into four main blocks:

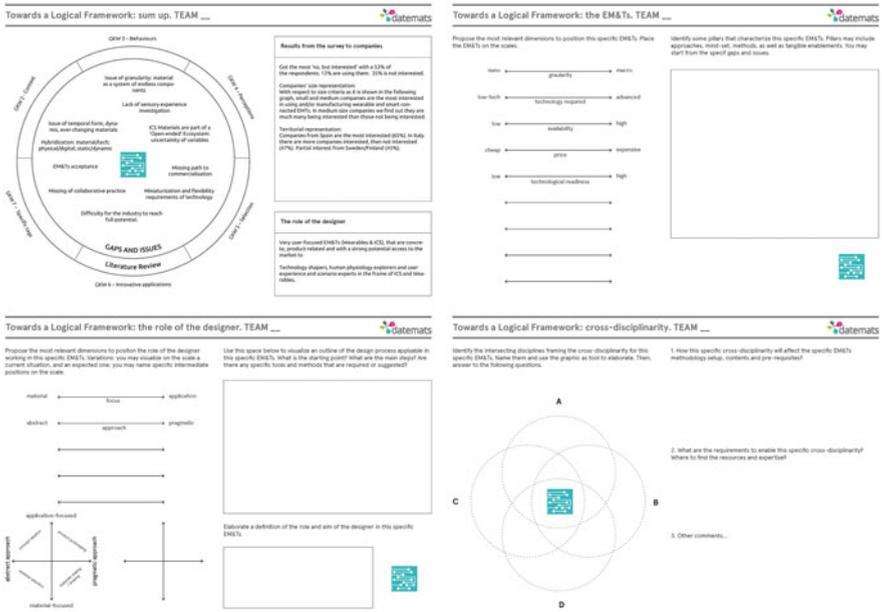


Fig. 6 The four canvases



Fig. 7 The collaborative workshop

1. Issues and Common Gaps for Each EM&T's.
2. Potential Methods.
3. Potential Approaches to design for complexity.
4. The 5 W: what, why, where, with whom, who.

Concerning the finding number one, we understood that ICS Materials EM&Ts area is characterised by the need for a holistic and hybrid approach considering material qualities & interactive behaviours.

The Nanomaterials EM&Ts area is characterised by the need for specialised labs and high-cost equipment for experimenting and the issue of scale and evidence of the technology.

The Experimental Wood-based EM&Ts area is characterised by not aiming directly for actual commercialization, which allows free ideation and ‘grazy’ experiments. The Advanced-growing EM&Ts area is characterised by a symbiotic relationship between the designer, living material and the issue of ethics.

The last classes of materials share the problem of time needed to grow and dry the material, which brings detachment between the moment of intervention of the designer and the moment of observation of the results.

They also share complex lifecycle and environmental matters, controversial perceptions, and fluctuation in price and availability of the materials and techniques.

Each EM&T stands at the intersection of three primary disciplines. Besides some minor distinctions and specifications, Design and Materials & Manufacturing are common areas for each EM&Ts, while the third discipline is specific for each area (see Fig. 8).

Besides some minor distinctions and specifications, Design and Materials & Manufacturing are common areas for each EM&Ts, while the third discipline is specific for each area:

- Computer Science field (e.g., digital technologies, electronics, Human–Computer Interaction) for ICS Materials. Other relevant disciplines and knowledge fields involved are Ergonomics, Psychology & Perception, and Sustainability & Circular Economy. The definition of the Application sector emerges as fundamental, e.g., Health, Sports, Military, but not limited to wearables, e.g., Automotive, Architecture, Furniture.
- ‘Hardcore’ Science (e.g., Material science, Chemistry, Physics) for Nanomaterials. Other relevant disciplines and knowledge fields involved in the area are Sustainability, Economics & Marketing, Psychology & Perception.
- Chemistry (e.g., chemical engineering, material sciences) for Experimental Wood-based materials. Other relevant disciplines and knowledge fields involved in the area are Biology, Engineering, Arts, Psychology & Perception, and Sustainability & Ecology. The interaction with the Service sector emerges as fundamental, e.g., new businesses for recycling and reuse for composting.
- Biology (e.g., biotechnological Science) for Advanced Growing materials. Other relevant disciplines and knowledge fields involved in the area are Chemistry, Ethics, Communication, Psychology & Perception, and Sustainability (e.g., engineering for production processes and lifecycle).

The potential methods are classified in case-centred (e.g. for specific material suppliers/manufacturing company, specific environment/context, specific application); contextualization (e.g. the use of analogies, metaphors, biomimicry); user-centred/scenario-creation (e.g. sense-making, unobtrusivity, and wearability);

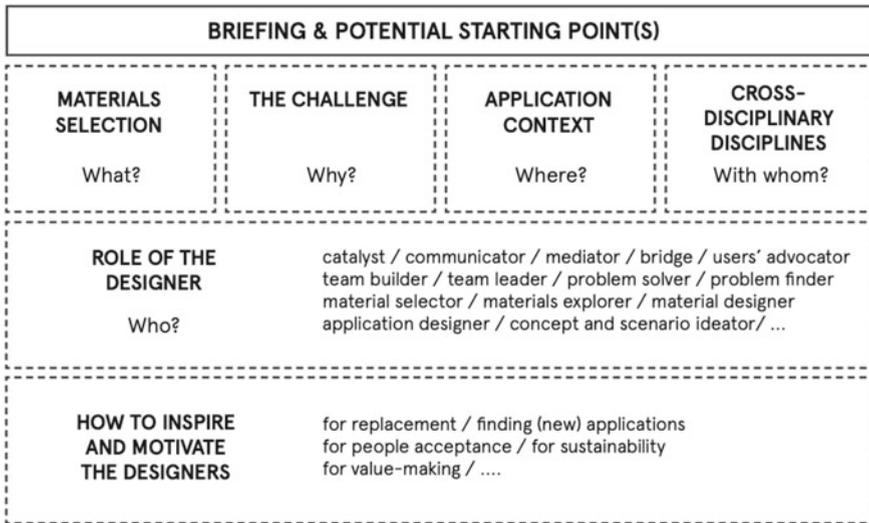


Fig. 9 The 5 W of the original design (teaching) method

throughout the process. It would prioritise hands-on exploration over sketching and visualising.

Design with the complexity means: learning about other fields by self-immersion or planned immersion; structure interdisciplinary teaching and co-teaching; building interdisciplinary teams and co-labs; including or establishing expert networks as a group of support.

The last block of findings outlines the potential starting point(s) for the new design (teaching) method and is presented using the 5 W: material selection (What); design challenge (Why) application context (where); cross-disciplinary disciplines (with whom); the role of designer (who) and finally: how to inspire and motivate designers for finding (new) applications, for people acceptance, for sustainability, for value-making, etc. (i.e., How?) (see Fig. 9).

5 Results: The Unique Design Method

Schön and Bennet (1996), described how the design, the creative, and learning practice itself could be observed as a conversation with materials, through which the practitioner gets to know materials.

In this regard, dealing with physical materials and product samples emerges as an efficient method for gaining knowledge about materials and for stimulating the creative process through direct exploration (Haug 2019; Rognoli 2010; Van Kesteren 2010; Pedgley 2010; Ayala Garcia et al. 2011).

New alternative methods involve multiple and alternative sources, such as ‘Material-produced’ information (i.e., direct experimentation with materials), ‘Interpreter-produced’ ones (i.e., discussion and confrontation with instructors, experts, and peers), and ‘Representation-produced’ ones, i.e., texts, videos, and pictures.

Those considerations and the findings summarised in the previous section brought to the elaboration of an original framework that foresees learning and teaching activities both cognitive and physical, based on identifying three main blocks: Understanding, Shaping/Experimenting, and Applying. Although those blocks are put in chronological succession, they are profoundly intertwined, iterating, and often simultaneous and overlapping in their definition (see Fig. 10).

Even if, each EM&T has its own specific needs and characteristics, we attempted to create a universal and common framework that has an inclusive a generalised nature, which tends to accommodate every definition and element and cover the complexity of every EM&T.

Hereafter the three blocks are described:

Understanding: it represents a diverse body of knowledge (e.g., explicit, tacit, theoretical, procedural, empirical) and multiple sources for acquiring knowledge

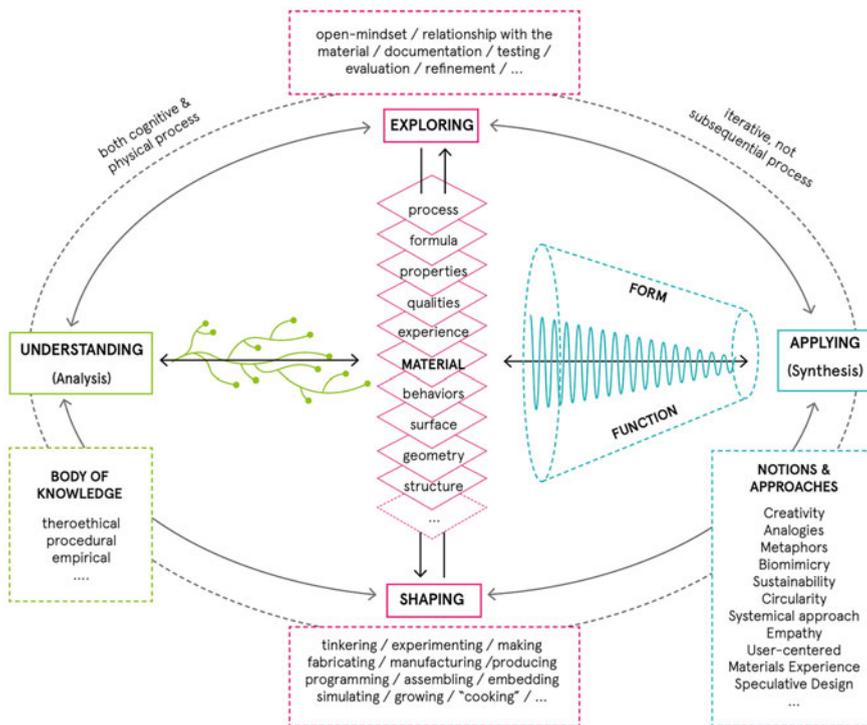


Fig. 10 The understanding, shaping/experimenting, and applying framework

(e.g., interaction with material samples, discussion with instructors, experts, and peers, lectures, texts, videos, and interviews);

Exploring/Shaping: a block where tacit knowledge is mainly acquired. In this block, the material is experimented and shaped, by hands-on exploration and in-labs exercises. While exploring emphasises the designer getting experience on the materials and processes by iterating, documenting, and evaluating, Shaping is focused on the material being manipulated and developed in many ways, e.g., tinkering and fabricating, growing, and cooking. The initial stages of this block move ahead from the Understanding phase by exploring all the different opportunities that the material can exploit, with trials and errors, obtaining successes and failures.

Applying: it represents the synthesis of the process when the material is embedded and encoded into a project. In this block, the leading strategies, and approaches such as creativity, metaphors, biomimicry, sustainability, systematic approach, user-centred design, materials experience, speculative design, etc.

Despite the universal nature of the framework, each block remains specific per each area, respecting the nature, complexity, and intersection with other disciplines. For instance, the understanding phase of ICS will include knowledge related to computer science, while the one related to Advanced Growing will consist of fundamentals of biology and so on.

The original framework delineated a new design method whose uniqueness stays in the re-elaboration of the traditional steps (discover, define, develop, deliver) into new, more active, and interconnected blocks: understanding, exploring/shaping, and applying and, its practical dimension. Indeed, the creative practice is actively supported by exploring and experimenting.

To this end, we created tools to give designers concrete examples to understand the complex nature of the EM&Ts and exploit the possible application.

In this regard, the understanding phase is supported by an alternative source of learning likewise Open Educational Resource. We created fit-on-purpose videos for each of the four EM&Ts (see Fig. 11).

We also generated tools that can be used contemporary, alternatively, or in sequence for the understanding, shaping, and applying parts namely: the material toolkit and the integration card.

The Aim of the EM&Ts transfer toolkit is to facilitate the understanding and application potentials of each EM&Ts. Every material example has its box, containing: Physical sample, ‘Understanding’ section, ‘Shaping’ section, and ‘Applying’ one (see Fig. 12).

Video presenting the learning materials for specific EM&T areas (D3.2)



Fig. 11 Alternative source for understanding

The understanding section contains basic knowledge about the material and the manufacturer, Technology Readiness Level, crucial characteristics but also information related to sensorial qualities and performance, sustainability, and smart properties. This shaping part contains information about the manufacturing process, the form in which the material is available and possible transformations. This information is useful to understand how the material can be processed for production, finishing, and transformation, to get to the final product.

The final section, the applying one contains information and pictures about the field in the material is currently used. Potential applications are listed, associated with meaningful case studies (see Fig. 13).

Finally, EM&Ts integration cards are to provide a tool to facilitate and inspire the process of integration of emerging materials and technologies, to envision new material possibilities. 11 cards are available to show examples of every possible area intersection among the four EM&Ts (see Fig. 14).

Each card is divided into two sections: integrations and opportunities. The integrations section includes an overall description of the areas' integration, highlighting characteristics and features of the category of materials. A visual board is included, comprehensive of applications, closeups, and texture samples, that can be useful to comprehend the potential of the integration and get inspiration for the design process. The opportunities section describes the opportunity of a combination of the areas, its Pros and Cons, academic and commercial references. Each opportunity shows a couple of case studies with pictures, a short abstract, and a link, that can be helpful as a concrete example of declination and application of the material/technology.

The exploring block is the more specific material-related one, and it relates to hands-on experimentation and material manipulation within a particular lab. The investigation can include programme, assembly, embedding, simulation, growing or cook (see Fig. 15).



Fig. 12 Material toolkit overview



Fig. 13 Understanding, shaping, applying

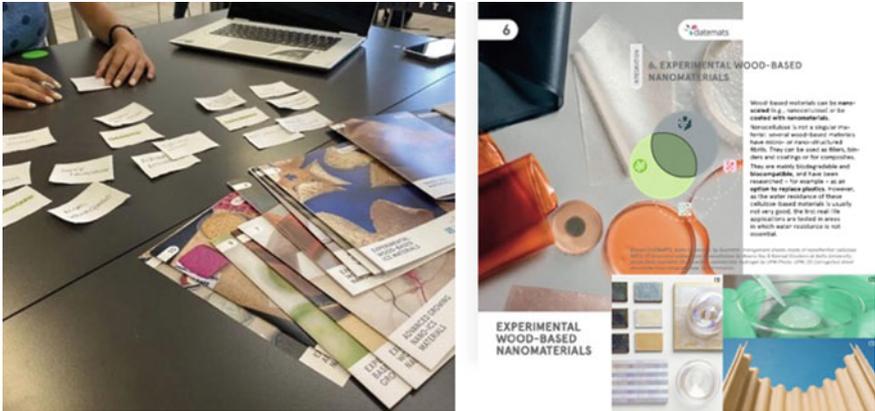


Fig. 14 The integration cards



Fig. 15 Exploring part in specific lab

6 The Teaching Method

The original framework is at the core of a new way to design with and for EM&Ts.

It was used to formalise training contents in Education and served as a blueprint for the contents and structure of the unique teaching method to be applied in the distinctive EM&T areas.

As said, each EM&Ts is framed in its specific cross-disciplinary nature. This has practical implications for the teaching method definition for each EM&Ts, defining the type of knowledge, skills, and competencies required and the expertise of the teaching staff.

Each EM&T stands at the intersection of three primary disciplines. Besides some minor distinctions and specifications, Design and Materials & Manufacturing are common areas for each EM&Ts, while the third discipline is specific for each area.

Therefore, we envisioned a course structured on 12 credits, divided into three modules based on the intersection identified through the literature review: Materials and Manufacturing (3 credits), Specific area per each EM&Ts, e.g., chemistry, biology (3 credits) Design (3 credits).

The three module covers the three main blocks of the original framework: understanding, exploring/shaping, applying. Being the subject in the intersection of

different disciplines, the modules can be carried out co-teaching, e.g., with experts in related disciplines.

Regarding the format, the course can have multiple formats, e.g., lecture and hands-on sessions, lab and discussion, group learning projects, or presentations, taking inspiration from the methods identified into the literature review. Moreover, the course includes the tools generated within the logical framework.

The contents are formalised into an academic syllabus. The structure of the template has been designed and shaped based on the format used in Academic teaching environments by taking into consideration the Descriptors of Learning Outcomes for Higher Education Qualification, to have a universal, normed, and comprehensive document as a legacy of the project after its execution.

The template is divided into different sections:

- **Rationale:** to explain the reason for the existence of the course and how it relates to the rest of the field or area's curriculum.
- **Course Aims and Outcomes:** divided into aims, learning objectives, and outcomes. Emphasis is put on thinking from the students' perspective and how the course can contribute to them professionally. In this section, the modules, specific learning objectives for each module, and related outcomes (describing substance and form) are presented.
- **Format:** to outline detailly and clearly the multiple formats used in the course, i.e., lecture & hands-on sessions, lab and discussion, group learning projects, and/or presentations.
- **Course requirements:** to present the tasks and assignments aligned with the specified learning outcomes. Requirements include the description of class attendance and participation policy, course readings (required texts and background readings), assignments for each module.
- **Grading procedures:** to explain how the grade is made of in each module, using percentage.
- **Tentative Course Schedule:** a table listing lectures/modules, topics, methods/tools, and assignments.
- **References.**

We then obtained four different syllabuses: Designing with ICS materials—wearable based; Design with Nanomaterials; Designing for and with experimental wood-based materials; Designing with Advanced-growing materials (see Fig. 16).

7 Discussion

This contribution has presented a new method for designing with and for specific EM&Ts, which aims to support designers through a cognitive and learning process shaped into three phases: understanding, exploring/shaping, and applying.

DESIGNING WITH ICS MATERIALS - WEARABLE BASED
(Department of Design, Politecnico di Milano)

I. Rationale:
This course teaches students with mixed background (design and engineering fields) to design with Interactive Connected Smart (ICS) materials in the wearable system domain. ICS materials entail the combination of electronics and smart and conductive materials to conventional or innovative materials, in order to construct a material system characterized by physical features and interactive behaviours. Designing with materials means that the design concept is framed and inspired by the domains of the technical properties and experiential qualities of the material. Understanding how to design with materials requires a type of knowledge that cannot solely be acquired through reading or lectures but must be obtained by applying it in a hands-on environment. This course provides the students with knowledge of how potential of ICS materials in different fields of application.

II. Course Aims and Outcomes:

Aim
The overall aim of the course is to practice the systems leveraging the ICS materials properties system (i.e., health, sports, well-being). The educational objective of the course is to acquire and skills for imagining and designing new objects that train design students in practicing as design materials, and computer science. More specific the projects related to using ICS materials are:

- Understanding the meaning, potentials, and critical issues related to ICS Materials, including Smart Materials and E-textiles (including sustainability).
- Understanding the meaning, potentials, and critical issues related to Wearable Technologies.

(2) practical skills:

- Knowing how to "tinkering" and experimenting in a cross-disciplinary environment, e.g., in a FabLab or in a makerspace with experts from different fields.

(3) design capabilities:

- The ability to transfer apply the knowledge from the material research and exploration in the design concept and prototyping.

III. Format:
This course has multiple formats. Module 1:

- From the Teachers: Theoretical Lec
 - Materials experience: what
 - Dynamics: what materials
 - Smart materials (technical)
 - The module includes the v embedded or separated) in the EM&T
- From the students: A scholarship i

Module 2:

- From the Teachers: Theoretical Lec
 - Basic of PIC
 - Basic of electronics
 - Basic of programming/code
- From the students (The module is)
 - Hands-on experimental pr
 - Tinkering, Material Tinkering

Module 3: Design project with a brief/ task
 prototyping and supported by demonstra discussions. The design approach is based on:

- Hybrid way to design con experience, the static and tempo
- Speculative design approach (as ex future)
- Deliverables: prototype, samples/ of the process.

IV. Course Requirements:

1. Class attendance and participation be acquired solely by reading, it is and practicing. Therefore, the stud

V. Grading Prc
Grades for the diff

1. Module (a) 1 (b) 1

2. Module (a) 1 (b) 1

3. Module (a) (b)

VI. Tentative Course Schedule

Module	Topic	Methods/Tools	Assignment
1.	Understanding	Lectures, watching online interviews with experts, desk research, group discussions, field research	Presentation of a paper: Written and oral.
2.	Exploring	Demonstrations, Hands-on experimentation (i.e. in the fab lab)	Presentation of material exploration: Oral and by exhibition of material samples and documentation.
3.	Design	Prototyping, concept development	Presentation of design: Oral and by exhibition of prototypes, drawing and other visual support (samples/demonstrations, documentation, videos, etc)

Fig. 16 Example of the syllabus

The new method, containing an original framework and several tools, was generated by capitalising on existing knowledge through a literature review and the systematisation of such knowledge through a collaborative workshop.

The new method's value and uniqueness do not lie in the theoretical domain since it was validated in four 5 days of professional workshops involving students with mixed backgrounds (design and engineering) at the master level and companies.

The four workshops were performed in four universities with expertise in the four EM&Ts: School of Design of Politecnico di Milano (ICS), School of Engineering, University of Navarra (Nanomaterials), Materials Lab of the Copenhagen School of Design and Technology (Advanced growing materials) and Chemarts material lab of Aalto University (Experimental wood-based materials).

We decided to perform the workshops within an education environment with students at the master's level (considered young designers) and companies launching

a real market challenge to verify the efficacy of the design method at a professional level and at the teaching one.

About thirty students work together in multidisciplinary teams to find solutions for those challenges and to produce product concepts, prototypes.

All the workshops were made of a combination of hands-on experimentation, design activities, and lectures and presentations by the teaching staff of the four universities and by companies launching a real design brief. In each workshop the students applied the new method developed within the project to design with four EM&Ts.

The teachers/researchers used the general framework with the already described exceptions due to the different nature of the four EM&Ts: specific lectures, experimentation, and co-labs.

At the end of the workshop, students answered a survey related to the method's efficacy, lectures and videos, tools, interaction with companies, and timeframe. The results elaborated by the four workshops were auspicious. Students found the method appropriate and the workshop format helpful to work with new EM&T (more than 85% rated the method as adequate); the supporting tools (material toolkit and integrations cards) were rated as highly satisfactory, while the most successful phase was considered the exploring one. The last result stressed the value of hand-on activities detected in the literature review.

The validation of the method was done in a reduced timeframe compared to a traditional design process. The time of the workshop was the most underrated parameter: getting familiar with the new EM&TS in terms of understanding and exploring takes time and the need for reflection.

In particular, the exploring phase that goes from coding to growing needs reasonable learning and practising period and, for instance, time for the material to grow (around two weeks) and to cook and dry (several days).

The performance of each workshop follows the original framework with one exception: to answer a real market-related design brief, there is a need to understand the final user. For this reason, we integrated an analysis related to the individuation of a proper sample of users and the understanding of their needs.

8 Conclusions and Further Development

This contribution aimed at answering these questions: what is the expertise needed to deal with these EM&Ts? How can we approach EM&Ts as designers? And as scholars/educators how can we educate designers of the future to design with and for always new and emerging materials?

To this end, a literature review on existing methods and approaches and a collaborative workshop with researchers and materials experts were performed.

As a result, we elaborated an original framework that foresees both cognitive and physical learning and teaching activities, based on identifying three main blocks: Understanding, Shaping/Experimenting, and Applying.

The original framework elaborated a new design (teaching) method to work with EM&Ts; this method envisions the usage of supporting tools such as a material toolkit and the so-called integration cards. Moreover, out of the framework, we created courses to be integrated in current Design curricula.

The new Unique Method to design with and for the 4 EM&Ts has proved successful in having a standardised practice and teaching methodology thanks to the application and validation to the design practice.

Nevertheless, a step forward in the implementation of the method is required: integration of methods and tools for the users' analysis into the understanding part as an element to move from experimentation to market, standardise time frame and prior knowledge for conducting and effective exploring phase.

References

- Abersek B (2016) Teaching with Analogies—examples of a self-healing porous material. *Probl Educ 21st Century* 70(1):4–7
- Ashbjorn Sorensen C (2017) A new approach to materials in Product Design Education—a shift from technical properties towards sensorial characteristics, pp 182–192
- Ashby MF, Cebon D (1993) Materials selection in mechanical design. *Le Journal De Physique IV* 3(C7):C7-1
- Ashby MF, Johnson K (2002) Materials and design: the art and science of materials selection in product design. Butterworth Heinemann, Oxford
- Ashby MF, Johnson K (2013) Materials and design: the art and science of material selection in product design. Butterworth-Heinemann
- Ashby MF, Cebon D, Silva A (2007) Teaching engineering materials: the CES EduPack. Cambridge University, Engineering Department, pp 1–13
- Ayala-Garcia C, Quijano A, Ruge CM (2011) Los materiales como medio para estimular procesos de creación. *Dearq* (8):44–53
- Barati B, Karana E, Hekkert P (2015) From way finding in the dark to interactive CPR trainer: designing with computational composites. In: Proceedings of the 9th conference on design and semantics of form and movement, May
- Barati B, Giaccardi E, Karana E (2018) The making of performativity in designing [with] smart material composites, April, pp 1–11. <https://doi.org/10.1145/3173574.3173579>
- BioHack Academy (2019) BioHack Academy. <http://biohackacademy.github.io/>. Accessed 20 May 2019
- Chemarts (2019) CHEMARTS. <https://chemarts.aalto.fi/>
- Cornish H (1987) Materials and the designer. Cambridge University Press, Cambridge
- Dietza P, Guthmanna A, Korte T (2006) Material-driven solution finding—functional materials in the design process. In Pham DT, Eldukhri EE, Soroka AJ (eds) Intelligent production machines and systems. Elsevier, Amsterdam, the Netherlands, pp 401–404
- Ferrara MR, Lecce C (2016) The design-driven material innovation methodology. In: 6th International forum of design as a process-IFDP16 proceedings-systems & design: beyond processes and thinking. Universitat Politècnica de València, pp 431–448
- Ferrara M, Lucibello S (2012) Teaching material design. Research on teaching methodology about materials in industrial design. *Strateg Des Res J* 5(2):75–83
- Ferrara M, Russo AC (2019) Augmented materials for tangible interfaces: experimenting with young designers. Outcomes and analysis. *Adv Intell Syst Comput* 903(April 2017):667–672. https://doi.org/10.1007/978-3-030-11051-2_101

- Ferraro V (2020) Wearable textile systems: design layered intelligent materials. In: Ferraro V, Pasold A (eds) *Emerging materials & technologies: new approaches in design teaching methods on four exemplified areas*. Franco Angeli; Design International
- Garcia CA, Rognoli V, Karana E (2017) Five Kingdoms of DIY-materials for design, June
- Groth C (2017) Making sense through hands: design and craft practice analysed as embodied cognition. https://aalto.finna.fi/Record/aaltodoc.123456789_24839
- Haug A (2019) Acquiring materials knowledge in design education. *Int J Technol Des Educ* 29(2):405–420
- Itälä J (2014) How design can contribute to materials research: explorative prototyping as a method for collaboration between design and materials science. Aalto University. Accessed <https://aalto.finna.fi/Record/alli.771920>
- Jahan A, Ismail MY, Sapuan SM, Mustapha F (2010) Material screening and choosing methods—a review. *Mater Des* 31(2):696–705
- Kääriäinen P, Tervinen L, Riutta N, Vuorinen T (eds) (2020) *The CHEMARTS cookbook*. Aalto ART Books, Helsinki
- Kääriäinen P, Niinimäki K, Lindberg A (2017) “CHEMARTSING”—an experimental, multidisciplinary, collaborative and future oriented pedagogy with wood based biomaterials. In: REDO cumulus conference. Cumulus International Association of Universities and Colleges of Art, Design and Media, pp 252–259
- Karana E, Hekkert P, Kandachar P (2008) Meanings of materials through sensorial properties and manufacturing processes. *Mater Des* 30(7):2778–2784
- Karana E, Hekkert P, Kandachar P (2010) A tool for meaning driven materials selection. *Mater Des* 31(6):2932–2941. <https://doi.org/10.1016/j.matdes.2009.12.021>
- Karana E, Barati B, Rognoli V, Zeeuw van der Laan A (2015) Material driven design (MDD): A method to design for material experiences. *Int J Des*. <https://doi.org/10.1080/00927872.2017.1392540>
- Karana E, Blauwhoff D, Hultink EJ, Camere S (2018) When the material grows: A case study on designing (with) mycelium-based materials. *Int J Des* 12(2):119–136
- Knauer M (2014) *Our place in materials*. Unpublished master’s thesis, Carleton University, Ottawa, Canada.
- Lecce C, Ferraro M (2016) The design-driven material innovation methodology. In: IFDP’16—systems & design: beyond processes and thinking. Universitat Politècnica de València, Spain. <https://doi.org/10.4995/ifdp.2016.3243>
- Manzini E (1986) *The material of invention*. Arcadia, Milan
- Materiability. (2017). *MATERIABILITY*. <http://materiability.com/>. Accessed 1 June 2019
- Materiom. (2018). *MATERIOM*. <https://materiom.org/>. Accessed 1 June 2019
- Morer P, Cazón A, Fernández MI, Thomson R (2020) Carbon-based & Nanomaterials and its relevance to Design Practice. In Ferraro V, Pasold A (eds) *Emerging materials & technologies: new approaches in design teaching methods on four exemplified areas*. Franco Angeli; Design International
- NANOLAB (2019) Nanolab. <http://www.nanolab.unimore.it/it/formazione-e-kit/il-kit-formativo/>. Accessed 15 June 2019
- Parisi S, Rognoli V, Sonneveld M (2017) Material tinkering: an inspirational approach for experiential learning and envisioning in product design education. *Des J* 20(sup1):S1167–S1184. <https://doi.org/10.1080/14606925.2017.1353059>
- Parisi S, Spallazzo D, Ferraro V, Ferrara M, Ceconello MA, Garcia CA, Rognoli V (2018) Mapping ICS materials: interactive, connected, and smart materials. In: International conference on intelligent human systems integration. Springer, Cham, January, pp 739–744
- Parisi S, Bionda A, Ratti A, Rognoli V (2019) Design for ics materials: a tentative methodology for interactive, connected, and smart materials applied to yacht design. *Adv Intell Syst Comput* 903(i):661–666. https://doi.org/10.1007/978-3-030-11051-2_100

- Pasold A (2020) Advanced growing materials—designing with living matter. In: Ferraro V, Pasold A (eds) *Emerging materials & technologies: new approaches in design teaching methods on four exemplified areas*. Franco Angeli; Design International
- Pedgley O (2010) Invigorating industrial design materials and manufacturing education. *METU J Fac Archit* 27(2):339–360
- Pedgley O (2013) Materials selection for product experience: New thinking, new tools. In: *Materials experience: fundamentals of materials and design*. Elsevier. <https://doi.org/10.1016/B978-0-08-099359-1.00024-2>
- Pedgley O, Rognoli V, Karana E (2016) Materials experience as a foundation for materials and design education. *Int J Technol Des Educ* 26(4):613–630
- Piselli A et al (2015) The shape of light: an interactive approach to smart materials. In: 20th International Conference on Engineering Design (ICED 15), July, 1–10.
- Piselli A, Dastoli C, Santi R, Del Curto B (2018) Design tools in materials teaching: Bridging the gap between theoretical knowledge and professional practice. In: *Proceedings of the 20th International Conference on Engineering and Product Design Education, E and PDE 2018*
- Rognoli V (2004) *I materiali per il design: un atlante espressivo-sensoriale [Materials for design: an expressive-sensorial atlas]*. PhD thesis. Politecnico di Milano
- Rognoli V (2010) A broad survey on expressive-sensorial characterization of materials for design education. *METU J Fac Archit* 27:287–300
- Rognoli V (2011) A broad survey on expressive-sensorial characterization of materials for design education. *METU Journal of Faculty of Architecture* 27(2):287–300. <https://doi.org/10.4305/metu.jfa.2010.2.16>
- Rognoli V, Levi M (2004) How, what, and where is it possible to learn design materials. In: *DS 33: proceedings of E&PDE 2004, the 7th international conference on engineering and product design education*. Delft, the Netherlands, 02.-03.09. 2004, pp 647–654
- Rognoli V, Parisi S (2018) *Tinkering with Mycelium: A case study* (vol 3)
- Rognoli V, Garcia CA, Parisi S (2016) The emotional value of do-it-yourself materials. In: *Proceeding of 10° Design and Emotion Conference, July 2017*
- Schön D, Bennet J (1996) Reflective conversation with materials. In: Winograd T (ed) *Bringing design to software*. Addison Wesley, Boston, pp 171–184
- Van Kesteren I (2010) A user-centred materials selection approach for product designers. *METU Journal of Faculty of Architecture* 27:321–338

Venere Ferraro Ph.D. in Industrial Design, is an Associate Professor at the Design Department of Politecnico di Milano. She has been Visiting Researcher at the University of New South Wales of Sydney (2006) and at the Media Lab of Massachusetts Institute of Technology (2009) where she runs research on Wearable Systems with the lens on design-driven and user-oriented approaches. She is a Member of the Experience and Interaction Design Research Lab; She participated in several International and National research, and she has been the principal Investigator of the research project POD: Plurisensorial (SAF€RA 2014 joint call). Venere is currently the Coordinator of the European Project ‘DATEMATS’ (KA2-2018). Her main research activity is focused on the role of interaction design in the use of disruptive technology (Wearable and smart textile). In particular, on how to exploit the potential of digital technologies to design experiential systems in both the private and public sectors. What characterises her research is human-centred design. The research interests lie in the field of wearable devices, smart interactive systems for well-being with particular attention to tools and methods for changing user behaviour. She’s the author of several international publications, and she holds International, National Patents and models.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



How Do We Approach and Involve Companies in Design Fields? Lessons Learned from Surveys and Participative Workshops



Alba Obiols

Abstract In the last few years, both materials and technologies are becoming one of the leading elements of product design practice as a lever to foster innovation and add value to final products. Despite the relevance of materials and technologies for advances in many fields, and particularly its importance to the success of the creative industries, there is a gap between the innovative design of products that meet the needs of the market and the research and development of new materials and technologies to be used in these products. The lack of collaboration between researchers and creative industries is at the heart of this issue (Innovamatnet, February 2013). Building on this ground the chapter shows the results of a survey submitted to more than one hundred companies in five different countries (Italy, Spain, Sweden, Finland, and Denmark). It was generated with the aim of collecting information regarding their specific interests and needs related to the four exemplified EM&T (ICS Materials, Nanomaterials, Advanced Growing Materials, Experimental Wood-based Materials) and the internal methods to manage knowledge related to them and the way they use to collaborate with academia and the channels they would prefer to use. The chapter also depicts the findings derived from a qualitative analysis done with academia and performed to identify their preferred channels to transfer knowledge. It finally describes the Company Manifesto, considered an engaging way to enhance and support the collaboration between Academia and the industrial sector.

1 Results of a Survey Submitted to More Than One Hundred Companies

In order to provide fundamental considerations regarding the current methods and tools used by companies as well as the existing relationships between research departments and enterprises that form part of the gap created between the academia and the industrial worlds, a study was developed to analyse and evaluate information

A. Obiols (✉)
Barcelona Design Centre, Barcelona, Spain
e-mail: albaobiols@icab.cat

regarding companies' specific interests and needs related to four EM&Ts, their methods and tools internally used by companies to manage of knowledge on that innovation area and to understand the ways they use to collaborate with academia, as well as the channels they would prefer to use. The study was carried out within the framework and under the umbrella of the objectives surrounding the Erasmus+ project DATEMATS "Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach", which goal was to create a transnational network among Universities, Research Centres and Organizations in contact with SMEs in order to develop and implement interdisciplinary new methods for both design and engineering students in the field of emerging materials and technologies, and to boost also knowledge and emerging material and technology transfers from academia and research centres to companies and vice versa.

The study elaboration embraced the collaboration of European Organizations of Industries involved in the definition and development of questionnaires addressing a total sample of more than one hundred companies in five different EU countries: Italy, Spain, Sweden, Finland, and Denmark.

The survey had a questionnaire format and referred to three main topics structured in three sections. The first section collected general company information: sector, size, departments, and business interests regarding the four EM&T areas.

The second section tackled the context of knowledge transfer within a business and industrial organization to identify internal methods to manage that knowledge: identifying skills needed, what tools they use to feed their knowledge and technology needs, methods followed, roles within the company to work on the EM&Ts areas, and previous projects implemented thereby. The third and last section approached the relationship between the company and the academia, including high education institutions, research and technological centres, and material libraries.

This last topic addressed issues such as the collaboration background of the respondent company with the academia to understand the ways they used to collaborate and the type of experiences, whether considered either negative or positive.

The study's main findings will be presented below according to each section and topic addressed. Firstly, EM&Ts' areas of interest according to company size and territory. Secondly, access to knowledge from the internal company's organization point of view. And thirdly, the relationship between companies and academia.

For what concerns EM&Ts' areas of interest according to company size and territory, wood-based EM&Ts are the most used or manufactured with 30%. Large companies are mostly not implementing them but are interested in applying them in the coming future. Italy is the country in which companies are mostly interested in wood-based EM&Ts. ICS wearable-based EM&T is the area where 53% of companies are interested in, though they don't implement it yet. SMEs are the most interested in using and/or manufacturing wearables, and Spain is where companies are the most interested in.

Advanced growing EM&Ts is the area which companies are the least interested in with 59%, and the company size is probably not a defining variable to explain the low interest in this area because that response about having no interest in was the most

answered in each category. According to territorial criteria, companies responding from Sweden and Finland were the most interested in this area.

Nanomaterials EM&Ts area represents the highest percentage, i.e. 67% of companies that manufacture and are interested in as well. Small and micro types of companies appear to be the most interested in applying nanomaterials EM&Ts in the coming future. Territorially, results showed a balance among all the four regions represented thereby.

Regarding access to knowledge and internal methods to manage it, more than 30% have a specific department to manage EM&Ts issues and less than 10% of the companies of the sample use to outsource the service, according to the results obtained. On the other hand, more than 10% of companies have no one assuming a role to conduct EM&Ts related activities and not even contract services to do so.

When asking about the channels used by the companies to get information about ongoing researches, updates, news, and trends on materials and technologies, the most common manner to stay closer to that knowledge is attending sector trade fairs while social media channels and newsletters are the least use for that purpose.

On the other side, technological centres are most popular when requesting technical information. Material libraries as well as their databases are the least consulted. To the question "Are you using specific methods or a structured methodology to find out and manage that information?", it was found that almost 80% of responses were negative. When approaching the gap between companies and academia, an important aspect is knowing the main difficulties a company may face searching for information regarding EM&Ts. As per the results, it happens to be the lack of time and the lack of material resources the two main reasons pointed out by companies.

Concerning the relationship between companies and academia, results showed that half of the companies collaborated with academia for product development and another 40% for projects in general. To the question "Has your company contributed with information, knowledge or know-how to academia for the last 5 years?", 60% of responses were positive, showing that more than a half of the sample had been open and active for collaboration with academia. Nearly one quarter said they had never collaborated with HEIs, research centres, and/or material libraries, the two main reasons highlighted were because academia seems remote and distant from the private sector and their fees are too expensive. However, for companies being in close contact with academia, results indicate that the most valuable reason for them to collaborate is they recognize it as a value to work with professionals with an extensive and profound knowledge in relation to the issues that they deal with.

When companies were questioned about their willingness to establish research projects with the university and deepen the potentialities of the EM&Ts, different realities were found. There are companies which present a long experience working together with universities. In these cases, it happens to exist an actual collaboration or past projects' references. Their conclusions in that regard are that universities and academia in general are seen as good partners for the research phase but are not considered competitive in terms of time and industrialization. On the other hand, they consider the fact that the output obtained from a research project with a university is not commercial, therefore the above-mentioned actually results unattractive

from a start-up's or small company's position. In the particular case that no collaboration is found, the context for that to happen is given by their business core and the consideration that interaction between users and emergent materials are essential starting points. For instance, they would be willing to collaborate if the new material was applied on their existing products to offer better features and an improved performance.

When addressing the issue about difficulties in accessing knowledge, companies focus on research-based papers and books, which are seen as guidelines applicable within a research lab that are very difficult to apply in an industrial environment. The difficulty is found when accessing academic knowledge either through scientific papers or hiring a highly qualified expert from academia to assess them in a specific area related to EM&Ts, because industry is basically practice-based when academia is mainly research-based.

Ultimately, the following conclusions came out from the Confederation of Danish Industry's; indeed it was difficult to have respondents from Danish companies giving their limited number so, a researcher from KEA made a fit on purpose interview to the Head of the Confederation.

Hereafter the main findings: Internships and collaboration between education entities and companies, integrating students in their projects, are crucial to improve the knowledge transfer activity.

Since large companies have R&D departments where developing their own knowledge, collaboration between design academia and industry through contests, or including business challenges in academic courses, are channels for knowledge transfer mainly in SMEs. In that context, there is actually an opportunity to cause a pull effect from companies by inspiring them and providing them inputs for new solutions and product ideas.

2 Results from a Qualitative Analysis Done with the Academia to Identify Their Preferred Channels to Transfer Results and Knowledge

Considering the Agenda for the modernization of Europe's higher education systems released in 2014, it presents various priority areas for higher education institutions. Among those key-points the following action is highlighted: "Strengthening the triangle of knowledge formed by education, research and innovation". The European communication recommends, first, public policies to encourage partnerships between higher education institutions and businesses; and second, higher education institutions to use the results of research and innovation in their educational offer to stimulate the development of entrepreneurial, creative, and innovative skills.

To this end, a qualitative analysis was carried out was to analyse the protocols used by academia for their knowledge transfer related activities addressed to the industrial world.

From the above-mentioned context, universities are nowadays required to carry out what has been named the *third mission*, which means to deal with the practices of technology transfer, knowledge transfer, and research results promotion. Researchers and educational practitioners have to transfer their know-how not only to the students through the development of educational activities and training methods but also to the third beneficiaries, industries, associations, and the market in general for exploitation and commercialization.

Therefore, the analysis examines the actual academic approach to deploy the so-called *third mission*. In order that the analysis could be carried out, the European Organization of Industries involved in DATEMATS set out a questionnaire with a total of eighteen enquiries addressing different aspects to be responded by researchers and academia's professionals. The set of questions span from what term is used for explaining the research impact in terms of social, cultural, and economic development to a more specific focus on how the research results are transferred: methods, activities, channels, difficulties faced when transferring results to companies, strategies to start collaboration with the industry, resources that universities have and use to boost that collaboration, etc.

Eventually, it is offered an overview of best practices implemented in the different universities' departments approached by the study. It is shown the current practices applied to deal with some of the difficulties and barriers that arise when it comes to technology transfer, knowledge transfer, and research results promotion. Researchers and educational practitioners present a broad sample of good practices when collaborating with companies and business professionals, having actually a significant impact in what we previously referred to as the *Triangle of Knowledge*, linking education, research and innovation and consequently, reducing the gap between Universities and Industrial worlds.

In order to explain the impact of research in terms of social, cultural, and economic development, 52% of HEI's interviewed use interchangeably both terminology, knowledge transfer and technology transfer. Knowledge transfer (26%) is more commonly used than technology transfer (17%), and rarely other terminology is used. Design department is the only one that uses other terminologies to explain the impact of research, such as design culture, anthropocentric design, knowledge transfers, and exchange.

As for the methods, *academic paper* (32%) is the most used method by academia to transfer knowledge. Although this trend is seen in all areas of specialization, Design areas also use *books* to spread their research. Material areas regularly use *patents* jointly with *papers*. And in the Engineering areas it's remarkable the fact that they also show a relevant use of *patents*, but also others like setting up *start-ups* involving business professionals and elaborating *product samples* to get the company's interest. About activities performed by HEIs to transfer results, while the development of *practical applications* (36%) are the most common, other activities mentioned like *training courses*, *hackathons*, or *focus groups*, which are actually used by Design and Sustainability areas, should also be taken into consideration. In terms of dissemination channels, the most used are *conferences* (29%), especially in

Design and Engineering areas, followed by *social networks* (19%) and *newsletters* (16%).

The main troubles expressed by academic respondents when transferring their results are the differences on *time perception* including the fact that academia can't adapt to the time reduction companies demand (25%) and *finding companies* willing to go through a knowledge transfer process (23%), representing both of them almost half of the total answers. Regarding formulas to contact industry from academia and make the first contact, they mostly address companies by sending *research publications* (36%). However, academia expresses that actually this first contact is normally done by companies. The importance of time management from academia's point of view is revealed by the 41% answering that *time management* may affect the scope of the knowledge transfer process, and 38% of the sample's respondents answered to *adapt their time* periods to the company demands.

The importance of language when transferring research results is seen by the fact that almost half of the answers (49%) agree that academia adapts the results to a more understandable language, however, the other half of respondents (44%) consider that technical language is not a barrier for transferring knowledge to companies.

Lastly, addressing the fact that knowledge may be transferred into the company having an impact in the way company's target users consume and relate to the company's products or services, user's perspective is integrated in the process, however, that integration is mostly seen after a theoretical analysis about the user's perspective in that subject in particular (50%), it is less seen but also applied that users are involved personally in the knowledge transfer processes (38%).

3 Best Practices in Knowledge Transfer Methods

To foster a peer-to-peer learning, academia was approached regarding best practices when collaborating with companies and third parties from the industrial world: "*Could you describe a best practice regarding the collaboration with companies/third parties?*".

Most of them pointed out the following practices: showing economic benefit companies will have when collaborating with HEIs; responding to all companies' needs and priorities as for requirements, objectives, time frame, and knowledge improvement, according to the market demand; and applying collaborative research programmes funded by national and EU funding programmes. Nevertheless, there are other best practices mentioned that may contribute to shorten distance between HEIs and companies for knowledge transfer: setting up collaboration agreements between parties to run a research; specialized workshops for companies' improvement; establishing non-disclosure agreements with companies; collaboration with talent incubators which followed the students' projects' development bringing them to the market; the company sets a brief and frames a problem to work closely with students in the design process.

Given all the data and results obtained, a comparative analysis was provided in view of the context in companies regarding their access to new knowledge about emerging materials and technologies and how they manage and integrate them internally in their innovation and business strategies. This analysis has been implemented identifying weaknesses, challenges, and opportunities in terms of channels and methods used by both actors, academia, and companies, having problems and difficulties on both sides: when transferring research results and cutting-edge technology to companies and when these companies search for new information and need to deal with innovative applications.

Although analysis' reflections raised widely divergent issues between industrial and academic world, some relevant concurrent trends arise thereto. Below, the main weaknesses, challenges, and opportunities in that regard are explained.

Channels used by companies to access new knowledge, and innovative applications do not match with those popular channels in the academic sector. While social networks are the second channel most used by academia, companies that are not yet implementing EM&Ts, but are willing to do so, show that social media is the least used (5%).

The most used method in academia to transfer their knowledge is through academic papers and patents (53%), although companies don't feel familiar with scientific publications.

Two of the most used formulas to contact companies are sending scientific publications (36%) or a book resulting from the research activity (22%). Academia uses a much more theoretical method than the one demanded by companies with a more result oriented and commercial perspective.

Academia's results in general show a minor use of methods such as elaboration of product samples (14%) and development of start-ups involving business professionals (9%).

The academia's difficulties found when transferring innovative knowledge to industry—differences on time perception (25%), differences on interest and/or motivation (14%), the agreement regarding the problem formulation with the company (12%), and the language (11%)—could explain why companies still identify reasons for not collaborating.

The second trouble mostly expressed by academics when transferring their research results to companies is that they do not know how to find out companies willing to go through a knowledge transfer process (23%).

The companies' reasons for not collaborating are that they think collaboration itself seems complicated and academia is remote and distant from the private sector (40%); besides, companies don't realize how collaboration could help their businesses and think that there is no need to do so (26%).

Half of the academic respondents do not adapt their language because 44% do not think that technical language may be a barrier to transferring knowledge to companies. For only 2% of the respondents from academia language is always adapted to the target audience.

Companies find difficulties in accessing new knowledge from academia, resulting in the second main barrier to adopt innovative technology, it is expressed as the

information is hard to find (23%) plus they find restricted access to that information (14%).

Within the top three channels most commonly used by companies to get new information on EM&Ts are sector trade fairs and conferences. In this scenario we find that conferences are also considered as one of the channels mostly used by academia. Nonetheless, conferences for academia may differ from those addressed to companies. Therefore, an opportunity arises for academia to be more present in trade fairs and conferences, not only the scientific ones, but also those approaching the industrial sector.

From companies' perspective, curricular education is seen as an effective way to transfer innovative knowledge to students who will become part of companies; in the current context, academic references are mostly applied during the research phase but not in the product development, collaboration may only be seen as convenient if it leads to a commercial product.

A few academic respondents approached the industrial focus when answering how they use to transfer their research results, for example, they share research results during their classes to students or during professional courses to companies; they elaborate product samples, prototypes, technical briefs, and similar to provide companies the knowledge to improve and optimize their products, services, and processes, also collaborating directly with them to develop new products; and one case expressed to have an observatory for knowledge transfer.

Considering the activities that academia performs to transfer their knowledge to companies, up to 75% of cases involve companies and practical applications, for instance, 36% develop practical applications with or without companies, 21% develop case studies, and 21% implement workshops addressed to companies.

Although language is not expressed as a relevant difficulty by companies (5%), there is a clear link between the channel used to transfer knowledge and the kind of language adopted. *Papers and patents* (53%) as methods the most used by academia, and academic *conferences* (29%) as the most used channel, it seems that scientific and technical are the predominant languages, and obviously they don't need to be adapted in those cases. However, when *sector trade fairs* and *internet search* are identified as the two main channels for companies to access to new knowledge, academia should consider it to necessarily adapt their scientific and technical language to the final target, the survey's results show an only 2% of HEIs who specifically do so, albeit they also show that a 49% adapt their results to a more understandable language.

By defining channels and the language accordingly for knowledge transfers to the industrial world, academia has a real chance to overcome those problems found by companies when searching EM&Ts information—information is hard to find (23%) and there is restricted access to that information (14%)—as well as proving that academia is not remote and distant, so making collaboration evident and simple.

4 Conclusions

Transferring knowledge from academia to companies has become a key issue to improve the competitiveness of the countries' economies. In this regard, universities are recognized to have both missions, education, and research. All the same, they are required to deal with knowledge transfer and research results promotion, in other words, to develop what has been called the third mission. In that regard, universities have been considered a driver for social and economic development.

Consequently, the research community has to spread its knowledge and know-how not only to the students but also to the third beneficiaries such as companies, industrial professionals, and associations, aiming at commercially exploiting the research from academia to have an impact on market activity and on society. Hence, they contribute to the link between education, research, and innovation. In that context, knowledge transfer effectiveness is crucial. In this regard, below, relevant outcomes and reflections are explained based on the results obtained from the survey conducted among the Universities involved in the DATEMATS project, and the comparative analysis carried out with these results and those obtained from the survey and several interviews conducted with private sector representatives.

In the above-mentioned context, channels, methods, and activities to get in touch and to collaborate with companies must be taken as a crucial matter because, at the present, companies find two main barriers to adopt innovative technology: it is considered an expensive investment, and they do not have knowledge to implement it. They find difficulties in accessing new knowledge from academia expressing that the information is hard to find and there is restricted access to that information. Besides that, companies still identify reasons for not collaborating with academia, pointing to their thoughts about collaboration being complicated; academia seems remote and distant from the private sector; and they don't know how collaboration could help their businesses realizing that there is no need to do so.

In relation to the mentioned topic, academia finds difficulties when transferring innovative knowledge to industry in differences on time perception, differences on interest and motivation, the agreement regarding the problem formulation with the company, and the language. And the second trouble mostly expressed by academics when transferring their research results to companies is that they do not know how to reach companies which want to collaborate and run a knowledge transfer process.

Considering these facts above-mentioned, academia can approach those challenges to conduct their goal thereby and to overcome the problems found by companies as well as defeat those reasons for not collaborating with academia by adopting considerations that are exposed below:

- Keep in mind that there is a clear link between the channel used to transfer knowledge and the kind of language adopted. Since sector trade fairs and internet search are identified as main channels for companies to get new knowledge, academia should consider it to go beyond the adaptation to a more understandable language, and instead, expressly adapt their technical language to the final target.

- Industrial focus when defining how to transfer their research results, for example, elaborating product samples, prototypes, technical briefs, and similar to provide companies the knowledge to improve and optimize their products, services, and processes.
- Bearing in mind, as a strength, the activities that academia currently perform when transferring their knowledge to companies, since they already involve companies and practical applications, developing case studies and conducting workshops addressed to companies.
- Different solutions are suggested by HEIs to face the problems identified when transferring their knowledge. These solutions focus on the creation of common environments, where both academia and companies can share, exchange, and align activities, creating a peer-to-peer or a mutual win–win situation. Eventually, the goal is to promote mutual understanding and build bridges of communication and knowledge exchange between academia and industry. So that to be a reality, regular activities involving companies like training courses, workshops, hackathons, or focus groups, should be encouraged and carried out by HEIs, conceived as areas for: exchanging knowledge from academia to companies through training activities; a more straightforward communication, aligning languages; co-creating and setting up joint projects with common interests.

It is shown that these criteria, already used by HEIs' Design and Sustainability areas, would help to create an effective collaboration and guide companies in their innovation processes. Since design facilitates a user centred approach and helps the assimilation of new technology in the market, using *design thinking* methodologies in different dynamics of the workshop would be useful to achieve common interests of academia and companies.

At the present time, scientific publications—*papers*—arise as the most common method used by academia to transfer their results, and the industry expresses not to be familiar with it. Neither *patent* make companies learn about new findings. It is crucial to find **successful protocols in which companies could see contribution and benefits for their businesses**, for example, showing best practices of collaboration between companies and academia when developing innovation; having academic profiles in companies and vice versa, attracting research profiles with experience in the business world. In that regard, both industrial and academic spheres must **work together to establish common spaces, environments, and channels for a fluid and permanent exchange of interests and motivations**, like participation in trade fairs and conferences, collaborative projects development, generating both mutual confidence and participative workspaces to boost long-term relationships. Much likely, these scenarios would contribute to a more fluent and better bi-directional communication, aligning companies' demands with academia research and knowledge context, resources, and timings.

5 Company Manifesto: An Engaging Way to Enhance and Support the Collaboration Between Academia and the Industrial Sector

A Company Manifesto was presented to involve the industry and the business sector in a transnational network because of the project activities and therefore to contribute, to create, and strengthen a cross-field multiplier network.

The development for the setup of the manifesto document and this to be presented to companies including its format and the process followed to engage them, not only in a way they would sign up the manifesto but also how to make them part of the above-mentioned network.

The goal of the initiative was to create a transnational network among universities, research centres, innovation and design institutions, and companies to develop and implement interdisciplinary and transdisciplinary methods for education and training on EM&Ts. The objective thereby is to share approaches, knowledge, and needs among individuals coming from either the academia or the industry world, for further collaborations and to keep alive the connection after the end of the project.

5.1 Format Identification and Implementation

The manifesto was set up to be an agreement and a statement of intent by companies to keep updated about the project results, also to be part of a network formed by different kinds of research centres and enterprises and be involved in future activities related to the topic. The Manifesto description needed to be concise, precise, and straightforward to the issue. It was agreed that it wouldn't appear as a signing a legal document but to be an action to confirm companies' commitment in being part of a network to share information and participate in knowledge transfer related activities.

The format chosen to develop the Manifesto initiative was to subscribe to an online form through which to join the DATEMATS Companies Manifesto. The form included companies profile identification and specific statements for companies to give their consent and show their interest in participating in future project's activities and receive project related results. Below, the relevant sections and statements of the online form:

Type of company: Material Manufacturer, Potential Material Manufacturer, End-user of Materials, or Potential user of Materials.

Area of EM&Ts most interested in: Interactive Connected Smart (ICS) Materials: wearables, Nanomaterials, Wood-based Materials, Advanced Growing Materials.

"I am interested in Emerging Materials and Technologies knowledge and transfers with a design driven approach" with two given options: Yes or No.

"I am interested in being part of interdisciplinary workshops with other companies and students to test and assess new knowledge transfer methods" with two given options: Yes or No.

“I want to receive project results as well as being part of the above referred transnational network to be connected after the end of the project” with two given options: Yes or No.

Considering the information gathered from the Manifesto form, the interest of the companies involved is very transversal, most of the companies selected the three or all of the EM&Ts’ areas. All of the Manifesto form respondents expressed a yes in the above three statements.

The companies’ Manifesto was uploaded in one section of the DATEMATS website as a list of companies with their names, logos, and links to their organization websites as a tangible result to show. Therefore, one part of the action of joining the manifesto was also the consent to appear on the project’s website.

The initiative reached 57 companies resulting in a number above the 30 expected to sign the Manifesto. So considering the Manifesto description, these companies and industry professionals have become part of a network with access to the project’s outcomes, which involved a series of activities and publications addressing companies and professionals such as exhibitions and events, knowledge transfer days, final international conference, training guidelines in the field of EM&T, training workshops directed to managers, companies and students, and entrepreneurship workshops for EM&Ts related start-ups. As a result, it allows to develop new guidelines and approaches to technology, transfer knowledge from academia to industries, and to create new professional competences and entrepreneurial skills in young students.

5.2 Implications of the Manifesto’s Results During the Project Implementation and Beyond

The Manifesto initiative had a direct impact on other tasks and goals of the DATEMATS project. For example, the interdisciplinary EMT&s challenges were conceived as four experimental workshops, each one of them focusing on one of the four specific EM&Ts’ areas. All the workshops needed to involve companies, which were selected from those that signed the Manifesto and therefore they became part of the transnational network which one of its goals was to develop interdisciplinary methods for education and training on EM&Ts. When selecting companies to be part of the interdisciplinary workshops, it was agreed to select companies according to their experience instead of their interest, meaning that a company that is interested in an EM&T area has not necessarily experience in that area. Companies that already have experience in specific EM&Ts can provide materials and knowledge that students can use to prototype and design. It is not necessary that selected companies be the manufacturer of that EM&T, but that show expertise and application experiences. Therefore, an analysis was done by HEIs to the companies signing the Manifesto to identify their experience and expertise in the specific areas of EM&Ts. The HEIs contacted companies that were classified as interested in their

EM&Ts' area of specialization to start defining a design briefing and a challenge to be presented to students during the foreseen workshops.

As a result, the above-mentioned actions represented a first step to start building links and connecting the industry world with the academia and their students, so the ultimate consequence of the Manifesto initiative is that all the companies and academia being part of this network will have the means to share approach, knowledge, and needs for further collaborations and to keep alive the connection after the end of the project.

Alba Obiols presents a solid expertise in defining and implementing environmental sustainability strategies. During the last nine years she's developed social impact initiatives within different public and private organizations. Currently, she works as an Innovation and Circular Design Project Manager within the Barcelona Design Centre. There, she coordinates the area of circular economy and sustainability while managing research and innovation projects and dealing with funding opportunities, consortium building and partnership coordination. Her education and specialization are based on international and public affairs with a focus on the European regulatory framework. Ms. Obiols holds a Master Degree in International and European Union Law as well as two university degrees in Law and Business Management and Administration. She presents further professional training in the field of Climate Change Mitigation and Adaptation coordinated by the University of Melbourne, and in Clean and Sustainable Urban Development in Latin American and Caribbean region coordinated by the Inter-American Development Bank.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



A Supporting Tool to Design with and for EM&Ts: The Materials Toolkit



Gemma Esteban, Geraldine Kann, Veronica Sarbach,
and Daniela Amandolese

Abstract The chapter gives an exhaustive description of the so-called EM&Ts toolkit, a collection of tangible samples displaying emerging materials and technologies and containing five samples for each EM&Ts. Aim of the EM&Ts transfer toolkit is to provide a tool to facilitate the understanding and application potentials of emerging materials and technologies. Every material example has its box, containing: (1) Physical sample, (2) An “Understanding” card: it provides basic knowledge about the material and the manufacturer, Technology Readiness Level, crucial characteristics, and features. The sensorial qualities and performance, sustainability, and smart properties are listed for a clearer understanding of the materials potential; (3) A “Shaping” card: it contains information about the manufacturing process, the form in which the material is available and possible transformations. This information is useful to understand how the material can be processed for production, finishing, and transformation, to get to the final product. The card highlights, which processes that, have been associated with the material so far; (4) An “Applying” card: it gives information and pictures about the field the material is currently used. The material characteristics are compared with other better-known alternatives. In addition, other potential applications are listed, associated with meaningful case studies. The toolkit was created to be used as an aid in educational contexts with students and during workshops with companies and professionals. It is a powerful tool to provide students with information about the materials and their opportunities and limits, and to inspire them during the concept development. On the other side, it has potentialities to provide decision makers of the company with information about the emerging

G. Esteban (✉) · G. Kann
Materfad, Barcelona, Spain
e-mail: gesteban@fad.cat

G. Kann
e-mail: projects@materfad.com

V. Sarbach · D. Amandolese
Materially S.r.l. Impresa Sociale, Milano, Italy
e-mail: vsarbach@materially.eu

D. Amandolese
e-mail: damandolese@materially.eu

materials and technologies, their opportunities and limits, and to inspire them for innovation in product development. The chapter describes the continuous iterative process through which the toolkit was created and evaluated. Indeed, the toolkits have been used and tested in the academic context, with more than 100 students of diverse design backgrounds during EM&Ts workshops in Spain, Italy, Denmark, and Finland but also in professional context, during participative workshops with 94 companies, design studios, and professionals.

1 Introduction

Within the DATEMATS initiative, several outputs have been produced: the DATEMATS EM&Ts Transfer Toolkit is one of these, combining different project results in one tangible artefact.

The EM&Ts toolkit is a collection of tangible samples displaying five case studies for each of the four Emerging Materials and Technologies (EM&Ts) areas approached in the project:

- Advanced Growing EM&Ts
- Experimental Wood-based EM&Ts
- Interactive Connected Smarts (ICS) Wearable-based EM&Ts
- Nanomaterial EM&Ts.

Aim of the toolkit is to provide a means to facilitate the understanding and application potential of new materials and innovative technologies.

Traditionally in science and engineering, materials are characterized technically, through a series of studies aiming at probing and measuring the structure and properties of materials. In design, a holistic approach to materials is adopted which requires the characterization of materials for their experiential qualities, alongside the technical understanding. (Camera and Karana 2018)

The DATEMATS collection of materials samples, a total of 20, is not exhaustive but of illustrative nature to trigger interest in emerging materials or reconsider known physical matter under a new perspective.

The toolkit was created to be used in knowledge transfer activities in educational contexts with students, and during workshops with companies and professionals. It is a powerful tool to provide designers and producers with information about the material's properties, opportunities, and limits, and to inspire during the design process or innovate already developed products.

Each material sample is showcased in its box accompanied by an exhaustive description, and based on the developed DATEMATS methodology, that sheds light on the three main aspects to consider when designing with emerging materials and technologies. The explanations are summarised in *understanding*, *shaping*, and *applying* the EM&T, made easily assimilable through graphics, icons, and case studies.

Understanding material experiences can enrich designers' vocabulary and open up the design space for unique functions and expressions. (Barati et al. 2017)

The development of the DATEMATS EM&Ts Transfer Toolkits was planned in two separate project tasks which were led by the consortium partners Materially Srl (former Material ConneXion Italia) and FAD respectively. Nevertheless, strong spirit of cooperation and commitment throughout the whole creation process from both leaders and additional contributors characterised the collaboration. In the following paragraphs, the process that led to the first version and, after different evaluation steps, the creation of the final version is thoroughly described.

2 DATEMATS EM&Ts Transfer Toolkits—First Version

To start the creation process in a collaborative manner and ensure that expectations are met, a general brief indicating the goal and contents of the toolkits based on the available task description was shared with the all-consortium partners, to identify possible constraints and requests regarding the shape and collect suggestions for potential solutions. In addition, all task-related documents were shared online and made available for consultation and contributions.

2.1 Phase 01: Material Scouting

Materially, in collaboration with FAD, executed an in-depth scouting activity exploiting their in-house material database and established contacts with material suppliers, identifying more than 60 possible materials suitable for the DATEMATS EM&Ts toolkit. To facilitate collaboration and exchange of information between the partners, a shared spreadsheet was set up, categorising the scouted materials based on their characteristics responding to one of the four DATEMATS EM&Ts areas: Advanced growing EM&Ts, Experimental Wood-based EM&Ts, Interactive Connected Smart (ICS) Wearable-based EM&Ts, Nanomaterial EM&Ts. The data collected in the spreadsheet included basic information such as: pictures, commercial name, short material description, manufacturer, online references (supplier website), etc. The materials identified and pre-selected by Materially and FAD were presented to the experts of the four HEIs involved in the project—KEA for Advanced Growing EM&Ts, AALTO for Experimental Wood-based EM&Ts, POLIMI for ICS Wearable-based EM&Ts and TECNUN for Nanomaterial EM&Ts—which indicated their preferences and confirmed the final selection of at least five materials for each EM&Ts area (see Fig. 1).

The data of the selected materials was subsequently integrated with additional description to provide information according to the pedagogical framework, defined

AREA 4 - EXPERIMENTAL WOOD-BASED EM&Ts (by Aalto)				AREA 1 - ICS: WEARABLES EM&Ts (by Polimi)			
ID	Name of the Material	Description	Company Name and Website	ID	Image	Material	Supplier Name and Website
98	Plywood	...	...	1		Carbon fiber	Parsons Research AG
99	Colored Colored Paper	...	Wool (Pang Hong)	2		Chromic	AlTech Plastics
100	ADMIRAL BIR	...	Edward Industries GmbH	3		Agave™	System Advanced Materials, Inc.
101	PLANT FIBER BLEND	...	No Green Packaging	4		Single Push Button	Plug and Play
102	Wool	...	Math University	5		Artificial Palm & Tree	8 Trading Corp.
103	Ugreen	...	Cellulose Lab	6		Acrylic Paint	Black Composites
104	Bark Cloth	...	Myrtilis s.r.l.	7		Artificial Sunflower	McLuiff
105	...	...	Bark Cloth	8		Canvas	Canvas Technology
106	...	...	...	9		Pressure Sensitive Tape	Sealing Tape
107	...	...	...	10		Thermocole	Thermocole
108	...	...	...	11		ALUFLEX	Aluflex GmbH

Fig. 1 Over 60 materials scouted for the 4 EM&Ts areas

within the DATEMATS methodology, that identifies the following three aspects as crucial for designing with EM&Ts:

- Understanding—describing the EM&T with physical and senso-aesthetic parameters
- Shaping—describing the EM&T-specific transformation processes and techniques
- Applying—describing the EM&T application potentials with a real case example.

For each of these aspects, online freely available digital content related to the specific material was scouted, able to facilitate the knowledge transfer.

2.2 Phase 02: Collecting the Information

The collected information about each EM&T material is included in the toolkit on three separated datasheets, addressing the three aspects of DATEMATS’s unique design method—Understanding, Shaping, Applying—and accompanying the showcased physical sample. Several tools were created to gather the needed data about the

materials. These tools were shared with the consortium to be exploited and adapted for the creation of the final toolkit.

To facilitate filling in the datasheet for all the selected materials, an online form was created; a simple tool to uniform data collection and provides a standardised format useful for future integrations during DATEMATS project execution. In addition, using Google Form allows one to collect the answers in one excel file, thus creating a dedicated DATEMATS EM&Ts materials database (see Fig. 2).

The online form, divided into five sections, collects the following data:

- EM&Ts area.
- Understanding data to provide basic knowledge about the material and the manufacturer, Technology Readiness Level, crucial characteristics, and features. The sensorial qualities and performance, sustainability, and smart properties.
- Shaping data to provide information about the manufacturing process, the form in which the material is available and possible transformations. This information is useful to understand how the material can be processed for production, finishing and transformation, to get to the final product.
- Applying data to provide information and pictures about the field the material is currently used. In addition, data on significant case studies are collected.

To extract the gathered information easily from the online form (database) into the dedicated material datasheet, the architecture of the datasheet was defined via an excel file.

AREA - ADVANCED GROWING EM&Ts (by KEA)						
Name of the Material	Image	Description	Characterizing	Usage	Applications	Case stud
1 BIOLEATHER		This sheet is produced on a substrate from bacteria that is a biopolymer made in a specific way.	Light, flexible, translucent, elastic, made from a bacterial film. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Can be used for the production of shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Applications: shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	
2 Mini Biocomposites		Mini is a biodegradable biocomposite material made from natural fibers and a biodegradable matrix. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Mini is a biodegradable biocomposite material made from natural fibers and a biodegradable matrix. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Can be used for the production of shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Applications: shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	
3 MINDRY-PIVA™		A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Can be used for the production of shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Applications: shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	
4 MycoFlex Foam		A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Can be used for the production of shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Applications: shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	
5 MycoStone		A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	A biodegradable matrix of poly(methylmethacrylate) (PMMA) is a natural material produced through the molecular transformation of organic waste. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Can be used for the production of shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	Applications: shoes, bags, wallets, etc. It is a natural material that is biodegradable and has a high resistance to wear and tear.	

Fig. 2 Extract of list of selected EM&T materials

*All data required:

AREA

UNDERSTANDING

- Material name (include TM or ® if applicable)
- Website (if available in EN)
- Material producer
- Base material—the material belongs to the following material family:
- Main features—describe the material in one sentence
- Composition—components of the material
- Technology Readiness Level (TRL)
- Sensorial qualities
- Performance properties
- Sustainability properties
- Smart properties
- Variations—are there variations in colour, finishing, texture, pattern, etc. available?
- Testing—following testing results and standards are available for this material
- The material has the following certifications.

SHAPING

- Manufacturing process—how is the material made?
- Supply—the material is provided as
- Shape—the material is provided as
- Transformation processes—how can the material be shaped?
- Options—are there possibilities to customise the material?
- The material is compatible with
- The material system can be enhanced via.
- APPLYING
- Current application field
- Potential application fields
- Case study—commercial product applying the material (share a link)
- Concept applying the material (share a link)
- The material is comparable to
- The material is inspired by
- The material is better than similar commercially available materials because.

CONTACT DETAILS

2.3 Phase 03: Conceptualising the EM&TS Toolkit

Materially executed a series of activities—including desk research and benchmark on similar tools—to design the toolkit in an appropriate manner, involving whenever possible all-consortium partners (see Fig. 3).



Fig. 3 Inspirational images for concept

Based on the general brief, Materially ideated two concepts: the “book” and the “box” (see Fig. 4).

- Concept A, identified as the “book”, is focusing on an analytical approach, focusing on material observation, presenting one single material packed in its dedicated container, providing detailed information via the three datasheets. The physical sample cannot be manipulated (touched) but only observed, datasheets are not detachable. In this way, integrity of the samples and good conservation of the datasheet is guaranteed. Several “books” (at least 5) complete one EM&Ts area compendium.
- In alternative to the previous one, concept B, named the “box”, gives priority to interaction. A container is proposed, collecting all samples related to the specific EM&Ts area. Each material sample is equipped with its datasheets. This solution favours an explorative approach, facilitating material manipulation and experimentation.

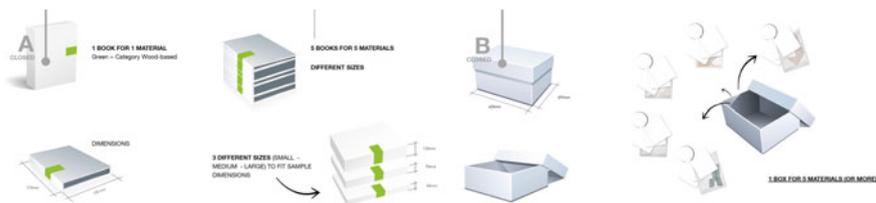


Fig. 4 Concept sketches

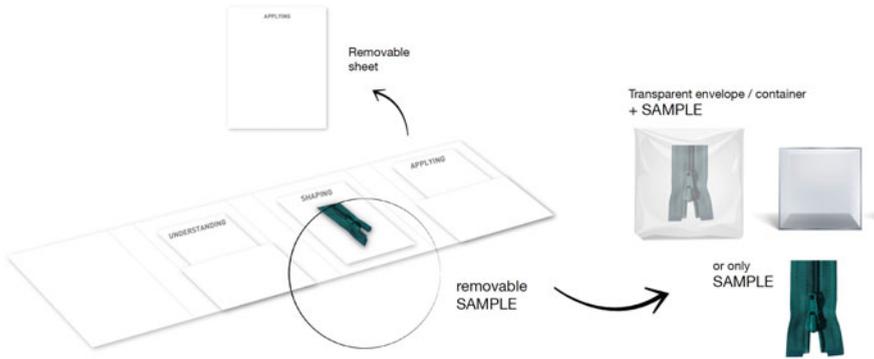


Fig. 5 Final concept sketches

After the presentation of the two initial concepts during the 3rd consortium meeting, the feedback and suggestions collected were integrated into a third proposal, optimising the advantages of the two previous ones in this final concept.

The final concept, called the “folder/book”, provides a single container for each material, but the sample and datasheets are removable offering the possibility to organise the knowledge transfer activities in an explorative manner (see Fig. 5). This guided interaction enhances material exploration, where manipulating the samples is appropriate, while assuring integrity and good conservation of the samples.

2.4 Phase 04: Prototyping and Production of the EM&TS Toolkit Version 1

Materially decided to optimise the dimensions of the single material container to be complying with the international standard format DIN A5, in this way the toolkits are handy and easily adjustable for the final version. In consultation with a local typography able to produce the 20 containers, Materially chose using laminated cardboard and foam board to create the toolkit drafts, applying die cutting and digital printing to trim and customise each EM&T material’s container. A mock-up was created to verify dimensions, functionality, and finalise the graphic layout. Finally, the manufacturers of the materials featured in the toolkits were contacted to receive the needed material samples (see Fig. 6).

The material sample container’s graphic layout was created based on the project’s visual identity (see Figs. 7 and 8). References include general information about the project’s goals, focus points—the four EM&T’s areas—involved partners and project funding references. Special attention was adopted to create coherence with the visual impact of the datasheets.

The graphic layout of the datasheets was designed based on the project’s visual identity and includes several infographics to convey the data in an effective and



Fig. 6 Toolkit mock-up inside view with sample placeholder



Fig. 7 Toolkit graphic layout, outside and inside

immediate manner, enhancing the user experience while exploring the materials. Format of the datasheet is conformed to international standards (A5 DIN) to foster large-scale fruition and dissemination.

Figs. 9, 10, 11, and 12 showcase the three datasheets (front and back page) of the product “Fenix NTM”, selected for the Nanomaterial EM&Ts area.



Fig. 8 Toolkit (first version) inside view

GRAFYLON® 3D
Directa Plus S.p.A
www.directa-plus.com/composite-materials

CARBON BASED

MATERIAL FEATURES AND COMPOSITION
A PLA-based additive manufacturing filament which contains Graphene Plus IG-1, extremely pure and crystalline graphene nanoplatelets (GNPs) that are safe for humans and contribute to improved mechanical, electrical and aesthetic properties of the material compared to traditional PLA filaments.

PHYSICAL PROPERTIES

REPEL	STIFFNESS	HEAT
IMPACT	SURFACE REFLECTIVITY	WEAR
ODOR	TRANSPARENT	NEUTRAL FRAGRANCY
WEAR	SURFACE HARDNESS	COGNITIVE
WEAR	WEAR	WEAR

PERFORMANCE PROPERTIES

ACOUSTIC CONDUCTIVITY	STAIN RESISTANCE
CHEMICAL RESISTANCE	THERMAL CONDUCTIVITY
FIRE RESISTANCE	UV RESISTANCE
IMPACT RESISTANCE	WATER RESISTANCE
SCRATCH RESISTANCE	WEAR RESISTANCE

AVAILABILITY
3D+ Active system proven in operational environment
Commercially available in large amount

TRL9

UNDERSTANDING

NANOMATERIALS EMATS
Entirely carbon-based materials, nano-scaled structures or composite blends whose properties are derived by surface and/or substrate doping. EMATS (EMATs) Mater composed at molecular level, which is smaller than micrometers, normally on scales of 1 to 100 nanometres.

SUSTAINABILITY PROPERTIES

BIODEGRADABILITY	RECYCLED PRE-CONSUMER WASTE
COMPOSTABILITY	RENEWABLE CONTENT
CARBON FOOTPRINT	RECYCLED POST-CONSUMER WASTE
RECYCLABILITY	TOXICITY

SMART PROPERTIES

ELECTRO-HEOLOGICAL	PHOTOCHROMIC
MAGNETO-HEOLOGICAL	PHOTOLUMINESCENT
PIEZOELECTRIC	SHAPE MEMORY
PHASE CHANGE MATERIAL (PCM)	THERMOCHROMIC
PHOTOCATALYTIC	THERMOELECTRIC

CERTIFICATES & TESTS

- ISO 14001:2015 certification for the production and commercialisation of pristine graphene nanoplatelets and graphene-based products
- ISO 9001:2015 certification for the production and commercialisation of pristine graphene nanoplatelets and graphene-based products of different morphologies
- Certification from an independent laboratory determining polycyclic aromatic hydrocarbons in a "Pure Graphene Fluor" graphene sample.
- REACH registration on chemical-free process for GNPs production.
- Ge-printed fabrics and enhanced membranes are certified Dermatologically Tested and Hypoallergenic.

UNDERSTANDING

Fig. 9 Material Fenix, card Understanding

GRAFYLON® 3D
Directa Plus S.p.A
www.directa-plus.com/composite-materials

CARBON BASED

MANUFACTURING PROCESSES
Through a unique technique called Plasma Super Expansion natural graphite is expanded, exfoliated and dried to create graphene nanoplatelets-based materials available in different forms such as powder, liquid and paste and suitable for a variety of uses. The manufacturer produces a highly consistent graphene nanoplatelets product - an important factor for commercial customers - and does not need any chemical or solvent additives. To create the filament version the graphene nanoplatelets are combined with PLA into a formulation suitable for extrusion.

SUPPLY

SHAPE

Filament

TRANSFORMATION PROCESSES

ADDITIVE MANUFACTURING	DIE CUTTING	LAMINATION	STITCHING
BLOW MOLDING	EXTRUSION	METAL WORKING TOOLS	THERMAL FORMING/ COMPRESSION MOLDING
CASTING	INJECTION MOLDING	PRINTING	WELDING
COLD PRESSING / DEEP DRAWING	LAB GROWING	RESTOMOLDING	WOOD WORKING TOOLS

SHAPING

NANOMATERIALS EM&Ts
Finely carbon-based materials, nano-scaled structures or composite blends whose properties are altered by surface and/or substrate doping thereof. MANO TECH Matter controlled at molecular level, which is smaller than a micrometre, normally on scales of 1 to 100 nanometres.

FOR MORE DETAILS AND MATERIAL CHARACTERISTICS

SHAPING

Fig. 10 Material Fenix, card Shaping

GRAFYLON® 3D
Directa Plus S.p.A
www.directa-plus.com/composite-materials

CARBON BASED

APPLICATION FIELDS
Rapid prototyping and 3D printing of design components, electronics, and fashion accessories.

COMPARISON

SIMILAR TO N/A	BETTER THAN Lower deformation, heat dissipation, improved gas and solvents impermeability.	INSPIRED BY N/A

CASE STUDY

APPLYING

NANOMATERIALS EM&Ts
Finely carbon-based materials, nano-scaled structures or composite blends whose properties are altered by surface and/or substrate doping thereof. MANO TECH Matter controlled at molecular level, which is smaller than a micrometre, normally on scales of 1 to 100 nanometres.

FOR MORE DETAILS AND MATERIAL CHARACTERISTICS

APPLYING

Fig. 11 Material Fenix, card Applying



Fig. 12 Toolkit (first version) Closed



Fig. 13 Toolkit (first version) Open

2.5 Phase 05: Evaluation and Handing Over

Materially created this first version of the DATEMATS EM&Ts transfer toolkit in tight collaborations with FAD, both hosting a material library, based on their experience of managing and using physical samples for knowledge transfer and consulting activities (see Fig. 13).

The consortium partners, especially the four involved HEIs, are the main users of the Toolkit in support of the ad hoc developed Design Teaching Method (DTM). Valuable feedback to improve the “EM&Ts transfer toolkits version 1” was gathered during the knowledge transfer activities where the DATEMATS DTM and its tools were validated. Subsequently, the following aspects were assessed and optimised in the final version:

MATERIALS—physical samples have been selected based on the needs and suggestions provided by the responsible partners of the four EM&Ts areas and their

availability; some materials might be substituted or added for the final version in order to effectively communicate the essence of the DATEMATS EM&Ts.

DATASHEETS—the content of the EM&Ts material datasheets are based on the DTM guidelines describing each material from three different point of view and providing information to enhance understanding, shaping, and applying of the materials; information provided on the datasheets might be substituted or extended in the final version in order to effectively communicate the DATEMATS EM&Ts properties and potentials.

FORMAT—the proposed format aims at providing an efficient and easy manageable tool with a strong attention to material exploration while facilitating interactive and module-based knowledge transfer activities; shape, dimension and material of the container might be modified in the final version in order to adjust the flaws and integrate insights gained during the project execution.

3 DATEMATS EM&Ts Transfer Toolkits—Final Version

In the process of updating and finalising the definite version of the EM&TS transfer toolkits, the materials kits continued to be shown to students and companies in dedicated knowledge transfer activities in 2020 and 2021 (Knowledge Transfer Labs held in Sweden, Italy and Spain and Mobility Workshops at Tecnum and Polimi) as a flexible tool to experience, understand and interpret each of the selected materials by providing data and tangible examples of the EM&Ts to transfer.

At the same time, the prototypes were examined exhaustively with the experts of each EM&Ts to obtain their suggestions and possible substitutions of the current showcased materials for their respective area.

Experts were also asked for new projects, references, and inspirations on their specific area to create digital mood boards for each EM&Ts that were then linked to the QRs of the toolkit boxes to be used by students during the upcoming activities. These mood boards were also intended to show that each EM&Ts has much more materials and projects than the five featured in the toolkit and the aim is to serve as an inspirational visual document that can be even more expanded.

The collected feedback for digital as well as physical improvements in form and content of the datasheets and boxes from the draft version was then analysed and filtered after testing them in the above-mentioned activities.

In addition, a booklet describing the knowledge transfer method and the related DMT (Design Methods & Tools) guidelines to interpret the samples for that specific EM&Ts, was integrated into the final version of the materials kits.

Finally, images with higher resolution were scouted by FAD and Materially so that the graphic designer could implement all digital changes. With the amendments and improvements, she also created a new graphic layout of the boxes and coordinated the production and printing of the final version of the EM&Ts transfer toolkit.

All this information was organised into spreadsheets.

Source	Areas	Feedback Toolkit v1 (Live revision of physical toolkit with experts via zoom May 2021)	Type of Feedback (POSITIVE / IMPROVEMEN	Type of Improvement (FORM / CONTENT)	Comments
Anke Pasold (May 26, 2021)	Advanced Growing - Materials - samples	Would be great to have 5 "families": 1. Mycellum (2 samples) 2. Algae based → add 1 (Ref: Algalink) 3. Cellulose based (process) (2 samples) 4. Mineral based (bacteria) → add 1 (Ref: biomasson) 5. IPHA	IMPROVEMENT	CONTENT	- Materials samples - Anke could link with the 2 new companies (Algalink+biomasson): Any update? Exact references to get from local providers? - Which ones do we keep from the samples where we have 2 samples? Mycellum + Cellulose based
Anke Pasold (May 26, 2021)	Advanced Growing - Datasheets (digital)	Change datasheets where samples will be modified	IMPROVEMENT	CONTENT	- Change digital +physical datasheets according to Anke's indications
Anke Pasold (May 26, 2021)	Advanced Growing - Datasheets (digital)	7 new projects showcased in the respective moodboard (i.e. open source biolab)	IMPROVEMENT	CONTENT	- QR on digital datasheet with moodboard for 1st Mobility WS Tecrun.
Anke Pasold (May 26, 2021)	Advanced Growing - Datasheets (digital)	Categorization: compostibility, biodegradability, toxicity A lot of empty sheets (i.e. smart properties due to area) link them to the one that have the properties in other toolkits Shaping: Transformation processes, might be useful to have link to processes /comments/resources	IMPROVEMENT	CONTENT	tdb
Anke Pasold (May 26, 2021)	Advanced Growing - Datasheets (physical)	Problematic of datasheets attachable/detachable Pre: you can take them out Con: you have to do the sorting afterwards. Box is complex and difficult to put them in order, a lot of box material (during presenting i.e.) Rubber/elastic bands, open like a fan, bookbinding, click to toolbox with a ring that could be detached	IMPROVEMENT	FORM	tdb
Anke Pasold (May 26, 2021)	Advanced Growing - Sustainable Box (physical)	Sustainable "feeling" in terms of biomaterials, color: white is problematic (gets easily stained with liquids and pastes), certification FSC not really circular, more important how the box is produced in terms of circularity	IMPROVEMENT	FORM	- ask Veronica how it has been produced for the prototype - change color white?
Anke Pasold (May 26, 2021)	Advanced Growing - Miscellaneous (physical)	Microflex material: "pitty to say don't touch it" Comparison to other toolkits: what is it "inspired by"? same info? in a lot of them no reference	IMPROVEMENT	FORM	tdb

Fig. 14 Excerpt from “Feedback Toolkit v1 | Transnational Milan + KTL 2020 | Experts 2021 | Mobility WS 2021” [EM&T Advanced Growing]

Below (from Figs. 14, 15, 16, and 17) is an excerpt of all four EM&Ts comments gathered during the feedback sessions and responses:

3.1 Phase 06: Revision and Update of Datasheets, Creation of DATEMATS Mood Boards and Glossary (Final Version)

All links to the 20 digital datasheets and layout for the boxes were included in the follow-up spreadsheet of the final toolkits for the completion of all tasks concerning the revision of the material parameters and design changes.

Fig. 18 shows the four respective EM&Ts mood boards created for Advanced Growing, ICS Wearables, Nanomaterials and Wood-Based.

For the 20 digital datasheets corrections of all four EM&Ts (each document accounting for 5 materials per area and 6 pages) the same schematic structure was used as follows:

Understanding:

- Materials features and composition
- Physical qualities
- Performance properties
- Availability (TRL)
- Sustainability properties
- Smart properties
- Certificates & Tests.

Source	Areas	Feedback Toolkit v1 (Live revision of physical toolkit with experts via zoom May 2021)	Type of Feedback (POSITIVE / IMPROVEMENT)	Type of improvement (FORM / CONTENT)	Comments
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Materials samples	PTF inks not sustainable: change it for a shape memory alloys/polymers or OLED, "Light Touch Matters" example	IMPROVEMENT	CONTENT	- First ask MaterFAD for samples inhouse - ask Materiality for pool of LTM materials, i.e. OLED (sth that is a system)
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Datasheets (digital)	7 new projects showcased in the respective moodboard (i.e. LTM example)	IMPROVEMENT	CONTENT	- QR on digital datasheet with moodboard for 1st Mobility WS Tecrun.
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Datasheets (digital)	FAD: Proposal skip toxicity, smart + sustainable properties in glossary; Polimi experts said it's empty, useless. Negative perception of sth that is missing or an error. Just put smart properties, otherwise too many blanks, e.g. Carbon footprint empty. Understanding: Vocabulary confusion: "physical properties" are actually qualities of the material (expressed qualitatively). Bars often don't make sense, info often confusing (pre-consumer waste) i.e. whether it is a shape memory or not. Meaning of gradient colors; FAD: intuitive system. Arch not clear, properties i.e. opaque or transparent, stiffness. Linear line like a bar more effective. TRL, positively appreciated, a lot of value for company. Suggestion to put in a more predominant way Shaping: tricky to understand terms: manufacture (how is it done) + transformation processes (possible processes applicable), maybe put "other possible processes", Supply: Arch "Product" Some samples named as products, others at systems, semi-finished. Designers and companies as users have to know what this concept means. Applying: "Comparison" Similar to Better than-inspired by not clear. When it's empty it's confusing. Depends on data available. Suggestion: avoid n/a. Maybe Novelty/Innovation instead of comparison: get rid of similar to better than-inspired by and just put case study. "Application fields" i.e. Chromosome datasheet Experimental interactive textile surfaces. "Potential application: wearables, dynamic soft surfaces, interior design, signaling, interactive flags, and automotive." Check. Put examples of limits of materials in terms of applications, washable or not, sustainability, inspirational tool to understand potentiality of application. (Forget about materials' limitations) Also check excel with feedback from Polimi's experts	IMPROVEMENT	CONTENT	- Standard sheets for every toolkit of the 4 EM&Ts or adapt to every family? E.g. smart+sustainable properties (ICS wearables + Wood-based) - Change graphic system (some are yes or no) - Integrated glossary in box to put more parameters? i.e. another QR that leads to glossary + if technical sheet needed by user, put a link to company's website. - Replace physical "qualities" not "properties", suggestion for every category. - TRL indication more evident - Confirm concept "product" in Shaping in "Supply" - Check references with Materiality - Check Applying: section "Comparison" Similar to Better than-inspired by.
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Datasheets (physical)	Smaller box+materials' samples. Detachable datasheets that fell out. No images to put them in order again. Suggestion of layers, getting rid of lateral wings (TR02).	IMPROVEMENT	FORM	tbd
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Sustainable box (physical)	Suggestion: Do not use polylat, but cardboard self-assembling (no sustainability and transport complications). Lifecycle of toolbox: 3 years because of materials' evolution and become obsolete very fast. Bottom-up-approach and populate toolkit with online interaction of users, seed of database. Open source (open source file that can be stapled and replaced, but also because it can be updated by users, ref. openmaterials by Catarina Mota or Materialom.org , with peer-review.)	IMPROVEMENT	FORM	tbd
Venero Ferraro, Stefano Parisi (May 28, 2021)	ICS: Wearables - Miscellaneous (physical)	Put name of project and image of materials to place them on the cover and/or edge of toolbox to be able to compare it.	IMPROVEMENT	FORM	Consider putting name of projects on edge of book + images on cover

Fig. 15 Excerpt from "Feedback Toolkit v1 | Transnational Milan + KTL 2020 | Experts 2021 | Mobility WS 2021" [EM&T ICS: Wearables]

Shaping:

- Manufacturing Process
- Supply + Shape
- Transformation Process.

Application:

- Application Fields
- Comparison
- Case Study or some inspirations of applications.

One of the general changes is that the datasheets are now composed of 7 pages in the new version in a leaflet format (instead of the 6 previous pages).

Another big change is that the entire content and images of three new materials samples for the specific datasheets PTF inks (EM&Ts ICS Wearables), Fenix

Source	Areas	Feedback Toolkit v1 (Live revision of physical toolkit with experts via zoom May 2021)	Type of Feedback (POSITIVE / IMPROVEMENT)	Type of improvement (FORM / CONTENT)	Comments
Robert Thompson (May 19, 2021)	Nanomaterials - Materials' samples	Materials' samples still ok, interesting way of presenting it. FTM SDP Maybe change content presentation to be less monotone, textiles different colors (maybe other colors), patterns, ornamental, gold version of wire, color texture, out of your senses. Visual aspect to understand technology: the series, i.e. binbox (nanocoding)	IMPROVEMENT	CONTENT	- Any suggestion on a material sample change for a more colorful/striking one? - Prevent from opening the samples and greyish association
Robert Thompson (May 19, 2021)	Nanomaterials - Datasheets (digital)	9 new projects showcased in the respective moodboard different type of uses/applications: scale, states of carbon: surfaces, powder, fibers, foam power of images	IMPROVEMENT	CONTENT	- QR on digital datasheet with moodboard for 1st Mobility WS Technus. - Maybe change graphene carbon nanofiber for another reference (since not everything is in English)
Robert Thompson (May 19, 2021)	Nanomaterials - Datasheets (digital)	Too many physical references that limit. Different states and shapes of materials: define more classical ones and decontextualize new one. Redefine textiles, materials in solid states, how surfaces are made, integration with higher intelligence (digitalization, communications like comparing computing systems to nanotech)	IMPROVEMENT	CONTENT	- new selections or add examples, imagery? to curate some more examples 'look&feel' to get unstocked from grey colors
Robert Thompson (May 19, 2021)	Nanomaterials - Datasheets (physical)	Ergonomic part of detachable datasheets: you shouldn't lose things before you open it. The way it is glued in with a lip that hits the sheet. Make them more differentiated, they all look the same, loose time putting them into order.	IMPROVEMENT	FORM	- Make them more differentiated, datasheets all look the same, loose time putting them into order again.
Robert Thompson (May 19, 2021)	Nanomaterials - Sustainable box (physical)	How long should the box last? certification of paper, ink?	IMPROVEMENT	FORM	tdb
Robert Thompson (May 19, 2021)	Nanomaterials - Miscellaneous (physical)	Overall less nano-scary, grey, more colorful examples. Should be more fun looking at it in general. Maybe stand the box up, better way to keep them open in the middle of the table to have a better look at the sheets.	IMPROVEMENT	FORM	tdb

Fig. 16 Excerpt from “Feedback Toolkit v1 | Transnational Milan + KTL 2020 | Experts 2021 | Mobility WS 2021” [EM&T Nanomaterials]

Source	Areas	Feedback Toolkit v1 (Live revision of physical toolkit with experts via zoom May 2021)	Type of Feedback (POSITIVE / IMPROVEMENT)	Type of improvement (FORM / CONTENT)	Comments
Piirjo Kääriäinen, Tarja-Kaarina Laamanen (May 27, 2021)	Wood-Based - Materials' Samples	Change Arboceel for pulp sheets Background 2 Categories: Raw materials (for experimenting, Arboceel, materials produced out of raw materials (onceel, Timberfell, Sulapac, Huhtamäki) for B2B commercial materials. Auto and KEA more in an experimental, early-stage environment.	IMPROVEMENT	CONTENT	- Pulp sheets shipped? small bag with wood chips, grinded pulp - Provide description/explanation for datasheet (early-stage or basic part of any of the 4 examples produced with pulp sheets in the toolkit).
Piirjo Kääriäinen, Tarja-Kaarina Laamanen (May 27, 2021)	Wood-Based - Datasheets (digital)	7 new projects showcased in the respective moodboard (i.e. more experimental projects) Parameters: toxicity (skip it) Introduce short, simple glossary for sustainability + smart properties (compostability, biodegradability) onceel-F: take out "F" TRIL appreciated Indicate from who the info comes from (company ref.) Manufacturing processes: only stitching; add textile processing Applying: Comparison "similar to" better cotton + viscose	IMPROVEMENT	CONTENT	- QR on digital datasheet with moodboard for 1st Mobility WS Technus. - Indicate that info comes from company - add textile processing in "Manufacturing processes" - Introduce short simplified glossary with some sustainability-smart properties with some parameters? - Revise and add comments directly on datasheets for more errors/updates (i.e. take out "F", cotton + of viscose)
Piirjo Kääriäinen, Tarja-Kaarina Laamanen (May 27, 2021)	Wood-Based - Datasheets (physical)	Problem of lose datasheets: n/a	IMPROVEMENT	FORM	tdb
Piirjo Kääriäinen, Tarja-Kaarina Laamanen (May 27, 2021)	Wood-Based - Sustainable box (physical)	Lifecycle of physical box and adequate materials: feel "plasticity", in Finland this is recyclable and no problem, maybe a more "look-feel more sustainable" Maybe cardboard corrugated instead of the foam of the boxes.	IMPROVEMENT	FORM	- ask Veronica how it has been produced for the prototype - explore cardboard alternative
Piirjo Kääriäinen, Tarja-Kaarina Laamanen (May 27, 2021)	Wood-Based - Miscellaneous (physical)	Heavily reminds of video format! Add a sentence kind of: "What is it for" This is your toolkit for ... purpose/inspiration on the first page	IMPROVEMENT	FORM	-consider changing size of box

Fig. 17 Excerpt from “Feedback Toolkit v1 | Transnational Milan + KTL 2020 | Experts 2021 | Mobility WS 2021” [EM&T Wood-Based]

(EM&Ts Nanomaterials) and Arboceel (EM&TS Wood-Based) were substituted for “Flexinol”, “Nnf Ceram” and “Kraft Pulp” respectively.

To better familiarise the user with the specific terminologies used in the datasheets, a new section called “Glossary” was curated and included in the new datasheet’s layout. (Confront the section of this Book called Glossary)



Fig. 19 Understanding section

3.1.2 Shaping Section

The Supply arche and Shape icons were redesigned into more clearer indicators (see Fig. 20).

3.1.3 Applying Section

The “Comparison” section was changed into “Comparison and Innovation”. Also, all case studies were reviewed as well as updated, and wherever possible, added when missing (see Fig. 21).

3.2 Phase 07: Box Layout (Final Version)

Based on the feedback received for adopting the final version of the EM&T's toolkits' box, the main considerations were to find a solution to the datasheets falling out of the box when displaying it. The comments received from experts and users had indicated that it was a good thing to take out the datasheets of each EM&T's box to explore the data more in depth, but that it was not easy to do the sorting afterwards. Some ideas on how to attach-detach datasheets were that they could be open like a fan, book

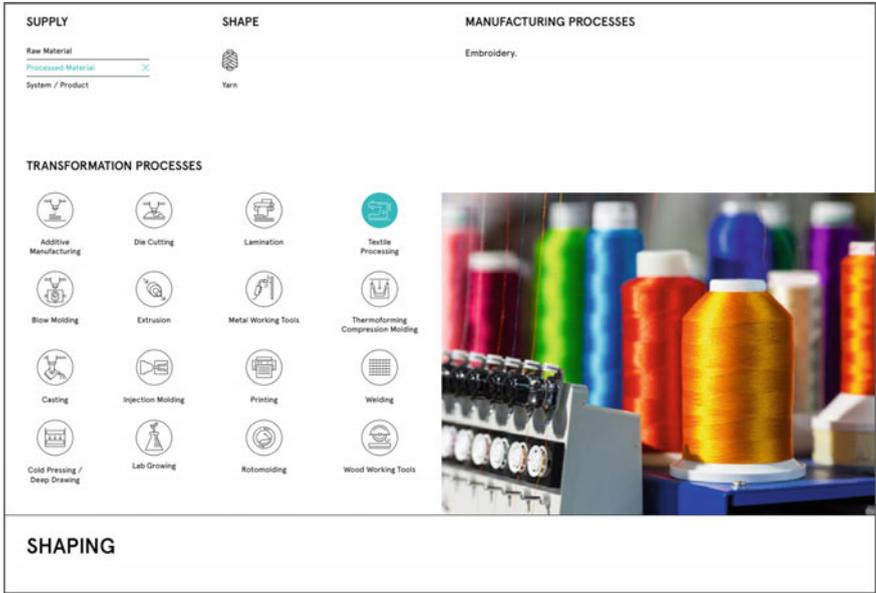


Fig. 20 Shaping section

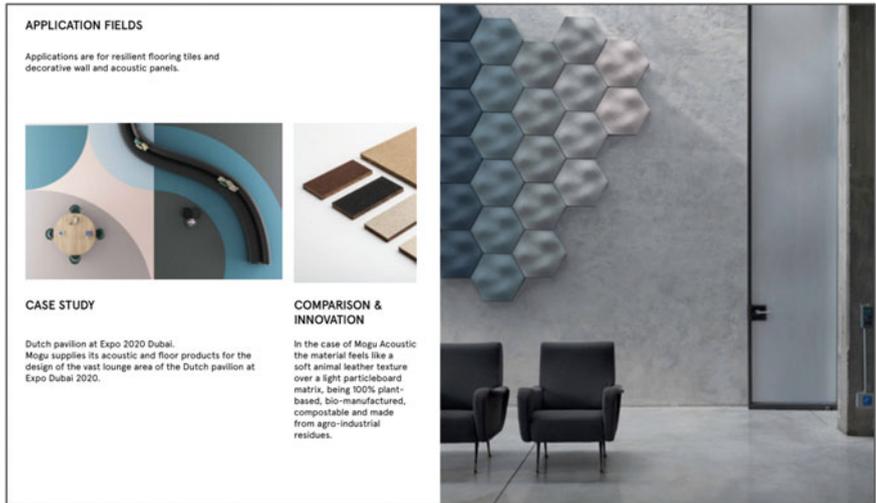


Fig. 21 Applying section

bended, or clicked to the toolbox with a ring. Also, more differentiation, for example with rubber bands or more distinctive datasheets might help to put the datasheets into order and each EM&T's toolkit again. Another input was to maybe stand the box up, as a better way to keep them open in the middle of the table to have a better look at the sheets.

The format of the datasheets and box of the prototype version was to be maintained since it is conformed to international standards (A5 DIN) and easier to foster large-scale fruition and dissemination of the toolkits.

Furthermore, in the process of revising the box, it was decided to keep the project's visual identity, while improving the design in a graphic, tactile, and logical sequence sense. Above all, it was important to give a clearer more intuitive twist for exploring the toolkits' data and materials as non- expert users while fostering their learning experience for later applicability to their own projects.

The content of the box was expanded with a text referring to the description and purpose of the EM&T's and DATEMATS project.

At the spine of the box the DATEMATS logo, EM&T area, and specific showcased material was inserted (see Fig. 22).

All social media, email, and contact were also added to the part of the logos of the consortium partners. To add the DMT (Design Methods & Tools) into the toolkit, FAD decided to put two additional QR on the toolkits' box with the links of the correspondent references with texts that lead to the information.

Also, and in line with the DATEMATS project values, a more sustainable production of the box with a sustainable "look & feel" was considered.

For this, an improved design of the box and datasheets layout for printing was proposed, reviewed, and implemented. The main inputs were to use a self-assembling

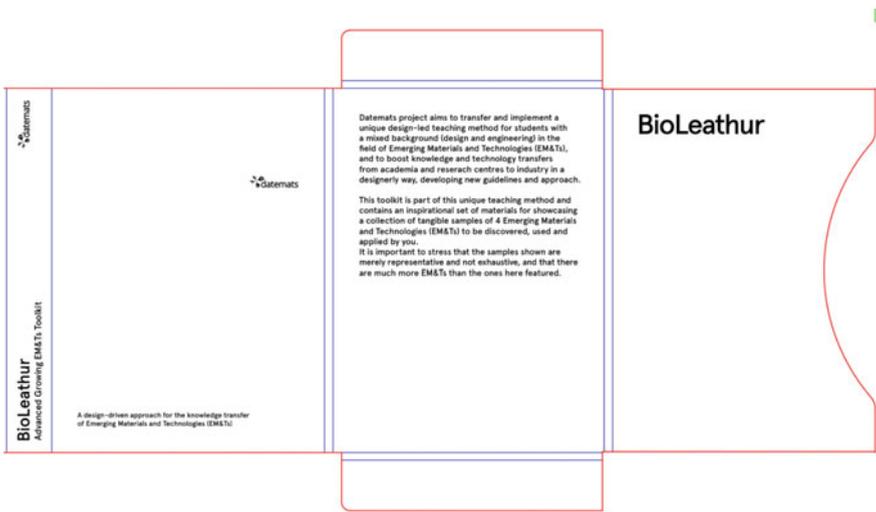


Fig. 22 Die cut template transfer toolkits final version outside

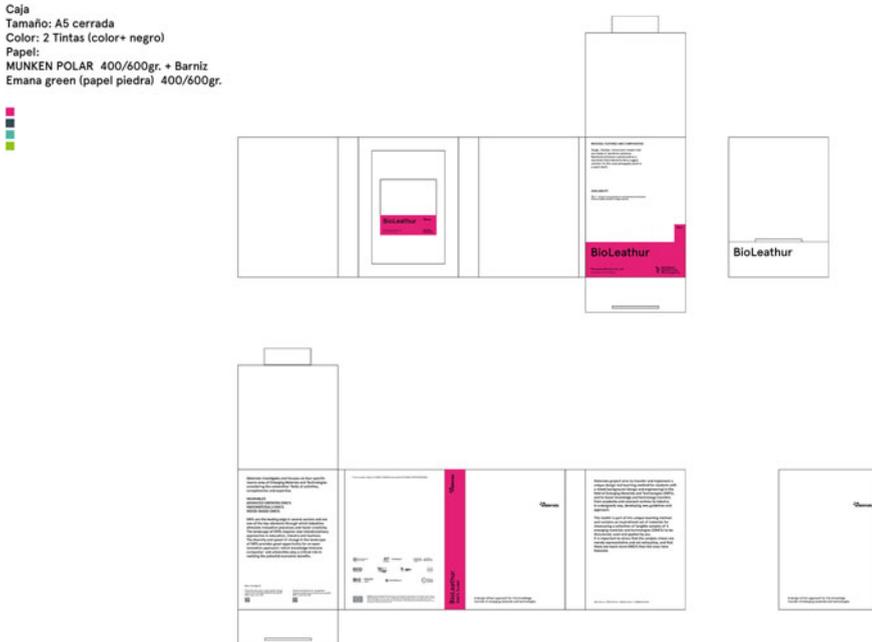


Fig. 23 Proposal box Munken polar

corrugated cardboard, sustainable paper, and ink for production. A substitute to the foam board where the materials samples lie in each EM&Ts box was to be found. It was decided to indicate on each box the materials that are being used for the toolkits' production, so a sentence explaining the purpose of the transfer toolkit was added.

Figures 23 and 24 show two options assessed, of which the craft version was the chosen one:

Finally, a booklet for each EM&Ts was designed and put into each box in an envelope. Also, each box was differentiated and marked with a rubber band of the respective colour of each area. The space for the materials samples had been also redesigned and the foam removed.

3.3 Phase 08: Production Result of the EM&Ts Toolkit's (Final Version)

Fig. 25 shows some images of the results of the final production of the 20 EM&Ts toolkit boxes:

Caja
Tamaño: A5 cerrada
Grosor: 3,5 cm cerrada
Color: 1 Tinta blanca
Papel: Craft
Gramaje: 400/600gr
Cantidad: 20 (con pequeñas modificaciones)
Goma elástica 4 colores

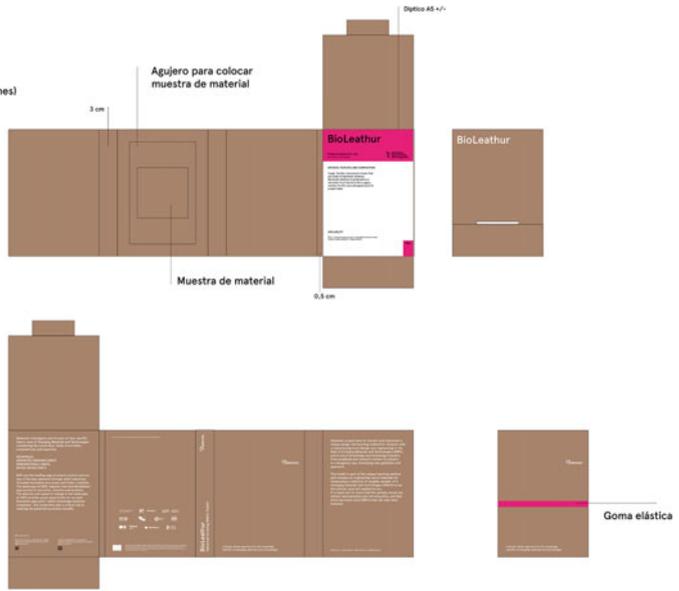


Fig. 24 Proposal box craft



Fig. 25 Final Toolkit images

4 Final Remarks on the EM&Ts Transfer Toolkit Process

During the process of improving the form and content of the toolkit from the first prototype to the final version it was important to maintain an inspiring and engaging set of materials to showcase a collection of tangible samples of all four EM&Ts, to be used by the target groups/potential beneficiaries such as academia and design professionals.

Also, it was important to stress that the samples shown in the toolkits are representative and not exhaustive, and that there are much more EM&Ts than the ones featured in the boxes.

The lifetime of the toolkits thus its material composition is approximately three years (because of the obsolescence of the materials samples or rather due to the evolution of the EM&Ts).

As part of the dissemination process the datasheets and layout of the box are going to be available as an open-source tool in a downloadable version on the DATEMATS' website.

Finally, the execution process of the toolkit provided a great opportunity to the involved partners' staff to assess and extend their expertise on emerging materials and knowledge transfer tools.

References

- Barati B, Karana E, Foole M (2017). 'Experience prototyping' smart material composites. In: Karana E, Giaccardi E, Nimkulrat N, Niedderer K, Camere S. *Alive active adaptive: proceedings of EKSIG2017, International conference on experiential knowledge and emerging materials*, June 19–20, Delft, pp 50–65
- Camera S, Karana E (2018) *Experiential characterization of materials: toward a toolkit*. In: Storni C, Leahy K, McMahon M, Lloyd P, Bohemia E (eds) *Design as a catalyst for change: DRS international conference 2018*, 25–28 June, Limerick. <https://doi.org/10.21606/drs.2018.508>

Gemma Esteban With a Degree in History from the Universitat de Barcelona, she is a cultural manager with a specialized professional background in the design and creativity sector. She has worked in the editorial field at *On Diseño* magazine and at *Sidi* (Selección Internacional del Diseño), managing actions aimed at promoting Spanish design to national and international level. Since 2010, as part of the FAD (Fostering Arts and Design) team, she has been participating in different initiatives that deal with every dimension of design (social, cultural, political and economic) and which have been realized in all types of formats: exhibitions; books and publications; festivals; promotional platforms; awards; congresses, conferences and debates; audiovisual projects; and services for professionals and businesses. She is currently part of the FAD projects department, and a large part of her work is focused on the coordination of Materfad, Barcelona's materials center, projects.

Geraldine Kann with studies in International Trade, Business and Marketing and a transversal career in project management in Spain, Germany and Bolivia. In 2018, she completed a post-graduate degree at IED in Trends Research on megatrends and consumer behavior to complete

and unify her strong analytical skills to pinpoint the driving forces behind the societal changes and the new opportunities this implies for diverse organizations. Geraldine's main interests range from circular entrepreneurship to emerging materials and technologies, all around food to urban mobility. She also currently works as a Consulting Project Manager at Materfad.

Veronica Sarbach is EU Project lead of Materially Srl Impresa Sociale and developed her expertise in project management of EU funded projects addressing material innovation, knowledge transfer and design for a circular economy during her former activity as Innovation Researcher and PM assistant in Material ConneXion Italia. Her active involvement in past and ongoing projects provides her with updated knowledge on design-driven material innovation (Light.Touch.Matters), research and innovation in sustainable material solutions (TRASH-2-CASH), knowledge transfer methodologies and tools. She managed the activities related to the development of creative concepts for Life M3P and currently coordinates the communication of project GRETE, FOSTEX and DATEMATS, as well as the creation of DATEMATS' knowledge transfer toolkit for emerging materials and technologies. She holds a bachelor's degree in product design, gained in 2006 from Nuova Accademia di Belle Arti Milano (NABA) and earned a master's degree in 'Colour design & Technology' from Politecnico di Milano.

Daniela Amandolese is member of Materially's EU Project team, developed her expertise during her former activity as Innovation Research and Library Manager in Material ConneXion Italia. Adjunct Professor at Politecnico di Milano (course Industrial Design) member of the Development Team of the Master Nature Generative Temporar IUAV of Venice for which she is visiting professor (courses Eco Materials & Reuse and Trend Research). She collaborated for a couple of years with the Politecnico di Milano as a researcher in the field of innovative materials and technology transfer. In the same years she has been working as a freelancer and has collaborated with companies such as Luxottica, YDF Young Design Factory, Som Group, Vismaravetro. She holds a Master's Degree Product Design from Politecnico di Milano.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Transferring Knowledge from Academia to the Companies: A New Method



Aitor Cazón-Martin

Abstract Collaboration between Academia and Industry must be considered as a path to innovation through the exchange of knowledge. Although this collaboration has existed for years by presenting and publishing together new methods in journals or conferences or through lectures or workshops taught by professionals with a focus on daily problems, differences in goals and timing are found as barriers for knowledge transfer. In an ideal scenario, this collaboration should lead to a win-to-win situation where companies increase competitiveness as it facilitates the integration and commercialization of new knowledge in their products, while Academia can obtain new research directions and additional financial power. In a real scenario, despite the efforts made to successfully carry out this transfer, there is still work to be done, since the literature shows that current methods used by Academia are not entirely working. In this chapter, the first section contains a review of published documentation that reflect the different practices that are being carried out for the transfer of knowledge between Academia and Industry to understand the current procedures for transferring knowledge, as well as the main channels used, and the barriers identified. The second section describes the new method or guide to facilitate this unidirectional knowledge transfer from Academia to Industry, especially when working with Emerging Materials and Technologies (EM&T). This method combines a Learning stage—to explain the fundamentals about the EM&Ts—and an Applying phase to explain specific strategies of how to come up with ideas to find new opportunities that link the emerging EM&T and the company's product strategy.

1 Literature Review for Knowledge Transfer

Knowledge transfer has been a primary concern to human being for centuries. Since the very beginning of our history, we have been learning new knowledge with each passing generation in many different life fields that, as a society, we are obliged to transfer to future generations. The knowledge that each generation inherits become

A. Cazón-Martin (✉)
Tecnun, University of Navarra, Pamplona, Spain
e-mail: acazon@tecnun.es

© The Author(s) 2023
V. Ferraro et al. (eds.), *Materialising the Future*, Research for Development,
https://doi.org/10.1007/978-3-031-25207-5_4

tools to improve future knowledge to come and to transmit to the next generation. At this point, it is reasonable to think that the way of transferring the knowledge should be related in some way to the type of knowledge to transmit. Then, two questions arise: (1) how can we define “knowledge”, and (2) could it be classified in some way?

A very general definition about knowledge can come from Oxford’s dictionary which defines it as “the information, understanding and skills that you gain through education or experience”. This definition can allow the reader to think that, indeed, knowledge can be classified in some way. In 1996, Polanyi (1996) distinguishes two types of knowledge: tacit and explicit.

- Tacit knowledge is more related to skills and experiences, is normally embodied in people (the knowers), and cannot be transferred without them [4]. It is the knowledge that people learn doing their job and cannot be codified or formulated by means of writings or drawings. Grant (1996) states that tacit knowledge is “knowing-how”.
- Explicit knowledge can be transferred without the presence of people because that knowledge has been previously codified or formulated by someone in the past. Grant (1996) defines it explicit knowledge “knowing-about”.

Tacit knowledge has been with the human being since the beginning of our history and, though not all tacit knowledge can be translated to explicit knowledge, most of this tacit knowledge was translated to explicit with the development of writing. However, a tacit knowledge becomes explicit only when instructions are clear enough to follow without the presence of the person that had that tacit knowledge.

Now that the types of knowledge are clear, how can this knowledge be transferred from the knower to the learner? Lockett et al. (2009) pointed out that the definition of knowledge transfer is still being controversial. beginning from the own denomination since many different names are used: “knowledge exchange” (Schartinger et al. 2002; Swart and Henneberg 2007), “knowledge dialogue” (Ruddle 2000), and “knowledge translation” (Czarniawska and Sevón 1996; Savory 2006). However, all agree that the existence of these two groups lead to a diversity of potential knowledge channels through which knowledge is transferred.

Given the diversity of knowledge, Brennenraedts et al. (2006) and Landry et al. (2010) summarized a variety of channels and activities that academic researchers use to transfer research-generated knowledge to industry. These are summarized in Table 1. As shown, channels include from the more orthodox activities like publications in books, journals, conferences, or workshops so the knowledge becomes available for many people; to other exclusive collaborations with companies by means of mobility of staff or licensing. When dealing with the binomial, type of knowledge—type of channel, researchers agree that, in general, explicit knowledge tends to be transferred by means of published research findings, and less media-rich activities like shared facilities and licensing patents. Controversially, tacit knowledge related to skills and experiences is better obtained by face-to-face contact meaning that internships, joint supervision, collaborative research, and the creation of joint ventures are the most

suitable for transferring this tacit knowledge (Karnani 2012; Alexander and Childe 2013).

In order to explore the frequency of use of different channels of knowledge transfer, Brennenraedts et al. (2006) carried out an interesting study with the help of all researchers of the Biomedical Engineering Faculty. They filled a questionnaire to measure the importance and frequency of use of the different channels of knowledge transfer. Results regarding frequency are shown in Table 2. As it can be observed, when asking Academia how frequently they use the abovementioned channels, they feel more comfortable with scientific papers, books, and conferences. The lowest scores were for licensing.

Table 1 Knowledge transfer activities

Knowledge transfer activity	Description
Scientific publications	Publication of scientific knowledge transferred in the pool of open science (Journal or Conference articles)
Practitioner-oriented publications	Books, magazines, online/social media, blogs, etc.
Teaching	Knowledge transfer achieved when students graduate and are hired by companies and other types of employers
Continuous cooperation in education	Contract education and training of professionals, Re-training of employees, influencing curriculum of university programs, providing scholarships, Sponsoring of education
Collaborative in R&D	Collaborative arrangements to conduct research undertaken by both academic and non-academic organizations
Intellectual property rights	Patents, licensing, etc.
Sharing of facilities	Shared laboratories, sharing of facilities (i.e. common use of machines), Common location or building (Science parks)
Informal knowledge transfer	Presentation to practitioners at events (e.g. seminars) or to specific organizations, interpersonal communications with practitioners, etc.
Spin-off formation	Development and commercialization of technologies undertaken by academic inventors through the creation of a spin-off company they own at least in part
Granted patents	Rights to anyone who invents or discovers any new and useful process, machine, article of manufacture, or composition of matter, or any new and useful improvement thereof
New product development	Knowledge transfer through new product development in which knowledge becomes embedded in a product
Mobility of people	Temporarily exchange of personnel of mobility from public knowledge institutes to industry or vice versa from industry to public knowledge institutes

Table 2 Preferred channel

Channel	Score (1–5)
Emitting licenses on university patents	1.17
Participation in fairs	1.35
Own double appointment	1.52
Temporarily exchange of personnel with industry	1.52
Teaching employees of the industry	1.52
University patents	1.61
Spin-offs	1.68
Contract advisement	1.73
Participation in boards of organizations	1.78
Participation in professional organizations	1.83
Contract research	2.02
Sharing facilities with industry	2.18
Not refereed publications	2.23
Supervision of a Ph.D. student	2.42
Colleagues who get (or have) job in industry	2.48
Graduates who get job in industry	2.48
Presentation of research at the industry	2.52
Networks based on friendship	2.91
Joint R&D projects with	2.98
Refereed scientific journals or books	3.2
Conferences and workshops	3.28

Despite these results were obtained taking as reference only one type of science field, in this case the biomedical field, these results could also be extrapolated to other science fields according to similar studies. In the European project “Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach (DATEMATS)” a similar questionnaire with a total of eighteen enquiries addressing different aspects to be responded was sent to researchers and academia’s professionals of 4 different universities involved in the DATEMATS project (Politecnico di Milano, Copenhagen School of Design and Technology, Tecnun Universidad de Navarra, Aalto University). The specialization area of the academic respondent were identified: sustainability, engineering, architecture, design, electronics material science. The size of the sample of respondents for this survey consists of forty-two in total coming from the four different universities (40% from Spain, 47% from Italy, 7% from Finland, and 5% from Denmark). The answers of the respondents were aligned with the study of Brennenraedts et al. (2006). Referring to the Academia methods to transfer research results, the answers obtained indicate that knowledge transfer is mainly done through (1st) the publication of articles (32%), followed, in the following order, by (2nd) patents (21%), (3rd) books publication (16%), and (4th) product samples elaborated specifically to get

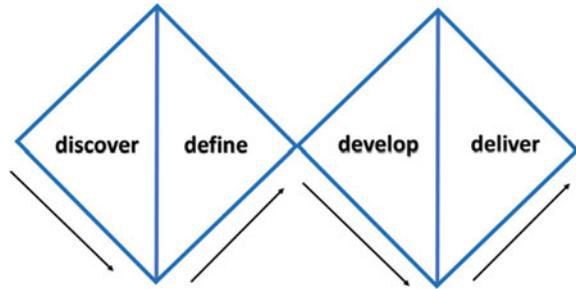
company's interest (14%). This behavior is common regardless of the area of expertise. When moving to a more dynamic (less academic) way of transfer, HEI's usually perform (1st) practical applications together with the company (26%), (2nd) developing case studies (21%), and (3rd) organizing workshops (21%). Respondents were also approached regarding the main troubles when transferring their results, the most common ones representing almost half of the total respondents are differences on time perception in academia and in industry including the fact academia can't adapt to the time reduction companies demand (25%) and finding relevant companies willing to go through a knowledge transfer process (23%).

Even if these channels are valid for knowledge transfer, there are various studies that point out that some individual factors like demographics, career trajectory, productivity, and the effect of scientific disciplines are also some other factors that affect the engagement undertaken by academic researchers in this knowledge transfer (Perkmann et al. 2013). Among these "other" factors, motivation could be the most important one. Chen et al. (2006) published that Academia has two main motivational factors that drive academic research: (1) extrinsic rewards (e.g. tenure, promotion, income increase), and (2) intrinsic rewards (e.g. an individual's satisfaction to achieve peer recognition and contribute to the discipline). Independently of what kind of motivation factors Academia staff follows, it seems that the selection of the proper professor is critical. An academics that engage with industry due to their personal willingness to make their knowledge base available to industry (Iorio et al. 2014) or because they sense the necessity of providing service to the practitioner community and promoting innovation through this acknowledge/technology transfer is of utter importance (Ankrah et al. 2013).

2 Guide Overview

The literature review showed that, although most of the researchers confirm that all the transfer activities undertaken are capable of transferring knowledge effectively, the channel to diffuse these results must be adequate to both Academia and Industries. One clear example is with journal papers: academia writes down and publishes research, so knowledge becomes public and accessible for many people; but companies argue that they have to hire personnel able to "translate" that publication to an actual application. As traditional channels are no longer effective, Academia usually has established activities that show practical applications of research results together with the companies along with activities to maintain companies' interest to maintain long term relationships and facilitate trust. These initiatives are done by means of workshops to make research methods and possible outcomes understandable, but here, there is not a consensus about what should happen in those workshops. This section will propose a guide to transfer the generated knowledge about EM&T to companies.

The proposed guide is based on the design thinking approach (Fig. 1). Design thinking is a process for creative problem solving to create a wide number of potential

Fig. 1 Double diamond

solutions and then narrow these down to a “best fit” solution. One of the most important aspects of this methodology is that it focuses on human values at every stage of the process and empathy for the people for whom you are designing is fundamental to this process. Nowadays, Design Thinking (<https://designthinking.ideo.com/>) is spreading in companies all around the world, diminishing hierarchies, creating an environment that challenges the status quo, and encouraging innovation and smart risk-taking. With design thinking, organizations can accelerate emerging technologies’ adoption process and reduce the resistance to change. When design thinking is deeply embedded in an organization’s culture, it becomes easier to adapt to the new trends and changing market conditions. In the context of these workshops, Design thinking principles and processes will inspire companies’ representatives to discover new opportunities that can emerge from EM&T application in their companies and product/services portfolio (see Fig. 1).

The guide is divided into three main parts. First, it covers a recruiting phase to catch companies’ interest about EM&Ts, so they feel the guide is going to be efficient in terms of time-investment. Then, a learning part is introduced to discover the basics about the EM&T they want to learn and finally, an applying phase is covered in order to define, develop, and deliver solutions that link the EM&T and the company’s core. Learning and Applying parts will have the help of some tools to design with and for EM&Ts.

2.1 Promotional Part

This part aims to catch the attention of potential companies interested in working with this EM&T and will be valid to distinguish whose companies are really interested in this transfer and, in the end, which ones are going to be involved with all their efforts in the rest of the activities.

For this pre-stage, an advertisement or short promotional video—different for each EM&T—showing the goodness of the EM&T and the potential of the EM&T for companies must be prepared. This short video (less than 30 s) should be published in Academia homepage and distributed among companies with which Academia has

contacts. It is advisable that all these videos are recorded by the Academia ad-hoc, hence Academia, or the researchers involved, can control the contents of the video and decide what to tell about the knowledge transfer activity of the EM&T.

2.2 Learning Part

After recruiting companies and prior to beginning with the LEARNING phase, staff from companies who are going to be candidate to be involved in the knowledge transfer must be selected. To this end, at least two people with different roles within the company shall be selected. On the one hand, a person with a technical background more focused in the daily technical aspects of the company; and on the other hand, a CEO profile with a wider vision of the company whereabouts so as to detect future applications of the EM&T. They must have power decision making within the company.

Once future knowers are selected and before moving to a more practical stage, the LEARNING part can begin. LEARNING establishes the basics about the EM&Ts that companies want to implement. This LEARNING is a two-step process: in the UNDERSTANDING phase, a more conceptual or theoretical knowledge about EM&Ts is explained to companies while in a later EXPLORING phase companies can touch or play with EM&T samples.

2.2.1 Understanding

Although a more practical approach is the core of this guide, a theoretical vision is still necessary to understand and introduce EM&Ts. The information this part must cover should be the answers to the following questions:

- What is the EM&T?
- What is the current status of the EM&T (Technology Readiness Level—TRL).
- What is it for? Possible applications at the current TRL.
- Expected developments in coming years and future applications expected.

This information can already be found combining several sources of literature, but companies do not have time for this search. So, in this stage a more visual and condensed content should be prepared by the Academia.

The first option to go for will be to explain this theory by life presentations made by materials experts so companies can interact with the expert since the beginning. If not possible, the most appropriate tool selected here will be a collection of media files (video preferably) that help to answer the abovementioned questions. The selection of the videos will be done according to the respective EM&Ts and having in mind the specific contents that want to be transferred to companies.

Regarding the preparation of the contents themselves, author wants to encourage Academia to record on-purpose media for this phase where the knowers (the

researchers from the Academia) explain the EM&T. This option will allow the distribution of the contents to the companies really interested in the EM&T, giving only to them that exclusive knowledge. Nevertheless, if media files generated by other researchers and found in platforms (YouTube, Vimeo, etc.) are willing to be used, the intellectual property/copyrights must be noted to know if the video as it is can be modified (trimmed/info augmented) if necessary, to improve the contents. Independent of the origin, these videos should feature:

- A paragraph of 3–4 lines indicating the learning outcomes expected after its viewing.
- A duration of less than 5 min. After that time, the viewer can lose interest.
- Markers identified with some keywords at specific key points (min: seconds), so the viewer can review and access specific aspects of the contents easily.
- An image quality of 720p at least.
- An audio in the proper language, preferably be in the local language of the company for a better understanding of the EM&T. If not, English should be the next option to follow.

These videos are presented to the companies with the help of an expert. This person should be an expert in the corresponding EM&T in order to briefly introduce what each video is about during the ongoing of the Understanding phase. Later, this expert will be leading the Exploring phase.

At the end of these videos, some questions can be included to help consolidating the contents of the videos. In addition, the expert of the Academia can solve any doubts that participants may have regarding the contents of the video, so she can verify that the company has learned the most fundamental aspects. If needed, the learning outcomes proposed by each video can also be quantified using for example kahoots.

Some video samples for the DATEMATS project can be found in the reference section for the understanding of WOOD-BASED (by Aalto), ADVANCED GROWING (by KEA), ICS: WEARABLES (by Polimi), and NANOMATERIALS (by Tecnum).

2.2.2 Exploring

The theoretical UNDERSTANDING part is followed by an EXPLORING phase aimed at making the company be aware of the full potentiality of the EM&Ts by touching or playing with EM&T samples. The key tools for this phase are the EM&T transfer toolkits (Fig. 2).

The EM&Ts toolkits are a collection of tangible samples that facilitates the understanding and application potentials of emerging materials and technologies. Hence, companies can interact with them and empathize with the material. Each kit must contain the following items (Fig. 3):

- Physical samples of the EM&T



Fig. 2 Example of transfer toolkit

- “Understanding” card with information about the material and the manufacturer
- “Shaping” card with information to understand how the material can be processed for production, finishing, and transformation
- “Applying” card with information and pictures about the field the material is currently used.

The idea is that the expert of the Academia explains the toolkits of the EM&T while participants play/touch them. The expert can also explain successful stories of companies that have implemented this EM&T and, if possible, these case studies should be close to the products/services that companies work with. This approach implies that several copies of the EM&T transfer toolkit are needed. It is thought in one per group. Perhaps it could be a good idea to have one toolkit for company, so, at the end of this collaboration, the company can get that toolkit to its facilities. This will be an excuse to find future collaborations/projects with it.

For this phase, people from companies can be working in groups of 3–4 people but trying not to mix people from the same company in the same group. If the knowledge transfer process is going to be done with people that belong to the same company, create the groups mixing people from different departments.

2.3 Applying Part

This dynamic part should be used to come up with the EM&T applications for every company. This involves the definition of the opportunities and the developing and



Fig. 3 Example of cards: understanding (top), shaping (center) and applying (bottom)

delivering of solutions. Although design thinking is becoming a well-known strategy for companies, it could be a good idea to explain the tools to be used in the following steps now, so everyone can know the steps to follow. Some useful material can be found in IDEO webpage, that offers a toolkit that contains the design thinking process overview, methods, and instructions that help to put design thinking into action [IDEO]. It could be a good idea to employ success stories from any company where design thinking was implemented in the specific EM&T.

Once the tools have been explained, participants working in the same groups created in the EXPLORING phase are asked to:

- Come up with as many possible uses as possible for the various materials. What kind of opportunities can the company find for that EM&T? Here, a Jam board with ideas written in post can be used (see Fig. 4).
- Select promising ideas to further develop and make simple mock-up models, illustrating and explaining their ideas (see Fig. 5).
- Present their best ideas to other groups to receive feedback.

This part should be led by a moderator that plans, guides, and manages each group event to ensure that the group’s objectives are met effectively, with clear thinking, good participation, and full buy-in from everyone who is involved. For this dynamic part, although advisable, the moderator must not be an expert in the EM&Ts but must have a deep knowledge about design thinking. Nevertheless, depending on the EM&T an expert could also join him/her to solve doubts groups can have specially when potential material uses sparked new questions among participants.

In this part, the moderator/expert should be especially aware about the background and experiences of the members of each team, since there is a big difference between receiving information and then create with those materials: if someone already has knowledge, it is difficult to innovate; if someone has no knowledge, it is difficult to create.

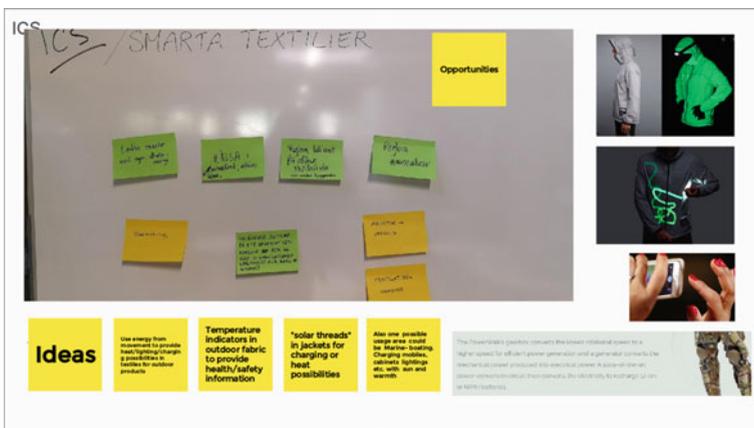


Fig. 4 Jam board used by online participants, with uploaded photo of actual whiteboard

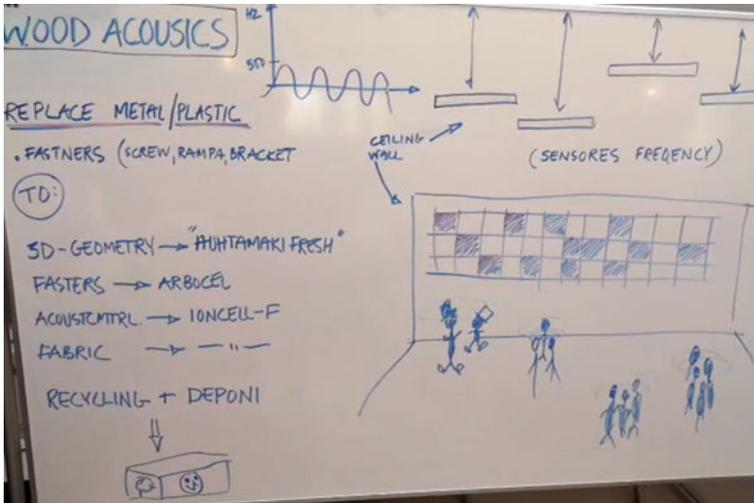


Fig. 5 Design concept of wood-based acoustic panels

2.4 Guide: Time Structure and Validation

Same as importance as the content of the knowledge transfer process is the timeframe dedicated to it with Academia and company moving along. The reader must take the timeframe suggested in the following lines as a guideline and must adapt it depending on the circumstances. The duration of this transfer activity is estimated for 4–5 h divided into the following parts (Table 3).

Table 3 Timings for the knowledge transfer activity

Part	Duration (')	Activity
Introduction	15	Goal of the activity. Schedule. Time Participating companies
	15	
Learning	30	Understanding Exploring
	45	
BREAK	15	
Applying	30	Defining Develop and Deliver
	60	
Presentations	30	Feed-back

3 Knowledge Transfer Labs: Guide Evaluation

The purpose of the knowledge transfer labs was to validate the EM&T knowledge transfer method developed. This guide was evaluated in 3 different countries (Italy, Spain, and Sweden) with the help of 94 companies that involved 124 people. The approach was hybrid, mixing on-site and online participants (Fig. 2). The EM&Ts involved were WOOD-BASED, ADVANCED GROWING, ICS: WEARABLES, and NANOMATERIALS.

In each workshop, the guide was followed, and the most important points were evaluated afterward by participants. These points included the presentations from material experts the EM&T Transfer Toolkit and the workshop format/method (see Fig. 6).

- Regarding the experts' presentations, participants found the contents relevant (rated 4.5 out of 5) and they felt nice to hear experts from different areas. Although in this understanding part experts try to explain things in an easy-to-follow way, some participants found some theory difficult to follow. They would like to have these presentations to read them carefully in order to understand better what the experts explained.
- Regarding the toolkit, participants found the datasheets relevant and easy to understand (4 out of 5). They appreciated the interaction and the round of questions to the experts about the sample book but pointed out that investing more time exploring the materials and the cards may have help them in the applying part. But in general, they found it as a good tool for coworking and ideas development.
- Regarding the workshop format, most of the participants agreed that the structure is enriching and very good as an introduction. To the question about suitability of the format to explore materials possibilities and properties, they rated it with 4.2



Fig. 6 Onsite and online participants discussing ideas in Sweden

out of 5. However, some suggestions about the extension of the workshop arise to investigate feasible proposals and come to plausible conclusion.

Evaluating the whole experience, and when asked to rate the most valuable activities for their learning, participants put presentations from the experts and the opportunity to interact with them at the top of their list. Collaborating with other professionals was also a popular choice.

4 Conclusions

Collaboration between Academia and Industry must be considered as a path to innovation through the exchange of knowledge. However, this transfer is not properly working since companies do not find useful the channels used by Academia, especially when dealing with EM&T. This chapter has proposed and validated new method or guide to improve this unidirectional knowledge transfer from Academia to Industry. This method combines a Learning stage and an Applying phase. In the Learning part, companies interested in the EM&T knowledge learn the fundamentals about the EM&Ts with the help of experts and video files. This learning process is complemented with a material sample toolkit where participants can feel/touch some physical samples while at the same time they can read particular properties written in datasheets within the kit (Understanding, Shaping, and Applying cards). Finally, in the Applying phase, design thinking tools are proposed to find new opportunities that link the emerging EM&T and the company's product strategy. The most valuable step for participants were the presentations and the feedback obtained from experts during the knowledge transfer activity.

References

- Alexander AT, Childe SJ (2013) Innovation: a knowledge transfer perspective. *Prod Planning Control* 24(2–3):208–225
- Ankrah SN, Burgess TF, Grimshaw P, Shaw NE (2013) Asking both university and industry actors about their engagement in knowledge transfer: what single group studies of motives omit. *Technovation* 33(2–3):50–65
- Bosley DS (1995) Collaborative partnerships: academia and industry working together (Symposium Part IV). *Tech Commun* 42(4):611–619
- Brennenraedts R, Bekkers R, Verspagen B (2006) The different channels of university-industry knowledge transfer: empirical evidence from Biomedical Engineering. Working Papers 06-04, Eindhoven Center for Innovation Studies, revised Feb 2006
- Chen Y, Gupta A, Hoshower L (2006) Factors that motivate business faculty to conduct research: an expectancy theory analysis. *J Educ Bus* 81(4):179–189
- Czarniawska B, Sevón G (eds) (1996) *Translating organizational change*, vol 56. Walter de Gruyter DATEMATS project. Understanding videos (2020) <https://www.youtube.com/channel/UC6CQUQsViUrbS99h-veQ6Nw/playlists>. Accessed February 2022

- de Wit-de Vries E, Dolfma WA, van der Windt HJ, Gerkema MP (2019) Knowledge transfer in university–industry research partnerships: a review. *J Technol Transf* 44:1236–1255
- Design Thinking for Educators Toolkit. <https://page.ideo.com/design-thinking-edu-toolkit>. Accessed February 2022
- Garousi V, Petersen K, Ozkan B (2016) Challenges and best practices in industry-academia collaborations in software engineering: a systematic literature review. *Inf Softw Technol* 79:106–127
- Grant RM (1996) Toward a knowledge-based theory of the firm. *Strateg Manag J* 17:109–122
- Iorio R, Labory S, Rentocchini F (2014) Academics' motivations and depth and breadth of knowledge transfer activities, c. MET Working Papers, c. MET-05—Centro Interuniversitario di Economia Applicata alle Politiche per L'industria, lo Sviluppo locale e l'Internazionalizzazione
- Karnani F (2012) The university's unknown knowledge: tacit knowledge, technology transfer and university spin-off findings from an empirical study based on the theory of knowledge. *J Technol Transf* 38(3):235–250
- Landry R, Saïhi M, Amara N, Ouimet M (2010) Evidence on how academics manage their portfolio of knowledge transfer activities. *Res Policy* 39(10):1387–1403
- Lockett N, Cave F, Kerr R, Robinson S (2009) The influence of co-location in higher education institutions on small firms' perspectives of knowledge transfer. *Entrep Reg Dev* 21(3):265–283
- Perkmann M, Tartari V, McKelvey M, Autio E, Broström A, D'Este P, Fini R, Geuna A, Grimaldi R, Hughes A, Krabel S, Kitson M, Llerena P, Lissoni F, Salter A, Sobrero M (2013) Academic engagement and commercialization: a review of the literature on university–industry relations. *Res Policy* 42(2):423–442
- Polanyi M (1996) *The tacit dimension*. Routledge, London
- Ruddle K (2000) Systems of knowledge: dialogue, relationships and process. *Environ Dev Sustain* 2(3–4):277–304
- Savory C (2006) Translating knowledge to build technological competence. *Manag Decis* 44(8):1052–1075
- Schartinger D, Rammer C, Fischer MM, Fröhlich J (2002) Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. *Res Policy* 31(3):303–328
- Swart J, Henneberg SC (2007) Dynamic knowledge nets—the 3C model: exploratory findings and conceptualization of entrepreneurial knowledge constellations. *J Knowl Manag* 11(6):126–141

Aitor Cazón-Martín is Associated Professor at University of Navarra—Tecnun (Spain). He holds a Ph.D. (2009) and a M.Sc. (2003) in Mechanical Engineering both from University of Navarra—Tecnun. In 2009, he holds a position the Industrial Design Area where is specialized in Additive Manufacturing covering the CAD/CAE steps and the final manufacturing of the part. He has been collaborating in more than 25 R&D projects funded by both private companies and public bodies leading to more than 23 scientific papers in peer-reviewed journals, 12 international conferences and 5 book chapters. Currently, he lectures on 'Prototypes', 'Eco-design', 'Validation Techniques' and 'Making & Hacking' to Bachelor students and 'Design and Testing of Machines' to Master students. He has supervised two Ph.D. theses and more 120 bachelor and master thesis projects. He has obtained a six-year research from the national committee for the assessment of the research action between 2012 and 2017 (CNEAI). He is reviewer of several scientific journals such as *Rapid Prototyping Journal* and *Advanced Manufacturing Technologies*.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Field Studies: From Ideation to Applications

Applying DATEMATS Methods and Tools to Nanomaterials: A Design Challenge by the Company Antolin



Robert D. Thompson Casas

Abstract A current area of R&D focuses on developing optimal workshop methodologies which are based on didact-creative programmes specifically tailored to stimulate creative insight within participants, through the delivery of perfected techniques in both knowledge transfer and creative development sessions. The overarching goal of these methods is to develop and deliver new and useful projected applications of material properties and technologies which, when combined, can progress into new and previously unforeseen advancements in innovation across diverse fields of applicability. Here, contending technologies, whichever they may be, are presented to a select public of participants, followed by various collaborative creativity techniques whereby the assimilated information is collected, categorized and then re-assimilated into new forms of innovative ordering, structuring and integrated storytelling. Although a number of creativity and technology building workshops exist, this particular study relates to the methods for developing new art applications from distinct physio-chemical traits found among a diverse collection of nanotech materials, including and in particular, carbon-based ones. An object of this paper is to disclose the specific didactic and creativity techniques used in a workshop setting which was performed in collaboration with the Antolin group who is a manufacturer and provider of helical carbon nanofibers. A further objective of this paper is to derive conclusive evaluations and insights regarding the successes and failures encountered during the knowledge transfer phases and their conversion into creative insights and market potential. Various creativity fostering strategies are presented as they were adopted through third-party mediated practices in similarity-finding, inductive and deductive reasoning, exercises in free-association/abstraction and visual Imagination of scientifically supported product outcomes.

R. D. T. Casas (✉)
Materfad, Barcelona, Spain
e-mail: training@materfad.com

1 Introduction: A Look into the Binary Relationship Between Problems and Solutions

There is great interest among universities and businesses alike to perfect didact-creative techniques which promote productive applications of neo intellectual property from diverse research fields, into viable innovation practices. Of particular interest today is finding ideal uses for emergent materials and related technologies (EMTs) stemming from R&D advancements in the areas of materials science and engineering.

Functionalizing knowledge into creativity is a specialized objective of actual collaborative research, shared between both academia and industry, which aims to foment increasingly efficient and rapid applications for new materials technologies into products, systems and their related services. Efforts in this regard can be grossly subdivided into two main tasks, namely a primary educational component, whereby knowledge regarding new materials and their properties is disclosed in some optimally didactic fashion, and another where the information is functionalized into actionable ideas, suitable for specific types of application. While the former task focuses on disclosing factual data, concerning quantitative aspects of scientific nature, the latter step is a more qualitative and intuitively inspired medium which serves to translate discrete concepts into less defined metaphorical abstractions of broader applicability.

Both tasks are dominantly expressed in a medium of specialized language use (terminology) and diverse forms of divulgative visual communication means (imagery, motion and diagrams). In fact, storytelling is a relatable didactic technique which is often used to convey and process information into new forms. Storytelling is a common communication tool since it aligns itself with the ways in which we experience phenomena of the real world, including how we come to grasp concepts underpinning highly complex processes of scientific observation, or more subtle emoto-artistic expressions in art. Story is the method by which we feel and recreate memory and creativity through pantomime, impersonation and metaphor. Both the processes of indoctrination and emancipation of ideas undermine notable non trivial challenges in their numerous methods of execution. Many factors, including but not limited to, set and setting, group dynamics, clarity in communications and generating a creative mood, can greatly affect the perceived outcome of didacto-creative workshops and the results they produce.

Academia has been refining its didactic techniques across diverse information delivery styles and conducting ongoing live experimentations in several domains of learning. For instance, a primary area of academia focuses on developing knowledge transfer protocols via competing delivery modes (lectures) and pathways (digital platforms). Among these there are other contending learning and inspirational tools (materials toolkits) which provide peripheral didactic support and means to reinforce learnt matter into relatable structured diagrams, especially during the transition from understanding to applying phases, providing intuitive, easy-to-understand visuals and comparative performance diagrams. These further serve as inspirational beacons for

the latter creative phases as they provide explicit examples of potential materials applications and cues set in place by example of third-party sources (didactic + inspirational materials toolkits).

As distinct areas of academic focus grow and subdivide into various specialized in-depth fields of study of isolated narrowing advancement, other contending efforts are promoted, in parallel, to instigate interdepartmental involvement and cross-pollination between competing areas of study. The aim of expanding knowledge across boundaries through horizontal transmission is to lessen the knowledge band gap across neighbouring areas of study with the goal of bridging the sciences with humanities forms of language, both mathematical and verbal.

Furthermore, transversal knowledge sharing has often demonstrated a tendency to catalyse information across a gradient of ramified potential driving discovery and inspiring disruptive ideas into spin-off technologies, which emerge by the effects of distinct intellectual domains into mixed synergies of opportunity.

Finding and perfecting ideal didactic methodologies of exchange constitutes a dominant key factor of how well and quickly newly learnt information is processed into new ideas. Indeed, for this to occur, several components must overlap and synchronize so that new information can be first assimilated then functionalized into something new or selectively different. In detail, information must first be transferred adequately through semantic comprehension (through effective linguistic communication), then it must be assimilated into cognition through comparative associations with known analogy (i.e. pre-existing known ontological frameworks and principles). Lastly, the information must be recalled into memory with acceptable accuracy whereas the memory can reconstruct a learnt concept into its original ontological precepts and outcomes with adequate detail, sequence and patterns of agency. This last component, recollection, is a highly variable factor over time and thus must be aided, in part, by mnemonic tools (memory enhancement and reinforcement methods). If the acquisition of information is the process of depositing conceptual phenomena into cognition through story, then knowledge is the corresponding act of recollecting and/or recreating that story in terms of meaning. The process of understanding, which is a step further than knowledge, is achieving mastery over the logic and causal sequence driving phenomenological events and the specific principles underpinning their nature. As understanding deepens, concepts can be simplified into larger clusters of relative influence and similarity but also mixed into each other with some degree of predictability over new outcomes. In other words, understanding not only coagulates known information into a collection of principles, but can further serve as a platform from which new principles can be extrapolated by analogy, projected forwards and integrated, through imagination, into new areas of directed focus. Imagination is the bedrock upon which creativity emerges by confluence of disparate types of understanding into new patterns of association. Imagination is also the narrative of thought, visual and/or verbal, which, through language, is called into being. In this sense, understanding is a fundamental and necessary precursor to the act of creative outcome and problem solving.

Effective pathways of data exchange are considered to be those in which information is conserved and accumulated into larger pools of shared knowledge from

source to destination. Commonly known as “knowledge building” activities, simple concepts are accrued, within the psyche, into a constructed body of knowledge whose structure can self-reinforce by the interlinking of new information with the old. As knowledge builds and integrates into experience through repetitive use and memory, it can then be reconfigured and coaxed into new data set patterns via experimental rearrangements and/or reinterpretations of its contents. At the very basis of creativity in fact lies this primordial tactic of manipulating assimilated information into new functionally and collaboratively structured directives. Of course limitations depend heavily on the quantity and quality of data available as much as the individual-to-group ability to process and communicate it accordingly. Creativity is triggered within the groups by setting up a problem void (mission statement) which challenges the status quo through confrontational conditions such as a paradox or a latent technological problem for which a solution must be found. The premise states that, while there are clear gradients of capacities among people, in terms of their inherent capacities, creativity is a rather ubiquitous feature of the mind and thus it can be inspired within anyone, given the right informational, emotional conditions and techniques. The second premise is that creativity is a systematic process which can be coaxed into diverse expressions through manipulations, elaborations and recombinations of its constituting foundational variables. The broader the bedrock of knowledge variables, the greater exponential outcomes of potential combinations can arise. This idea is, of course, antithetic to the more traditional idea of creativity as a random act of divine insight available to a few lucky individuals. Although creativity can happen in the natural world without agency, the type we cover is one founded upon directed applications of known data into directed goals.

The quasi-algorithmic approach developed in this workshop seeks to solve problems through clever assemblies of known artefacts and jettison them into orderly patterns of newly synergistic collaborations, whereas to create a thought-out concatenation of sequential material functions and properties into products. This requires insight as much as it does logical thinking, ability to extrapolate concepts out of their natural domains and transpose them in mapping terms over existing problems searching for fitted accommodations.

Diverse teaching methods demonstrate a spectrum of efficiency and avail over long-term understanding recollection of new information and its use potential across different innate intellectual dispositions of people (Ferrara and Lucibello 2012; Tamez and Vega Cantú 2019). Thus, one single method of information delivery is not recommended, but rather a diverse and rich platform of information delivery and processing is most probable to achieve assimilation in critical mass. Combinatory methods of information delivery such as those which enable both linguistic and visual disclosures into imagery and sensorial inputs also prove to ameliorate the rate and quality of information recall as the involvement of a multisensorial spectrum tends to encapsulate data into packets of higher definition information bits.

Using memory building techniques, such as repetition, emphasis and anchoring, which catalyse processed information into clustered subroutines are effective ways to boost memory recollection through the shorter pathways of associations which are

inherent between related information characteristics. Memory is essential to knowledge since you cannot know that which is not available to memory, thus mnemonic strategies are ligands which through recollection are able to cross link information into novelty.

A dominant objective of this workshop in general is to serve as an intellectual tool for understanding and applying solutions to everyday real-world difficulties (Sebastian and Jimenez 2016; Lisotti et al. 2014; De la Rosa 2007). While knowledge grants us some insight into a more accurate phenomenological explanation of real-world patterns, it is also the basis from which we may predict and explain future related outcomes through an extrapolative intent into newly imaginative potentials. Thus, because of information processing of a specific kind, new areas of actionable development can arise when knowledge is transmuted into creativity as it is mapped onto other unknown and speculative domains.

2 Language and Communication

An imaginative mind can be potentiated and directed in terms of meaningful objectives and planned execution when triggered by one stimulus or another and brought into an intellectual and emotional state whereby it begins to generate compositional stories of newly formed patterns from previously known patterns (Karana et al. 2013; Piselli et al. 2018a). Complexity can be built up from simple intertwining of stories, through language. These stories, which can be intellectually visualized and reinforced by the descriptive qualities of language, become the primary method of both didactic delivery and the mechanisms through which innovation is described, shared and finally realized into products. Language is an essential technology explored in this workshop, used both as a communications tool for technology transfer as well as a vehicle for the elaboration of inbound and outbound information flow. In this workshop, we are also testing how ideas can influence other ideas into existence by encapsulating them, in meme form, into resulting physical and ideological embodiments of design and the decisions which express the functional goals desired, the aesthetic choices through an approach invested in materials and their properties.

Indeed, our understanding, identification and recollection of reality is intrinsically and steeped in a linguistic medium. Furthermore, the depth and level of our understanding is described by our proficiencies in clarity and terminology use of the variables used to process inbound and outbound information. We cannot know what we cannot describe to ourselves nor others (Veelaert et al. 2016; Piselli et al. 2018b). Since language is itself, a structured algorithm embedded in cultural context, distinct languages and their use are noted to have differential impacts upon the subtleties of interpretational angles which individuals express.

Direct applications of technology into production through design and engineering is not a new phenomenon, however, efforts in making this transition more fruitful via the involvement of larger, multidisciplinary, multinational groups across a common linguistic medium and within limited time constraints, is.

Industrial advancements have always been brought forward by the catalytic effect of scientific discovery and our methods for understanding it and explaining it. Since innovation emerges from the presentation *ex novo* of new data, ideas become tendentially disruptive by virtue of the novel principles underpinning it as much as our ability to put into words the descriptive aspects of its novelty and differentiations (Bianchi and Lucibello 2018).

Indirect methods of innovation, on the other hand, which rely on and emerge as a concrescence of describing the overlapping phenomena between multiple technology mixtures are more complicated to describe as data variables are broader but, if it can be woven into a larger collective story, can reach higher applicable potential due to the multifaceted nature of exploitable combinations. This workshop explores a series of concerted collaborations between creative and scientific groups, both using distinct terminologies and composed of a variety of people with radically diverse educational backgrounds and interests (Ramalheite et al. 2010; Asbjørn et al. 2016). This segmentation was found to offer a more contrasting, creative and self-critical attitude of departure, which as a whole tended to accelerate the stages of idea development over less time. Among the variables which influenced group effort outcomes, though, were the strategic compositions of the groups, the linguistic methods used to impart information across them, as well as the idea fostering techniques which enabled a variety of fundamentally distinct directions of applicability across many sectors. This latter aspect was explored by allowing a multitude of approaches to flourish towards problem solving using a shared linguistic medium through which creativity could explore radically new imagination types and logical reasoning processes.

3 Educational Process

A full disclosure of the various nanomaterials and their properties was among the first steps in the workshop process. Information was delivered through spoken word with a comprehensive supporting glossary regarding the specific terminologies used to describe phenomena which can be expected to occur in the sector of nanomaterials and the processes of fabrication. Given that most of the activity of nanomaterials are, by virtue of scale and speed of action, not perceptually self-evident but in fact unperceivable by the senses, didactic contents covered by lectures were delivered in a specialized manner which would allow its contents to be comprehended via explanatory theoretical models supported by various forms of infographic support, delivered in parallel (see Fig. 1).

These included a variety of communication peripherals ranging from representational images of nano structures and elements, pictorial diagrams of illustrative nature and numerical tables disclosing quantitative performance qualities (see Fig. 2).

In addition to the explanatory videos describing methods of production and application of nano structures were disclosed so that one could understand behaviours of their influential properties. Time-lapsed diagrams were also used as valuable didactic tools to unpack complex pathways of material-based interactivity into understandable

the structured nature of language. Information can build upon previously learnt axioms and can be restructured to accommodate and integrate new data within related pre-existing concepts, through a categorical rating of their comparative similitudes and relativities. As new information is acquired, a clearer picture of general understanding concerning phenomenology emerges by effect of the interweaving effects of variables and their ability to fill-in ontological gaps underpinning causal interactions of interstitial nature, into a broader picture of overall clarity. The broader the scope and scale of available knowledge within a system, the more likely a concerted effort of creative development is likely to manifest with innovative success and differentiation.

In the case of nanomaterials specifically, special attempts to convey adequate storytelling is necessary as most nano scalar behaviours are completely non intuitive by virtue of their quantum confined emergent states. Initial lectures were given by a nanomaterial's specialist covering in detail the nature and behaviours of nanomaterials provided in toolkits covering the four main nanomaterials in their diverse qualities and properties. A particular emphasis was dedicated to exploring in-depth topics surrounding GANF carbon-based nanofibers which were provided by Antolin, the producer and leading corporate partner of interest who was given the task of launching the initial design challenge.

In conjunction to the materials expert disclosure, an inhouse GANF specialist from the Antolin group disclosed the more intimate and specific manufacturing and applications processes as well as the scope of their materials application trajectories of interest. Upon a full disclosure Antolin proceeded to launch their challenge to the parties involved in the workshop. While a main objective of the project was to focus on innovative applications of carbon-based nanofibers within vehicle interiors (Antolins' main area of industrial specialty), other non-directed innovations were solicited for finding alternative applications within completely unrelated sectors (i.e. packaging, agriculture).

As the workshop progressed, participants were invited to examine other related principles surrounding nanomaterials, in general, through exposure to didactic pills which were provided by other third-party corporate participants also involved in the field, concerning different aspects of nanotech materials and classes along with a wide variety of potential applications. The pills were selected strategically to deliver a well-rounded exposure to various aspects surrounding nanomaterials in general, with the goal of expanding their usability potential while concomitantly granting cautionary insights into the necessary limitations and safety requirements when working with submicron particles. The pill sessions also covered different aspects and domains of nanomaterials application and research across distinct affiliated sectors which use nano technologies, from medical to energy production, nutrition and nanoelectronics.

4 Toolkits

Didactic content disclosed in the lectures was further corroborated by a series of individual materials toolkits, produced for public use in the form of a box folder

containing materials samples and a collective set of quick reference info-guides. Each box was conceived to represent a single material and a number of corresponding leaflets containing literature which displayed the pertaining material properties as well as methods of production, use, properties, safety hazards and related technology readiness levels. Toolkits are a crucial component and object of evaluation in this workshop methodology as they represent the solution to a didact-creative gap which currently exists in the field of design. As most innovation is burdened with voids in knowledge and access to reliable sources of consolidated information necessary for advancements, especially in the precise area of materials science, the toolkits represent an attempt to devise an easy to use go-to source which bridges this gap and enable a more confident application of materials with greater degree of inspirational intent. In the attempt to achieve this content wise, the toolkits are conceived to provide both a combination of sensorial and intellectual inputs which stemming from the access to a physical material sample and collection of explanatory literature, respectively. Within the literature, there was a series of materials properties ratings visually quantifying all the salient materials' unique properties and characteristics. This was communicated via a series of individual property performance rating charts (for instance, electrical conductivity can be given a rating of 1 to 5, if applicable). For ease of use, ratings were provided only for relevant properties, thus each toolkit, in accordance with the materials being featured, was unique in terms of its peculiar profile but equal to all others in terms of its didactic formatting, thus comparative analysis between two or more materials could be done rapidly and reliably (see Fig. 3).

A material sample of small dimensions was included within a central void of the box structure and left open and accessible to users so they could touch the material and evaluate its sensorial qualities live. Surrounding the sample are various logistic and identification information blocks containing the trade name, class and a manufacturer's contact information. Among the disclosing information topics, materials



Fig. 3 Exploring the toolkit

are also noted for their available formats, colours, finishes and physical/chemical profiles. The main point of the property rating charts was to convey to the user a rapid qualitative visualization of relative and comparative material qualities in each and every distinct property ultimately enabling the user to extrapolate one or more intuitive applications of the material with a basis of confidence.

Physical samples provided sensorial and somatic appreciation regarding visual, haptic, aromatic and physical expressions, while the literature provided qualitative and quantitative technical disclosures pertaining to related measurable phenomena (i.e. flexibility, abrasions resistance, electrical conductivity). Both the combination of a sample and detailed literature content together was conceived to foster a concise yet comprehensive overview and understanding of materials and thus ideally become the trigger point and origin for stimulating insight into inspirational dispositions towards a gainful potential towards their application in new ways. In a nutshell, toolkits aimed to provide the minimum amount of relevant technical knowledge necessary to foment a maximum creative application potential through the extrapolation of principles into actionable qualities. Lectures were also didactically engineered to deliver information in a constructive easy to grasp way. In part this was done through setting many examples while reducing the data packets to their minimum common information denominators. Learning curves were also compounded by several repetitious affirmations of underlying scientific principles whereby the knowledge building and memory recollection processes were aligned into efficient blocks. Individual materials were described in terms of their specific structures and compositional natures, and the general contributions of each onto each other. Lectures further covered other logistical aspects of the materials such as the spectrum of available formats and expectational predictions of synergistic effects potentially manifest from their integrability within other material classes and families.

5 Nanomaterial Disclosure

Among the four nanomaterials presented to the student body, a first one was GANF carbon-based graphene oxide nanofibers, which are submicron, vapour grown structures having an elongated aspect ratio and overall length less than 100 nanometers. GANF nanofibers possess several advantages as they possess and impart high toughness and tensile strength to material substrates and, depending on where they are positioned at concentrations within a material, can provide various distinct functions such as filtering and/or elevated surface hardness in conjunction with anticorrosive protection to a substrate. In addition to these qualities, these carbon-based fibres can conduct heat or become a substrate itself upon which other metals can be deposited to enhance electronic conduction or optoelectronic capacitance.

A second nanomaterial presented was Bionox produced by Apta Colour. Bionox pigments are nanometric TiO_2 particles sized between 10 and 100 nm which, when included within a substrate, grant photocatalytic properties to the host materials. Photocatalysis is an optochemical phenomenon wherein, upon absorption of sunlight

and in the presence of surrounding oxygen (air), TiO_2 pigments acquire catalytic abilities and thus are able to accelerate mineralization of certain pollutants into oxidized states. Additionally, TiO_2 particles possess tensioactive properties which as a secondary effect impart antifouling surface properties by virtue of their high affinity to water film forming over surfaces, rendering them less tacky to paints and dirt particles. TiO_2 particles also possess oxidative properties which have a bactericidal effect in most cases. Relatively non toxic, these particles can also provide rheological modifications to viscous liquids for industrial applications.

A third nanomaterial presented was Grafylon produced by Direct Plus. Grafylon is a PLA polymer-based filament composite having a low volume fraction of graphene nanostructure within its matrix. Graphene, which typically embodies a nanoplatelet configuration, is known to possess and impart onto materials, when embedded as a reinforcement, high mechanical strength and electrical/thermal conduction. Even at low volume fractions, polymer substrates can acquire numerous advantages such as good thermal dispersion and dissipation, excellent mould reproduction and integrability into electrical structures. Furthermore, graphene within polymers grants several improvements such as surface hardness and resistance to impact and crack propagation, even at lower temperatures.

A fourth nanomaterial presented was Nanotex by Crypton. Nanotex is a SiO_2 nanoparticle additive which can be embedded into and throughout textile fibre matrices whereas to cover their surfaces with a water repelling and highly resistant coating, thus preventing the fibres from absorbing water within and throughout. SiO_2 particles can be applied onto textiles via various methods of application some of which more permanent than others but, all in all, they drastically improve the lifespan of textiles by acquiring antifouling properties and self-cleaning abilities, warranted by the superhydrophobic nature of SiO_2 nanoparticles. Given the high priority of GANF over the other nanomaterials it was emphatic to explore the majority of its potential applications across diverse sectors of need and innovative impact, thus the various groups were given specific inputs towards fomenting ideas in five different areas, namely energy, food, biology and pollution control.

6 Team Forming

The student body comprised a blend of diverse people having distinct multidisciplinary backgrounds. Teams were formed by designers and engineers to include the broadest possible profiles between participants and thus grant maximum variability in creative and analytical abilities. Groups of 5–6 people were formed and given the task of selecting a group name.

The groups comprised a generally regular distribution of males to females with diverse backgrounds. Roughly half of the students were designers (graphic, product and interior) and the other half were engineers (chemical and mechanical).

7 From Knowledge into Creativity Through Language

The main objective of the workshop was to identify areas of opportunity and methods which would inspire the transition of knowledge regarding nanomaterials into creative yet scientifically backed applications in business. For this to occur it was found that gross challenges resided in both the knowledge transfer process, from lecturers towards the audience (input phase), and the following creative transformation process (output phase) of ideas (see Fig. 4).

In order to achieve a certain level of efficiency and validity in this process, the workshop was to be structured so as to optimize both the quality and delivery of communication while stimulating creativity through techniques suitable for a multi-disciplinary audience. A great deal of emphasis was placed on the proper use of language and terminology to bring clarity and understanding of the scientific data disclosed to ensure minimal gaps of misinterpretation, while concurrently allowing examples of how assimilated information could be granted new meaning through use of analogies and comparative abstractions. This method intended to constantly stimulate a relatedness between newly acquired information and its direct application into potential advantages towards creative outcomes.

The tested hypothesis aimed at evaluating whether the process of functionalizing knowledge into creativity could be stimulated within multidisciplinary groups by setting up a structured didact-creative dynamic which promoted constant alternation between distinct mental faculties, analytical and intuitive, which are typically divided in the brain. Language use, as a medium for information transfer and transformation, was considered a key medium for the intermingling of both mental abilities. Through the constructive nature of language and narration, symbolic forms of knowledge (data clusters) can be brought into the visual mind and then mixed into newly functionalized

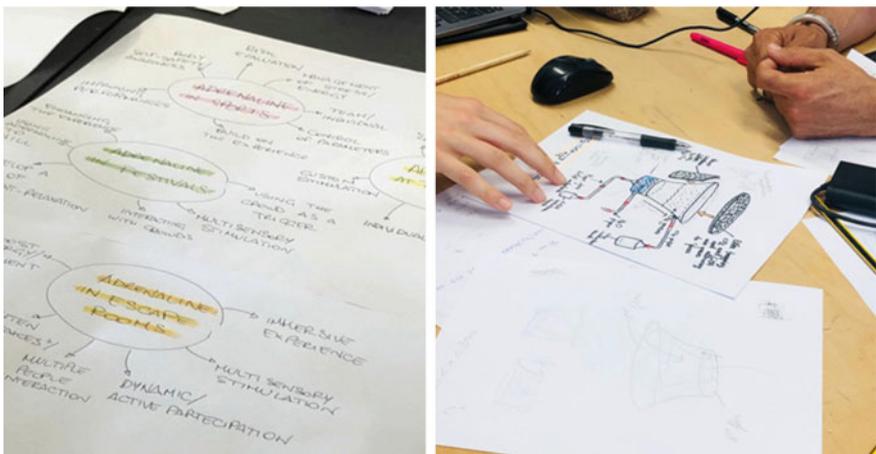


Fig. 4 Students generating ideas

assemblies of associated hierarchical order. By analysing data and abstracting it into more generalized meaning and action pattern, information is thought to be reducible into minimum common denominator terms sufficiently general whereby its reduced nature can be altered in focus, meaning or intent to assume a malleable character which can finally be reattributed towards other indirectly unrelated, even radically different areas of use. In this way we tested whether information, regardless of its complexity or nature, could systematically coax creativity into being through transmutation of one type of information into another.

A creative state of mind is one where a confluence of knowledge of diverse kinds is brought into an abstracted state through a creative use of language. Creative processes thus often play with words and their meaning in order to stimulate a visual imagery alternative kind through reinterpretations and configurational relationships of data. As a result, known variables may be manipulated into a number of distinct alternative outcomes, through reinterpretation and recombination, into novel opportunities arising from interactive potentials of these and their directed intent. Furthermore, upon skilful gain of such practices, what is known, in terms of raw data, can be recalled into memory and subsequently projected forwards into new configurations with some degree of predictable outcome. This process however is mentally constructed using the narrative logic and structure of language which serves as a semiotic medium and compiler.

Knowledge is a necessary precursor to the creative process as the latter can be seen as a process of recombination in various forms of the former. Language is also a vehicle which, by elaborations of its contents, enables the known to be shared and propelled forwards into different shades of attributed value and emotional overtone. For instance, the use of humour or dramatization in the process of communication can redirect, respectively, the underpinning intent of ideas whereas to trigger emotional cues which divert the outcome and focus of the innovation process. Language connects phenomena of the real or imaginary world with human experiences through the unfolding of story. Yet, while descriptive, language also possesses sufficient interpretability across communication channels to warrant significant variability of interpretation, which overall affects the evolution of existing ideas into new ones by propagation of error. Specifically, language is the main communications technology and pathway by which knowledge is structured then promoted into understanding by erecting an intuitive assessment of how observed causal patterns fall in line or into conflict with the way we relate to other known real-world patterns.

How clearly, we can explain something in simple terms and weave it into meaning through story and imagery using language as a medium, not only is it an indication of how intimately we understand it, but also how effectively we may apply it in a creative process. They started to envision the idea by putting the knowledge they acquire into real ideas whose function would apply the principles regarding physic and chemical behaviours of the various nanometric materials.

8 Results

The students who participated in the workshop worked with the company GRUPO ANTOLIN. This company is a multinational company that manufactures the automotive interior market internationally and is a global supplier of roofing substrates. The challenge proposed by Antolín to the students was to find new applications for carbon nanofibers (GANF). These new applications can be applied to a wide variety of sectors such as the automotive industry, electronics, textiles or energy.

The briefing proposed by the Antolin group required additional information to help understand the scope of the material with which the students were working. To do this, they were given this information: regulations, technical data, associated patents, etc. Likewise, the first version of the Material Integration Files tools was delivered.

In addition to this company, TECNUN had the collaboration of four different companies that participated through pills. They were the following:

GRAPHENEA. High quality graphene producer. They design, manufacture and supply graphene-based chips and materials for your research and industrial needs.

IKERLAT. It is a specialist in the development and manufacture of personalized polymeric particles. Today, with fifteen years of history, the company has established itself as a reference in the market for polymer dispersions.

CEIT BRTA. It is a non-profit research centre whose main activity is to carry out research projects in collaboration with organizations. Among other fields, they investigate bioapplications of nanomaterials.

BURDINOLA. It is a safe one-stop supplier for working with nanomaterials. They run the safest and most efficient laboratory projects in the world, laboratories where researchers enjoy working to make the world a better place.

At the beginning of the workshop, the students were informed about the expected results of the work they would have to do. The work teams would be made up of students from each of the participating universities. The final works as a result of the process were collected in; a final oral presentation, a physical prototype of the solution (if possible) and a poster. These results were very useful for carrying out dissemination activities that showed the new methods applied.

Regarding the presentation, each team prepared a short presentation of 10 to 15 min that took place on the last day of the workshop. In this way the students were able to explain the ideas generated throughout that week. This brief presentation was addressed to the company that proposed the challenge, who will be able to understand and provide feedback to the team.

As for the prototype, students were asked to create a physical prototype of the solution to support the oral presentation. Depending on the solution and the EM&T, some prototypes were easier to create.

Regarding the poster, each team produced a poster following a template provided by the researchers of each HEI. The template has included sections in which each team described the project, the number of EM&T involved and the level of preparation of the related proposal with the market.

Fig. 5 The nano house project



Some of the works presented by the students are listed below: (for a deeper understanding see appendix with all the projects).

1. Nanohouse (see Fig. 5)

A temperature-controlled and water-collecting system that increases crop quality and opens up new possibilities for plants in new places.

The greenhouse is a system that changed the way plants grow and that radically changed the field of agriculture. Proper of this system are the light, an essential element for photosynthesis, the heat, which empowers the growth of the plants and the water, the other unmissable protagonist. Thanks to the properties of nanomaterial, and specifically of carbon nanofibers, we saw in this system a huge potential that can be enriched by these materials.

Adding doped aluminium rods to the greenhouse we are able to transfer the constant temperature from the deep soil to the environment of the greenhouse. Moreover, due to the hygroscopic qualities of the CNF, we can collect and recover part of the water contained in the air. That allows us to expand the places of use of greenhouses, controlling the heat inside them and optimizing the use of water, thanks to the many properties of nanomaterials.

Nanomaterials permit introducing smart and sustainable features into the components of this greenhouse. Optimum harvesting conditions could be achieved using the minimum amount of resources, in any outside environment. Superior thermal conductivity and peculiar surface treatments given by the carbon nanofibers allow for a temperature-controlled and water-collecting closed system. Taking advantage of geothermal energy, a renewable and relentless source of energy, superconductive CNF rods efficiently transmit constant deep ground temperature (around 15 °C) up to root level. Further temperature regulation (up to 22 °C) is achieved thanks to a light-polarizing CNF mechanism actuated by shape memory alloys, that accumulates heat inside the greenhouse. Special surface coating in the aluminum tubes enables water condensation that is redirected towards the plant roots, reducing water consumption.

2. Pollution Vacuum (see Fig. 6)

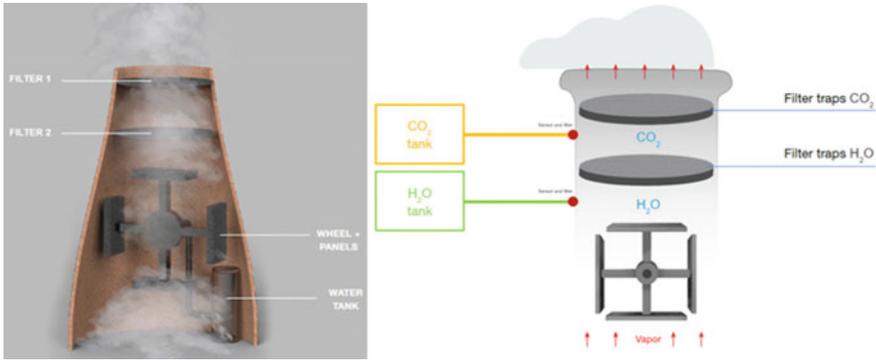


Fig. 6 Pollution vacuum project

The product is a combination of an automatic system combined with filters infused with carbon nanofibers that captures CO₂ and creates H₂O to feed plants in greenhouses.

This product has a double value that helps to reduce the contamination of CO₂ while assisting the growth of the plants optimizing the air cleaning further. It would function in the industrial factory chimneys in collaboration with the agricultural industry. It would be a service provided by the factory to generate more profit by selling their pollution. The principle of the concept is based on the following chemical reaction: $\text{LiOH} + \text{CO}_2 \rightarrow \text{H}_2\text{O} + \text{Li}_2\text{CO}_3$.

The main idea is to use the carbon nanofibers as filters and sensors in the solution proposed. It would help to capture the CO₂ produced and measure the moisture level in the filtration panels. Nanoparticles are playing a crucial role in enhancing the chemical process of capturing CO₂ and producing water. Furthermore in the chemical process, the filters have to be dried, thus the thermal conduction of the nanomaterial plays an important role to fulfil this condition. The solution would allow companies to make profit from their own pollution while selling the captured elements to agricultural industries. The product still needs to be tested and detailed to develop a fully functional solution.

3. Windflower (see Fig. 7):

Nanostructure tecXtile to catch pollen and re-spread it WindFlower is a simple system adopted to collect pollen, store it and re-spread it, thanks to the material's properties (carbon nanofibers).

Wind Flower is a "home" product designed for an individual use for families but with a social and collective output. The product has to be put in open spaces, such as gardens, terraces, fields, balconies and daily it collects flying pollen from air. Collected pollen can be spread right after or stored in the fridge and re-spread. The product also embeds a playful identity because of the sail's origami structure that when folded creates a kite that spreads pollen from above.



Fig. 7 Windflower

This is possible thanks to the skeleton which is 3D overprinted with a PA filament also implemented with nanocarbons. The object tries to maximize the complexity of the structure and the joint. There has been minimized the number of different materials, creating reversible connections and avoiding complex joints, replaced by the specific properties of nanomaterials. The panel has a velcro to attach it to the structure and to close it.

9 Conclusions

We conclude that the techniques applied in the materially driven creativity workshops were successful in providing adequate technical delivery of information via the supporting literature of the materials toolkits. We further conclude that the various methods for stimulating creative applications of the delivered information through in-detail explanatory storytelling, in conjunction with exercises focused upon the extrapolation, decontextualization and abstraction of the underlying scientific principles, were effective in stimulating a transversal mixture of influential insights across the multidisciplinary teams. Our conclusions support the idea that to truly innovate from a fresh perspective is to innovate without the boundaries of prejudice or excessive focus on limiting knowledge-based factors. We find that to create from new points of reflection requires totally new forms of knowledge as a precursor. Further, our findings appear to confirm that knowledge regarding materials and their usable properties are confined to the understanding abilities of the individual and their ability to translate its contents effectively. However, to offset individual limitations, a multidisciplinary group of strategically selected individuals having complementary abilities determined to be the best fit for dissipating uncertainty as well as stimulating a self-critical approach to problem solving.

Other conclusions reflect upon a proper use of language as being a key contributor and necessary baseline, to limit misinterpretation, and enable a focused team directive towards creative goals. The use of associated diagrams and video support,

in concomitance with verbal explanations, were found to be very successful methods for building a story which can be assimilated into experience and memory.

Another finding revealed that even in the best of explanatory situations, knowledge regarding new content is always pseudo-interpreted by the observations and intellectual biases and tendencies of the observers. However, it was found that even misinterpretations can still contribute to the creative process in a positive manner by simple chaotic contribution to the group creativity potential, when harnessed accordingly. Thus interpretations of information, providing they are not too skewed from reality, can be normalized within group sharing and even used, in a subsequent moment, as creative fuel for stimulating radical ideas during the creative session.

A last reflection supports the idea that, during the creative phase of the workshop, an unbiased, free-range attitude towards idea sharing is needed, to enable a proper set and setting which accommodates and empowers a friendly and unbiased planar hierarchy of contributions across all team members.

References

- Asbjørn C, Jagtap S, Warell AL (2016) Material selection in industrial design education—a literature review. In DS 83: proceedings of the 18th international conference on engineering and product design education (E&PDE16), Design education: collaboration and cross-disciplinarity, Aalborg, 8–9 September 2016, pp 708–713
- Asbjorn Sorensen C (2017) A new approach to materials in product design education—a shift from technical properties towards sensorial characteristics. In: International conference 2017 of the design research society special interest group on experiential knowledge (EKSIG), Rotterdam, 19–20 June 2017, pp 182–192
- Bianchi R, Lucibello S (2018) New interdisciplinary perspectives of research on the role of design with new materials: ‘open’ spaces-methodologies-design process. 4D designing development developing design. In: Conference proceedings, Kaunas-Lithuania, 28–30 September 2017, pp 244–255
- De la Rosa JM (2012) Using nanoHUB.org for teaching and learning nanoelectronic devices in materials engineering a simulation-based educational approach to the study of carbon nanotubes. In: Proceedings of the 2012 IEEE global engineering education conference (EDUCON), pp 1–4
- European Centre for the Development of Vocational Training (2005) Identification of skill needs in nanotechnology, 76 pages.
- Ferrara M, Lucibello S (2012) Teaching material design. Research on teaching methodology about materials in industrial design. *Strateg Des Res J* 5(2):75–83
- Haug A (2019) Acquiring materials knowledge in design education. *Int J Technol Des Educ* 29(2):405–420
- Karana E, Pedgley O, Rognoli V (eds) (2013) *Materials experience: fundamentals of materials and design*. Butterworth-Heinemann
- Karana E, Barati B, Rognoli V, Zeeuw van der Laan A (2015) Material driven design (MDD): a method to design for material experiences. *Int J Design* 9(2):35–54
- Lisotta A, De Renzi V, Goldoni G (2014) The NANOLAB project: educational nanoscience at high school. *MRS Online Proceedings Library Archive*, 1657
- Olteanu RL, Gorghiu G, Gorghiu LM (2017) Introducing responsible research and innovation dimensions in non-formal education activities dedicated to industrial application of nanomaterials. *J Sci Arts* 2:331–340

- Piselli A, Dastoli C, Santi R, Del Curto B (2018a) Design tools in materials teaching: bridging the gap between theoretical knowledge and professional practice. In: DS 93: proceedings of the 20th international conference on engineering and product design education (E&PDE 2018a), Dyson School of Engineering, Imperial College, London, 6–7 September 2018a, pp 193–198
- Piselli A, Baxter W, Simonato M, Del Curto B, Aurisicchio M (2018b) Development and evaluation of a methodology to integrate technical and sensorial properties in materials selection. *Mater Des* 153:259–272
- Ramalhete PS, Senos AMR, Aguiar C (2010) Digital tools for material selection in product design. *Mater Des* 31(5):2275–2287
- Schulz M, Yin Z, Alvarez N, Shanov V, Pai D, Pixley S, Kim J (2013) Teaching nanoscale engineering to accelerate academic industrial innovation. In: 10th WSEAS international conference on engineering education 2013 (Education—Vol. 13), pp 20–22
- Sebastian V, Gimenez M (2016) Teaching nanoscience and thinking nano at the macroscale: nanocapsules of wisdom. In: 2nd international conference on higher education advances, HEAd'16, Valencia, 21–23 June 2016
- Tamez Ramírez MS, Vega Cantú, YI (2019) Nanotechnology learning through product development. *Int J Interact Des Manuf*
- Veelaert L, Du Bois E, Ragaert K, Hubo S, Van Kets K (2016) Bridging design and engineering in terms of materials selection. In: Proceedings of 7th international polymers & moulds innovations conference, pp 319–326

Robert Thompson Scientific Director of Materfad, boasts a multifaceted profile and is determined to create synergies between new materials, creative professionals and business. From 1997 to 2001 he studied mechanical engineering applied to medicine, with a double major in medical prosthetics and medical ethics at the University of Massachusetts Amherst. After working for a time, he decided to continue his education and, after spending a few months exploring ideas, he was accepted at the Art Center College of Design in Pasadena, California where he studied product design and automotive design from 2003 to 2007. Thanks to his good academic results he was invited to form part of an international programme that took him to France, to the INSEAD business school in Fontainebleau, where in 2006 he followed a special programme combining product design with business strategies. As scientific director, he is responsible for the in-person and online training programme of the materials center, defines the research and knowledge dissemination lines, directs the materials acquisition programme, supervises the drafting of content for the projects and workshops in which MATERFAD participates and directs the materials consultancies requested by businesses

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Applying the DATEMATS Method and Tools to Wearable ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies for Caring and Well-Being



Stefano Parisi

Abstract The chapter presents and discusses the theoretical background, original methodology, format, and results of the workshop “Interdisciplinary challenge on Emerging Materials and Technologies (EM&Ts)” with a focus on Interactive Connected and Smart (ICS) Materials for Wearable Technologies. ICS materials are defined as systems combining inactive materials, stimuli-responsive smart materials, and embedded sensing, computing, and actuating technologies. They can sense and communicate data from the body or the environment, and they can perform interactive behaviours. One of the application sectors where these are more exploited is wearable technologies. These materials can be embedded into clothing or worn on the body as electronic textiles (e-textiles), implants, or accessories. The challenge was used as a way to transfer new knowledge on innovative materials to design and engineering students and to establish a dialogue between students, researchers with extensive materials-focused expertise, and companies interested in EM&Ts. The workshop presented in this paper was held at Politecnico di Milano, Design School, from 12 to 16 July 2021. The methodology of the workshop follows a framework built by collecting, analysing, and systemically formalising innovative tools, methods, and approaches for designing and learning how to design with advanced materials. It identifies three phases: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project. This framework defined the original structure and agenda of the whole workshop. Therefore, the workshop was based on a combination of hands-on experimentation, design activities, and lectures by the teaching staff of the four universities and by partnering companies (design pills). Students applied this unique design methodology developed within the project to design with four Emerging Materials and Technologies (EM&Ts). The method and tools developed by the staff supported students in understanding, exploring, and shaping, and applying EM&Ts, and finding design

S. Parisi (✉)

Delft University of Technology (TU Delft), Delft, Netherlands

e-mail: s.parisi@tudelft.nl

© The Author(s) 2023

V. Ferraro et al. (eds.), *Materialising the Future*, Research for Development,
https://doi.org/10.1007/978-3-031-25207-5_6

103

opportunities from their integration. Indeed, the main EM&Ts explored in the workshop are Interactive Connected and Smart Materials (ICS Materials), but all the other EM&Ts researched in the project were integrated: Nanomaterials, Experimental Wood-based Materials, and Advanced Growing Materials. In this interdisciplinary challenge, a real-life design brief was given to students with the cooperation of two partner companies: Comftech and SCILIF. The joint challenge with the title “Designing with ICS Materials: a dialogue between e-textiles and active lighting technologies” was about using the two patented technologies produced by the companies—a textile sensor detecting biosignals, and SunFibre active lighting system—as a platform to develop interactive, connected, and smart tangible interfaces for new application sectors focused on emotions and stress management, from well-being to entertainment, to safety. Twenty-three students worked together in six multi-disciplinary teams to find solutions for this challenge and to produce product concepts, prototypes, and material samples. The results are described and discussed in the chapter and include interactive garments for healthcare, improving safety at work, sharing emotions in leisure activities, and for the well-being of elderly people and kids. The discussion of the results and the whole methodology is informed by the feedback provided by students through a questionnaire and by teaching staff observation.

1 Theoretical Background: ICS Materials and Their Implication in Design and Learning

ICS Materials is a recent and inclusive definition to describe complex and hybrid material-based systems with sensing, actuating, and interactive capabilities. With these capabilities they can sense and communicate data from the body or the environment, and they can perform interactive behaviours (Parisi et al. 2018; Rognoli and Parisi 2021a). To do this, they can combine inactive materials—for example, textiles, often used as a support—, stimuli-responsive smart materials—for instance, thermochromic pigments and shape memory alloys, and embedded sensing, computing, and actuating technologies—for example, touch sensors and LED technologies. Among different industries, from interactive furniture to smart architectures, one of the application sectors where these are more exploited is wearable technologies. Indeed, these materials can be embedded into clothing or worn on the body as electronic textiles (e-textiles), implants, or accessories. They have applications in health management, sportswear, industrial workwear, temperature control for well-being and safety, and entertainment, just to mention a few of them. In this sector, ICS material finds a design space overcoming most of the technological challenges implied by these technologies and bringing aesthetical and functional advantages. ICS materials enhance aesthetic enjoyment by triggering the effect of surprise and by creating multi-sensory experiences. Moreover, they have the transformative role of making invisible data tangible and information more accessible, enabling users to

behave more awarely and proactively. Smart textiles and wearables may have a huge impact on the sport and healthcare industries: indeed, they can be used to monitor and support body activities. For example, they can be used for health prevention and rehabilitation. ICS materials allow wearables to constantly adapt to the users' needs for their well-being. Also, they can monitor environmental data and stimulate awareness and conscious behaviours, by creating functional and emotional relations between people and other entities (people, environments, and other artefacts).

As the definition of ICS Materials is an umbrella that encompasses components with different roles—such as sensors, actuators, connectors, processors, and so on—and of different natures—computational, mechanical, chemical, and even biological, the phenomenon has been observed before and investigated by scholars in Design, Material Science, and Human–Computer Interaction leading to concepts and definitions that approaches such materials from different angles.

Brownell (2014) elaborated the concept of expanded matter or x -matter, i.e., materials effectively enhanced with additional capacities, such as tracking, sensing, responding, and interacting, by the integration of information technologies. Similarly, Augmented Materials (Razzaque et al. 2013) refer to materials with generic physical and computational properties, in which electronics are seamless and embedded during the fabrication of the material. The definition of Computational Composites (Vallgård 2009) identifies composite materials in which at least one of the components has computational capabilities. Smart Material Composites (Barati 2019) highlight how smart materials can work together in a system.

The application of these materials in design projects introduces new requirements in design and teaching methods and techniques. Indeed, such material contributes to unfolding a critical reflection and a call to action on shifting products towards a novel dimension characterized by hybridization, dynamism, and interactivity. To frame the workshop methodology, a State of the Art has been carried out (Parisi 2020) and is here shortly introduced, focusing on approaches, methods, and tools applied in design processes and learning environments.

In Design and Engineering schools and universities, teaching activities have already been carried out with a focus on the application of smart, interactive, and connected materials. Although these experiences are still relatively recent and experimental, it is possible to recognize precise design and teaching methods, approaches, and tools that have been applied to transfer knowledge, experiment, ideate, and develop a design with interactive, connected, and smart materials. Among these methodologies, some of them are focusing specifically on ICS Materials (Parisi and Rognoli 2021; Ferraro and Parisi 2020a, b), others broadly on materials with interactive, connective, and smart characteristics (e.g., smart materials, smart material composites, tangible interactive surfaces, e-textiles), while others address generically emerging material, including interactive and smart materials, but not limited to. I present a selection of design processes and teaching experiences identified from the literature review and based on our experience as educators, pointing out the most relevant observations on the approaches, methods, and tools applied.

Mixed sources for learning and understanding interactive and smart materials. One of the most applied approaches to gain knowledge about materials is the mixed

approach (Haug 2019), combining multiple learning sources. Examples of these sources are direct experimentation with materials, reading texts, watching videos, and discussions with peers, instructors, and experts. Tangible materials samples are efficient tools to gain an understanding of novel materials and stimulate the creative process through direct manipulation (Haug 2019; Pedgley 2010; Rognoli 2010). In this respect, one of the problematic issues when dealing with advanced materials—including smart materials—is that physical samples might not be easily accessible. Therefore, it is fundamental to provide designers and students with the opportunity to understand interactive and smart materials in the absence of physical samples. Examples in education show tutors replacing samples with other alternative learning materials in the format of databases (Hölter et al. 2019) and in the format of canvases or cards (Colombo 2016). Considering the novelty of interactive and smart materials, other principal sources for gaining and sharing information and inspirations are open-access platforms presenting case studies, instructions, and tutorials, like Materiability (<http://materiability.com>) by Manuel Kretzer and Openmaterials (<http://openmaterials.org>) by Catarina Mota. Kretzer (2017) argues that it is a priority that designers acquire active material literacy before applying them, including learning, using, and qualifying their potential. The suggested learning approach is through multi-disciplinarity, hands-on explorations, digital fabrication, access to open-source information and technologies, and the development of speculative and critical applications. Similar approaches are shared within the FabricAdemy programme (<https://textile-academy.org>), coordinated by Anastasia Pistofidou (FabTextiles/Iaac FabLab BCN) and Cecilia Raspanti (TextileLab Amsterdam/Waag Technology & Society).

The role of application and contextualization. The methods presented in these pages are fundamentally embedding Active learning (Bonwell and Eison 1991). In material education for design, students are often engaged within a design challenge or a project brief, as it conventionally happens in practice. This denotes a tendency towards application-oriented design processes in education and training programmes for designers. These methods are based on applying the materials into a product, challenging their limits and potentials, and promoting new product development and innovation. Often, they involve stakeholders, for example, companies, to contextualize the materials and reinforce the connection between Academia and Industry (Piselli et al. 2018). Another common approach is context-driven. Whether it is an industrial sector, a situation, or a broader social scenario, the context is defined as a starting point of the design process and provides borders to the limitless possibilities of interactive and smart materials. In a context, interactive and smart materials and their resulting application will be situated in a discourse with industry and society involving not only technological limitations and opportunities but also social necessities. Indeed, one challenge related to interactive and smart materials arises from the significant risk of developing a product embedding an emerging material or technology without creating real value for society. On these lines, the Design-driven Material Innovation Methodology (DdMIM) (Lecce and Ferrara 2016) is a systematic approach for design students and practitioners, research centres, and small-medium enterprises, based on the understanding of the broader socio-cultural scenario before selecting advanced materials, including smart ones. It allows the development of one

or more materials starting from scientific discoveries, material patents, or production processes, identifying scenarios of application, and developing new products DdMIM has been used in the application of smart materials and interactive technologies for tangible interfaces in products and interiors in design workshops at the School of Design of the Politecnico di Milano (Ferrara and Russo 2019).

Speculative and critical design approach. Some other methods are based on a speculative design approach using critical thinking and prototyping to question technological, societal, and ethical implications of advanced materials and technologies in future scenarios. This approach overcomes their evident current technological limitations and scarce availability by envisioning and projecting future development and application of interactive and smart materials. In this respect, Barati et al. (2015) argue that a “designer’s naïve perspective with respect to every technical detail of a technology allows them to see new applications”. One example of a speculative design method in the context of smart materials is the Dystopian Thinking. It uses science fiction-based scenarios as a starting point to generate ideas for smart materials and wearable applications in future or alternative situations. The design process was supported by a toolkit based on inspirational cards and canvases. With a more hands-on approach, the InDATA project team at the Design Department of the Politecnico di Milano (<http://www.indata.polimi.it>) carried out an experimental design activity in the format of the Hackathon “Data < > Materials”. The design process was focused on developing interactive devices and wearables by combining speculative design, do-it-yourself bioplastic making, electronics programming, embedding, and digital fabrication with the support of the Fab Lab environment (Parisi et al. 2021). The design process used future scenarios involving the use of technologies as a starting point and was facilitated with mixed learning and design tools with the aim of understanding materials and technologies and carrying out material experimentation, concept ideation, and prototyping.

On these lines, another design approach is the one applied by young designers and students at the Institute for Material Design IMD at the Offenbach University of Arts and Design (<http://imd-materialdesign.com>). There, they are dealing with active material systems, augmented with digital, adaptive, or interactive components. The design process is based on hands-on exploration and prototyping of materials demonstrators, working in a hybrid design space where form, material, and technology overlap. The results of this hybrid practice are prototypes encouraging the discussion about material authenticity and speculative applications (Parisi et al. 2020).

In the workshop Coded Bodies (<https://codedbodies.com/>), interaction designer Giulia Tomasello engages companies, design practitioners, and students in a design process combining traditional textile techniques, sensing and actuating technologies, smart materials, and biological textiles to develop a speculative concept and prototype physical soft wearables, adaptive structures, and active second skins.

Multi-disciplinary approaches. The urgency for creating a multi-disciplinary environment to learn, experiment, and develop applications of interactive and smart materials is expressed in a large number of cases. Indeed, the interactive and smart materials area is mainly situated in the intersection between design, materials, and

interaction, practically involving electronic circuits design and material crafting, along with design capabilities. Since only a few cases reported to actually operate in this multi-disciplinary field with co-tutoring or cross-field collaborations (Schmid et al. 2013), this is still a significant gap. Cross-disciplinary knowledge includes sustainability. The design process used at the Interactive Organisms Lab coordinated by Katia Vega focuses on exploring sustainable interactive objects and wearables starting from hands-on exploration with organic and growing materials (mycelium) combined with interactive technologies (Lazaro Vasquez and Vega 2019).

Experiential learning through a material-centred approach. An approach that is fundamentally embedded in design practice and education is Experiential learning (Kolb 1984). This approach allows designers to gain procedural knowledge about novel materials by learning through making (Pedgley 2010). Most of the mentioned methods emphasize direct experimentation through exercises and hands-on exploration. Material tinkering is a goal-free and playful exploration with physical components—both materials and technologies—for understanding their potentials and guiding further developments (Alarcón et al. 2020; Asbjørn Sørensen 2018; Parisi et al. 2017; Rognoli and Parisi 2021b; Santulli and Rognoli 2020). Schön and Bennett (1996) described how the design process could be approached as a conversation with materials, through which the practitioner gets to know the materials.

On these lines, the Enactive Environments Lab (<http://www.enactiveenvironments.com/>) founded by Karmen Franinović reflects on the direct exploration of responsive and active materials (Franinović and Franzke 2019) in creative research processes as a negotiation with materials—with their form, behaviours, and interaction as one—rather than imposing ideas and forms on them. Both creative hands-on explorations using analogic and digital materials, tools, and methods, and the experience of the user enhance embodied and situated knowledge engaged in both tacit and creative processes and physical interaction.

Therefore, it becomes necessary to create methods based on the central role of materials in the design process. Often one material or a selection of materials is the starting point of the design process. This is the case for the Material-Driven Design (MDD) method developed by Karana et al. (2015). Practicing this method, practitioners and students start from a material at hand and design for material experience, by tuning their physical qualities, sensory profile, and emotional and meanings associations. This method targets novel materials with yet limited applications and unrecognizable identity—including interactive and smart materials—to foster meaningful materials experiences and ultimately materials acceptance by the society and the market. The method was applied to designing with and for intelligent composite materials, precisely an underdeveloped piezoelectric and light-emitting smart composite material (Barati 2019).

Simulation techniques. One of the problematic issues of designing and teaching for interactive and smart materials is often the scarce access not only to material samples, but also to equipment, facilities, and multi-disciplinary environments to experiment and produce prototypes. Instead, simulation can be used to exemplify or mimic the sensory qualities or the physical behaviours of the intended material by creating, collecting, and combining other material samples (Karana et al. 2015).

Metaphors and analogies can be used to inspire and communicate the performance and behaviours of smart and interactive materials. Experience prototyping and body storming techniques can be used to physically explore, test, and define the functionality and performances of ICS materials in the early stages of the design process or in the absence of physical materials or equipment (Piselli et al. 2015). Even in hands-on experiences, metaphors can be used to inspire forms and behaviours in the ideation phase. This is the case of the design process applied by Schmid et al. (2013) focused on developing glass-based tangible user interfaces, starting from the suggestions provided by the glass itself, which is then implemented with electronics. Simulation techniques can replace physical samples and inspiring forms and interactions.

User-centred approaches. The user interaction and expectations in relation to the material aesthetics and performances are essential, both considering physical body involvement and emotional engagement. In the design process described by Russo and Ferrara (2017), the role of the whole-body experience and somaesthetic was vital in ideating with interactive materials. In another case (Colombo 2016), the role of user experience in dealing with smart material-based interactive products is emphasized in the use of tools for enhancing product sensory experience. Like the afore-described MDD method, these processes are fundamentally user-centred, considering the user involved since the initial stages, often through user studies.

Findings from the review identify the current State of the Art on methods, approaches, and tools to use by design and engineering practice and education when involving interactive, connected, and smart materials. These informed the setup of an original workshop for ICS Materials in the wearable sector, in the scope of the project DATEMATS. The objectives and structure of the workshop are presented in the following section.

2 The Workshop “Designing with ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies”—Objectives and Structure

The workshop presented in this paper was held at Politecnico di Milano, Design School, from 12 to 16 July 2021. The methodology of the workshop follows a learning and design framework developed in the scope of the project DATEMATS, working as a foundational methodological model to adapt and translate into the different activities of the projects (Parisi and Ferraro 2020; Ferraro and Parisi 2020a, b). The DATEMATS methodology (Fig. 1) has been adapted in the four international workshops for students and in several events addressed to companies. The methodology was built by collecting, analysing, and systemically formalising innovative tools, methods, and approaches for designing and learning how to design with advanced materials. It identifies three phases here concisely described: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate

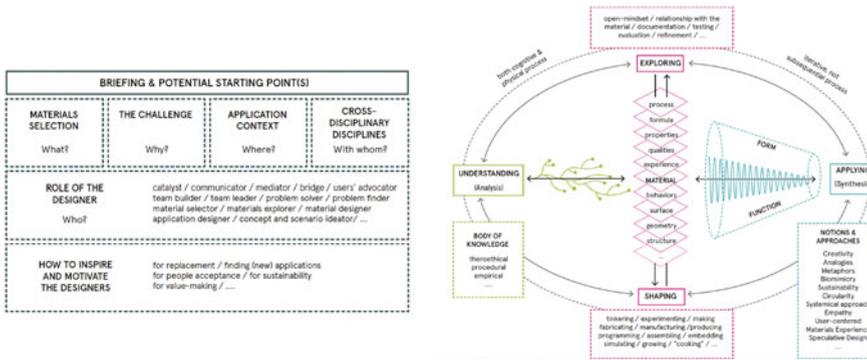
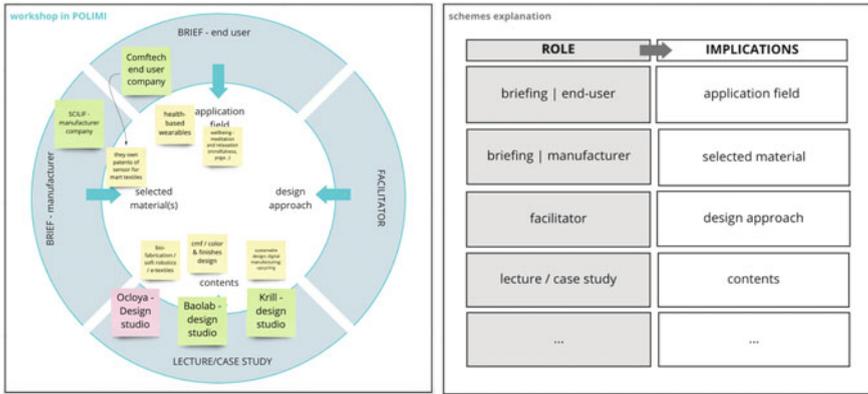


Fig. 1 The DATEMATS methodological framework

ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project (see Fig. 1).

This framework defined the original structure and agenda of the whole workshop. Therefore, the workshop was based on a combination of hands-on experimentation, design activities, and lectures by the teaching staff of the four universities and by partnering companies (design pills) (see Figs. 2 and 3). Students applied this unique design methodology developed within the project to design with four Emerging Materials and technologies (EM&Ts). The method and tools developed by the staff supported students in understanding, exploring shaping, and applying EM&Ts, and finding design opportunities from their integration. Indeed, the main EM&Ts explored in the workshop are Interactive Connected and Smart Materials (ICS Materials), but all the other EM&Ts researched in the project were integrated: Nanomaterials, Experimental Wood-based Materials, and Advanced Growing Materials.

The challenge. In this interdisciplinary challenge, a real-life design brief was given to students with the cooperation of two partner companies: Comftech and SCILIF. Methodologically, the contribution that the involvement of the companies brought to the workshop was both related to the selected materials and technologies to use as a starting point and the scenario of applications. Comftech is an Italian company that creates and sells wearable monitoring systems made from cloth. Comftech smart garments enable accurate measurement of a range of physiological parameters and offer reliable, continuous, and non-invasive monitoring (see Fig. 4). SCILIF is a Czech company that applies new technologies to make life safer (“Science for Life”). Their SunFibre Wearable Active Lighting Technology is a unique optic fibre lighting system encased in a textile coating. It increases visibility in darkness or low-light conditions. Comftech’s textile sensor and Scilif’s SunFibre are a technological pairing full of potential, as together they form a complete smart material system: the former is a sensor, the latter an actuator (see Fig. 5). The joint challenge with the title “Designing with ICS Materials: a dialogue between e-textiles and active



Figs. 2 and 3 A schematic representation of the actors involved in the workshop at Politecnico di Milano, with an explanation of their implications and contributions in the workshop. A schematic explanation of the roles and implications of the actors involved in the workshop at Politecnico di Milano

lighting technologies” was about using the two patented technologies produced by the companies—a textile sensor detecting biosignals, and SunFibre active lighting system—as a platform to develop interactive, connected, and smart tangible interfaces for new application sectors focused on emotions and stress management, from well-being to entertainment, to safety. The concept of well-being and stress management had a big emphasis in the framing of the briefing for the challenge, considering the current relevance and urgency that the topic represents in many fields, including design. It is widely acknowledged that mental health and well-being have increasingly become prominent issues to tackle, especially in recent years, considering the aftermath of the recent COVID-19 pandemic. Keeping a regular fitness routine, good sleeping habits, and contemplative and meditative activities are recognized as beneficial for improving users’ relaxation, stress relief, and ultimately mental well-being. Wearable artefacts based on smart textiles have the potential to support users in improving well-being and awareness in users’ regular and special daily activities—including those based on sport and fitness routines, social and work activities, self-care, good sleeping habits, contemplation, and meditation. In this comprehensive scenario, textile sensors can detect and monitor physiological signals—such as heartbeat and breathing. Simultaneously, lighting technology can perform actuation to communicate information and stimulate body conditions with the use of rhythm, intensity, and colours. The technological platform constituted by these two components can even be combined with other elements making the wearable able to perform complex interactions, adapt to users’ needs or preferences, or stimulate body conditions such as by changing shapes or temperature.

Design-pills. Three design studios working on materials-related topics were invited to take part in the workshop as lecturers. They presented their design

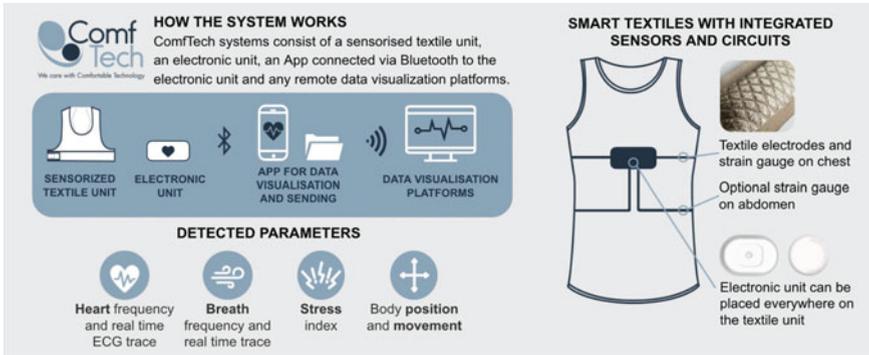


Fig. 4 A summarized description of ComfTech textile sensors technology

SunFibre
Wearable Active Lighting Technology

ABOUT PRODUCT
SCILIF SunFibre Active Lighting Technology is a **unique patented optic fibre lighting system** that increases visibility in darkness or lowlight conditions. Unlike retroreflective safety elements, SCILIF SunFibre emits light through optic fibres encased in a textile coating, ensuring active protection.

- Up to 3 km visibility in all directions (360°)
- Mechanical durability and bendability
- High washability and easily integrated
- Almost invisibly and easily integrated
- Operation time up to 60 h
- Easy haptic control with Control Button
- Wide selection of colours
- Variable modes of operation

CERTIFICATES: CE, RoHS, REACH, EN441

SCILIF
scilif.com

Fig. 5 A summarized description of Scilif’s SunFibre active lighting technology

approaches and case studies from their professional practice with short presentations—the so-called “design pills”—and engaged students in an active discussion around design methods and tools in practice, often with the support of prototypes and samples. Krill Design is an Italian start-up born in 2028 proposing a Green Economic model of business that combines the need to recycle waste and create new materials by leveraging Circular Economic, Technological Innovation, and Creativity. They support people and organizations embracing sustainability through circular design. They enhance food waste through a process based on circular economic concepts, which makes it possible to transform organic scraps to generate Circular Materials and Circular Design. Boosting the re-valorisation of organic waste, Krill Design proposes converting it into innovative materials in pellet and filament format to 3D print products that collaborate to the reduction of pollution, promoting the transition from a linear to a circular economy system. Their pills were titled “From Trash to Treasure – circular design with reclaimed organic materials” (see Fig. 6). Baolab



Figs. 6 and 7 Image from the Design Pills by Krill Design. Image from the Design Pills by Baolab

is an Italian design studio that works in the field of Industrial Design with expertise in the fields of design strategy, research on materials and exclusively advanced technologic processes, colour & trend forecasting, and cmf design (colour, material, and finishing). Baolab professionals work at enhancing the sensorial qualities of a product, in consideration that consumers are most likely to link to their personal use. Their pill was titled “Material-Driven Design with a CMF approach” (see Fig. 7).

Ocloya Studio is the professional design practice by Loana Flores. It establishes a link between traditional textiles and new technologies, and she focuses on pedagogy and sustainability. She presented the pill “Experimentations with e-textiles and bio-textiles”.

Teaching staff. Teaching staff from the four Higher Education Institutions (HEI) engaged in the DATEMATS project were involved, bringing their unique knowledge and expertise on each EM&T area and design-related topic, from creativity techniques to sustainability. The teaching staff supported students in every phase of the workshop, with presentations, discussion moments, and tutored group activities. The technical staff from the Prototyping Lab of the Politecnico di Milano was also involved in in-lab hands-on activities. A total of 7 tutors were involved in the workshop.

Tools. In the different phases of the workshop, the tools developed in the scope of the project’s DATEMATS to support the methodology were used (see Fig. 8), in particular:

- The EM&Ts toolkit. A collection of 5 boxes for each EM&T including exemplar cases of materials of each area with tangible samples and textual and graphical



Fig. 8 Images of students using the tools during workshop activities

descriptions on properties and qualities of the materials—including environmental and smart attributes—, their manufacturing process, and their application potentials. They were mainly used in the first phase of the workshop to understand EM&Ts.

- The EM&Ts integration cards. A deck of cards showing the potentials and limits of combining two or more EM&T areas, by means of case studies, lists of advantages and disadvantages, and references to the scientific literature. They were used throughout the workshop to inspire students.
- Communication materials. A poster and presentation template were used to communicate in a homogenous and intuitive way the results of the workshop.

Activities. The workshop structure was built around the three phases of the DATEMATS methodology, namely: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project. In this section, the main learning and design activities are described in chronological order, day by day.

Preparation. One week before the beginning of the workshop, an online meeting with all the participants was organized by the hosting teaching staff. The workshop's structure and objectives were introduced, and an interactive group-making activity was performed. In this activity, students were asked to introduce their background, skills, and expertise, in order to create multi-disciplinary teams. Participants were asked to get prepared before the beginning of the workshop with suggested reading and videos produced in the scope of the DATEMATS project.

DAY 1. The focus of the day was to understand the EM&ts by means of theoretical lectures, discussions with experts, and samples exploration. The day started by welcoming the participants, introducing the agenda overview, and introducing the objectives and activities of the workshop. The brief of the challenge was presented

by Polimi with the support of an informative and inspirational presentation on wearable technologies. Presentations by the two companies followed, namely “Wearable systems for remote monitoring” by Comfttech, and “Wearable Active Lighting...a new market segment” by SCILIF, and a discussion moment with “questions and answers” with the companies followed, with the support of a hands-on exploration of the companies’ technologies (see Fig. 9). After this initial phase, students were introduced to the 4 EM&Ts, namely ICS Materials, Nanomaterial, Experimental Wood-based materials, and Advanced Growing materials, with presentations by the materials experts involved in the project, and a tutored group activity based on the exploration of the EM&Ts Toolkits and inspirational cards for EM&Ts integration. Day 1 ended with the first design pill by Baolab: “Material-driven design with a CMF approach”.

DAY 2. The objective of the first half of the day was to discover the EM&Ts by experimenting with them and shaping them into simple explorative artefacts. The day started with an introduction to the tutored group activity: “Discover the materials and technologies through Exploring & Shaping, and block coding and circuits making” by Polimi Prototypes Lab Staff. An in-Lab hands-on experimental tutored groups activity followed and took place in the Polimi prototypes Lab. Different exercises involving the use of sensors, actuators, and micro-processors were proposed to students, aiming at the ideation of simple wearable objects. The activity aimed to support the exploration and understanding of the EM&Ts and stimulated the imagination and inspiration of design opportunities related to the brief. Tinkering was



Fig. 9 Highlight on activities performed during Day 1: presentations from the companies and samples exploration

used to inspire idea generation within the design process (see Fig. 10). The activity ended with a presentation of the results, discussion, and feedback. The activity was followed by a design pill by Ocloya, with the title “Experimentations with e-textiles and bio-textiles”. The second half of the day was focused on a tutored group activity aiming at discovering the context and searching for opportunities based on the market and competitor analysis, the potential users and target, the research of design case studies, and desk research tasks. The expected outcome was research about the context through maps, visualization, benchmark, personas, and other tools.

DAY 3. The objective of the day was to define the concept idea. An extensive tutored group activity based on idea development and definition was carried out throughout the day, first focusing on brainstorming and mind-mapping activities, funneling in the development and definition of 2–3 ideas for each group (see Fig. 11). The ideas were presented to the companies and teaching staff in an intermediate presentation (see Fig. 12). Feedback from the companies helped to select one most promising design idea to develop further in the following phases. A design pill by Krill Design was presented, with the title “From waste, value for the future. Circular Design with reclaimed organic materials”.

DAY 4. The objective of the activities on this day was to develop the project through the application of the EM&Ts. An extensive tutored group activity took place, based on project development and prototyping. The expected outcomes of the activity were concept development and prototyping and production of samples.

DAY 5. The last day was focused on finalizing the prototypes and presentations, ending with the final project presentation to the companies and teaching staff, followed by feedback (see Fig. 13). The outcomes of the application of the method



Fig. 10 Highlight on activities performed during Day 2: material tinkering, and in-lab hands-on activity with interactive technologies

in the challenges are delivered, including the final presentation, a poster, and an (optional) physical prototype of the solution.

3 The Results: Six Smart Wearable Artefacts for Safety, Care, and Well-Being

The six concepts resulting from the workshop are described and discussed in this section. They include interactive garments for healthcare and caring, improving safety at work, sharing emotions in leisure activities, and for the well-being of elderly people and kids. For a deeper understanding, see the appendix with all the projects.

3.1 LIGHTCARE: A Smart Garment for Elderly Care

Project by Luca Cappetti, Davide Franci, Laura Pizarro, Sara Saccoccio.

LightCare (see Fig. 14) is a smart garment that monitors stress levels thanks to Comftech's smart textiles. Using SunFibre's lighting technology, it displays the mood of the person wearing it, calling others to action. It is a product system consisting of two wearable garments: one, integrated with sensors to be placed in direct contact with the skin and is able to monitor the person's stress level and health status; the others are worn over the clothes and, thanks to SunFibres, display the person's mood translated into colours. Depending on the stress level of the user and the situation in which they are, the colours of the light will vary to express different needs, based on colour psychology norms, e.g., red for anger and stress, orange/yellow for attention, green for safety, and blue for calmness. It is designed to be used by older people struggling to express themselves. It aims to stimulate empathy through colour and encourage interaction with others.

Moreover, the system includes as an extension a SunFibre frame in the form of a decorative piece of furniture that can be placed in the caregiver's house to inform them of the elderly person's status and whether they need intervention in a non-intrusive way. Clothing and decorative furniture are therefore two different devices to help and treat the stress of the user. In this concept, Comftech's textile sensor and Scilif's SunFibre are a technological pairing full of potential, as together they form a complete smart material system: the former is a sensor, the latter is an actuator. This wearable smart garment uses conductive threads to weave the circuit on the fabric itself and actuators, such as touch buttons and textile push buttons. It is therefore a coherent system that is fully developed in the fabric and thus offers otherwise unparalleled flexibility and comfort. In addition, the Nano-Tex nanomaterial fabric used as a substrate for the concept offers particularly suitable performance in conjunction with previous technologies. It is waterproof and non-conductive, elastic, close-fitting, and particularly durable. It was also chosen for its resistance to washing, dirt-repellent,

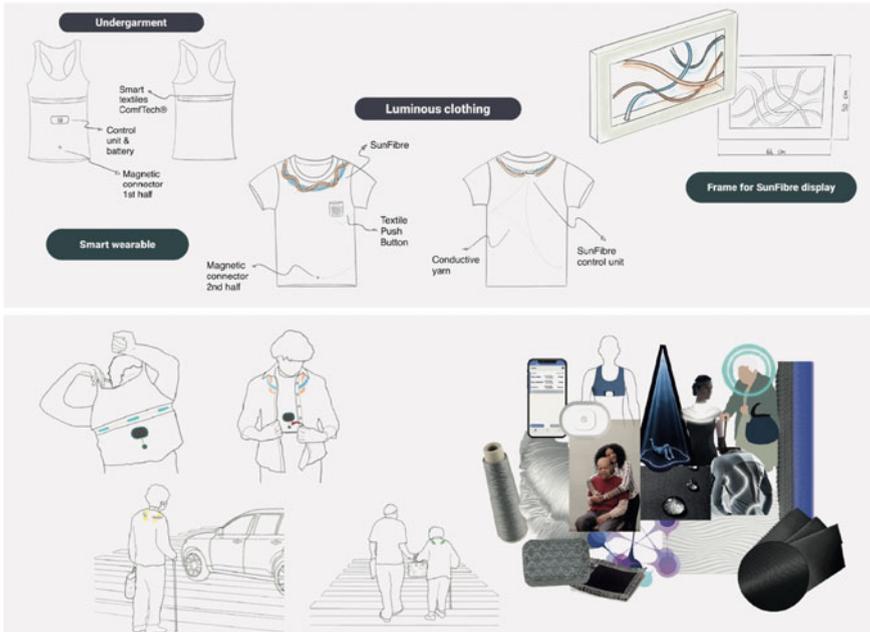


Fig. 14 Visualizations of LIGHTCARE: a smart garment for elderly care. Project by Luca Cappetti, Davide Franci, Laura Pizarro, Sara Saccoccio

and breathability, which are desirable characteristics for wearing on the skin. In conclusion, sometimes dependent people, both physically and mentally, need help but as they don't like to ask for it or feel like a burden they don't do it. This concept aims to save them from having to ask for help; people will do it automatically when they see the need reflected in the luminous device. In addition, the decorative device will help these people to understand their emotions and needs and we will keep their loved ones informed in a discreet and aesthetic way. Future steps for the concept are exploring a better integration with heavier clothes, integration in all types of clothes using a removable light system, and a more effective direct therapy on elderly people by means of this concept.

3.2 *U-EMOTIONS: An Emotional Exploration Aid for Children*

Project by Leonardo Cariga, Roxana Tavoosi, Elisa Igoa.

The core idea of this project is to propose a wearable and non-invasive tool to help children to communicate, express, and understand their feelings better during their development. It also facilitates parents in understanding the emotional growth

of their kids. U-Emotions (see Fig. 15) is a well-being system for children to help them understand how they feel, using the technologies of the companies as a sensing and communication tool. Comftech's textile sensors are indeed a powerful tool for understanding and communicating with our bodies. Instead, Scilif's SunFibre can be used to communicate with others and provide feedback in a very intuitive and quick way. The technology is contained in a Ioncell-F (95%) and Ecolastane (5%) t-shirt.

Through this wearable garment, the sensors can collect data. The actuators can make them visible through the light activation, showing different patterns and colours according to the kid's emotions. Ecolastane gives flexibility to the garment. Ioncell-F is based on fibres coming from cellulose pulp. This material presents very good characteristics related to transpiration and soft contact with the skin, which is an important requirement in products for children. Further steps for the development of the concepts concern the inclusion of a tactile-sensitive conductive textile to improve the product or integrating sound effects that respond to the stimulus of the child. Another possibility could be integrating AI mechanisms in order to be more effective in understanding the behaviour of the child and helping to be more effective in identifying different emotions.

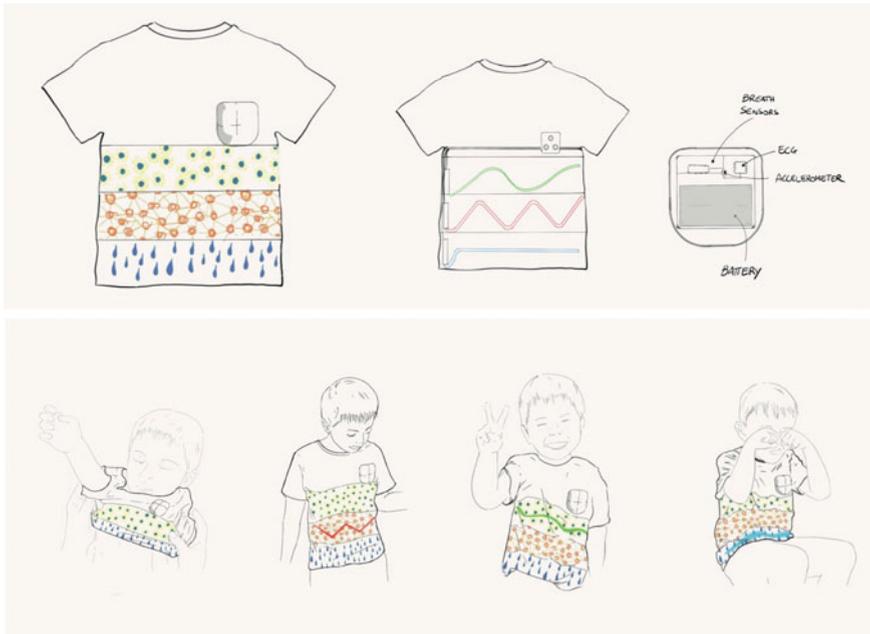


Fig. 15 Visualizations of U-EMOTIONS: an emotional exploration aid for children. Project by Leonardo Cariga, Roxana Tavoosi, Elisa Igoa

3.3 SENSE-E WORKPANTS: Tech-Wear for Repetitive Strain Injuries Prevention

By Alice Ballestra, Ludovica Bonaldo, Francesco Carlucci, Hanna Selim.

The concept (see Fig. 16) is focused on integrating Scilif's SunFibres and ComfTech's sensors into the fabric of couriers' clothes to detect movement that may trigger RSI (Repetitive Strain Injury) and improve their visibility during shifts. Repetitive Strain Injury is a broad term to describe the pain felt in muscles, nerves, and tendons caused by repetitive movement and overuse. Sense-e Workpants can help prevent RSI through early detection of strains and anticipate needed therapy or rehabilitation by integrating strain gauge textile sensors in vulnerable areas of the body to measure the movement. During the operation time of the device, it collects and stores data and then shares it to the company. Then, they would be able to elaborate the data through AI systems and optimize the work hours of their staff and give feedback to the workers. For what concerns smart textiles, this concept exploits the stretch qualities of the conductive silicone circuits, which allow having an adherent connection between the underpants and the skin of the user, without obstructing the movement while working. Alternatively, to the entire underpants, it is also possible to have more accurate local bends for knees, shoulders, and wrists. Connected to this smart textile, there is a central unit, contained in a plastic shell, for which Sulapac biopolymer is used, thanks to its optimal characteristics of resistance and insulation. The connection between the unit and the smart underpants can be by metal buttons or just by the contact between two surfaces made by superconductive Carbon NanoFibers (CNF). In fact, for their structure and orientation, they guarantee a perfect and strong joint between the parts together with excellent electrically conductive properties.

3.4 CAREN: A Wearable Monitoring System for Hospitals

Project by Andrea De Bernardi, Mikel Lasa, Shonglin aka Raveesha Rajendra Gaekwad, Shuai Liu.

Caren (see Fig. 17) is a wearable technology that aims to enhance a patient's medical care response in wards and hospitals where individual bed monitors are not available for every patient. Caren is ideally designed for basic wards in hospitals where it is often not possible to give attention to each patient all the time. This design solution proposes to aid the nurses and doctors in identifying a patient in need of urgent help. It uses SunFibre's optical fibre to visually alert the medical staff nearby, whether it is while the patient is sleeping or walking in the halls of the hospital. The SunFibre is triggered by Comftech's sensor that senses any kind of distress from the patient's body. In case of severe situations, where immediate treatment is needed, the technology can be easily removed, and the garment can be opened at once because of the snap buttons in the centre front. This project uses a combination of Nanomaterials and ICS materials. These textiles have numerous potential applications, such as the



Fig. 16 Visualizations and prototype of SENSE-E WORKPANTS: tech-wear for repetitive strain injuries prevention. By Alice Ballestra, Ludovica Bonaldo, Francesco Carlucci, Hanna Selim

ability to communicate between devices, conduct energy, and improve physical and mechanical performance. It can be used as a non-invasive monitoring wearable for healthcare, as optical fibres may be easily integrated into a textile. Future development of the concept regards improving the sustainability and comfort of the garment.

3.5 *JACKTIVE: A Sportive Jacket to Alert for Panic Attacks*

Project by Diego Piracoca, Sara Kashfi, Sonia González, and Bianca Muresan.

Jacktive (see Fig. 18) is a jacket for hiking that helps people to calm down during a panic attack, through sensory and visual stimuli integrated into the garment. Thanks to Scilif's SunFibre it allows to improve people tracking when rescue actions are needed. More than being a simple garment, this sportive and smart jacket aid people during a panic attack, helping them to calm down using a diaphragmatic movement around their chest to stimulate and guide the breathing rate single-handedly, by means of controllable inflatable parches. This response is activated when Comftech's textile sensors located in the wrists identify an abrupt change in the breathing and heart rate. At the same time, the system turns the optic fibre lightings on to make the identification and tracking of people easier in environments with tough visibility in



Fig. 17 Visualizations and renders of CAREN: a wearable monitoring system for hospitals. Project by Andrea De Bernardi, Mikel Lasa, Shonglin aka Raveesha Rajendra Gaekwad, Shuai Liu

the forest or at night in case of disorientation during hiking. The concept makes use of ICS Materials in combination with nanomaterials and growing materials. The textile of the jacket is formed by three layers of materials, one of them is the Aquapel, graphene printed on a textile to transmit the electrical signals, and polyester to protect the user from any wet substance. The project proposes to use wearable smart materials and exploit their functional advantages in sensing several biological variables of the human body to trigger a response during panic attacks. Polyhydroxyalkanoate (PHA), a polymeric growing material, gives the project a sustainable input to decrease the environmental impacts during its product life cycle. In terms of feasibility, the project is still in a conceptual phase because the application of the graphene to connect two electrical components and the inflatable patch is still in the phase of testing its reliability. Further development of the concept regards product testing, feasibility, integrating sound to control the panic attack, and exploring the possibility of partnering up with hiking guides and integrating a GPS system.



Fig. 18 Visualizations and prototype of JACKTIVE: a sportive jacket to alert for panic attacks. Project by Diego Piracoca, Sara Kashfi, Sonia González and Bianca Muresan

3.6 ADRENALIGHT: A Smart Garment for Shared Adrenaline Experiences

By Adriana González, Giuseppe Fazio, Martina Paramatti, Andrea Ettorina Tremari.

Adrenalight (see Fig. 19) is a wearable system that allows you to show and share your instant excitement in extreme, adrenaline group experiences, through multi-sensorial stimulation. The concept is thought to be used in any kind of adrenalinic group activity to function at its best. The main purpose of this is because the product detects some body parameters (such as heart rate and breathing activity) that analyse the adrenaline experience and replicate all these feelings into visual feedback. The goal is to involve all the people into an adrenaline situation and to use one person as a trigger for the others to regulate the level of adrenaline if it's too low for others. The main idea is to enhance the adrenaline of the users by monitoring their constants with Comftech sensors and provide a visual answer with Scilif lights. These sensors are fully integrated into the textile band, this provides the user a comfortable and washable option, which does not disturb the user. Also, the feedback provided by the light is related to the user's constants and the people around wearing these wearables. The external part of the wearable will also be made with a sustainable textile made of 100% bio nylon. This innovative thread with a renewable energy origin makes this fabric a profitable solution. Although the technology used is completely developed

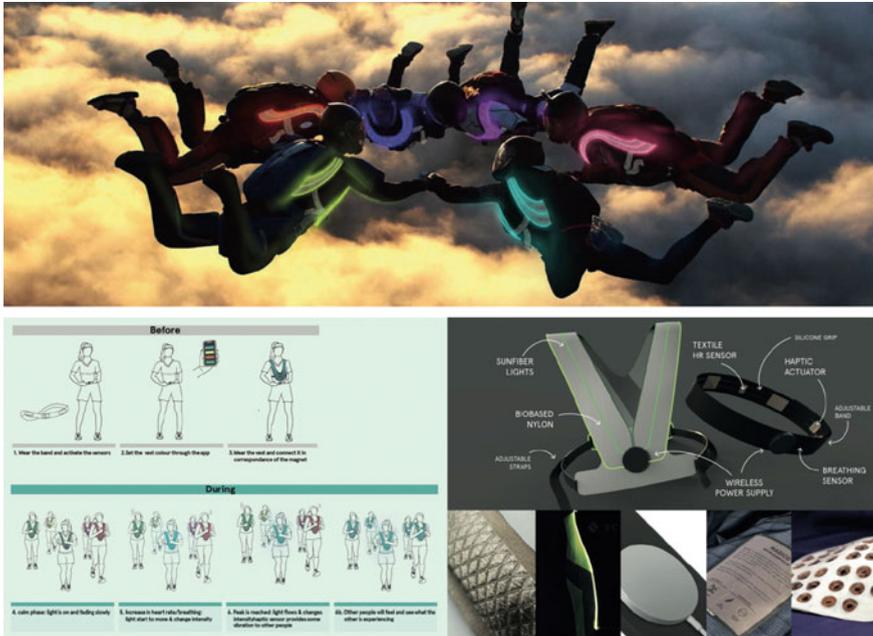


Fig. 19 Visualizations of ADRENALIGHT: a Smart garment for shared adrenaline experiences. By Adriana González, Giuseppe Fazio, Martina Paramatti, Andrea Etorina Tremari

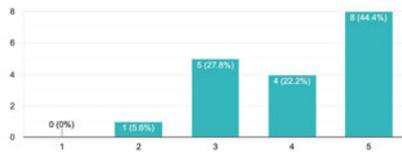
individually by these companies, the integration of them offers a new solution for the market. Future opportunities for this wearable could be developed by including technologies such as biomaterials.

4 Discussion and Conclusion

The discussion of the results and the whole methodology is informed by the feedback provided by students through a questionnaire to evaluate different aspects of the workshop and by teaching staff observation. Data were collected by the triangulation of observations of the activities (rapid ethnography) with direct questions to participants to provide contextual feedback, analysis of responses to questionnaires, and analysis of the results of the workshop (i.e., design solutions), including the analysis of workshops materials (e.g., posters and presentations).

The questionnaire was based on quantitative data, by rating on a Likert scale of 1–5, and qualitative data, by open questions. Eighteen over twenty-three students replied, corresponding to 80% of the participants. The questionnaire was divided into different sections to assess and elaborate on different aspects of the workshop,

Rate the whole program and your satisfaction with the workshop.
18 responses



What was most valuable for your learning?
18 responses

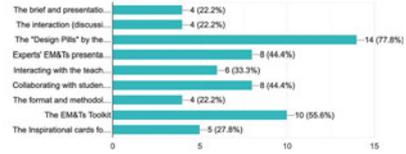
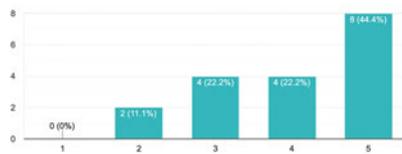


Fig. 20 Workshop feedback, charts 1 and 2

from the overall organization to the applied tools and methodology (see Figs. 20, 21, 22, 23, and 24).

The overall satisfaction is high (chart 1, average = 4.01 on a scale from 0 to 5) and the objectives of the workshop are fulfilled in terms of acquired knowledge (chart 3, average = 4.22 on a scale from 0 to 5) and of transferred methodology and tools (chart 4, average = 3.84 on a scale from 0 to 5). Students addressed that

The workshop "EM&Ts Interdisciplinary challenge" increased my knowledge about emerging materials and technologies.
18 responses



The workshop "EM&Ts Interdisciplinary challenge" transferred a methodology and tools that I could use in future projects and my future practice
18 responses

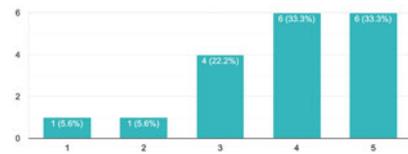
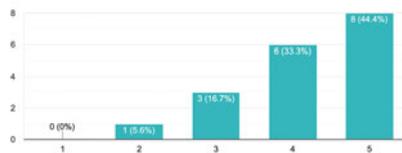


Fig. 21 Workshop feedback, charts 3 and 4

The activity supported the exploration and understanding of the EM&Ts
18 responses



The activity supported the imagination and inspiration of design opportunities related to the brief
18 responses

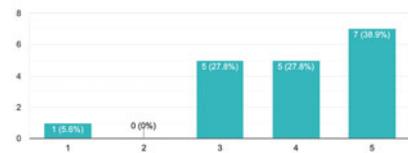
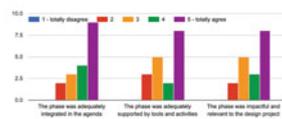
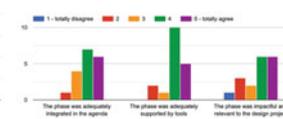


Fig. 22 Workshop feedback, charts 5 and 6

About the "Understanding the EM&Ts" phase.



About the "Exploring/Shaping the EM&Ts" phase.



About the "Applying the EM&Ts" phase.

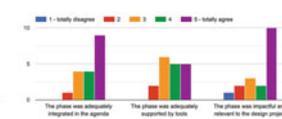


Fig. 23 Workshop feedback, charts 7, 8, and 9

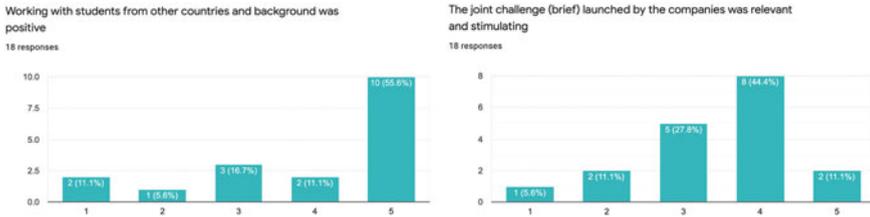


Fig. 24 Workshop feedback, charts 10 and 11

at the beginning of the workshop they had expectations to improve their material knowledge and at the end of the workshop they realized they received a lot of input in this regard. Students acknowledged they learnt how to use the provided tools and methodology and they would apply them in future projects. Indeed, the knowledge transfer toolkits were identified as one of the most valuable sources of learning (chart 2, 55.6% of the participants, representing the second most mentioned item).

Timewise, students reported that they experienced that the initial phases—namely, Understanding—were too long before diving into the actual project and for this reason it was challenging for them to complete the project, given the constrained time frame. Hands-on activities were acknowledged by students as useful to support exploration and understanding of EM&Ts (chart 5, average = 4.17 on a scale from 0 to 5), and to facilitate imagination and inspiration of concept ideas (chart 6, average = 3.94 on a scale from 0 to 5). They expressed that by experiencing first-hand the EM&Ts through samples and tinkering, they were able to visualize how to integrate them into a project. However, some students expressed that they would expect more hands-on and prototyping activities. Indeed, the complexity of ICS Materials requires a more extensive preparation and lab resources to approach them in a way that makes it possible to produce a wide collection of samples and prototypes. The constrained time frame of the workshop represents a limit in this regard.

Students reported that while tools were provided to them to facilitate in the initial phases, not adequate tools were developed for the Applying phase (chart 9, average = 3.72 on a scale from 0 to 5, compared to average = 3.83 for Understanding phase in chart 7 and average = 4 for Exploring/Shaping phase in chart 6). However, students recognized the inspirational card for EM&Ts integration as a tool to use in different phases: to explore design opportunities during the exploration phase and to stimulate creativity during the ideation phase, i.e., in the development of the first concept ideas; for the components design in the finalization phase. It was generally welcomed as a tool useful to combine ICS Materials with other EM&T areas. Even though it is evident that in the workshop project, students did not combine more than two different areas—and three areas in one project, students confirmed they really do believe that this the inspirational card for EM&Ts integration is a tool that they would use for future projects and from which they could always get inspired. As a result of the use of this tool, integration with experimental wood-based materials and advanced growing materials encouraged the development of more environmentally

sustainable solutions for ICS Materials, for example by using PHA, Ioncell, and Sulapac.

Multi-disciplinary and cross-cultural aspects in team making were also identified as a positive aspect (chart 10, average = 3.94 on a scale from 0 to 5), and as one of the most valuable sources of learning (chart 2, 44.4% of the participants, representing the third most mentioned item).

The brief was generally positively received (chart 11, average = 3.4 on a scale from 0 to 5) and identified as characterized by challenging and prominent social and technological issues. However, students expressed that the combination of the two materials in a wearable application limited the diversity of ideas between the groups. Instead, they would prefer more open challenges. Nevertheless, given the compressed timeframe of the learning experience, the teaching staff opted for a quite delimited design space.

The involvement of companies and design studios in an academic learning environment was highly appreciated. Also, students identified that the most valuable sources of learning were the design pills by the design studios (chart 2, 77.8% of the participants, representing the second most mentioned item), followed by materials expert researchers' presentation (chart 2, 44.4% of the participants, representing the third most mentioned item), and interaction (chart 2, 33.3% of the participants, representing the fourth most mentioned item). Students appreciated that they could see examples of how professionals apply their design methods and approaches and how they are applying EM&Ts to products. The positive result in knowledge transfer coming from the pairing of scholarly teaching and case studies from the professional field is evidenced here. In addition, students reported that even though the tools were very useful to have an introduction to the topic or a glimpse of inspiration for the project, the interaction with expert researchers of the teaching staff was necessary to really understand the topic and to dive faster into the project. On the other hand, companies expressed that this learning experience was an opportunity to get in touch with new content developed within the Academia, i.e., fulfilment of the knowledge transfer goal of this experience. Also, they expressed enthusiasm about the fresh and creative ideas students were able to generate and present to them, thanks to the provided learning environment and setup.

In conclusion, students were encouraged to take part in the challenge of ICS Materials' sustainable and smart inclusion into everyday life as a catalyst for social, environmental, and technological change. By applying these novel tools and emerging contents to train young and future designers we provided them with the knowledge and hands-on skills for systematic understanding and prototyping and generating capabilities and solutions to bring to society and to industry. This education and design experience is evidence of how much is relevant for design educators and researchers to develop and implement techniques to train design students as future professionals, by consolidating the knowledge triangle involving research, education, and industry, through cooperation between Academia and Industry. This workshop and the overall DATEMATS project advocate the urgency for Academia to develop teaching methods to transfer knowledge and skills about emerging materials and technologies so that young designers could be updated and could respond

to the demand of the industry. In my opinion, this approach will create job and industrial opportunities for knowledge and technology integration, exploitation, and collaboration. Hopefully, once prepared and trained, former students themselves will transfer novel knowledge and an aware mindset that ultimately will positively contribute to fulfilling technological challenges, and mitigating and solving societal and environmental issues, today and in the near future.

Acknowledgements I thanks the students, and all the teaching staff and project partners involved in the workshop, in particular Prof. Venere Ferraro who coordinated the workshop; the design professionals involved in the design pills—Emma Clerici, Manuela Bonaiti, and Guido Masotti from Baolab, Domiziana Illengo, Sofia Duarte Poblete and Victoria Rodriguez Schon from Krill Design, and Loana Flores (Ocloya); the two partnering companies and their members who participated to the workshop—Markéta Králová and Peter Skrla (SCILIF), and Alessia Montani (Comftech); the lab technicians from the Prototype Workshop at the Design School of the Politecnico di Milano.

References

- Alarcón J, Rognoli V, Silva C, Brañes J (2020) Educating in collaborative symbiosis or how research synergies make sense in different territories? In: Proceedings of INTED20 14th annual international technology, education and development conference, IATED, Valencia, Spain, pp 8975–8982. <https://doi.org/10.21125/inted.2020.2452>
- Asbjørn Sørensen C (2018) A material framework for product design. Licentiate thesis, Faculty of Engineering and Department of Design Sciences, Lund University. <https://doi.org/10.13140/RG.2.2.22693.55527>
- Barati B (2019) Design touch matters: bending and stretching the potentials of smart material composites. PhD thesis, Delft University of Technology. <https://doi.org/10.4233/uuid:59434a52-d848-4e9d-9a86-1a9414737125>
- Barati B, Karana E, Hekkert PPM (2015) From way finding in the dark to interactive CPR trainer: designing with computational composites. In: Proceedings of the 9th international conference on design and semantics of form and movement (DeSForM 2015), Politecnico di Milano, Milan, Italy, pp 129–137. <https://www.drhu.eu/publications/2015-DeSForM.pdf#page=130>
- Bonwell CC, Eison JA (1991) Active learning: creating excitement in the classroom. ERIC higher education reports. <https://eric.ed.gov/?id=ED336049>
- Brownell B (2014) From matter to x-matter: Exploring the newfound capacities of information-enhanced materials. *Mater Des* 90:1238–1247. <https://doi.org/10.1016/j.matdes.2015.03.027>
- Colombo S (2016) Dynamic products: shaping information to engage and persuade. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-319-33117-1>
- Ferrara M, Russo AC (2019) Augmented materials for tangible interfaces: experimenting with young designers: outcomes and analysis. In: Karwowski W, Ahram T (eds) Intelligent human systems integration 2019. IHSI 2019. Advances in intelligent systems and computing, vol 903. Springer, Cham, pp 667–672. https://doi.org/10.1007/978-3-030-11051-2_101
- Ferraro V, Parisi S (2020a) What do we need to design innovative teaching methods for ICS Materials in the wearable domain? In: Ferraro V, Pasold A (eds) Emerging materials and technologies: new approaches in Design Teaching Methods on four exemplified areas. Design International series. Franco Angeli, pp 115–125
- Ferraro V, Parisi S (2020b) Building a unique method to teach how to “design” with and for ICS Materials in the wearable domain. In: Ahram T, Taiar R, Langlois K, Choplin A (eds) human interaction, emerging technologies and future application III, advances in intelligent systems and computing, 1253. Springer, pp 238–243

- Franičević K, Franzke L (2019) Shape changing surfaces and structures: design tools and methods for electroactive polymers. In: Proceedings of the 2019 CHI conference on human factors in computing systems, 1–12. <https://doi.org/10.1145/3290605.3300355>
- Haug A (2019) Acquiring materials knowledge in design education. *Int J Technol Des Educ* 29(2):405–420. <https://doi.org/10.1007/s10798-018-9445-4>
- Hölter M, Piselli A, Colombo S, Del Curto B (2019) A material database framework to support the design of shape-changing products. In Karwowski W, Ahram T (eds) *Intelligent human systems integration 2019*. IHSI 2019. Advances in intelligent systems and computing, vol 903. Springer, Cham. https://doi.org/10.1007/978-3-030-11051-2_98
- Karana E, Barati B, Rognoli V, Zeeuw van der Laan A (2015) Material Driven Design (MDD): a method to design for material experiences. *Int J Des* 19(2):35–54. <http://www.ijdesign.org/index.php/IJDesign/article/view/1965>
- Kolb DA (1984) *Experiential learning: experience as the source of learning and development*. Prentice Hall, Englewood Cliffs
- Kretzer M (2017) *Information materials: smart materials for adaptive architecture*. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-319-35150-6>
- Lazaro Vazquez ES, Vega K (2019) Myco-accessories: sustainable wearables with biodegradable materials. In: Proceedings of the 23rd international symposium on wearable computers, pp 306–311. <https://doi.org/10.1145/3341163.3346938>
- Lecca C, Ferrara M (2016) The design-driven material innovation methodology. In: *Congresos de la Universitat Politècnica de València, Systems & Design: Beyond Processes and Thinking*. <https://doi.org/10.4995/IFDP.2016.3243>
- Parisi S (2020) Towards a definition of ICS Materials in Design Education: Approaches in specific teaching methods. In: Ferraro V, Pasold A (eds) *Emerging materials and technologies: new approaches in design teaching methods on four exemplified areas*. Design International series. Franco Angeli, pp 92–104
- Parisi S, Ferraro V (2020) A logical framework for designing with and for emerging materials and technologies (EM&Ts). In: Ferraro V, Pasold A (eds) *Emerging materials and technologies: new approaches in design teaching methods on four exemplified area*. Design International series. Franco Angeli, pp 153–169
- Parisi S, Rognoli V (2021) Design for ICS materials: the development of tools and methods for the inspiration and ideation phases. In: Rognoli V, Ferraro V (eds) *ICS materials: interactive, connected, and smart materials*. Design International Series. Franco Angeli, 203–217
- Parisi S, Rognoli V, Sonneveld MH (2017) Material tinkering: An inspirational approach for experiential learning and envisioning in product design education. *Des J* 20(sup1):S1167–S1184. <https://doi.org/10.1080/14606925.2017.1353059>
- Parisi S, Spallazzo D, Ferraro V, Ferrara M, Ceconello MA, Ayala-Garcia C, Rognoli V (2018) Mapping ICS materials: interactive, connected, and smart materials. In: Karwowski W, Ahram T (eds) *Intelligent human systems integration*. IHSI 2018. Advances in intelligent systems and computing, vol 722. Springer, Cham, 739–744. https://doi.org/10.1007/978-3-319-73888-8_114
- Parisi S, Holzbach M, Rognoli V (2020) The hybrid dimension of Material Design: two case studies of a do-it-yourself approach for the development of Interactive, Connected, and Smart materials. In: Karwowski W, Ahram T (eds) *Intelligent human systems integration 2020*. IHSI 2020. Advances in intelligent systems and computing, vol 1131. Springer, Cham, pp 916–921.
- Parisi S, Bolzan P, Stepanovic M, Varisco L, Mariani I (2021) Between digital and physical. Envisioning and prototyping smart material systems and artifacts from data-informed scenarios. *Design Culture(s)*, Cumulus Roma 2021. June 8–11, 2021. Sapienza University of Rome
- Pedgley O (2010) *Inigorating industrial design materials and manufacturing education*. Middle East Tech Univ J Fac Archit 27:339–360. <https://doi.org/10.4305/METU.JFA.2010.2.19>
- Piselli A, Garbagnoli P, Cavarretta G, Del Curto B (2015) The shape of light: an interactive approach to smart materials. In: Proceedings of the 20th international conference on engineering design (ICED 15), vol 9, pp 1–10. <https://www.designsociety.org/publication/38130/>

- Piselli A, Dastoli C, Santi R, Del Curto B (2018) Design tools in materials teaching: bridging the gap between theoretical knowledge and professional practice. In: Proceedings of the 20th international conference on engineering and product design education (E&PDE2018), pp 193–198. <https://www.designsociety.org/publication/40765/>
- Razzaque MA, Dobson S, Delaney K (2013) Augmented materials: spatially embodied sensor networks. *Int J Commun Networks Distrib Syst* 11:453–477. <https://doi.org/10.1504/IJCND.2013.057721>
- Rognoli V (2010) A broad survey on expressive-sensorial characterization of materials for design education. *METU J Fac Archit* 27(2):287–300. <https://doi.org/10.4305/METU.JFA.2010.2.16>
- Rognoli V, Parisi S (2021a) ICS materiality: the phenomenon of interactive, connected, and smart materials as enablers of new materials experiences. In: Rognoli V, Ferraro V (eds) *ICS materials: interactive, connected, and smart materials*. Design International Series. Franco Angeli, pp 203–217
- Rognoli V, Parisi S (2021b) Material tinkering and creativity. In: Cleries L, Rognoli V, Solanki S, Llorach P (eds) *Material designers. Boosting talent towards circular economies*, pp 20–25. <http://materialdesigners.org/wp-content/uploads/2021/03/MaDe-Book-1.pdf>
- Russo A, Ferrara M (2017) Smart solutions, “smart aesthetics”? *Des J* 20(sup1):S342–S353. <https://doi.org/10.1080/14606925.2017.1352872>
- Santulli C, Rognoli V (2020) Material tinkering for design education on waste upcycling. *Des Technol Educ Int J* 25(2):50–73. <https://ojs.lboro.ac.uk/DATE/article/view/2713>
- Schmid M, Rümelin S, Richter H (2013) Empowering materiality: inspiring the design of tangible interactions. In: Proceedings of TEI '13. <https://doi.org/10.1145/2460625.2460639>
- Schön D, Bennett J (1996) Reflective conversation with materials. In Winograd T (ed) *Bringing design to software*. ACM Press, pp 171–189. <https://doi.org/10.1145/229868.230044>
- Vallgård A (2009) Computational composites: understanding the materiality of computational technology. PhD thesis, IT University of Copenhagen. <https://doi.org/10.13140/2.1.4769.2487>

Stefano Parisi is a Postdoc at TU Delft, Faculty of Industrial Design Engineering, working on Materials Experience. Stefano researches and teaches in the area of materials for design, focusing on innovative and emerging materials and processes, including smart and bio-based materials for product and wearable applications. He explores design, knowledge transfer, and training methodologies, with an emphasis on materials experiences, sustainability, and future scenarios. On this and related topics, he has written publications, co-supervised graduation projects, participated in conferences, given lectures and workshops, and carried out research and consultancy activities. Stefano completed his PhD in Design, with the thesis ‘Design for Hybrid Material Systems. A Material Augmentation framework for meaningful experiences’, in 2021. He worked as a Research Fellow (equivalent to Postdoc researcher) at the Politecnico di Milano, Department of Design, from 2020 to 2022.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Applying DATEMATS Methods and Tools to Advanced Growing Materials: Ideating Material Value Streams Through Symbiotic Growth of Production Residues and Microbes



Anke Pasold

Abstract This chapter documents the Interdisciplinary Design Challenge on Advanced Growing Materials organized by the Material Design Lab at the Copenhagen School of Design and Technology (KEA). It was to try the framework, tools, and didactic materials developed in the DATEMATS project on the ideation with microorganisms by relating and merging the former with Material Design Lab's employed didactic and creative takes. It was to answer how to firstly ideate with something that is invisible to the eye, that one needs to understand, collaborate with, and care for to achieve successful outcomes, and that needs time to create the final material and respective form before and while it secondly is being applied and how this thirdly could be successfully implemented in the application search in a real-life context with no prior knowledge and within a minimal time frame. In the following, the considerations behind the curation of both brief and schedule that would enable this merge are laid out. Typically employed tools and methods are related to the DATEMATS tools and methods, presented and argued for, and the five results are explored considering the Design Challenge's set goals. The below discussions utilize a three-way informed evaluation based on (1) on-site observation, photo, and video documentation with subsequent protocol studies (Dorst and Cross, *Des Stud* 22:425–437, 2001) combined with notes and conclusions drawn from supervision as well as result evaluation, (2) direct feedback by the students through the conducted survey, and (3) the feedback received by the company. Combined, they give clear indications of the frame's potential and limitations when working with EM&Ts like Advanced Growing Materials and a view to following iteration improvements and further integration.

A. Pasold (✉)

Copenhagen School of Design and Technology, Copenhagen, Denmark

e-mail: ankp@kea.dk

© The Author(s) 2023

V. Ferraro et al. (eds.), *Materialising the Future*, Research for Development,
https://doi.org/10.1007/978-3-031-25207-5_7

133

1 Advanced Growing Materials as an EM&T within DATEMATS

Advanced Growing Materials within the DATEMATS project are materials from the controlled cultivation of microorganisms that can be directly grown and/or manufactured into their subsequent form, function, and performance by tapping into the organism's natural growth behavior.

The microorganisms (in the following, synonymously referred to as microbes) in focus are fungi spores, bacteria, yeast, and algae. Their natural growth processes in symbiosis with their respective ecosystems create a vast range of constitutions that can be harvested as alternatives to currently used polymers. Bacteria can build cellulosic and mineral materials while fungi are employed to act as binders of residues toward the creation of rigid, soft tissue growth for the creation of pliable foams and textiles or as means of potential coating. Furthermore, microbes find applications in fabric dyes and enjoy an interest in their capacity to produce PHA through both bacteria and algae.

Their cultivation can be controlled toward resulting material properties: specific functions and performances through altering the particular combination of the growing substrate, which constitutes the food source for the microorganisms, and the accurately curated growth environment. What microbe is being mixed with what residue under which conditions will be the deciding factors in the creation of a broad palette of soft, rigid, porous, solid, foam-, or textile-like outcomes for application in such diverse areas as medical (due to their biocompatibility), consumer products (due to their formability, properties, material sourcing affordances, and healthy outlook), and construction (as lightweight, healthy, regenerative resources with excellent properties within insulation, water-repellency, and fire specifications while sequestering CO₂ for the product's life).

Microbes are of particular interest in sustainability discussions due to their regenerative nature, their circular potentials, and the fact that they can grow on organic residues from other production lines, with which they create new forms of controlled symbiosis. Furthermore, they are looked at for the potential of harvesting their growth results in a final form as an established product. The process often referred to as biofabrication, can, at the same time, achieve the material creation and form-giving process in the mold by tapping into the organisms' natural growth behavior, supporting, altering, and adapting the very same toward the desired results in specific applications.

2 The Interdisciplinary Design Challenge on Advanced Growing Materials

The Interdisciplinary Challenge on Advanced Growing Materials was held at the Copenhagen School of Design and Technology's Material Design Lab from August



Fig. 1 Social activities around the challenge to support the group working

31 until September 3, 2021, with a predecesing online introduction and, after a short post-processing incubation period, a time-delayed online project presentation.

The participating 21 students from the four different HEIs represented more than 11 different cultural backgrounds and more than seven diverse disciplines from small to big scale, Jewelry design to Fashion and Textile Design, Production technology, Digital and Interaction Design, Design and Engineering to Communication and Media. Throughout the four intense on-site days, they worked in five diversified, interdisciplinary teams with a broad span of expertise (see Fig. 1).

It is important to note that only two had prior and, at that, minimal contact with the EM&T, and several students had never worked in an experiential (Kolb 2014), hands-on, material-driven (Karana et al. 2015) ideation manner before, which was to be the primary access line for entering the envisioned material explorations and the approach toward ideating within the Design Challenge's frame.

3 Material Design Lab as a setting

Material Design Lab, as part of KEA's lab cluster, is an experimental environment consisting of three didactically interconnected research, development, and learning spaces. They comprise an on-site franchise of Material ConneXion New York (*Material ConneXion//Every idea has a material solution.*® 2022) with 1500 innovative material samples of commercially available solutions on display, an interactive collection of raw materials and material processes, and a lab at its core, which was the stage for the hands-on experiments and the project ideations (see Fig. 2).

The latter's hybrid format as a classroom, material, and project lab allows for material analysis, exploration, creation, and eventual application to form and function.

As a unit, the three are curated with a view to the *inspiration, understanding, exploring, shaping, and application of materials* through scientific and experiential investigations, with learning spaces set up as cross-disciplinary meeting points for all things material acting as both a field-specific frame and an exchange platform

between KEA's educational program areas, which comprise Design, Architecture and Construction, Technology, and Digital.

While the eventual application of the materials is discipline-specific, the understanding process is typically run independently and advantageously across the application fields. The didactic formats range from independent cross-disciplinary teaching modules to workshops, project explorations, course-integrated introductions, and inputs to extracurricular activities.

Projects at the lab are typically developed in a hands-on, material-driven manner with the matter at the core of the exploration toward application for involved companies.

Context focuses on agenda items in sustainability for an understanding of materials with transcending outlines of ideation and exploration into one continuous, integrated process focusing on aspects such as material resource streams, sourcing, local anchoring, and circularity that are all part of the complexity of interrelationships between all material facets.

Two of the spaces were didactly incorporated into the Challenge.

The material library, apart from serving as a potential additional on-site resource during the students' process, was utilized for forming a general material mindset giving the participants insights on material categorizations, compositions, and considerations with a view to such material properties as compostability and recyclability, their carbon footprint, their content sources, toxicity, and weight.

In this capacity, it was seen as both a helpful primer and a goal to aspire to. The Challenge was kicked off there, and students were encouraged to take the first browse and familiarize themselves with the topics during the morning welcome. For continuous exposure, each consecutive morning was also started there.

The lab was the stage for all other material explorations and input and feedback sessions, facilitating creative brainstorming, hands-on learning, and prototyping in and with the materials. It was here that the students conducted both the exploring, experimenting, and experiencing through materials and the sketching, making of



Fig. 2 The displayed 1,500 samples can be experienced with the senses. Data on them and another approximated 5,500 can be sourced from the accompanying database (Picture on the left. Image by Stefano Parisi) Experts from the four HEIs, Dinesen, and BOM gave their introductory presentations in the space



Fig. 3 The industrial kitchen area of the lab as a stage for the students' material preparation and exploration processes (Image on the left. By the author). Group table area for ideating, brainstorming, 2D and 3D sketching, and prototyping (Image on the right. By the author)



Fig. 4 Six workshop tables (one for each of the five groups, one for the on-site experts to be part of the making process) were set up in one half of the lab. Each contains the necessary requisites and a frame for their first ideation task, creating a ready-set-go atmosphere. The toolboxes were accessible throughout the whole workshop

mold, actual material samples, and eventual prototypes. It was also here that most input and feedback sessions were conducted. This setup allowed the students to stay within their explorative space, close to their material needs and samples. They could switch between the shared worktop table in the big industrial kitchen area, where material preparation and explorations were taking place, to the group's table used for the Design Challenge ideations and the creation of prototypes and forms (see Fig. 3).

For the duration of the workshop, the students were grouped into five interdisciplinary teams, each assigned a table in the workshop area of the lab that was to remain theirs throughout the process (see Fig. 4). The tables were equipped with a designated requisite box containing all the necessary safety, prototyping, ideating, recording equipment, and DATEMATS and Material Design Lab's didactic materials.

The five DATEMATS toolboxes (see also Chapter "[A Supporting Tool to Design with and for EM&Ts: The Materials Toolkit](#)"), that were specifically developed for Advanced Growing Materials containing material samples on two diverse mycelium materials, two diverse bacterial cellulose materials, and a PHA material with



Fig. 5 Lab scenarios in dedicated spatial arrangements

connected information on understanding: data and properties and applying: manufacturing and product examples, were set up on the central table, becoming the stage for lectures and the on-site selection of tactile samples in diverse development stages (see Fig. 5).

The students would return to their tables to put the newly acquired knowledge into practice in their diverse stage prototyping, smoothly shifting between the industrial kitchen area with material preparation, the area of inspiration and knowledge setup with the toolboxes and tactile samples, and their table for ideation in 2D and 3D as well as consolidated mold creation.

4 Shaping the Design Challenge

In the structuring process of the Design Challenge, several aspects had to be considered to successfully connect the company to the EM&T and integrate both with the DATEMATS framework in the available time. The Design Challenge was to get the students into the right explorative mindset by framing a concrete application context and a general application frame by adding a direction the students' ideation should take. This required the pre-working through the company's DNA to have a ready approach for exploration toward ideation.

The brief, in solid alignment with the adapted schedule, furthermore, needed to assist in handling the pre-identified challenges within working with Advanced Growing Materials in this framework (Pasold 2020a). These will be further explored within the creation of the schedule, where they play an even more essential role.

With that in mind, the brief was to lay out four areas of guided framing that incorporated the essential aspects relating to the 5 As' framework (Glăveanu 2013). Firstly, the overall context through a general material approach and responsible resource activation within a given ecosystem (this was set as Material Design Labs operational requirement) and the specific context of the company leading to a pre-selection of focus areas and parameters informed by those two areas. This would, secondly,



Fig. 6 Images of Dinesen's universe: Schwarzwald with their material resources, the family generations, and the company's core product (Courtesy of Dinesen)

lead to the weaving of a story outline to benefit both the company's communication universe and the use of material. As the project's guiding constraints, it was thirdly to include angles in the form of primary generators (Darke 1979) as notions of the projects' directions. Lastly, a suggestion of tactics was to provide a perspective on the expected and realistically achievable results.

With these considerations in place, the company could be chosen, and the teams' path through the Challenge brought into a schedule.

For the Challenge, we partnered with Dinesen, a traditional, Danish family-owned company that creates bespoke solutions in wood. The company is now in the hands of the 4th generation that is continuing the path of deep-rooted traditions and values (see Fig. 6).

What made them especially interesting is the awareness and appreciation of the raw material they are working with—which is communicated through sensual storytelling to their clientele—and their desire to expand their existing solutions and processes to more sustainable ones.

Those currently comprise the careful selection of partners, i.e., cutting trees through sustainable forestry and creating a material stream where the residues of the production, which involves sawing and planning the trunks to the users' requested specifications, create a lot of offcuts and diverse-sized wood particles. These are, respectively, sold, donated, or otherwise repurposed, the former through co-labs and sponsoring, the latter through the making of firing bricks as an energy source in the production plant. A process which, while being more resource than wasteful, contributes to a heightened CO₂ admission to the atmosphere and makes the material lost for other applications.

After a detailed exploration of the company's core values, the starting point for defining the Design Challenge was three of the company's existing focus areas, which were extended and more clearly defined in the brief:

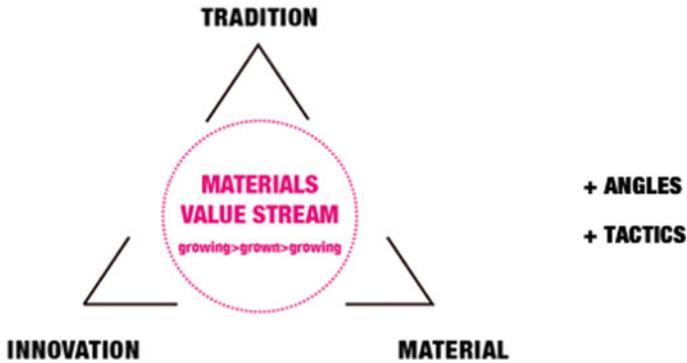


Fig. 7 Parameter triangulation for the brief (Illustration by the author)

- A strong tradition that the company has stayed true to throughout its existence and the therewith connected robust set of values.
- Their continuous search for innovation on both business and product levels. They have succeeded in moving with the times by tackling critical current issues, like sustainability in what immediately seems like a simple cut field.
- At the core of their DNA stands a singular material: wood of four different species, namely: ash, oak, douglas fir, and pine.

Within that, Dinesen is already considering material streams: the saw production residues compressed into resources for heating and as a starting resource for creative explorations by others (see Fig. 7).

The created brief is, therefore, a triangulation of (1) the traditions of the value-driven company with the students being asked to consider the family business component as well as the ethical approach to choosing partners and their overall apparent respect (and love) for their resource, (2) their continuous search for innovation which within the brief was extended beyond the use of all remaining residues of the woody stem into enabling the best possible way of using the whole tree and challenge conceptions of (giving it) the longest possible life, and (3) the symbiotic material opportunities for residue materials that lie within designing with microorganisms, that are present in the forests/nature's/soil's ecosystems.

The overall aim or focus was thereby placed on the creation of a materials value stream that cycles from the tree as a growing resource to the tree's grown residue to the symbiotic growing of new material constitutions: organic residue material and microbes combined in the next growing process, the result of which could be reintroduced to the original growth cycles and environments.

These were extended with inspirations to angles or possible strategies, introduced in the line of primary constraints linking them to objectives or concepts to form a starting point and enable a way into the problem (e.g., Biskjaer et al. 2020). In part informed by Dinesen's universe and existing explorations, in part by macro material agendas that lie at the heart of Material Design Lab's explorations, the students were

asked to consider such aspects as upcycling, local sourcing and local use, diversity in every tree and every product, symbiosis in nature mirrored in symbiosis in process, and product and wood with all senses.

With view to the project's time frame, the above was additionally contextualized through such tactics as speculative applications. These were also seen as expectation alignment on the level of outcomes.

The final brief came to sound as follows:

Within the realm of the living from growing to grown to growing, we would like you to help us push our boundaries and advance Dinesen's sustainable approach by sourcing the production's residues (our own: sawdust, wood wool, planks, and the forestry's: bark, needles, branches) into new materials and/or speculative applications that esteem to our strong set of values and place us at the forefront of sustainable creation in symbiosis with our resources.

This opened opportunities for the handling of a growing, regenerative material whose grown and discarded state was taken into the frame of growing materials again, thereby instead of creating what previously might have been considered waste into a new material value stream within one continuous cycle that can be taken back into its original ecosystem, possibly even with the same original material components seeing that, fungi live in symbiosis with the trees in their natural ecosystems. (Note: notwithstanding more extensive ecological discussions, e.g., the extent of returned biomass, aspects that were noted upon and put forth for discussion throughout the Challenge.)

5 Creating the Design Challenge's Schedule

In the process of defining the schedule details, several EM&T-specific challenges were identified (Pasold 2020c) and, respectively, marked as points of awareness. These would inform and adapt the initially laid out DATEMATs' scheme to accommodate the needs of more material-centered (this was equally found to apply for the Wood-based EM&T, see *ibid.*) explorations and Advanced Growing Materials, in particular. These were also part of an eventually integrated expectation alignment concerning the extent of the exploration field and the achievable application level of the projects' results.

As strategic decisions and points of reference, they will be touched and reflected upon with a view to the DATEMATs framework and tools relating to the Design Challenge's evaluation points through the phases and the results.

There lies a general complexity within material design processes (Pasold 2020c) with their common challenges of length and depth of understanding phases, drying times, eventual tests, iterations, and application creation, as also extensively explored in the literature on MDD (Karana et al. 2015) and biomaterial design. These are further complicated when entering the realm of biodesign and the therewith connected dealing with microorganisms. Positioned across several disciplines, the field-related

knowledge needs to be combined with requirements on the work environment to avoid contamination, challenges related to the invisible nature of the microbes that cannot be explored through sensual processes, and the non-conceivability of the outcome before and after the required incubation, which does not merely encompass a change of state but of appearance and performative qualities.

When put in the context of a concise challenge, where an interdisciplinary group is to solve a real-life brief with limited or no prior knowledge of the EM&T, several measures must be taken.

Therefore, it was decided to *focus on the field of exploration*, which would tackle both the process-inherent complexity and the project-related time constraints. This was important both with a view to the vast variety of microbes, the usually required, time-extensive pre-explorations to get an innate understanding of the specific organism collaborated with and their range of possibilities that can be extrapolated from the experiments results in as well as the accordingly chosen combinations and the eventual laying out of a conceptual frame pointing toward applications. In creating the brief, the field of actively engaged exploration was accordingly narrowed by working with one strain of white oyster mushrooms to create mycelium. This was finely fitting into the growing cycle: where mycelium constitutes part of the forest the tree grows in and is then used to combine residue materials again through binding the fibers in the following growth process with the potential of going back into the cycle at the end of its life, in the process being able to bind CO₂ rather than emitting it. With a strain of a reasonably high success rate, this was to guarantee the direct value output for a workshop of such a short duration.

In the same way, as it was possible to extend into the other EM&Ts looking for combinatorial opportunities, this did not exclude the possibility of venturing into other microbial sources, information on which was available throughout the Challenge. They were just not actively explored.

Furthermore, the time component was addressed through an *upfront introduction and a delayed project presentation*. This allowed, on the one hand, direct immersion into the topic and explorations; on the other, a sufficient incubation period for the prototypes and, therefore, tangible results. These were furthermore kept to a level of conceptualization rather than finished applications.

Dealing with the unknown and invisible was solved through *immediate familiarization through hands-on explorations* to see through the hands (e.g., Groth 2017; Ingold 2013; Pallasmaa 2010).

This process was helped along through EM&T- and lab-specific didactics such as procedural demonstrations, targeted lecture input, and extensive on-site samples, as well as continuous guidance and input, as further elaborated below.

Apart from those EM&T-related points of awareness, two further aspects connected to the use of the facilities and successful material processes had to be considered. These were partially integrated, though in a significantly reduced format. Before entering the lab, there are guidelines and rules for activities and conduct in the space, the handling of equipment and chemicals, their responsible use and their responsible disposal, ways of processing, and possible implications on the environment. These were included in the *pre-introduction* with a short repetition on-site

supplemented by continuous expert presence during the Challenge and *very guided processes*.

The usual comprehensive introduction to working in both a scientific and experiential or phenomenological manner and the introductions on material perspectives entailing ecological and resource questions were included in the Challenge’s activity planning and discussions rather than being framed within a separate introductory lecture and related tasks and exercises.

As a means for personal process documentation and in the frame of evaluation procedures, findings, steps, procedures, recipes, observed reactions, and properties are typically required to be meticulously recorded in lab journals (Pasold et al. 2018; Pedgley 2007). Instead, they were handled through group-internal photo proofing by the students and group-external documentation by experts, staff, and other groups, and, e.g., in the “frame exercise” through internal documentation utilizing sketching, note-taking, and making.

Once these points of awareness had been identified for the adaptation of the schedule, they also gave a clear indication of the necessary inputs along the way.

On a purely pragmatic side, the overall on-site program was adapted to the shorter time frame, allowing for a half-day preparation off-site and a half-day presentation after the completed incubation time.

The resulting schedule considered understanding in constant cycles with exploring and, respectively, shaping or applying with a gradual extension of both frame and range of freedom, starting from understanding the EM&T and progressing toward understanding the implications of applications within specific contexts toward solving the brief (see Fig. 8). This aligns with thinking and making inside of growth toward perpetual beginnings (Hallam and Ingold 2014).

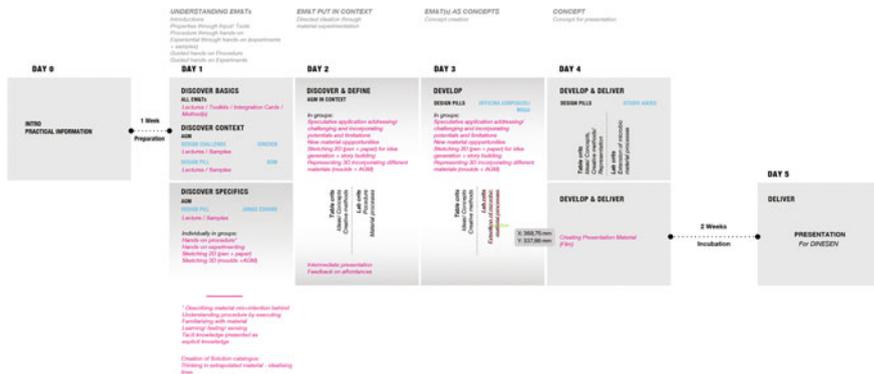


Fig. 8 Schedule for Interdisciplinary Design Challenge on Advanced Growing Materials, adapted from the overall DATEMATS schedule Including Overall themes (Bold), Input format (in Magenta), and Activities (Creation and illustration by the author)

5.1 DAY 0—Intro and Practical Information

A pre-info session was organized to tackle several practical issues such as the overall organization, the overall program, venue, and a concise introduction to Material Design Lab alongside mentions of proper conduct in the facilities, a very compressed form of a lab introduction, and the available resources to engage with upfront. This would allow the workshop to start as a head-on experience: The students could arrive with a general idea about what to expect and what was expected.

Remark: In general, this was perceived as a helpful introduction. For the most significant part, it prepared them well for arriving in the right mindset for the days to come. Students did, however, express an inherent need for more detailed program information and would have liked to know more about the challenge and program details beforehand. This, though partially brought in connection with a generally observed desire for concrete insights in uncertain situations and a need for less abstract conditions when missing actual spatial relations, should be considered for future iterations.

5.2 DAY 1—Understanding the EM&T(s)

The challenge was started in our on-site material library as an introductory backdrop to the world of innovative materials, helping to understand the presented EM&Ts as exemplary areas for several other existing EM&Ts areas. It served as an immersion into the material world in general, the Advanced Growing Materials in particular.

The program comprised **Discovering the basics** of the project, its developed framework, tools, and methods, and the 4 EM&Ts presented by the respective experts from the 4 HEIs. It further included **Discovering the specifics** of the **Design Challenge's scope and context** through the presentation of the company and the Design Challenge itself and **Discovering the specifics** of the EM&T in focus: Advanced Growing Materials as a broad field, within the scope of sustainability and their potential within the company's challenge.

The input was supplemented by two design pills and a guided hands-on demonstration leading up to the conducting hands-on procedures of cellulosic inoculation procedures on a pre-chosen combination of material elements, form experiments, and mold creation. They were designed as initial, framed, and fast-paced ideations to a specific task within the explored EM&T, aimed at familiarizing them with the topic, knowledge collection, and competence acquisition without a concrete application frame. They were supplemented by procedure logs that could be flexibly accessed throughout the week to avoid uncertainties around the processes and aided by simple, readily supplied materials and equipment.

Remark: The exploring and shaping activities were done individually in groups. This allowed for a group effort toward preparing and understanding the material: microbes + substrate and an individual decision and making process toward completing the task.

Both observations and evaluations showed that this activity was beneficial in creating an initial understanding of how to design with microbes, including the Understanding of the prerequisites necessary, the processes related, the possibility afforded, the unique opportunities to be sourced, and the framing to be considered. It also effectively served as a means of familiarization that enabled the building of confidence for the further process by the competent enabling of the frames within which ideation could happen.

Getting to know procedural methods helped to gain insights into the way of working. Executing the procedure itself allowed everyone to have a hands-on feel of the materials, thereby making the microbes tangible. Students immersed themselves deeply and stayed till long after finishing time, which was taken as a sign of actual engagement in exploring an area that caught the students' interest. Most notably, usually perceived reluctance to material explorations was not evident through the laid-out task that slowly proceeded toward creating design solutions. Furthermore, the intentional making process within a limited experimentation space served as a valuable democratic group exercise that helped in the further collaborative process.

5.3 DAY 2—Putting the EM&T(s) into Context

Presenting the previous day's work for feedback which focused on mold-technical issues in terms of incubation and successful results as well as form limitations and further material affordances, Day 2 proceeded to extend the procedure with another group of materials, pointing to the extension toward other microbes while at the same time relating it to an actual ecosystem context. This was done by ideating with the material's natural affordances toward an extreme context application. It opened the explorative, speculative thinking space and caught the students' awareness of the microbes' potential within given ecosystems, creating symbioses with organic and non-organic substances. Diverse application techniques, such as sketching in 2D and 3D, brainstorming, different material samples, other speculative applications, imagination, simulation, and transference exercises, were put to the test expanding the toolset for the eventual ideation for the solving of the brief. Having gained an understanding of the scope, potentials, procedures, and properties, it was, as the next step, time to return to the brief and ideate within the concrete context of the company. The learned was to be taken into the Design Challenge's context for first ideations.

Remark: The ideation within a context on a speculative level was to encourage the widening of material and microbic space and the thinking of applying the material affordances, sourcing their more comprehensive range of potential. The most significant part of the group actively engaged in the exercise, and the effect became apparent when moving on toward integrating the EM&T with Dinesen's universe.

Only a select few saw it as repetition, possibly missing the opportunity within the exercise, which, additionally, supported the storytelling aspect of the final presented solutions as it heightened the awareness of interrelations.

5.4 DAY 3—*The EM&T(s) as Concepts*

For further progression in the projects' ideation, the day started with two pills that widened the scope both with regard to the so-far-experimented with strain constraints and a look into material innovation on the chemo-biological scale supplemented by a necessary outlook toward the market through an industrial lens.

Remark: This expanded the explorative space and the overall realm of possibilities while at the same time introducing necessary market restraints pushing the projects' level of ideation. The students started to incorporate thoughts on ecosystems, local potentials, circular nature, and more practical issues. The range of microbes was expanded, and the merging of several EM&Ts started to manifest more concretely. More varied and interesting discussions were getting closer to implementing ideas into slowly forming concepts that could be verified with project-internal and -external experts.

5.5 DAY 4—*The Challenge's Concept*

With input on the representational nature of the produced outcomes, the students created their prototypes and presentation material.

Remark: By this point, students had reached an autonomous working stage. They were finalizing their project ideas and started on the representational tasks putting all the learned into action and a visualized form creating design probes and video presentations that had a vital storytelling aspect relating well to the company. The lab was filled with a busy, creative atmosphere with several excursions to the nearby "nature" plots to collect representational prototypes material. The workshop's materials in focus, wood residues, and microbes, were set aside and replaced by a broad mix of branches, cardboard, and 3D-printed molds, with an occasional return to the toolkits for final validation. It was then that the team members' backgrounds stepped into the foreground toward materializing the ideas into a presentation that culminated in a final social gathering as a wrap-up to the workshop in a fluid motion from finishing touches to conclusive comments overall were very positive.

5.6 Day 5—Presentation

Presentation with the company was scheduled for two weeks after the last on-site workshop day, allowing the created models to incubate and grow into their prototypical state as preliminary design concepts. The students received feedback from three experts, the facilitator, the company, and their peers.

Remark: Integrating the final solutions in the incubated state into the presentation was essential, and it elevated the project and completed the experience. It was, however, regrettable that such an intrinsically hands-on approach had to be handled online. Ideally, the feedback would have been on-site for the tactile experience of the created solutions. On the upside, the delay in presentation allowed reflection on the learned and the produced, which was an additional valuable factor. Furthermore, the experts' and company's feedback could be more refined through an upfront study of the presentations.

6 Working with DATEMATS Logical Framework

The logical framework for designing with and for Emerging Materials and Technologies developed in the DATEMATS project (Parisi and Ferraro 2020) was incorporated in different steps throughout this Challenge.

6.1 Understanding

The innate material understanding required for collaborative material exploration and parallel concept ideation was conducted in a fast-forward process. Through lecture input and discussion with experts, interaction with physical material samples of different stages of microbial development, both successes and failures, and diverse applications, paired with the developed DATEMATS toolkits with extended material information. Combined, this introduced the students to the nature of microbes, their needs, specificities, and their affordances, and possibilities.

The high number of tactile samples was connected to recounting processes through lab journals and existing applications that were just as much laid out as contextual, historical, and scientific work insights. This was to incorporate the lab's general focus on a hands-on material understanding approach that encompasses scientific knowledge and experiments and sensual explorations in a presented rather than self-experienced manner. Understanding the EM&T toward the three other phases: exploring, applying, and shaping within the limited timeframe, required the careful preparation of the input from the experts as well as continuous guidance to achieve a well-functioning flow between hybrid cognitive and physical processes.

Remark: The Understanding phase is typically placed between or as the sum of exploring, shaping, and applying. This, in turn, requires considerably longer process phases. Fast-forwarding immersion worked well within the Design Challenge when combined with a solid body of knowledge provided through different sources in a framed, spiral progression. Here, the support of material samples and applications and the toolboxes and their comprehensive information worked well when combined with ample opportunity for knowledge retrieval through lecture input on the one hand and especially through discussion, targeted Q&A, and guidance.

6.2 Exploring/Shaping

The failure to iterate within this short timeframe, as that stands in strong contradiction to the microbes' requirements of an incubation period in order to grow, was addressed through immediate hands-on processes through several advancing stages within very framed tasks. The exploring phase was not run in iterative processes per se. Those were instead simulated by producing a vast number of prototypes requiring automated production and putting the body of knowledge into practice. This was to build confidence in handling the unknown and unexplored (on own premises) and to create an immersed understanding. Advances were made built on feedback from the experts that would give approximated insights into the created results. In a second step, the exploration was expanded by a combinatorial exercise of applying the materials' unique properties in a speculative exercise to a context.

Remark: The chosen path into exploring through guided, restricted experiment spaces helped the students gain confidence in working with the material and gave them a chance to perfect their mold-making expertise or, for a not unsubstantially big part of the group, gain some.

A small group failed to see the point of the speculative applications, which were seen as repetitious material experimentation.

Additionally, it became apparent that working in this manner places an inherent requirement on the students for a basic form-language and aesthetic Understanding to be developed before embarking on such explorations. It is equally helpful to have an established practice of making, developing, learning, and expressing through materials and prototypes (Ramsgaard Thomsen and Beim 2011).

6.3 Applying

With the awareness that application and actual shaping can be challenging when working with this particular EM&T (Pasold 2020b), suggestions for strategies were already implemented into the brief, accommodating the lack of immediate feedback for eventual iterations. The students were to work speculatively with storytelling, abstracting, simulating, and emulating.

Remark: Being prepped through the tasks run in the two iterations, supported by input on examples of applied materials, the students were enabled to apply different strategies.

6.4 Understanding, Exploring/Shaping, and Applying—The Phases Combined

That said, working in a hands-on, material-driven manner, the Understanding, as well as the possibilities for Applying and Shaping, are typically gained through Exploring (Schön 1992) in one continuous iterative process, where making and growing are intrinsically linked to each other and the thinking through and of (Architecture Foundation 2020).

Courses in the lab typically use a multi-method approach of co-evolutionary processes (Dorst and Cross 2001). In the case of the Design Challenge, they had to be carefully moderated through a combination of expert-presented tacit knowledge, procedural demonstrations, and own explorations on guided tasks to enable a better basis for creative exploration and felt design iterations. Within the workshop, these stages were supplemented and, in part, substituted by three lines of input: an external, external–internal, and an internal dialogue. The schedule incorporated (1) continuous input through lectures, (2) the provision of a wide range of tactile samples of different nutrition-microbe combinations displayed in material design experimental stages in petri-dishes, tangible prototypes, and eventual forms in products, (3) the project’s developed toolkits with implemented properties and application potentials and further resources included in the extra materials, (4) demonstrations, and (5) actual applications in parallel to the continuous, on-demand possibility for supervision, feedback by experts and Q&A along the way.

All types of input served vital purposes in this fast-forward immersion into the topic, with students continuously receiving feedback on their ideas and downfalls, preconceived estimations, and scientific and procedural corrections throughout the process.

The most vital support was, indeed, the continuous input. Table crits on ideas, concepts, and creative methods went alongside Lab crits on procedure and material (microbes, nutrition, and incubation conditions) and form-giving processes, the latter with a focus on the creation of appropriate molds and the proper procedures for them.

To limit the complexity of the area, the phases were combined in different constellations and to different extents employing the knowledge spiral between explicit and tacit knowledge (Nonaka et al. 1995). This is exemplified in (Fig. 9) on Understanding, Exploring, and Shaping that was put into action in the first task to ensure the learning of the basics through a guided, confidence-building process that would enable further work on the brief (see Fig. 9).

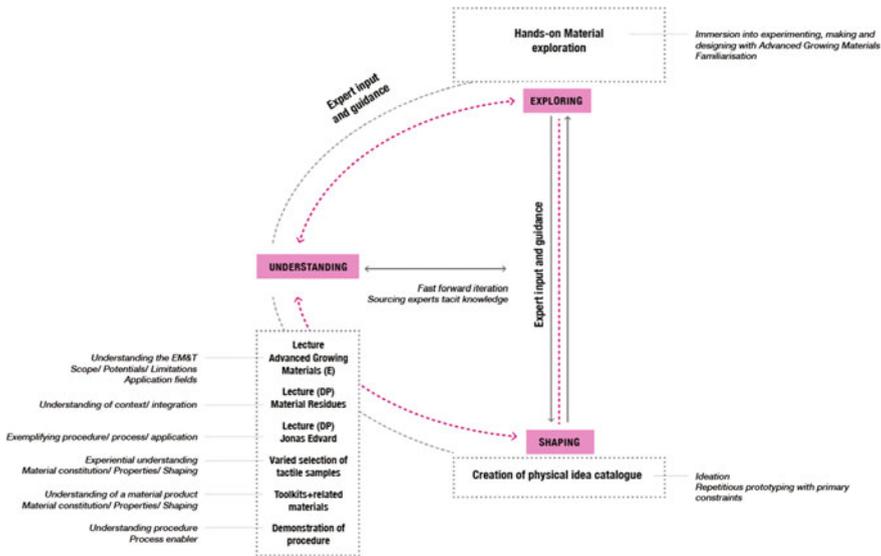


Fig. 9 Connecting didactic takes on Understanding–Exploring–Shaping exemplified on the structure of Day 1 (Illustration by the author, based on Stefano Parisi’s framework model)

The same strategy was continued for the second day with an expansion into applying for the eventual expansion of integrating the learned through all four phases toward solving the brief.

Expert input with their tacit knowledge was at the center of all the cycles, and conclusions could be drawn with a broader field of experience. In addition to that, connected input by experts allowed for an informed ideation process with in-built iteration, faster feedback, and evaluation on testing to lead to further refinement stages, based on professional guessing on what will work and what will not, combined with fast-access changes.

7 Supporting through Design Pills

To support the students’ journey, design pills were incorporated in such a way that they took supporting acts in the numerous themes touched upon throughout the phases of the workshop, interactively helping both the gradual extending of the Understanding of the sphere and the solving of the brief both in relation to each other and as one integrated process.

Apart from Dinesen, the students met five companies, each entrusted with a particular aspect of the workshop’s program and a concrete brief on their input. This was aligned with students’ ideation progress to expand relevant knowledge and expertise continuously. In addition, three of the pills gave guidance within their areas of input

expertise, which extended the exchange of knowledge, allowed for specific Q&As that limited the necessity for the search for relevant, especially scientific knowledge substantially and therefore acted as a proof of concept and enriched the project's developments.

Starting with a general mindset for residue awareness, the current approaches for reintegration into material cycles, and how to incorporate such thinking into the material stream, BOM—the Bank of Materials presented their efforts toward responsible material use as an altered residue view and a contextualization.

Jonas Edvard, a Danish artist, and designer working in the field of material science and applied design experiments, was invited as the maker's view. His input was to lay out the material opportunities for experimentation and form-giving and facilitate the early part of the challenge. The students were getting an initial contact with the material and product creation and the related procedures feeding into the Understanding and Exploring of the framework.

Followed by a hybrid material researcher and designer's view, *Officina Corpuscoli* provided insights into the research of microbes toward novel material constitutions and products as well as artistic and speculative applications, broadening the scope and opening new lines of inquiry and discussions. At this point in the progress, it was necessary to touch upon all areas of the framework Understanding, Exploring, Applying, and Shaping, where both the operating across scale, the introduction of different perspectives to the material affordances: Art, Installation, Research, Material, Real-life product application became valuable inputs.

A real-life production view was offered by *ogou*. The focus of the input was to be placed on the encountered challenges when ideas enter an industrial context. Here it was not only to include facilities and controlled incubation environments but also the markets and consumer views, the necessary extension of their aesthetic understanding, and the needed compromises to fit into those requirements with related conflicts of ideation and reality. This would provide input to Shaping and a necessary contextualization of the market.

Finally, the speculative application view presented by *Studio Aikieu* in their role as a curator was looking at the use of materials as a means of idea mediator, creating speculative applications and how to present such ideas by providing input within the Applying and Shaping for representation.

Throughout the program, the pills extended the level of abstraction while ensuring a continuous widening of the students' horizons. Additionally, this resulted in a perceived fast progression of the level of competence along the path of ideation.

Remark: The pills and their placement in the students' progress worked exceptionally well. The students evaluated them as very helpful and relevant, and the effect could be traced back to their progression in the ideation. Combining the contribution of the pills and their respective roles as material manufacturer, creative practitioner, creative researcher and innovator, producer, and curator with ample opportunity for Q&A, input, and guidance on procedures, projects, prospects, potentials, and possibilities as well as more specific scientific insights was very advantageous. This was enabled through on-site presence, an invaluable factor for the hands-on approach, and the topic's complexity.

Merely one of the contributions was delivered online. Given their topic on speculative applications and presentation through design probes, it worked very well, nonetheless.

8 Five Diverse Answers to One Brief

Apart from a vast number of explorative models, that were produced in the first and second generation of the material ideation phase, which, respectively, provided a comprehensive base-level understanding of how to work with the microbes in terms of handling, conditions, mixing, making, growing and how to source and apply their specific material affordances as well as contextualize them into a defined ecosystem, there were five concepts presented (see Figs. 10 and 11).

They span reasonably wide but take all inspiration from the brief (For a deeper understanding see appendix with all the projects).

Fulfilling the Design Challenge on very different levels, they comprise a systemic solution in the form of a whole ecosystem for the forest or the respective buyers' backyard (Recosystem), a holistic and applied solution for family gatherings (Skovit), an ingrown tracking system to the tree's origin (Forest Archive) as well as slightly more artistic takes relating to both the symbiotic aspects (Fungi × Dinesen) and the sensual universe of Dinesen (Under the forest).

All five concepts clearly show that the groups have initially understood the Advanced Growing Materials, the procedures, creative working potentials, and affordances. This becomes apparent in the presented ideations and respective applications.

Through that, they display that working within the set restraints was beneficial for the students not to be overwhelmed by the complexity of the task at hand. The concepts thereby show a deep integration of the context, the ideas toward the



Fig. 10 Each group was to fill a frame of ideations for the first task, which was completed individually in groups (Image on the left. Photo by author). Speculative applications as solutions to the second task in groups (Small selection on the right. Photo by author)

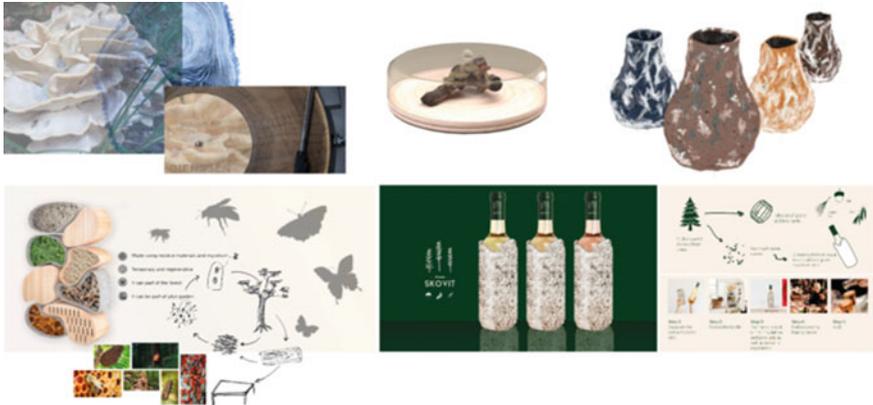


Fig. 11 The five concepts. In clockwise order from the top left: Under the forest by Luca Cappetti, Claudia Perez, Laura Rusanen/Fungi × Dinesen by Anders Christian Felsager, Andrea de Bernardi, Ignacio Esnaola Ganuz/Forest Archive by Jon Aranburu, Juraj Tomaic, Alejandra Alarcon/Skovit by Sara Saccoccio, Guillermo Ortiz, Pauline Rousseau, Irene Purasachit/Recosystem by Alessandra Sisti, Ana Apaolaza, Niina Hyry

ecosystem, the given angles, the symbiotic potential of the residue, and the microbes. Furthermore, they relate them to the family and sense aspects in Dinesen’s universe, presented through equally appropriated storytelling.

Three concepts incorporate the symbiotic potential that lies within the microbe-residue combination with a view to their ecosystem as the core of their concept.

The Design Challenge laid the basis for a natural integration of two EM&T areas. Seeing that it centered around wood residues, Aalto’s Wood-based EM&T and KEA’s Advanced Growing Materials were a natural match. This was taken up as an immediate opportunity and specifically further explored by three groups.

And finally, the company commented on the projects through their lens by thanking the students for “*growing Dinesen in new directions.*” They thought the outcomes “*interesting and mind-opening for possible futures with a process and format that was beneficial.*”

More specifically, Hans Peter remarked on Skovit fitting well within their existing universe of communicating trees as a great extension to the Sense of Dinesen from smell to taste, seeing opportunities within the realm of gifts or a promotional line. Recosystem is not only a great project title but a great extension to their current palette of bee hotels in the form of a very rounded concept. Under Forest affords the poetic potential to the sound of Dinesen and the notion of individualized and slow-grown products extending to other societal movements, and the Forest Archive beautifully portrays the tree as the valuable resource it is, embedded within an ecosystem.

9 The Students' Evaluations

The survey was answered by an evenly distributed number of students across the four participating HEIs and therethrough gave insight into the different schools' and backgrounds' constitutions (see Fig. 12).

It showed that the Design Challenge on Advanced Growing Materials was received very positively.

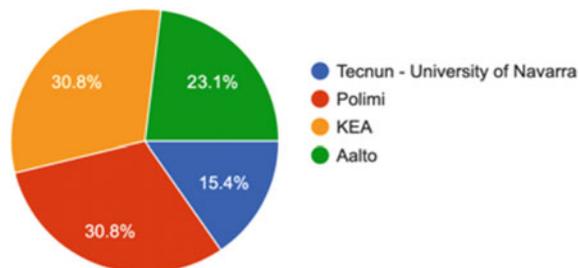
With an average of 60–80% in total agreement and a further 10–20% in agreement on the given evaluation points. Here the students rated the didactic resources as well-employed, the interaction with the staff as very beneficial, and the important contents and materials as relevant that were interesting and well conveyed through different formats.

The presentation by the briefing company Dinesen was easy to understand and engaging, and the connected Challenge brief was consistent with the EM&T, the project description, and the students' expectations.

Equally, most students thought that the DATEMATS' Methodology: Understanding and Exploring/Shaping was well-integrated into the agenda, supported by tools that were "impactful" and "relevant" to the design project. They notably remarked on the Material Design Lab's typical approach of "hands-on exploring and understanding" and "touching the proper material" as something they "really liked," that was "very interesting" and "necessary when trying to understand the properties on a deeper level." Furthermore, the hands-on approach was attributed as being a "beneficial team-building activity." The planned activities and phases were relevant to the scope of the Interdisciplinary Challenge, and "all the materials were very valuable."

The speculative approach in the Applying phase was, for the most part, enthusiastically embraced as an exercise where "one could just let go and explore." It was seen as "very gainful for understanding and exploring possible future implications of those materials," "helped to understand the wider context of the application possibilities," and "discover new things." It furthermore was evaluated as "working well in contexts where groups do not know each other well to work creative and without rules" and "think outside the box," and for some, it was referred to as a "new technique to add to their design toolbox."

Fig. 12 The survey respondents' division between HEIs



While the schedule was described as “well-managed but still pretty tight” with the students’ expressed “understanding for limitations regarding the learning scope and expansion to a more diverse selection of growing materials,” there was a consensus that the workshop was too short “to both get to know the EM&Ts and to come up with a design proposal for a company.” Some called it “a bit intense to come up with a complete concept and presentation plus visual in such a short time.” This moderate agreement on the duration of the workshop being adequate even stands in contrast to the high engagement, with 23.1% working outside the classroom hours. The desire to use a longer duration on “the exploration of more diverse ranges of microbes, processes, and possibilities,” was expressed.

Furthermore, students also uttered a need for more concrete information before the workshop regarding schedule, brief, and content.

The design pills by the design studios and companies were evaluated to have provided inspiring inputs to the students’ design projects by demonstrating different and relevant design approaches to dealing with emerging materials and technologies. Their distribution and length were adequate, and “the presentations were really enjoyed.” Nevertheless, they were also perceived as competing with the achievable results. The “tight schedule” was seen as a “problem,” and “the following of the same” resulted in “very little time to develop the project.”

The toolkits were rated with 100% in their relevance to helping understand the EM&Ts’ potentialities and their possible integration. They are evaluated in more detail in the toolkit section. The Inspirational Integration Cards for EM&Ts Intersection were equally seen as applicable, with more than half the groups actively integrating two EM&Ts.

Working with students from other countries and backgrounds was looked upon very positively. The group-making was agreed to “have facilitated the execution of tasks and activities” during the Challenge, and multidisciplinary and cross-cultural collaborations were summarized as beneficial to the process, where “the meeting of new people with different backgrounds helped them to widen their approach.”

The students concluded with summarizing comments along the line of the Interdisciplinary Challenge on Advanced Growing Materials having “increased their knowledge about emerging materials and technologies,” “transferring a methodology and tools that they can use in future projects and future practice,” and “made them more interested in pursuing global opportunities like this.”

Overall, the Challenge was referred to as “eye-opening” regarding the material opportunities, the future developments, and the conceptualization of a project within the time frame. The latter being seen as only two days separating the getting to know the EM&T and the ideation. It was thought to be “stimulating and consistent with the description of the activity, the DATEMATS project, and their expectations.” They “learned a lot about these materials,” “new ways of creative thinking, experimentation, and exploration” (see Fig. 13).

Most notably, the teams expressed a natural desire for further explorations, “*more growing, more microbes, more sensing (the latter being related to the Dinesen Challenge and the sensing angle),*” and that “*the work atmosphere had been spectacular*”

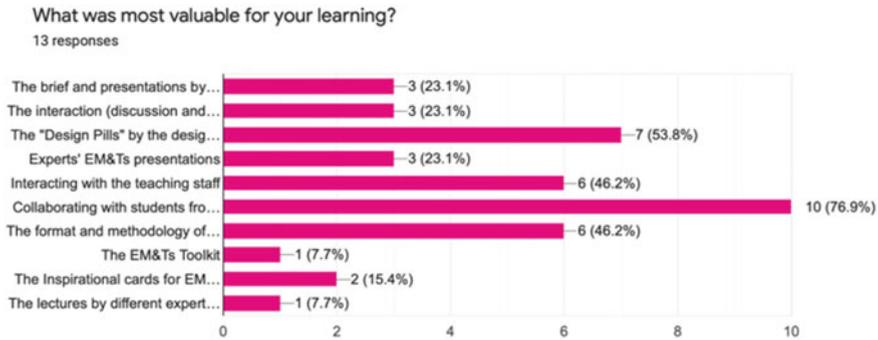


Fig. 13 Survey's learning impact evaluation

in a four-day exploration, where "the being able to really try to use the material was both the most valuable aspect and at the same time the most challenging one."

Rated as most valuable for the learning experiences were (1) the collaboration with students from other universities, cultures, and fields of expertise. Here, it is worth mentioning that there was only one single standing comment on typical group challenges, which makes for a very high success rate. (2) the Design pills followed by (3) the interaction with the teaching staff and of equally high importance (4) the format and methodology of the workshop, which refers to the combination of DATEMATS framework and the EM&T and lab-specific adaptation or more precisely the merging of the two for the Interdisciplinary Design Challenge.

The brief presentation, the interaction with the company, and the EM&T expert presentations, on the other hand, are seen as necessary backdrops for the Challenge, creating the overall frame for the Challenge rather than actual learning experiences.

10 Overall Reflections

There are some overall reflections on the diverse strategies taken toward implementing the framework with Material Design Lab's frames, methods, and processes, with the EM&T of Advanced Growing Materials and Dinesen as the Design Challenge company. Several key factors that made the Interdisciplinary Design Challenge work well with the set-out scope of trying the framework in a company context were identified.

Dinesen was a great match for the restricted scope of microbial explorations, and the overall theme, angles (constraints), and tactics worked well along with the students' project progress. The students' creative processes were constantly engaged and dedicated to the challenge. The brief was evaluated as an excellent fit for the EM&T, and the challenge and the given framing worked well. There were no doubts or uncertainties expressed, and the results clearly show the path from understanding

how to work with the EM&T to the eventual competent application into concepts. Understanding the company's DNA is thereby seen as a vital part.

The brief's constraints and guided process allowed for a fast-paced progression.

It is also interesting to note that none of the groups chose a pure material path. Despite the brief allowing for such. Instead, all groups went for actual applications.

Combined, the decidedly most valuable inputs are the pills, their relevance and placement, the experts' input, the continuous guidance, and the hands-on approach as a way into the EM&T.

Altogether, they served the students to achieve a general level of knowledge, competencies, and skills within the area, so much so that the projects' TRL ratings are slightly too positive. It furthermore showed that the input through lectures must be precise and short to deliver a well-curated body of knowledge without distracting from or delaying the project's work. The relevance of the talks to where the students were in their process was seen as essential in the planning and is confirmed through the students' feedback.

The more basic schedule changes undertaken were found to apply to both Wood-based and Advanced Growing Materials and are seen to potentially find relevance in EM&Ts with material-centered (Pasold 2020c) explorations at their core. They need to allow for hands-on exploration, delayed results, exploring through more aided means to run alongside the experiential explorations, and more consistent guidance. The continuously provided input, being able to ask specific questions with a high success rate of being able to get a satisfying answer, ensured a quick but natural flow of information (Dorst and Cross 2001) between experts and students, students and didactic materials (both methods, information, and toolkits), material samples and students.

The hands- and head-on immersion into the topic put everyone in a comfortable mindset for the explorations. It made up for fast progress to being able to ideate with microbes that enabled the creation of prototypes adjuring to material affordances throughout task 1, material connectedness to a specific context in task 2, and, eventually, a holistic and realistic approach to solving the brief.

Working individually in groups allowed for a gradual getting to know each other, with the groups gathering around the preparation of the materials while allowing for individual perspectives and processes on the ideation with related form and application decisions.

The hands-on material approach was generally regarded as very beneficial to the process.

The DATEMATS toolboxes, probes, and tactile samples were apart from providing valuable information in the case of the first, enabling and encouraging engagement and conversation about materiality giving concrete insights on the working of and with microbes.

It is also interesting that otherwise perceived cultural and disciplinary diversity challenges, which can cause difficulties in teams, were not apparent within the Challenge. Instead, the teams seemed to manage to integrate their different expertise within their projects, e.g., the production expertise of the Forest Archive team. Therefore, group work was equally seen as highly beneficial and positively contributing

to the projects' processes and output. The supported problem–solution co-evolution (Schön 1987), in part enabled by the framework and in part by its specific interpretation, was a supporting act in the collaborative design (Wiltschnig et al. 2013). This is seen as a combination of group-making and the didactic methods applied. Significantly, the hands-on direct material immersion enabled a focus away from the group through an individual understanding, allowing for the usual group dynamics to not take over. Only one comment was given on the necessary compromise within the group's setup, concluding a very high success rate.

Everyone, including the course conductors, commented on the time being too short. There was a strong desire for more diversity and a more extensive field of exploration, which seem to have an apparent correlation and therefore, only be provided through more extended runs.

Combined with the on-site material samples, the toolkits are valuable sources for developing and framing concrete solutions.

The framework was used as an organizing backdrop of schedule and brief creation rather than an actively used requisite. In retrospect, it was also seen as helpful by students along the path of understanding the phases.

On a final note, two local members of two of the groups returned to the lab to refine their prototypes for the final exhibition in Milan through a 1:1 scale model, involving more precise form considerations and formwork toward a successful mold, the trying of the concept of bio-welding, and the finishing of the prototypes toward the integration of such details as labeling (see Fig. 14).

This renewed iteration gave further insights into the students' progressions and enabling, where they, for the first time, ran the complete making process with the



Fig. 14 Refining the prototypes for Forest Archive and Skovit for the final exhibition in Milan (Photo by author)

possibility of checking on the growing prototypes. They chose to work simultaneously at the lab, which allowed another insight as a beneficial output of the project: design intelligence (Speaks 2002).

Acknowledgements Special thanks go to Dinesen and the participating companies for providing their valuable time, knowledge, and expertise during the specific phases of the Design Challenge, to the internally contributing experts from the four HEIs, the group of motivated students that left one hopeful for the future full of complex challenges that can only be solved in such interdisciplinary multicultural teams.

It was an inspiring and fruitful short week.

References

- ArchitectureFoundation (2020) 100 Day Studio: Tim Ingold—Making Growing Thinking—YouTube. Architecture Foundation. <https://www.youtube.com/watch?v=FptmjWzj6Vw>
- Biskjaer MM, Christensen BT, Friis-Olivarius M, Abildgaard SJJ, Lundqvist C, Halskov K (2020) How task constraints affect inspiration search strategies. *Int J Technol Des Educ* 30(1):101–125. <https://doi.org/10.1007/s10798-019-09496-7>
- Darke J (1979) The primary generator and the design process. *Des Stud* 1(1):36–44. [https://doi.org/10.1016/0142-694X\(79\)90027-9](https://doi.org/10.1016/0142-694X(79)90027-9)
- Dorst K, Cross N (2001) Creativity in the design process: co-evolution of problem-solution. *Des Stud* 22(5):425–437. [https://doi.org/10.1016/S0142-694X\(01\)00009-6](https://doi.org/10.1016/S0142-694X(01)00009-6)
- Glăveanu VP (2013) Rewriting the language of creativity: the five A's framework. *Rev Gen Psychol* 17(1):69–81. <https://doi.org/10.1037/a0029528>
- Groth C (2017) Making sense through hands: design and craft practice analysed as embodied cognition. Aalto University. https://aalto.finna.fi/Record/aaltodoc.123456789_24839
- Hallam E, Ingold T (2014) Making and growing: anthropological studies of organisms and artefacts. In: *Making and growing: anthropological studies of organisms and artefacts*. Ashgate Publishing Ltd.
- Ingold T (2013) *Making: anthropology, archaeology, art and architecture* (Paperback)—Routledge. Routledge. <https://www.routledge.com/products/9780415567237>
- Karana E, Barati B, Rognoli V, Zeeuw van der Laan A (2015) Material Driven Design (MDD): a method to design for material experiences. *Int J Design* 9(2):35–54. www.ijdesign.org
- Kolb D (2014) Experiential learning: experience as the source of learning and development. <https://www.google.com/books?hl=da&lr=&id=jpbeBQAAQBAJ&oi=fnd&pg=PR7&dq=D.+A.+Kolb,+Experiential+learning:+Experience+as+the+source+of+learning+and+development.+FT+press,+2014.&ots=Vo7SpS0ZOf&sig=BZMoC0crV4ytNBRggqVD6DirZxA>
- Material ConneXion//Every idea has a material solution.® (2022) <https://materialconnexion.com/>
- Nonaka I, Takeuchi H, 竹内弘高 (1995) *The knowledge-creating company: how Japanese companies create the dynamics of innovation*. Oxford University Press
- Pallasmaa J (2010) *The thinking hand: existential and embodied wisdom in architecture*. Wiley
- Parisi S, Ferraro V (2020) A logical framework for designing with and for Emerging Materials and Technologies (EM&Ts). In: Ferraro V, Pasold A (eds) *Emerging materials & technologies: new approaches in design teaching methods on four exemplified areas*. FrancoAngeli
- Pasold A (2020a) *Advanced growing materials—designing with living matter*. In: Ferraro V, Pasold A (eds) *Emerging materials and technologies—new approaches in design teaching methods on four exemplified areas*. FrancoAngeli

- Pasold A (2020b) Experimental-experiential approaches to designing with advanced growing materials. In: Ferraro V, Pasold A (eds) *Emerging materials and technologies—new approaches in design teaching methods on four exemplified areas*. FrancoAngeli
- Pasold A (2020c) The four EM&Ts—a synthesis of a literature review. In: Ferraro V, Pasold A (eds) *Emerging materials and technologies—new approaches in design teaching methods on four exemplified areas*. FrancoAngeli. <https://library.oapen.org/handle/20.500.12657/41797>
- Pasold A, Marko M, Meid A, Skala M (2018) *Growing materials—a process documentation*. Material Design Lab/KEA
- Pedgley O (2007) Capturing and analysing own design activity. *Des Stud* 28(5):463–483. <https://doi.org/10.1016/j.destud.2007.02.004>
- Ramsgaard Thomsen M, Beim A (eds) (2011) *The role of material evidence in architectural research: drawings, models, experiments*. The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation
- Schön DA (1987). Educating the reflective practitioner: toward a new design for teaching and learning in the professions. Jossey-Bass. <https://aalto.finna.fi/Record/alli.747043>
- Schön DA (1992) Designing as reflective conversation with the materials of a design situation. *Knowl-Based Syst* 5(1):3–14. [https://doi.org/10.1016/0950-7051\(92\)90020-G](https://doi.org/10.1016/0950-7051(92)90020-G)
- Speaks M (2002) Design intelligence: or thinking after the end of metaphysics. In: *Architectural design—versioning: evolutionary techniques in architecture*. Academy Press
- Wiltschnig S, Christensen BT, Ball LJ (2013) Collaborative problem-solution co-evolution in creative design. *Des Stud* 34(5):515–542. <https://doi.org/10.1016/j.destud.2013.01.002>

Anke Pasold is an Associate professor at the Copenhagen School of Design and Technology, where she has been developing the Material Design Lab for both, advanced research and interdisciplinary teaching purposes. The core lab development is focused on methodological and technological structuring of new material-educational programs, enabling collaborative research projects and innovation-driven student projects to evolve around questions on considered material design and its impact. Graduated from both Architecture and Design institutions with studies in Germany, Spain, Australia, and Italy, Ankes’s multidisciplinary background forms a specific knowledge and methodological capacity to conduct research with a focus on material practices across design scales. Studies are particularly focused on advanced design methodologies, material formation, and fabrication processes, which she explores by means of experimental prototypes, linking research to applied solutions. Anke has received and developed projects funded by private Danish foundations and from the EU Horizon programs with results published at leading international conferences, in International journals, as editor and author of books on material research and design.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Applying DATEMATS Methods and Tools to Experimental Wood-Based Materials: Materiality in an Ideation Process



Tarja-Kaarina Laamanen and Pirjo Kääriäinen

Abstract This chapter provides an overview of the DATEMATS Experimental wood-based materials workshop and student projects, and a more detailed description of one team's ideation process. The workshop was held at the Chemarts facilities of Aalto University, Finland, in January 2022. A total of 19 students from four different universities and from the fields of design and engineering participated in a five-day workshop creating innovative applications for interior panels made of cellulose waste. The company challenge was given by Honext from Spain.

1 Introduction

Chemarts is a community and learning environment that combines design expertise and chemical engineering in the field of bio-based materials. Its overarching thematic structure is based on sustainability, learning about sustainable materials, and exploring concurrent real-world challenges. These themes are driven by the complexity of the problems, and no solutions are known beforehand. The goals of the learning are connected to new knowledge and solutions beyond traditional disciplines or at the edge of disciplines. Chemarts applies the 'learning by doing' approach, in which a hands-on, early stage explorative process of making materials is central (Laamanen and Kääriäinen, accepted). Learning by doing utilizes the learner's natural ambition to learn in concrete, real environments. It enables learning through the inquiry process and knowing how (Kivinen and Ristelä 2002; Laamanen and Kääriäinen, accepted). In Chemarts, material exploration is the starting point for material-driven idea generation, experiments, and concept proposals.

Due to the above-mentioned ambitious goals, Chemarts courses are typically several weeks long (see Laamanen and Kääriäinen, accepted). The DATEMATS *Experimental wood-based materials workshop* reported here was an opportunity to try out how the Chemarts' approach could be introduced in a short-term workshop. The workshop applied principles of collaborative learning, which is common today

T.-K. Laamanen (✉) · P. Kääriäinen
Department of Design, Aalto University, Espoo, Finland
e-mail: tklaaman@gmail.com

© The Author(s) 2023
V. Ferraro et al. (eds.), *Materialising the Future*, Research for Development,
https://doi.org/10.1007/978-3-031-25207-5_8

in design and engineering education. It is a student-centred teaching strategy in which students of different levels of ability or background work in small teams, and all team members participate in completing the assigned task (Emam et al. 2019). The tendency is for design education to move towards the reality of design practice, in which projects are almost exclusively collaborative endeavours, often requiring multidisciplinary and interdisciplinary expertise (see Valtonen and Nikkinen 2022). Transformation towards a sustainable future starts by working and reflecting with people from various backgrounds, ideas, and working styles (Valtonen and Nikkinen 2022). In this workshop, the teams were heterogeneous: the students had diverse backgrounds and experiences, and aimed to simulate a real-life design situation (see Emam et al. 2019).

In this chapter, we focus on materials and material knowledge as part of the workshop. The emerging circular economy and eco-design have led to an urgency to study and develop material-related education for designers. The knowledge involved in the new materials and technologies within science and engineering is vast and ever increasing (Ferraro and Pasold 2020). An educated understanding of the potential of new materials and technologies is essential. Future designers need skills that cut across disciplines to help learn how to develop and use materials to embrace multiple properties, including aesthetic, technical, functional, and sustainable features (see Haslinger and Bang 2015, 27).

In our very brief literature review, we discuss the characteristics of collaborative design ideation and the materiality in the design. After this, we provide an overview of the workshop and projects of five international student teams. Subsequent sections discuss the case study of one team's process in more detail. Our aim has been to understand how working hands-on with materials enables the emergence of insights into the collaborative idea-generation process. The team's process was video recorded and analysed qualitatively. The team's process is reported here in chronological order, and we explain nine critical events and the related material facilitation of the idea generation in the recorded episodes.

Finally in the conclusion, we reflect on the outcomes. The results of this analysis highlight how the team used typical design representations and practices to communicate their ideas, to create new knowledge, and store it. External sources of inspiration and information were used most in the idea-framing phase and the representation created by the team themselves increased in the latest phases of the process. Sketching activity played a surprisingly small role in idea generation. However, the role of the self-made material was vital. It worked as a source of inspiration in a joint material practice, i.e., material sketching that helped draw the final idea and concept together.

We conclude that this type of short workshop is most suitable for senior students who already master the design process quite well. It works as an inspiring introduction to making and using experimental cellulose materials in the design process.

2 Collaborative Design Ideation

Collaborative design is an activity driven by communicative practices and representations for mediating ideas (Artman et al. 2005). A central aspect of successful collaboration is sharing the evolving representations as well as negotiating, elaborating, accepting, or abandoning ideas (Lahti et al. 2016). We focus on a collaborative ideation process, which started by framing the given task. *Framing* refers to ‘the creation of a standpoint from which a problem can be successfully tackled’ (Dorst 2011, 525). Framing the situation starts with gathering information and inspiration to generate ideas, moves on to choosing a promising idea(s) then refining and developing the idea, and finally ends with the design concept.

Idea generation is the interaction between previous experiences and new external influences (Laamanen and Seitamaa-Hakkarainen 2014). Different practices such as information gathering, collecting sources of inspiration, and sketching (Goldschmidt 2003; Keller et al. 2006) or techniques such as mind-mapping or brainstorming help map out the possibilities for the current design task. In a collaborative setting, the design team aims for a shared understanding of the data that have been gathered, and acts on that data through organization, externalization, pruning, and interpretation (Kolko 2010). At the same time, the idea space narrows and constraints are created (Kolko 2010; Laamanen 2016). Selecting an initial *key idea* suitable for further development and refinement is essential. *Key* refers to a certain openness in an initial idea to avoid committing too early. It constrains the process and inspires new ideas when developed further in an explorative process (Laamanen 2016; Lawson 2006). The iterative process continues in idea development. The idea is defined and refined through a range of decision-making and problem-solving, requiring experimental practices and information-gathering activities that are sometimes repeated multiple times (Mace and Ward 2002). Idea refinement can include the adaptation of an idea or set of ideas via conceptual combination (i.e., combining aspects of multiple ideas) or elaboration (i.e., extending the development of a particular feature) (Watts et al. 2019). The idea is tested and refined by materializations such as quick sketch models. A physical model enables one or more aspects of a product to be demonstrated (Hess and Summers 2013). It is a valuable tool for communicating in a team, as well as sometimes a tool for exploring new ideas (Jacucci and Wagner 2007). A finalized idea, i.e., a product concept includes a detailed description of the form, behaviour, and features of a product, its specifications, and justification of the current situation. However, in this context, the resulting concepts are at a very experimental level.

3 Materiality in Design

Material or representation is often needed to mediate the activity in product design. Some sort of representation, such as a sketch, document, material, diagram, or prototype is typically involved in communicating one’s thoughts to others, be this a team

member or a client. These different types of graphical, verbal, and physical representations are generated and transformed from the ideation to the finalization phase (Laamanen 2016).

For product designers and engineers, material knowledge is essential, because the work is mostly based on hands-on practice (Haslinger and Bang 2015). General knowledge of the materials relates to, for example, the selection available, their technical properties, their sustainability, their experiential qualities, their cost, and how they can be processed. This type of knowledge can be gained at least partly from different information sources (see Härkki et al. 2016, 2). However, when working with emerging materials or in scientific material research, the design approach differs from conventional product design processes. Through material exploration and experimentation, designers and engineers gain an understanding of the materials' properties and behaviours even at the beginning of the material development process. New insights support not only product development, but also ideating completely new applications (Härkäsalmi 2017).

Playing around with materials, samples, and prototypes, and studying their qualities reveal associations on many levels, extending thinking and helping decision-making (Kosonen and Mäkelä 2012). Sensorial attributes are links between the physical composition of the material and the associations created from it (Haslinger and Bang 2015). Sensory experiences such as seeing, touching, smelling, gesturing, heaving, and moving convey 'informational cues' from objects (Jacucci and Wagner 2007).

Kirsch (2010) labels the interactive process of projecting structure and materializing it as the most fundamental process of thought. However, this is a two-way street: materiality also affects and shapes our mental functioning (Wertch 1991). Therefore, previous experiences of materials and the related embodied knowledge enable us to imagine feel and other properties even from images, before the physical making phase (Groth and Mäkelä 2016).

These imaginary explorations and visions are especially important for designers when making material choices. The better the repertoire of design and material knowledge, the more solutions can be seen and expressed (Alesina and Lupton 2010). Designers typically make material choices based on existing materials. However, Haslinger and Bang (2015, 30) observed that if the selection process is only based on existing materials, this restricts participants and products, and only properties already known to the participants are articulated.

4 Overview of the Workshop of Experimental Wood-Based Materials and Student Projects

4.1 Workshop Description

The DATEMATS workshop was held at Aalto University, Finland. Its content was based on the joint DATEMATS workshop structure, following the framework of ‘*understanding, experimenting and applying*’ (Parisi and Ferraro 2020, 153–169). However, the schedule and the programme were adapted to enhance the specific needs of experimental wood-based materials. Altogether 19 students from four different universities and from the fields of design and engineering participated. All of them were already in their third, fourth, or fifth year of studies. The design process was carried out in five teams of three to four students. The company challenge for the workshop was given by Honext, a young Spanish company that focuses on sustainability and the utilization of cellulosic waste streams. Honext asked the students to develop *innovative interior applications for cellulose waste panels*. Four other companies gave presentations during the week to broaden the students’ understanding of the potential of wood-based materials.

4.2 Learning Environment

Chemarts courses are usually held in a specific learning environment that is designed for hands-on material experimentation and is a combination of a designer’s studio or kitchen and a chemistry laboratory, equipped with tools and materials from both realms. It is an open space located in a large, high-ceilinged hall, which contains a variety of laboratory equipment and prototyping machinery. In this case, the student teams had their own home bases—long and steady laboratory tables where the main ‘cooking’ activities took place. The students moved around fetching ingredients, weighing them at separate workstations, or carrying the prepared ‘cookings’ to the oven at the other end of the large hall. Three of the teams shared this environment, so the space was filled with talk and, now and then, strong whirring noises from the blenders. The tutor went around to check the students’ progress, helping them, sharing knowledge, demonstrating, and sometimes shouting advice to everyone together. The first part of the workshop, understanding, involved predefined experiments and students were given laboratory guides that summarized instructions for laboratory work and recipes for the four assigned tasks. In addition, students could use all the resources available, for example, material samples on the walls and shelves, recipes for additional experiments, and the Chemarts Cookbook (Kääriäinen et al. 2020). The raw materials and ingredients had their own distinct sensory elements such as structure and smell, which influenced the making experience and also left traces for the final experiments.



Fig. 1 Workshop schedule

The workshop consisted of four distinctive social settings (see the workshop schedule in Fig. 1): (1) the experts’ and organizations’ presentations, (2) making and designing in small teams, (3) discussions with experts and tutors, and (4) students’ presentations. The making activities included cooking various materials, making the final prototype, designing digital models, and preparing the presentation. Students could also perform two more experiments. The making took place in a laboratory space and the designing (ideation process and finalizing the concept) was mostly done in a classroom. Tutoring was ongoing in the laboratories and classrooms, and the presentations were held in a regular classroom setting.

5 Summary of Student Projects

The Honext product—interior panels made of cellulose waste—was not available for prototyping, but the company representative described the technical and visual properties of their product to complete the information available on their website. Four out of five teams decided to include material development in their concept. One team created the concept of a functional, aesthetic divider with integrated carbon foam that would work as an air filtration system (see Fig. 2); another explored a flexible mobile fitting room combining rigid and flexible materials (see Fig. 3); the third used textile waste for visual effects (see Fig. 4), and the fourth created the concept of a recyclable retail window display system made of Honext panels and fungal materials (see Fig. 5). The fifth team focused on innovating a new functional

retail use for the panels, using only material experimentation to communicate their assembly idea (see Fig. 6).

(For a deeper understanding see appendix with all the projects).

The Honext company representative gave the team constructive and insightful feedback. She asked questions about, for example, the aesthetic and technical aspects of the proposed concepts, and pondered their applicability, use, recyclability, and future scenarios. In general, Honext considered the student ideas good, some of them even promising and worthy of more detailed testing and development. All the student project posters are presented as an appendix.

Almost all the students answered the feedback questionnaire ($N = 17$). Overall, their feedback was very good. The students considered all the content (pill talks, expert talks) interesting and well explained, and felt that the didactic resources were used appropriately, and the materials were easy to understand. In addition to the DATEMATS Inspirational cards for EM&T integration and Toolkits as well as the Chemarts Cookbook was mentioned as useful. The framework of ‘understanding, exploring, applying’ received good reviews. The answers to the open questions revealed that online talks were considered somewhat challenging, and that the time reserved for the workshop was slightly too short. Over half of the students (58%) reported that they had worked overtime. The answers to the open questions revealed that the briefing (too short) and materials (lack of samples) given by the Honext aroused mixed thoughts and they received varying ratings, although good overall. The involvement, discussions, and feedback of the company were considered good. Experimental hands-on work with materials was experienced as highly inspiring, useful, enjoyable, and even the best part of the workshop. According to the students, the workshop supported idea generation by enabling them to concretely understand the properties of the materials and by facilitating collaboration. The multidisciplinary, international teams were appraised positively. However, the students wished they had been better introduced to the other students and that they had had more leisure activities (which were sadly not possible due to COVID-19) and information about Finland.



Fig. 2 Material experiments and small divider prototype with air filtration system



Fig. 3 Material experiments of cellulose leather, small prototype, and mobile fitting room concept

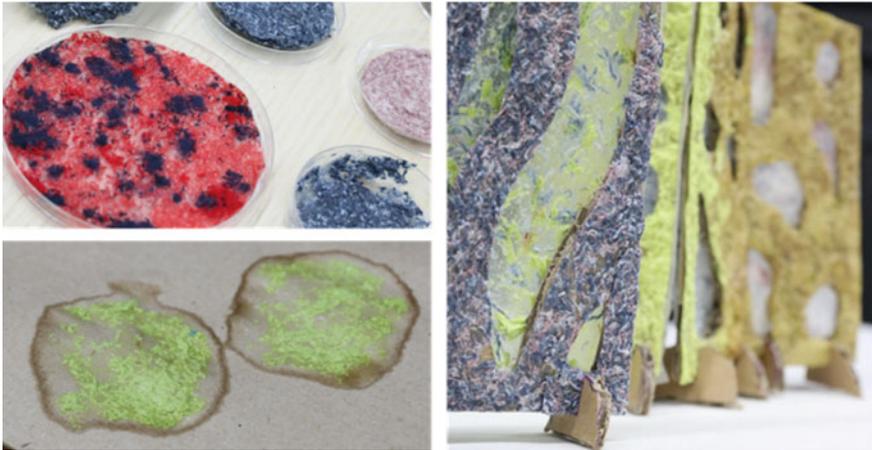


Fig. 4 Material experiments with textile waste and ideas for wall applications

Some students experienced the amount of information as challenging to take in, but overall learning rated it as good.

We conclude that the method seems to support new thinking in idea generation and concept creation. A five-day workshop is very short for diving deeply into wood-based material development, and real-life applications easily remain



Fig. 5 Material experiments and concept of recyclable retail display consisting of wood-based panels and pre-grown fungal materials



Fig. 6 Material experiments for modular interior designs for retail

distant. However, the tutors found the systematic implementation of the DATEMATS framework of ‘understanding, exploring, applying’ useful for developing future experimental material courses.

6 Materiality in One Team’s Process

To better understand the students’ ideation processes, we decided to follow and analyse the work of one of the teams. The aim was to examine *how materiality (different representations and materials) enabled the emergence of insights into the*

collaborative idea-generation process. In the analysis, we traced *critical events*. We identified how materials advanced critical events, which in turn advanced the design process.

7 Method

7.1 Participants

The team was selected so that none of the members had any previous experience with Chemarts' courses. The selected team included Zoe, a sustainable fashion design BA student and Jade, who had a bachelor's degree in product design and was studying design and engineering at BA level. Michael was studying mechanical engineering and design engineering as a double BA degree and Elena was continuing her chemical engineering studies at MA level (names have been changed). The students did not know each other beforehand and represented four different nationalities.

7.2 Data Collection and Data Analysis Methods

We used video recording as a data collecting method. This allowed us to capture real-time, naturally occurring data. By video recording we could follow the activities of the student team in distinct social settings. We recorded most of the students' processes (including making and designing in small teams and discussions with experts and tutors). This produced 12 hours and 30 minutes of video material from a single camera. However, we presumed that the students advanced their ideas outside the recorded sessions. Therefore, in order to 'catch up' with the process, a researcher also asked the team to summarize their activities and reflect on their learning at the end of the day and sometimes between working sessions.

The students followed the workshop schedule and therefore, as expected, the video-recorded data included episodes of (1) carrying out the assigned tasks, (2) the students' own experiments with materials, (3) framing the design task, (4) ideating with materials, (5) refining the idea and finalizing the concept, (6) making and presenting a prototype.

The analysis consisted of typical qualitative content analysis practices (Krippendorff 2013) with the help of ATLAS/ti software. Qualitative content analysis was utilized in a generic manner, rather than making a detailed analysis of communication, i.e., interaction analysis (Katila and Raudaskoski 2020).

Powell et al. (2003, 416) define a critical event (based on the research literature), as a construct that represents a contrasting change from students' previous understanding. We identified nine critical events, and according to their occurrence, we were able to narrow them down to Episodes 2, 3, 4, and 5 for deeper analysis.

Table 1 Summary of critical events

Critical event	Time	Episode
1. Choosing own material experiments (decision)	Tuesday AM 08:00–15:17.	2
2. Discarding window idea (decision)	Wednesday AM 01:10:22–01:10:32	3
3. Cellulose leather (demonstration)	Wednesday PM 05:04–07:46	4
4. Problem is found (Eureka! moment)	Wednesday PM 09:51–11:07	4
5. Context is found (Eureka! moment)	Wednesday PM 35:39–35:49	4
6. The idea for the structure (Eureka! moment)	Wednesday PM 1:03:41–1:05:36	4
7. First prototype (demonstration)	Wednesday PM 1:09:06–1:17:45	4
8. Shimmering wood panel pattern (proposal)	Thursday AM, 01:12–06:50	5
9. Final structure (decision)	Thursday AM 27:45–31:06	5

Table 1 presents a summary of the critical events and the date and time when they emerged as well as some related episodes. Three of the events were decisions (1, 2, and 9), one of them was a proposal (8), two were demonstrations with material (3 and 7), and three of them were Eureka! moments (4, 5, and 6).

We found that one of the critical events qualitatively changed the process trajectory. This so-called watershed critical event (see Powell et al. 2003), here Critical event 4, connected sequences of critical events in Episode 4 (Ideating with materials), marked by an orange hue in Table 1. These sequences created the most intensive phase of the process during which the idea was found and formulated. Next, we describe the whole ideation process and the critical events.

8 Results

8.1 *Towards Framing the Given Design Task*

The first critical event defined the materials the team had for use in the rest of the process. On the same morning (Tuesday), the team had finished the assigned material experiments. On the same afternoon, the team gathered around their workstations in the laboratory and browsed the Chemarts Cookbook (Kääriäinen et al. 2020) together. The discussion revolved around the images they saw in the book, and which materials seemed interesting. They carefully examined the photographs and discussed the assumed features of these materials (see Fig. 7). The focus of the discussion was on cellulose leather. They had decided to also make transparent material, but this was only mentioned in passing during the rest of the process.

During this event, they created tentative visions for the use of the chosen materials; three of the students pondered the possibility of layering them in Honext panels. Thereby, from the beginning, the brief and the interests and requirements of the client were borne in mind, although they had only seen images of the Honext panels and received a verbal description of its features.

The discussion during this first critical event illustrates how the students applied material thinking before having the actual material in their hands (see Groth and



Fig. 7 Examining detail in the photograph of cellulose leather



Fig. 8 Two framing sessions: Tuesday afternoon in the lab and Wednesday morning in the classroom with consortium experts

Mäkelä 2016). It can be assumed that the students' previous knowledge of the leather type of materials and the product images gave them ideas on how to use it in this design task.

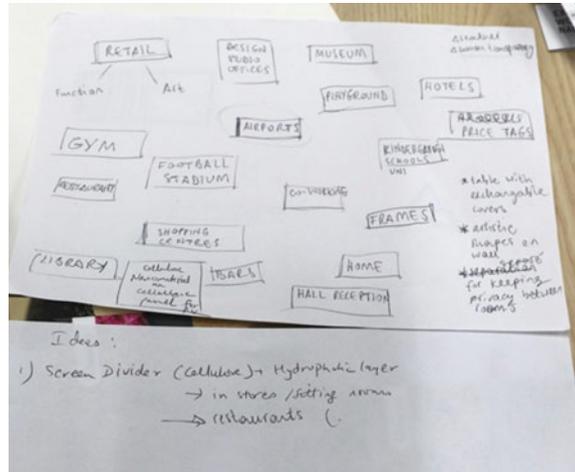
After choosing the materials (cellulose leather and transparent material), the students started making them, spending about half an hour cooking samples in pairs. However, as there was a delay between making the material and the finished product, they spent the rest of the day framing the design task and idea space with impartial information. For some reason they did not ask the tutors for material samples (cellulose leather or transparent material).

Three of the students were in attendance when they began the very typical design practices—searching for images of already existing products, sources of inspiration, and information and discussing them, while sitting together in the lab (see Fig. 8). They browsed internet sources and images, but also utilized the DATEMATS Material Integration cards.

Moving between ideas from the cards and other sources, the students collected the potential contexts and product proposals into a document (see Fig. 9). This document, containing ideas of 'what could be', was the first concrete example of a shared object in this collaborative process. The team continued working on it the next morning (Wednesday) and communicated their notes to Elena who had been absent the previous evening.

A second critical event occurred on Wednesday morning. It had already been agreed that the idea of a screen divider for privacy had potential. Also, a fitting room idea with a signalling function emerged. However, Elena introduced her proposal of a window application, which could harvest solar energy. Her chemical engineering background enabled her to create this idea from an a Material Integration Card. The group spent some time finding out how it could work. They searched for information on the internet and Jade made some sketches in order to understand the function. She did not share the sketches with the team, they seemed to be more like thinking tools for Jade. The discussion went in turns of elaborating and evaluating the screen idea and window idea. Discussion of the window idea highlighted that it was quite complicated for the team in terms of the new information required. The available materials did

Fig. 9 First shared document created during the process



not sufficiently help the discussion. There were also gaps in communication, partly because of the students' different educational backgrounds. In the end, a discussion with one of the experts made them discard the idea as too difficult for such a short workshop. After this decision, they narrowed down the key idea to be developed further as the screen divider.

8.2 Ideating with Materials

On Wednesday afternoon, qualitative change in the process took place. The students took all their samples to the classroom in order to continue framing the task, but now with the help of materials (see Fig. 10).

Fig. 10 Material samples made by Team 4: cellulose leather (left) and transparent material sample (top right). The team also made paper samples





Fig. 11 Critical event 3: cellulose leather demonstration, proposing flexible spiral fitting room

The afternoon contained a sequence of five critical events during which the key idea developed into the final idea (see Table 1). The first of the sequence of events (Critical event 3) was Zoe's demonstration using a cellulose leather sample. Zoe and Michael took cellulose leather samples in their hands, right at the beginning of their meeting, turning and folding them, making sense of their material properties. Direct experiences with materials naturally lead to associations (see Haslinger and Bang 2015). Materials suggest ways in which they could be used, their behaviour and properties suggest different types of structure, surface, and connection (Alesina and Lupton 2010). Their flexible nature triggered Zoe to propose a cylinder—a spiral fitting room space in which the door could be bendable (see Fig. 11). This was critical, because Jade reacted to it by suggesting that the flexible material (leather) could be covered with strips or pieces of Honext panel so that the form could be bendable and at the same time rigid. Some minutes later, Michael proposed combining several screen dividers, so it could be used as a movable fitting room. These proposals paved the way for the later pivotal events.

Critical event 4, i.e., the watershed event, emerged when Jade started thinking about a crowded shop. This was a clear Eureka! moment. The transcript below highlights how they found the design problem. From this point onwards, it was possible to evaluate the features of earlier solution proposals at the same time as the problem.

Jade: Haa, I'm thinking, you know when like, for example Primark, which is, I mean it's like filled with lots of people and sometimes you don't even want to go to the fitting room

Elena: OH MY GOOD, YEAAA! (claps her hands together)

Jade: Because you just want to try instead of...

Elena: Are you thinking what I am thinking?!

- All: Laughing
- Jade: I was just thinking about the purpose, because sometimes
- Elena: It ..a.. a mobile, mobile
- Zoe: Fitting rooms
- Elena: Fitting rooms exactly
- Zoe: Laughs
- Jade: Yea I don't know if it is possible to do, even, not just Primark...
- Elena: Anywhere yeah!!
- Jade: ..But places where you just want to try something, like you don't really want to try in front of everyone, but you don't want to go to the fitting room. I don't know if it's like good idea
- Elena: Mobile fitting room could be a great concept
- Jade: Probably it could be with...
- Elena: It could be box of four panels and you work with whatever, motion sensing idea and yea, same idea but
- Zoe: On wheels
- Elena: Yea
- Jade: I don't know
- Zoe: I feel that's new
- Elena: Yea (0:11:07)

After this event, the team discussed the form, as well as a suitable context for the fitting room. Jade challenged the regular box shape, and they pondered variations. Zoe took the leather spiral fitting room idea up again, because it enabled flexibility and gave the fitting room a social aspect. Jade elaborated on this, and they both made some sketches. Their discussion highlighted the material aspects they had to imagine, such as the anticipated behaviour of the new cellulose leather on a large scale, as well as the nature of the Honext panel they had not concretely seen. Below, Fig. 12 presents the examples that were developed from the spiral idea and imagined combinations of the rigid panel part and cellulose leather as the flexible part.

When discussing the context, the students evaluated where the sustainable fitting room idea would be feasible, and how it would support the user experience. The

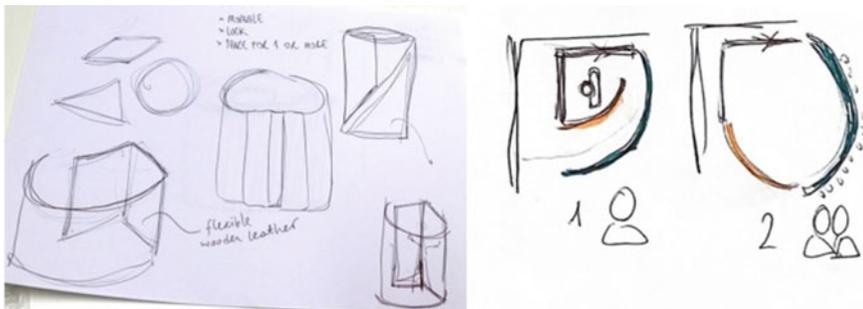


Fig. 12 Sketches of fitting room ideas



Fig. 13 Critical event 6. Michael demonstrated the idea of the structure and the others participated

vintage market context emerged as a new proposal by Jade when the consortium expert entered their discussion. The students discussed this context for twenty minutes and accepted it as the most suitable, making this Critical event 5. The expert made two important remarks that acted as enabling constraints later in the process: (1) she reminded them that the structure needed to be rational, for example, from a logistics point of view; and (2) she suggested that instead of thinking ‘rigid and flexible’ they could think of the whole thing as flexible, but with supporting structure.

After this, the team again pondered the form and structure for a while, and Jade suggested that they use the earlier mentioned layered structure panel (strips or any other form) on leather. Further elaborating this idea, Michael proposed a structure, in Critical event 6, that would combine the many necessary solution requirements (movability, adaptability, supporting structure, social aspect, rational form) that they had set during the process. This highlights not only elaboration but also the use of conceptual combination, i.e., idea refining by combining aspects of multiple ideas (Watts et al. 2019). His suggestion for the structure was based on one large cellulose leather piece to which the panel pieces would be attached, leather enabling flexibility between them. Thereby, the very initial, intuitive idea of layering, already taken up in the first critical event, also became part of this proposal.

Michael started demonstrating the idea with paper and cellulose leather samples. Jade and Zoe wanted to grasp the idea and joined in, trying out the structure (see Fig. 13). It was a moment of shared material discussion and ‘sketching’, during which they could feel the idea in their hands to be able to make an initial estimation of its material and spatial functionality. This type of activity continued when they made the first sketch model in Critical event 7 (see Fig. 14).

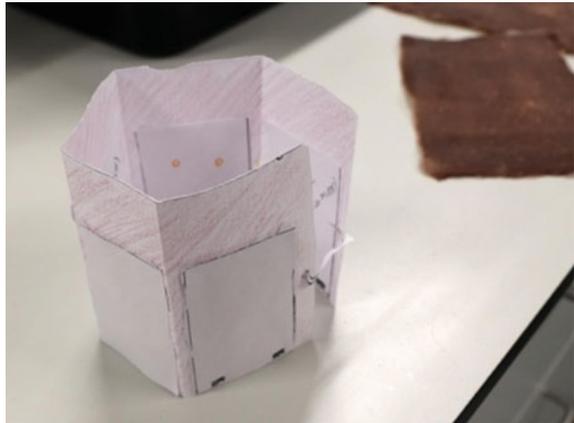
The sketch model helped them try out the proposed structure and how it would function in different compositions (see Fig. 14). It also became an important shared object, a tool to finalize the idea. Although it was made from paper, it became the first materialization of their idea of combining two types of material.

As a three-dimensional object, the sketch model enabled turning, folding, and adding new things such as a mirror and a rack (see Fig. 15). Thereby, this sketch model became an evolving object and finally a storage vessel for the knowledge produced during the ideation phase, as well as an important tool for the next phases.



Fig. 14 Critical event 7. Trying out modifications in the sketch model

Fig. 15 Sketch model

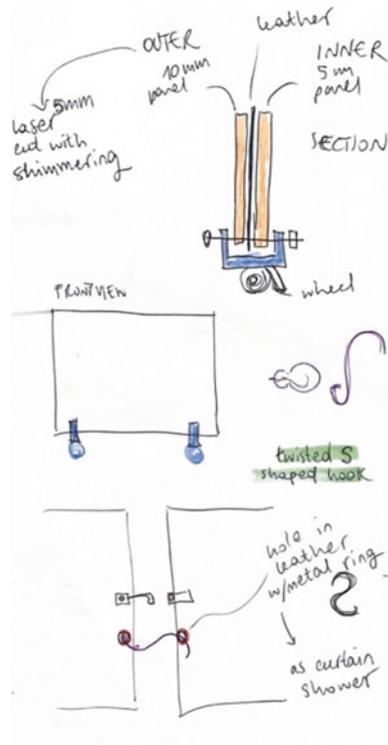


8.3 Refining the Idea and Finalizing the Concept

On Thursday morning, Critical events 8 and 9, the last two, finalized the team's idea and concept. In Critical event 8, Jade proposed applying a 'Shimmering Wood' pattern (structural colour produced from nanocellulose) to cover the panels. She suggested that they discard the idea of signalling (which would have needed electricity or batteries) and instead integrate a nanocellulose-based shimmer for a unique look. The group had seen an example of 'Shimmering Wood' on the Material Integration cards but had not fully understood the idea. Jade had learned more when discussing it with her roommate. She had found a video of the material, which now also helped the others team members grasp the idea. The suggestion was accepted, and in the end, they decided to use 'Shimmering Wood' as laser cut patterns which could be customized for each customer.

The decision concerning the final structure was the last critical event, number 9. The movability of the fitting room had been a requirement that the team had pondered along the way. At this point, the team decided to add wheels, and Michael suggested

Fig. 16 Sketches containing details of the final structure of the fitting room idea



a specific construct that would also provide some structural support. This discussion was enhanced by examples from the internet, but the most important aspect was the drawings that Jade and Michael made to explain the final structure. The sketches in Fig. 16 contain details agreed on in the finalizing phase, complementing the sketch model (see Fig. 16).

9 Conclusions

In this chapter, we have described the five-day *Experimental wood-based materials workshop* held at Aalto University in the Chemarts learning environment. The workshop structure followed the DATEMATS framework of ‘*understanding, experimenting and applying*’, adapted for experimental wood-based materials. Five international and multidisciplinary student teams worked on a design challenge involving interior panels produced from cellulose waste. We reported one team’s ideation process and related materiality in more detail. During the workshop, the team carried out the core elements of the design process. This resulted in the creation of an artefact that solved an identified design problem and met the given design brief. It was an

open-ended design process in which the problem was defined in the middle of the process.

Cross (1997) characterized the emergence of an idea in collaborative design as a gradual process of building creative bridges between a problem and a solution rather than making an immediate, significant creative leap. This was also highlighted in this study. Nine critical events in the students' collaborative process illustrated how the ideas were built gradually and iteratively from the first initial insights.

The team spent most of the workshop developing their idea together. Thus, the team members, as well as other peers, were themselves important sources of information. Despite some communication challenges, the team was able to elaborate on each other's ideas, which ensured the emergence of the critical events. However, the consortium's expert guidance also had an important influence.

The team used typical design representations and practices to communicate their ideas and to create new knowledge as well as store it. External sources of inspiration and information were used mostly in the framing phase. Towards the end, the team naturally created more of their own representations and the use of shared representations increased. In the team's process, the shared representations were the document of collected ideas, sketches, and the sketch model. However, the drawn sketches played a surprisingly small role in the idea generation in the sense of shared objects among the team. The sketches were mostly shared in pairs, first when the flexible round form ideas of the fitting room were generated and second when the technical structure of the fitting room was developed. The DATEMATS Material integration cards for EM&T's integration served the team quite well. However, it became obvious that the students could not understand all the examples thoroughly enough and did not have time to explore them in more depth. Due to these restrictions, the team chose realistic ideas instead of pursuing more speculative visions.

The results highlight that understanding the material or the material's imagined features is an important part of the process, even when not concretely present. This became evident as the team worked with impartial knowledge of the materials. They had no real panel material at all, and the cellulose leather samples were not ready until the middle of the workshop. These samples were vital. They worked as a source of inspiration, and flexibility triggering important insights. Joint material practice emerged in a material demonstration and followed in the form of the small-scale sketch model of a mobile fitting room. The material samples and the first sketch model were central for communicating the materiality of the concept idea to the peers, tutors, and the company.

We conclude that this type of short workshop is most suitable for senior students who already master the design process quite well. Although it cannot provide an exploratory process of developing one's own recipes and materials (see Laamanen and Kääriäinen, accepted) it could work as an introduction to making and using experimental cellulose materials in the design process. According to the feedback collected, the students greatly enjoyed the making part; it was new to them. They said that they had not known, for example, that colour can be derived from plants. The use of self-made material and the goal of integrating several technologies of course brought new perspectives to the design process. It was a challenge that differed from

normally encountered problems and whose outcomes were not predictable, even for the teachers. These types of tasks often simulate a sense of inquiry and curiosity in the learner (Garner and Evans 2015, 73), hopefully leaving an impactful trace in the memory and an interest to continue working in the field of developing sustainable materials.

References

- Alesina I, Lupton E (2010) Exploring materials: creative design for everyday objects. Architectural Press, Princeton
- Artman H, Ramberg R, Sundholm H, Cerratto-Pargman T (2005) Action context and target context representations: a case study on collaborative design learning. In: Kochmann T, Suthers D, Chan TW (eds) Computer supported collaborative learning: the next 10 years! international society of the learning sciences. Lawrence Erlbaum Associates, Mahwah NJ.
- Cross N (1997) Descriptive models of creative design: application to an example. *Des Stud* 18(4):427–440. [https://doi.org/10.1016/S0142-694X\(97\)00010-0](https://doi.org/10.1016/S0142-694X(97)00010-0)
- Dorst K (2011) The core of ‘design thinking’ and its application. *Des Stud* 32(6):521–532. <https://doi.org/10.1016/j.destud.2011.07.006>
- Emam M, Taha D, ElSayad Z (2019) Collaborative pedagogy in architectural design studio: a case study in applying collaborative design. *Alex Eng J* 58:163–170. <https://doi.org/10.1016/j.aej.2018.03.005>
- Ferraro V, Pasold A (2020) Emerging materials & technologies. In: New approaches in design teaching methods on four exemplified areas. Franco Angeli. Available from: <http://ojs.francoangeli.it/omp/index.php/oa/catalog/book/556>
- Garner S, Evans C (2015) Fostering motivation in undergraduate design education. In: Tovey M (ed) Design pedagogy. developments in art and design education. Routledge, UK.
- Groth C, Mäkelä M (2016) The knowing body in material exploration. *Stud Mater Thinking* 14(2):1–11. Available from: <http://artofresearch2014.aalto.fi/papers/Groth.pdf>
- Goldschmidt G (2003) The backtalk of self-generated sketches. *Des Issues* 19(1):72–88. <http://www.jstor.org/stable/1512057>
- Hasling KM, Bang AL (2015) How associative material characteristics create textile reflection in design education. *J Tex Des Res Pract* 3(1–2):27–46. <https://doi.org/10.1080/20511787.2015.1210916>
- Hess T, Summers D (2013) Case study: evidence of prototyping roles in conceptual design. Proceedings of the 19th international conference on engineering design (ICED13), design for harmonies, vol.1: design processes, 19–22 August 2013, Seoul, Korea, pp. 249–258. <https://www.designsociety.org/publication/34849/Case+study%3A+Evidence+of+prototyping+roles+in+conceptual+design>
- Härkki T, Seitamaa-Hakkarainen P, Hakkarainen K (2016) Material knowledge in collaborative designing and making. A case of wearable sea creatures. *Formakademisk* 9(1):1–21. <https://doi.org/10.7577/formakademisk.1480>
- Härkäsalmi T (2017) Cellulose-led design research knowledge production through material exploration and experimentation. In: Kääriäinen P, Tervinen L (eds) Lost in the wood(s) - the new biomateriality in Finland. Aalto Arts Books, Finland
- Keller AI, Pasman GJ, Stappers PJ (2006) Collections designers keep: collecting visual material for inspiration and reference. *CoDesign* 2(1):17–33. <https://doi.org/10.1080/15710880600571123>
- Jacucci G, Wagner I (2007) Performative roles of materiality for collective creativity. Proceedings of the 6th ACM SIGCHI conference on creativity & cognition 2007, 13–15 June, Washington DC, USA. Available from: <http://dl.acm.org/citation.cfm?id=1254960&picked=prox&CFID=450532934&CFTOKEN=79948967>

- Katila J, Raudaskoski S (2020) Interaction analysis as an embodied and interactive process: multimodal, co-operative, and intercorporeal ways of seeing video data as complementary professional visions. *Hum Stud* 43:445–470. <https://doi.org/10.1007/s10746-020-09553-4>
- Kivinen O, Ristelä P (2002) Even higher learning takes place by doing: from postmodern critique to pragmatic action. *Stud High Educ* 27(4):419–430. <https://doi.org/10.1080/0307507022000011534>
- Kolko J (2010) Sensemaking and framing: a theoretical reflection on perspective in design synthesis. In: Durling D, Bousbaci R, Chen L, Gauthier P, Poldma T, Roworth-Stokes S, Stolterman E (eds) *Design and complexity - DRS international conference 2010, 7–9 July, Montreal, Canada*. <https://dl.designresearchsociety.org/drs-conference-papers/drs2010/researchpapers/67>
- Kosonen K, Mäkelä M (2012) Designing platform for exploring and reflecting on creative process. *Procedia Soc Behav Sci* 45:227–238. <https://doi.org/10.1016/j.sbspro.2012.06.559>
- Kirsh D (2010) Thinking with external representations. *AI Soc* 25(4):441–454. <https://doi.org/10.1007/s00146-010-0272-8>
- Krippendorf K (2013) *Content analysis: an introduction to its methodology*. Sage, London
- Kääriäinen P, Tervinen L, Vuorinen T, Riutta N (2020) *The chemarts cookbook*. Aalto University, Espoo
- Laamanen T-K, Kääriäinen P (accepted) Exploring bio-based materials in an interdisciplinary learning environment—outlining the design inquiry cycle. *Proceedings of DRS conference 2022, 25th June–3rd of July, Bilbao, Spain*.
- Laamanen T-K (2016) *Generating and transforming representations in design ideation*. Helsinki University.
- Laamanen T-K, Seitamaa-Hakkarainen P (2014) Interview study of professional designers' ideation approaches. *Des J* 17(2):194–217. <https://doi.org/10.2752/175630614X13915240575988>
- Lahti H, Seitamaa-Hakkarainen P, Kangas K, Härkki T, Hakkarainen K (2016) Textile teacher students' collaborative design processes in a design studio setting. *Art Des Commun High Educ* 15(1):35–54. https://doi.org/10.1386/adch.15.1.35_1
- Lawson B (2006) *How designers think? the design process demystified*, 4th edn. Elsevier, Oxford
- Mace M-A, Ward T (2002) Modeling the creative process: a grounded theory analysis of creativity in the domain of art making. *Creat Res J* 14(2):179–192. https://doi.org/10.1207/S15326934CRJ1402_5
- Parisi S, Ferraro V (2020) A logical framework for designing with and for emerging materials and technologies (EM&Ts). In: Ferraro V, Pasold A (eds.) *Emerging materials & Technologies. New approaches in Design Teaching Methods on four exemplified areas*, (pp.153–169). Franco Angeli. Available from: http://ojs.francoangeli.it/_omp/index.php/oa/catalog/book/556
- Powell AB, Francisco JM, Maher CA (2003) An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *J Math Behavior* 22:405–435. <https://doi.org/10.1016/j.jmathb.2003.09.002>
- Valtonen A, Nikkinen P (2022) *Designing change*. In: *New opportunities for organizations*. Aalto University.
- Watts L, Medeiros K, Steele L, Mumford M (2019) Minding the gap between generation and implementation: effects of idea source, goals, and climate on selecting and refining creative ideas. *Psych Aesth Creat Arts* 13(1):2–14. <https://doi.org/10.1037/aca0000157>
- Wertch J (1991) *Voices of the mind. A sociocultural approach to mediated action*. Harvester Wheatsheaf, London

Tarja-Kaarina Laamanen is postdoctoral researcher and university lecturer. She has background as a maker, as well as wide-ranging design and craft teaching experience in adolescent and adult education. Her focus as a researcher is on the materiality of designing, design ideation, and related representations, design process, as well as design education in a sociocultural framework.

Pirjo Kääriäinen is Associate Professor of Design and Materialities at Aalto University's School of Arts, Design, and Architecture. Her background is in textile design and manufacturing. Together with professor Tapani Vuorinen she has facilitated the interdisciplinary CHEMARTS collaboration between the School of Arts, Design, and Architecture (ARTS) and the School of Chemical Engineering (CHEM) since 2011. CHEMARTS aims to inspire students and researchers to explore design-driven approaches in materials research and to create future-oriented concepts, applications, and business seeds for a more sustainable world of materials.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.



Critical Reflection on the Learning Process: Envisioning Future Development

María Isabel Rodríguez-Ferradas^{1,*}, Venere Ferraro², Pirjo Kääriäinen³, Anke Pasold⁴

¹University of Navarra – Tecnun, Gipuzkoa, Spain

²Department of Design, Politecnico di Milano, Milan, Italy

³Department of Design, Aalto University, Espoo, Finland

⁴Copenhagen School of Design and Technology, Copenhagen, Denmark

Corresponding email: mirodriguez@tecnun.es

venere.ferraro@polimi.it, pirjo.kaariainen@aalto.fi, ankp@kea.dk

Abstract

DATEMATS project focused on Knowledge & Technology Transfer of Emerging Materials & Technologies (EM&Ts) through a Design-Driven Approach. Emerging Materials represent a crucial factor in obtaining better performances and innovative solutions and enhancing the product language in terms of new experiences and original expressive-sensorial dimensions and are at the core of everything we build. So, the project started with questions: *How do you keep up with the latest developments on future materials? What kind of teaching methods support students' learning process?*

In this regard, after three years project, a consortium of ten partners involving four (4) Higher Education Institutions (HEI), two (2) Industrial design development & business centres, two (2) Material libraries, and two (2) VET organizations developed and implemented an interdisciplinary new method for both design and engineering students in the field of emerging materials and technologies.

We developed a unique design (teaching) method to design with and for the new materials, and educate future designers, willing to work in the realm of EM&Ts. More in detail, the consortium focused on four exemplified areas: Interactive Connected Smart Materials, wearable based (ICS), Nanomaterials, Advanced Growing Materials, and Experimental Wood-Based Materials. Through desk research, collaborative and participatory sessions a new method shaped in three phases: understanding, shaping, and applying was generated. Given the added value of material exploration, the method is supported by fit-on-purpose tools: the material toolkit and the integration cards. The method and its tools have been proved successful by the results of

four design challenges executed within the main HEIs (See Section 2 of the Book). The present contribution aims at unfolding the phases of the unique design (teaching) method by highlighting if and how to delete, modify, or implement some of them in relation to each of the explored areas.

The Method Applied to the Four Areas: Pros and Cons

The project started with the evidence of a lack of standardized teaching methodologies tailored for designing for and with emerging materials and technologies, to be used both in design and engineering curricula. (See Chapter “[Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design Method](#)”).

The new Unique Method to design with and for the 4 EM&Ts shaped into three main blocks has been proven successful to solve the issues highlighted into Chapter “[Designing with and for Emerging Materials: Framework, Tools, and Context of a Unique Design Method](#)”. By Applying the method through design workshops some issues are still pending:

1. Issues in common with ICS and Nano.
2. Issues in common with Advanced Growing and Experimental Wood-Based Materials.

ICS Materials EM&Ts area is characterized by the need for a holistic and hybrid approach considering material qualities & interactive behaviours.

The Nanomaterials EM&Ts area is characterized by the need for specialized labs and high-cost equipment for experimenting, and the issue of scale and evidence of the technology.

Both the areas share problematic lifecycle and environmental matters, controversial perceptions, and fluctuations in price and availability of the materials and techniques.

The Experimental Wood-Based EM&Ts area is characterized by not aiming directly for real commercialization, which allows free ideation and “crazy” experiments. The Advanced-growing EM&Ts area is characterized by a symbiotic relationship between the designer and the living material and the issue of ethics.

Both the areas share the issue of time needed for the material to grow and dry, which brings detachment between the moment of intervention of the designer and the moment of observation of the results.

Hereafter a confrontation between each area and the pertinence with the new design (teaching) method and tools is highlighted.

Nano Materials

Throughout the DATEMATS project two main problems were identified in the method developed to educate students to design with and for nanomaterials.

The first problem is the “invisibility” of nanomaterials and their phenomena. Nanomaterials are the “invisible” materials on a scale from 1 to 100 nanometers able to generate extra performance in optical, magnetic, electrical, physical, and other properties (Morer et al. 2020). Most of their activity is, by virtue of scale and speed of action, unperceived by human senses. Therefore, expensive, and specialized labs and high-cost equipment are needed to visualize their behaviour at the nanoscale.

This is a fundamental difference of nanomaterials in relation to the other three EM&Ts involved in this project. This characteristic of nanomaterials generates barriers, mainly in the “Understanding” block of the unique design method, related to difficult-to-understand phenomena, resulting from complex chemical and physical interactions due to non-intuitive nanoscale behaviours by virtue of their quantum-confined emergent states.

The second problem is the high safety requirements when working with nanoparticles due to the toxic effects that they can have on human health and the environment. The study of toxicity of nanoparticles is still a field of knowledge in continuous development and due to the vast number and complex interaction of nanoparticles with different biological systems, there is still no universal toxicity mechanism or assessment method for them (Ramanathan 2019).

This situation generates a relevant problem in the “Exploring/Shaping” block of the unique design method in which the materials are expected to be experimented and shaped, by hands-on exploration and in-lab exercises.

The experience on the application of the novel method in the workshop focused on nanomaterials and developed at Tecnum showed that, to overcome the above-exposed problems, two specific strategies provide very positive results.

First, the role played by experts in nanomaterials and the dialogue that they establish with students in the activities developed in the “Understanding” block, helped students to evolve from very abstract ideas about nanomaterials to a more comprehensive knowledge of the phenomena behind their “superpowers”. The use of pictorial diagrams and videos showing production methods for nanomaterials helped the experts to binding storytelling to help students to assimilate the new knowledge and fill-in their ontological and language gaps. Secondly, the role played by companies, both launching a challenge to the students and sharing with them the pills of knowledge about their experiences with nanomaterials, was key for the students in the “Exploring/Shaping” block. In some way, the experiences lived by the companies from different sectors and contexts, in their journey to develop industrial solutions based on nanotechnology and their trial-and-error storytelling shared with students, created a kind of library of “lessons learned in the skin of others”. This body of experiential knowledge transferred to the students made up to some extent of the impossibility of having their own hands-on experiences with these materials. Moreover, from these contacts, students realized that nanomaterials are an area of growing

interest for many innovative companies from a big range of different sectors that can contribute to their employability in their professional future.

These critical considerations lead us to the conviction that “practical skills” in the case of nanomaterials are not so related to the technical or experimental skills of a designer or engineer, such as in the other emerging materials cases, but to “social skills”. Nanomaterials knowledge is one of the most interdisciplinary areas of emerging materials and technologies because they encompass disciplines such as applied physics, materials science, physical chemistry, physics of condensed matter, biochemistry and molecular biology, and polymer science and engineering.

In this context, the designer’s role, as facilitator, translator, and coordinator of a process of integration of different areas of knowledge related to nanomaterials is critical for transforming the potential of nanotechnology into marketable products and applications. The “social skills”, that students develop with our method, can be described as the ability to establish a multidisciplinary dialogue and translation process with the aim of developing innovative functions based on nanotechnology for a product or application.

The training for this role can be enhanced by additional tools to the toolkit and the integrated card developed in the DATEMATS project. An interesting area of future research could be the development of physical or digital gamification tools that can help students to understand and learn in a more experiential and interactive way about the different phenomena related to nanomaterials and their potential for application.

Considering the great interest detected in the fields of sustainability and health by students that participated in the workshops developed in the DATEMATS project, an interesting line could be the development of gamification tools focused on exploring how these phenomena can contribute to progress in solving great challenges of humanity in the twenty-first century associated with these areas, such as the following:

- Environmental-related challenges such as removing carbon dioxide from the atmosphere to curb global temperature rise, remove microplastics from the sea, or the reduction of the consumption of natural resources, such as metals or rare earth elements thanks to the use of nanomaterials to increase their performance in several applications such as electronics. Or even improving the recycling of existing earth elements in products due to nanomaterials.
- Health-related challenges such as development of innovative cancer therapies with reduced toxicity or early diagnosis and treatment of currently incurable neurodegenerative diseases such as Alzheimer’s or Parkinson’s.
- Energy-related challenges such as making solar energy cheaper, through highly efficient conversion of the solar energy or the storage of the converted energy or achieving efficient hydrogen storage systems for large-scale applications of hydrogen energy.

ICS Materials

Within the Framework of the DATEMATS project, the topic of ICS Materials was explored at the School of Design of Politecnico di Milano. ICS Materials belong to the class of the so-called *Hybrid Material Systems*, i.e., material-based systems with different degrees of complexity combining inactive materials, smart material components, and embedded sensing, computing, and actuating technologies (Rattaque et al. 2013).

They mainly perform shapeshifting, light-emitting, and colour-changing behaviours, but they are not limited to these. The seamless combination of elements into a material system might enable less intrusive and more *inclusive experiences*, a more immediate and engaging interaction, and sustainable integration of technologies into everyday practice. (Karana et al. 2016) Examples of these are smart textiles with embedded electronics able to translate environmental and personal data into tangible expressions, enabling multi-sensory, engaging, and proactive interactions. Such materials arise as potential enablers of *meaningful dynamic and interactive materials experiences* as tangible interfaces for a diversity of applications, from interactive architecture to smart fashion, from autonomous vehicles to smart and conversational objects. In the word “experience” we can focus the attention on the refinement of the DATEMATS’ unique method. Indeed, the new design method divided into three blocks: understanding, shaping/exploring, and applying does not embrace method and tools to design with a for *user experience*.

While working with ICS Materials, the user interaction and expectations in relation to the material aesthetics and performances are essential, both considering physical body involvement and emotional engagement.

The design process needs to be fundamentally user-centred, considering the user involved since the initial stages, often through user studies.

The application of the DATEMATS framework and tools to the workshop with companies at the School of Design was highly successful; throughout the five intensive days, all the phases correctly met the intended learning outcomes and the full understanding of the materials’ features, potentialities, and application.

Within this framework the user was completely missing so that, it was not possible to verify the effectiveness of the idea generated by the students.

In this regard, we suggest to split the understanding phase into two ones: the first related to the understanding of the materials and the second one to the understanding of the user by applying the traditional methods and tools for the user analysis (i.e., survey, semi-structured interviews and so on).

Moreover, in order to verify the user experience a testing phase after the prototyping one is encouraged. Authors suggest referring to Interaction Frogger, A Design Framework to Couple Action and Function through Feedback and Feedforward according to which, the user experience is verified through the direct and natural coupling between the user’s action and the product’s functional feedback through the unification of action and reaction on the following six aspects; time, location, direction, dynamics, modality, and expression (Wensveen et al. 2004).

Experimental Wood-Based Materials

In the DATEMATS project the theme of Experimental Wood-Based materials was built on the Aalto University Chemarts activities. The core idea of Chemarts is to inspire students with varying backgrounds to learn about bio-based materials through hands-on experimentation. In Experimental Wood-Based materials the first phase of *understanding* is quite long and essentially tied with the second step, *exploring*. Students move back and forth between these phases, and the process typically consists of several cycles, sometimes resulting in failures or unexpected findings. It can be said that even the longer courses held in the Chemarts context are *the beginning of understanding* for a novice working with these materials. Parallel to informative and inspirational lectures and readings, the students engage from the first days in practice-based materials exploration. Through this they start gaining an understanding of how wood-based materials such as cellulose, lignin, or bark, are worked and used for one's own material visions. The *applying* phase results often are very creative, but mostly only at a pre-innovation stage. Thereby, the *understanding* and *exploring* phases get more weight than the *applying* phase.

During the DATEMATS one-week workshop the approach was slightly different. In our experience, the intense DATEMATS workshop followed the typical design process with specific emphasis on materials. Students were asked to read about the related materials and methods beforehand. However, the time frame was too short for students to gain a proper understanding of the wood-based materials, not to mention the use of other materials with the help of the integration cards and materials toolkits. These tools were useful in inspiring and triggering ideas, but for proper understanding and even starting to try out different EM&Ts by exploring, there should be a summer school, minor programme shared among the four EM&Ts, or a series of thematic workshops. Short workshops, however, can inspire students to continue their studies in the fields of material development or material-driven design. Even brief hands-on making sessions can enhance a student's understanding and learning process, as the feedback revealed. In addition, company involvement in the form of pills and challenges is a very efficient method to increase students' motivation which positively impacts their learning process. In the future we will implement company challenges also in our other material-focused courses.

In general, we need to be cautious when considering the integration of several EM&Ts in short workshops. In the case of Experimental Wood-Based Materials integration increases complexity which can be problematic from the resource exploitation and disposal point of view. Especially when the aim is that students apply the circular economy principles in their design, integration of different materials becomes very challenging for the students. Therefore, for the proper EM&T integration in education, tutors and experts need to have deep experience of material integration in order to facilitate such courses.

Advanced Growing Materials

Adapting the Advanced Growing Materials approaches to the DATEMATS frame challenged Material Design Lab's basic didactic take. Generally, Modules aim at extending the *Understanding* of materials beyond the data-based through a hands-on experimental approach towards novel material applications relevant to current resource discussions.

This was particularly noted in the combination with the points of awareness identified in the project's first phase. The micro-scale of these invisible material collaborators, the long incubation time, and the specific protocols to follow, the work conditions to comply with to not contaminate the material, to name just a few, became the main points of concern for the curation of schedule, brief, and content. The limited timeframe was required to convey an overall idea of this complex and vast field in a very concrete manner to lead to *Application*.

This was tackled through a great degree of guiding and limiting the scope. The resulting frame adaptation was achieved through detailed curation to provide the students with successful outcomes. This, in turn, limited the range of explorable materials and therefore stood in contrast to the students' expectations of gaining a more comprehensive, while at the same time very concrete, insight into the pervasive world of microbes. The project's complexity was further increased by focusing on the different EM&T areas.

The main concern within the adaptation, however, lay in the timeframe's contradiction with Material Design Lab's overall approach of more lengthy exploration modules, where *Understanding* is reached at the centre of material research and extensive hands-on *Exploration* as a combined sum of the areas. This active engagement in hands-on experimentations is central for all material-centred EM&Ts. Material Design Labs didactics aim at a parallel line of research that is scientifically and phenomenologically founded. Here the students *Understand* not only the material affordances but also learn to ask relevant questions that place the materials into local, ecological, cultural, and historical contexts, all of which combined create a sound platform for ideation and eventual *Application* in a responsible manner and in line with resource-related challenges. *Shaping* and *Application* follow suit once an initial understanding is reached, typically leading to several further iterations adding to the overall material understanding.

The two explorative phases are run over several weeks, where the first is dedicated to the in-depth *Understanding* and, in most cases, the creation of a (new) material, and the second aims at forming and contextualizing. Both phases have a solid hands-on focus with the students immersed in the material. Combined with theoretical input, introductions to different methods and tools, and demonstrations, this creates a strong(er) foundation for ideations than are achievable within such a short workshop format.

Specifically, within the field of Advanced Growing Materials, the time displacement between making and result evaluation of the explorations can only be seen after the incubation period making the hands-on learning through the experimentations

very time-consuming. They are, however, essential if the outcome is to contribute with new innovative solutions that have a positive impact. In this regard, the process was seen as too isolated from overall material concerns while simultaneously needing to lead to an application.

The promotion of which can be misleading within such a short timeframe. This was most notably recorded in two areas. (1) the student's reading of the process of *Understanding, Exploring, & Shaping* posing a distraction to the *Applying*, and (2) the student's evaluation of the level of *Application* their concepts had achieved. Most projects were rated with an unusually high TRL, giving credit to the applied methods of making students comfortable in experimenting with and the eventual *Application* of the learned as solutions to the brief. This is, however, conflicting with the actual state of progress. In a continuous process, this experienced confidence level might even hamper the progress.

General Consideration and Further Development

The DATEMATs frame needs to be seen within the context of realistically achievable goals and communicated as such. It enables a high level of knowledge dissemination and first immersion potential. This, in turn, can install knowledge and competencies combined with a portfolio of a diverse selection of methods that allows being employed beyond the specific EM&T at hand. It can inspire and plant the first seeds. To do so, it is essential to note that aiming at achieving a base-level understanding; such short formats place a lot of extra requirements on the students. Apart from an advanced level of design expertise, they need to come equipped with an initial understanding of form-finding and form-creation, aesthetics, manufacturing, concept illustration, and storytelling skills. These were exemplarily achieved through the careful setting of the teams but set a requirement on having different backgrounds at one's disposal.

On the other hand, the DATEMATs frame can also instil a perceived level of expertise that springs from the methods conveying tacit knowledge to students instead of them gaining the same through experience. The latter is seen as particularly important on the innovation potential, which becomes limited at least within this specifically applied timeframe.

Therefore, the frame's future potential is seen in introductory notions to diverse fields of EM&Ts, which can lead to further explorations. The extensive preparation material required could subsequently be integrated into longer courses rather than the attempted reverse.

In this context, it might even be beneficial to explore the frame towards a grouped approach according to the different EM&T: material-centred, user-centred, and application-centred, as suggested in the preliminary finding of the DATEMATs project.

References

- Karana E, Pedgley O, Rognoli V (2015) On materials experience. *Design Issues* 31(3):16–27.
- Morer P, Cazón A, Fernández MI, Thomson R (2020) 2 Nanomaterials. *Emerging Materials*.
- Ramanathan A (2019) Toxicity of nanoparticles—challenges and opportunities. *Applied Microscopy* 49(1):1–11.
- Razzaque MA, Dobson S, Delaney K (2013) Augmented materials: spatially embodied sensor networks. *Int J Commun Netw Distrib Syst* 11(4):453–477.
- Wensveen SA, Djajadiningrat JP, Overbeeke CJ (2004, August) Interaction frogger: a design framework to couple action and function through feedback and feed-forward. In: *Proceedings of the 5th conference on designing interactive systems: processes, practices, methods, and techniques*, pp. 177–184.
- Zimmerman J, Forlizzi J, Evenson S (2007) Research through design as a method for interaction design research in HCI. In: *Proceedings of the SIGCHI conference on human factors in computing systems*, pp 493–502.

Glossary

Stefano Parisi¹

¹Delft University of Technology (TU Delft), Delft, Netherlands

Aim and Methodology of the Glossary

The glossary consists of a comprehensive selection of the relevant and recurrent terms used in the deliverables of the DATEMATS project, from the EM&Ts Toolkits to the publications. The glossary aims to facilitate the establishment of a shared and coherent language among all the actors involved in the project (e.g., partners and students). The deliverable is not mentioned in the project proposal, thus not compulsory, but necessary. The glossary is included in the e-book (Deliverable 5.1) as a chapter at the end of it. At the first stage, keywords and recurring concepts and notions are retrieved from the deliverables of the project and clustered into categories. For each of these notions, definitions are identified from existing literature. A few significant definitions and notions that are not retrieved from the deliverables are included to inspire the glossary. Every deliverable helped identify a consistent and thorough terminology, through backwards and forward searches. As a result of an iterative process, the glossary is made of 3 main sections:

- Emerging materials, manufacturing and design processes
- Sustainability
- Smartness

Emerging Materials, Manufacturing, and Design Processes

Advanced Growing Materials

Materials from a controlled cultivation of organisms (bacteria, yeast, algae, mycelium, etc.) that are directly grown and/or are manufactured into their subsequent form, function, and performance by tapping into the organisms' natural growth behaviour (bio-fabrication). They are potential renewable resources for the future.

Bio-Based Materials

The term bio-based refers to materials derived from biomass, such as plants, trees, or animals.

Biodesign

Biodesign is the integration of design with biological systems, often to achieve better ecological performance. In contrast to design that mimics nature or draws on biology for inspiration, biodesign incorporates living organisms into the design as building blocks and material sources.

Biofabrication

Biofabrication is usually defined as the production of complex biologic products from raw materials such as living cells, matrices, biomaterials, and molecules.

Biomimicry

Biomimetics or biomimicry is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems.

Composite

Materials comprised of two or more components with significantly different physical or chemical properties, that when combined, produce a material that behaves differently from the individual components. The individual components remain separate and distinct within the finished structure. Examples of engineered composite materials include carbon fibre-reinforced polymers, metal matrix composites, ceramic

matrix composites, cement, and concrete. Wood is an example of a naturally occurring composite material.

Designing with Materials

Designing with materials means that the design concept is framed and inspired by the domains of the technical properties and experiential qualities of the material. Understanding how to design with materials requires a type of knowledge that cannot solely be acquired through reading or lectures but must be obtained by actively exploring and experimenting.

Design Thinking

Design thinking refers to the cognitive, strategic, and practical processes by which design concepts (proposals for new products, buildings, machines, etc.) are developed. Many of the key concepts and aspects of design thinking have been identified through studies, across different design domains, of design cognition and design activity in both laboratory and natural contexts. Design thinking is also associated with prescriptions for the innovation of products and services within business and social contexts. Some of these prescriptions have been criticized for oversimplifying the design process and trivializing the role of technical knowledge and skills.

Digital Manufacturing

Aims to improve product design and manufacturing processes across the board seamless integration of information technology systems across the supply chain. Digital manufacturing focuses on reducing the time and cost of manufacturing by integrating and using data from design, production, and product use; digitizing manufacturing operations to improve product, process, and enterprise performance, and tools for modelling and advanced analytics, throughout the product life cycle.

DIY Materials

Do-It-Yourself Materials are created through individual or collective self-production practices, often by techniques and processes of the designer's own invention. They can be totally new materials, modified, or further developed versions of existing materials.

Double Diamond

Double Diamond is the name of a design process model popularized by the British Design Council in 2005 and adapted from the divergence–convergence model proposed in 1996 by Bela Banathy. It suggests that the design process should have four phases: Discover; Define; Develop; Deliver.

Emerging Materials and Technologies

Novel, advanced materials and disruptive technologies in the process of becoming in a way that cannot easily be predicted. New materials and modifications to existing materials to obtain advanced processing procedures, superior or special performances in one or more characteristics that are critical for applications under consideration, including sustainability properties, as better alternatives to the convention.

Experimental Wood-Based Materials

Materials that are processed either chemically or mechanically from trees or other plants. They include cellulose fibres, fibres (micro- or nano-structured) and derivatives, lignin, bark extractives, and novel combinations of these. They offer one possible pathway towards a more sustainable material world: they come from renewable sources, can be modified on a chemical level, and can be used for recyclable or biodegradable products.

Expressive-Sensory Qualities of Materials

The sensorial, subjective, qualitative, and unquantifiable, profile of materials. This notion looks at design materials as instruments to characterize a product from the points of view of perception, interpretation, and emotion.

Fab Labs

Fab labs (fabrication laboratories) are a global network of local labs, enable invention by providing access to tools for digital fabrication. Fab labs share an evolving inventory of core capabilities to make (almost) anything, allowing people and projects to be shared. Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programmes.

Holistic Design

Holistic design is a design approach which sees a design as an interconnected whole that is part of the larger world. It goes beyond problem-solving to incorporate all aspects of the ecosystem in which a product is used.

ICS Materials

Interactive, Connected, Smart materials. It is an umbrella definition including materials and material-based tangible components able to establish a two-way exchange of information, to respond contextually and reversibly to external stimuli, linked to another entity or to an external source, and programmable not only through software. They include sensors, actuators, conductive materials, smart materials, and other elements that can be classified under this label. They can be combined to build hybrid material systems with interactive behaviours.

Material-Driven Design

A design process starts with a material (or a material proposal) and ends with a product and/or further developed material. It facilitates designing for material experiences.

Materials Experience

It describes a holistic view of materials in design, emphasizing the role of materials as simultaneously technical and experiential. Materials Experience is defined as the experiences that people have with, and through, the materials of a product. The four levels of materials experience are: the sensorial experience, related to how people sense materials; the affective experience, related to emotions elicited by the material; the interpretive experience, related to the meanings evoked by the material and are associated with abstract concepts; the performative experience, acknowledges the active role of materials in shaping ways of doing, physical actions and practices. Each of these components of materials experience is highly intertwined, subject-, object-, context-, and time-dependent attributes.

Material Characterization

Characterization, when used in materials science, refers to the broad and general process by which a material's structure and properties are probed and measured. It is a fundamental process in the field of materials science, without which no scientific understanding of engineering materials could be ascertained.

Material Families

Classes of materials. They can be divided into natural and synthetic materials. The principal families of materials are polymers, ceramics, metals and alloys, and composites.

Materials Library

A collection based on material samples. The purpose is to collect, classify, catalogue, digitalize, and make material samples accessible in a library. The concrete samples are, such as text and picture, an information resource and is a complement to the library's traditional medium.

Material Selection

Material selection is the act of choosing the material best suited to achieve the requirements of a given application. Many different factors go into determining the selection requirements, such as mechanical properties, chemical properties, physical properties, electrical properties, and cost. These must be weighed during the material selection process.

Nanomaterials

Nanomaterials are chemical substances or materials that are manufactured and used on a very small scale. Different types of nanomaterials are available in design, such as nano-cellulose, nano-clay, and smart nanomaterials.

Process

In a broad sense, the set of operations that are used to control or give the appropriate qualities to a material, ranging from the microscopic level to the macroscopic level, maintaining a pre-established balance between the costs that can be faced and acceptable levels of performance.

Speculative Design

A critical frame of designing thinking which considers possible futures through a series of fictional objects and systems. This form of material interrogation is used to stimulate debate, imagination, and critical thinking in publics.

Tinkering

Hacking and manipulating physical interaction materials in a naive, playful, and creative way. “Thinking with the hands.” An educational method of creative experimentation with physical and digital elements, in a practical way, playing, without a precise goal. Tinkering is a form of informal learning where you learn by doing.

Technology Transference

Transition of a technological solution (a material or a transformation process) from the manufacturing sector in which it was developed towards other sectors. The term is also used, with a similar meaning, in the passage of a technological solution from one country to another at a different level of development.

User-Centred Design Approach

User-centred design (UCD) is an iterative design process in which designers focus on the users and their needs in each phase of the design process. In UCD, design teams involve users throughout the design process via a variety of research and design techniques.

Wearable Technologies

Smart electronic devices with micro-controllers embeddable into clothing or worn on the body as implants or accessories. Applications: e.g., health, sports, well-being. The expression wearable device refers to electrical or mechanical systems, which are worn on the human body by means of incorporation into items of clothing, or as an additional apparatus, which is fixed, by straps or harnesses. This kind of device is made up of “wearable” sensors. Wearable sensors and systems are defined, as wearable sensors/actuators and sensor-based communicative systems that can monitor and/or stimulate, and/or treat, and/or replace biophysical human functions.

Sustainability**Biodegradability**

Ability to be broken down into carbon dioxide, water, and biomass by the natural action of microorganisms (aerobic and/or anaerobic). It is misleading to merely claim biodegradability without any standard specification. If a material or product is

advertised to be biodegradable, further information about the timeframe, the level of biodegradation, and the required surrounding conditions should be provided, too.

Carbon Footprint

A measure of the carbon emissions that are emitted over the full life cycle of a product or service and usually expressed as grams of CO₂-e. Carbon neutral refers to activities where the carbon inputs and outputs are the same.

Circular Economy

A circular economy, following the model outlined by the Ellen MacArthur Foundation, is an economic system aimed at eliminating waste and the continual use of resources. Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing, and recycling to create a close-loop system, minimizing the use of resource inputs and the creation of waste, pollution, and carbon emissions. The circular economy aims to keep products, equipment, and infrastructure in use for longer, thus improving the productivity of these resources. All “waste” should become “food” for another process: either a by-product or recovered resource for another industrial process, or as regenerative resources for nature, e.g., compost. This regenerative approach contrasts with the traditional linear economy, which has a “take, make, dispose” model of production.

Cleaner Production

The continual effort to prevent pollution, reduce the use of energy, water, and material resources, and minimize waste—all without reducing production capacity.

Composting

Ability to go through the process by which materials biodegrade through the action of naturally occurring microorganisms and do so to a large extent within a specified timeframe. The associated biological processes will yield CO₂, water, inorganic compounds, and biomass which leaves no visible contaminants or toxic residues. The products can be classified into “Home compostable” or “Industrial compostable”, having each of them with specific temperatures, conditions, and timeframes defined by international regulations.

Cradle to Cradle

Cradle-to-cradle design (also referred to as 2CC2, C2C, cradle 2 cradle, or regenerative design) is a biomimetic approach to the design of products and systems that models human industry on nature's processes viewing materials as nutrients circulating in healthy, safe metabolisms. The term itself is a play on the popular corporate phrase "cradle to grave", implying that the C2C model is sustainable and considerate of life and future generations—from the birth, or "cradle", of one generation to the next generation, versus from birth to death, or "grave", within the same generation.

Dematerialization

Decreasing the consumption of materials and resources while maintaining the quality of life.

Design for Sustainability

An integrated design approach aiming to achieve both environmental quality and economic efficiency through the redesign of industrial systems.

E-Waste

Electronic waste, especially mobile phones, televisions, and personal computers. E-cycling is recycling electronic waste.

Life Cycle Analysis (LCA)

Life cycle of a product refers to all stages of a product's development, from raw materials, manufacturing through to consumption and ultimate disposal. LCA is an objective process to evaluate the environmental impacts associated with a product, process, or activity. A means of identifying resource use and waste released to the environment, and to assess management options.

Recyclability

The capacity of a product to be reduced all the way back to its basic materials, reprocessing those materials, and using them to make new products, components, or materials. Recycling refers to materials that are processed in practice (as opposed to materials for which recycling is technically feasible), this varies from one region to the other invoking the regulations and technologies of each country.

Recycled Pre-Consumer Waste

Pre-consumer waste refers to waste produced by manufacturers or industries before being released for consumer use. Pre-consumer waste refers also to the reintroduction of manufacturing discards back into the manufacturing process, in this case it is often not considered “recycling” in the traditional sense. Pre-consumer waste is produced in large quantities, while this is easier to collect and sort, high amounts of pre-consumer waste are non-recovered.

Renewable Content

Materials that are replenished at a rate equal to or greater than the rate of depletion and must be produced using regenerative practices or, in a transition phase, using sustainable practices.

Recovered Material

Material that would have otherwise been disposed of as waste or used for energy recovery but has instead been collected and recovered (reclaimed) as a material input thus avoiding the use of new primary materials.

Recycled Post-Consumer Waste

Post-consumer waste is the waste produced at the end of a consumer product lifecycle. Post-consumer waste has served its intended purpose, passed through the hands of a final consumer, and has been discarded for disposal or recovery. It usually refers to the household waste we generate every day and does not include manufacturing or converting wastes. Depending on the type of waste, governmental legislation and the action taken by the consumer, post-consumer waste is recycled, sent to landfill, or incinerated.

Sustainable Materials

Sustainable materials are materials with a relatively positive impact on communities and the environment that are used to build products, deliver services, and develop environments such as buildings.

Zero Waste

Turning waste into a resource; the redesign of resource use so that waste can ultimately be reduced to zero; ensuring that by-products are used elsewhere and goods are recycled, in emulation of the cycling of wastes in nature.

Smartness**Electrorheological**

Change in the rheological properties (viscosity and viscoelasticity) of a material caused by an electrical stimulus. Magnetorheological Change in rheological properties (viscosity and viscoelasticity) of a material caused by a magnetic field.

Piezoelectric

A phenomenon exhibited by certain materials, which when applying mechanical stress, generate electrical energy. The effect can also be inverse, that is, they can present small deformations when an electrical current is applied.

Phase Change Material (PCM)

Materials considered latent heat storage units: They are capable of absorbing or releasing a large amount of thermal energy when they undergo a phase change (from solid to liquid, from liquid to gas, or vice versa).

Photocatalytic

A substance that increases the speed of a chemical reaction by the effect of light or other forms of radiant energy.

Photochromic

Reversible colour change induced by the indication of sunlight or UV. The colour disappears when the fountain ceases.

Photoluminescent

Is the emission of cold light caused by the absorption of electromagnetic radiation (visible light, UV, X and cathode rays). There are two types of luminescence: fluorescence (emits light only during absorption of radiation) and phosphorescence (stores absorbed radiation, so that it continues to emit light for a time after the stimulus subsides).

Shape Memory

The material with this property recovers its initial shape after being permanently deformed (plastically) when heated above a characteristic transition temperature of the material. In addition, while regaining its form, in some cases it is able to perform work. The characteristics of these materials, depending on the temperature, contemplate superelasticity (which grants large elastic deformations in a specific range of temperatures), simple shape memory effect (in which the material remembers a single shape, when heated), and which can be educated to achieve a double shape memory effect (in which the material memorizes two shapes in a hot and cold state).

Thermochromic

Reversible or irreversible colour change induced by temperature changes.

Thermoelectric

Property that supposes a change of voltage in response to a variation of temperature and vice versa.

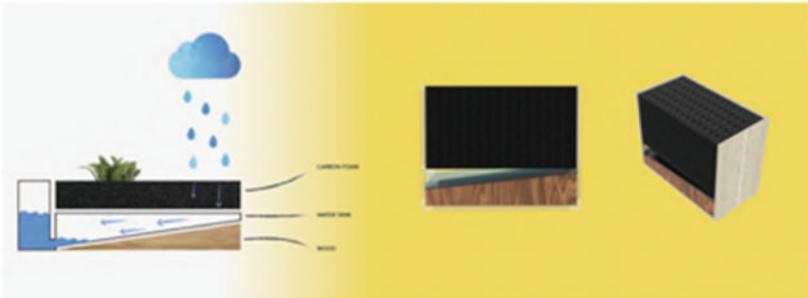
MENINA

Filtrating and gardening kit



A planter for rooftops, collecting rain water. A layer of carbon foam composite act as bed for plants and as filter for water, to be collected in the tank underneath.

Menina's purpose is to collect drinking water. A pyrolyzed carbon foam with a small porosity allows for good quality drinking water. A carbonized elastic foam with high porosity creates space for the roots of plants to expand freely. There is no need to use soil, because the foam is dipped in the water. In addition, this layer is lightweight and works as insulation. Information about the expiration of the filter gets collected through carbon conductivity and micro-controller and appears on a display. When the filter is expired it needs to be replaced. The whole kit is designed with sustainable approach.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Ana Apaolaza
Mechanics & Industrial
Design, TECNUN

Ainara Alcain
Mechanics & Industrial
Design, TECNUN

Claudia Perez
Mechanics & Industrial
Design, TECNUN

Michaela Hladka
Product Dev. & Integrati-
ve Technology, KEA

Nafise Hosseini
Design for the Fashion
System, Polimi

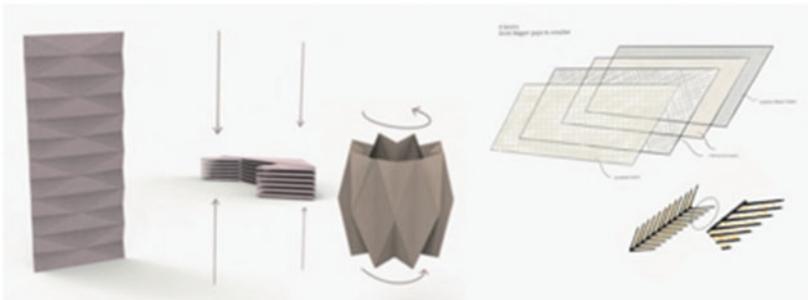
WIND FLOWER

Aerial pollen collector



An origami shaped cloth panel, made of carbon nano-fibres-infused textile, collect pollen from air, store it and re-spread it.

The loss of bee population requires to design for the future of our planet. Wind Flower is a 'home use' product for private use, but with a collective output. When placed in open spaces, such as gardens, balconies, it collects flying pollen particles, that can be spread later. It embeds a playful shape: the sail origami structure for pollen collection that, when folded, becomes a kite sprinkling pollen from above. The panel is composed by a textile with carbon nano-fibres, that works as a filter and it captures airborne pollen thanks to its structure.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Sonia Gonzalez
Mechanics & Industrial
Design, TECNUN

Laura Pizarro
Mechanics & Industrial
Design, TECNUN

Elisa Igoa Viguria
Mechanics & Industrial
Design, TECNUN

Ignas Valavicus
Product Dev. & Integrati-
ve Technology, KEA

Anna Vezzali
Integrated Product
Design, Polimi

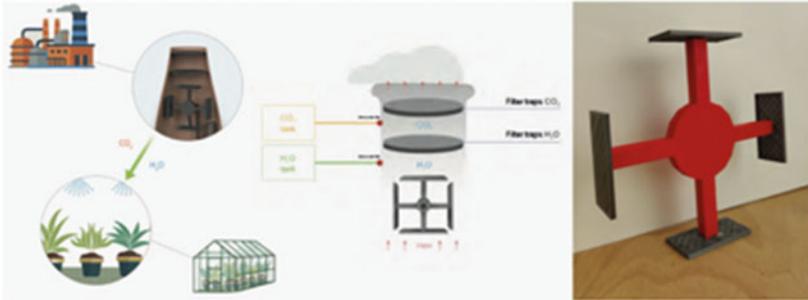
POLLUTION VACUUM

CO₂ and H₂O harvesting system for factories



Combination of an automatic system combined with filters infused with carbon nanofibres that captures CO₂ and creates H₂O to feed plants in greenhouses.

The vacuum helps to reduce CO₂ air pollution, while assisting plants growth, concurring further to the air quality improvement. Designed to be placed in industrial chimneys, in collaboration with agricultural industry, the principle of the concept is based on the chemical reaction $LiOH + CO_2 \rightarrow H_2O + Li_2CO_3$. Carbon nano-fibres are used as filters and sensors, to capture the CO₂, measure the moisture level in the filtration panels, allow the reaction to produce water and then be heated to dry the filters. It would be a service provided by factories to generate more profit by selling their pollution.



Areas of materials involved.



Feasibility of the idea.



Adriana Gonzalez
Mechanics & Industrial
Design, TECNUN

Aitor Juaristi
Mechanics & Industrial
Design, TECNUN

Mikel Lasa
Electronical Engineering,
TECNUN

Dovile Peculyte
Product Dev. & Integrati-
ve Technology, KEA

Elisa Mastrogiacomio
Design & Engineering,
Polimi

NANOHOUSE

Synergistic greenhouse structure



Interaction between CNF and the elements in a greenhouse. A temperature-controlled and water-collecting system increasing crop quality and opens up new possibilities for plants in new places.

Superior thermal conductivity and carbon nano-fibres (CNF) surface treatment allow for temperature-controlled and water-collecting closed system. Taking advantage of geothermal energy, super-conductive CNF rods efficiently transmit constant deep ground temperature (~15°C) up to root level. Further temperature regulation (up to 22°C) is achieved thanks to a light-polarizing CNF mechanism actuated by shape memory alloys, accumulating heat inside the greenhouse. Special surface coating in the aluminium tubes enables water condensation that is redirected towards the plant roots, reducing water consumption.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Alice Ballestra
Design & Engineering,
Polimi

Javier Bereciartua
Mechanics & Industrial
Design, TECNUN

Nerea Fuentes
Industrial Design, TECNUN

Theo Latuierie
Product Dev. & Integrati-
ve Technology, KEA

LIGHTCARE

Smart garment for elderly care



A smart garment that monitors stress level, thanks to Smart textiles ComTech. Through the use of SunFibre, a lighting tech, it displays the mood of the person wearing it, calling others to action.

Lightcare consists of two garments: one, integrated with sensors, to be placed in direct contact with the skin and able to monitor a person's stress level and health status; the other is worn over the clothes and, thanks to bright SunFibre, displays the person's mood translated into colours. It is designed for older people struggling to express themselves to stimulate empathy through colour and to encourage interaction with others. Moreover, the system includes a SunFibre frame for the care-giver's, to inform them of the elderly status and whether they need intervention in a non-intrusive manner.



Areas of materials involved.



Feasibility of the idea.



Luca Cappetti
Design & Engineering,
Polimi

Davide Franci
Integrated Product
Design, Polimi

Laura Pizarro
Mechanics & Industrial
Design, TECNUN

Sara Saccoccio
Digital and Interaction
Design, Polimi

CAREN

Wearable monitoring system for hospitals



A wearable technology that aims to enhance a patient's medical care response in wards and hospitals where individual bed monitors are not available for every patient.

Caren is ideally designed for basic wards in hospitals where it is often not possible to give attention to each patient all the time. It aids the nurses and doctors in identifying a patient in need of urgent help. It uses SunFibre to visually alert the medical staff nearby, whether it is while the patient is sleeping or walking in the halls of the hospital. The SunFibre is triggered by ComfTech's sensor that senses any distress of the patient. In case of severe situations, where immediate treatment is needed, the garment can be easily removed at once thanks to the snap buttons in the centre front.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Andrea De Bernardi
Digital and Interaction
Design, Polimi

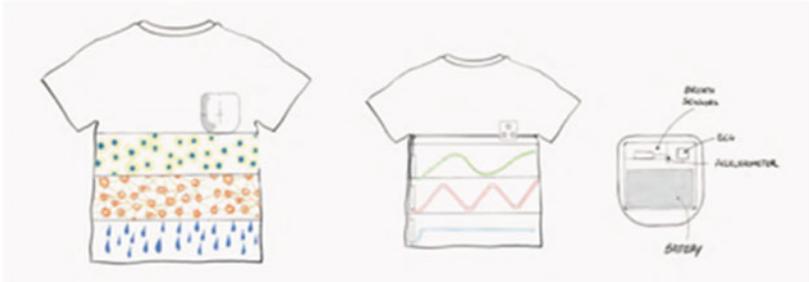
Mikel Laso
Electronical Engineering,
TECNUN

Shonglin Gaekwad
Design for the Fashion
System, Polimi

Shuai Liu
Desing & Engineering,
Polimi

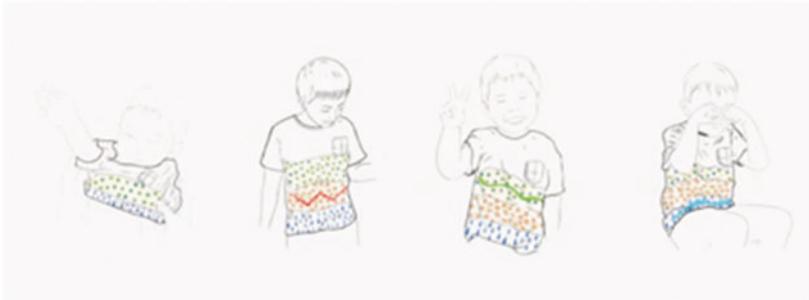
U-EMOTIONS

Emotional exploration aid for children



A tool for children to communicate, express and understand better their feelings, during development. It also helps parents to understand their kid's emotional growth.

U-Emotions is a well-being system for children, to help them understanding how they feel. Everything is contained in a loncell-F (95%) and Ecolastane (5%) t-shirt. ComfTech sensors are used to understand the body and collect data about the child's emotional state. Data interpretation is immediately shown by the SCILIF light fibres, to communicate them to others and give feedback in a simple and quick way.



Areas of materials involved.



Feasibility of the idea.



Leonardo Cariga
Desing & Engineering,
Polimi

Roxana Tavoosi
Design for the Fashion
System, Polimi

Elisa Igoa
Mechanics & Industrial
Design, TECNUN

JACKTIVE

Sportive jacket to alert for panic attacks



Jacket for hiking that helps people to calm down during panic attacks, through sensory and visual stimuli, integrated into the garment. It also allows tracking in harsh visual conditions.

More than being a simple garment, this sportive and smart jacket aids people during a panic attack, helping them to calm down using a diaphragmatic movement around their chest to stimulate and guide the breathing rate single-handedly. This response is activated when the sensors located in the wrists identify an abrupt change in the breathing and heart rate. At the same time, the system turns the optic fibre lightings on to make the identification and tracking of people easier in environments with tough visibility in forest or at night in case of disorientation during hiking.



Areas of materials involved.



Feasibility of the idea.



Diego Piracoca
Desing & Engineering,
Polimi

Sara Kashfi
Digital and Interaction
Design, Polimi

Sonia González
Mechanics & Industrial
Design, TECNUN

Bianca Muresan
Design & Business, Com-
munication & Media, KEA

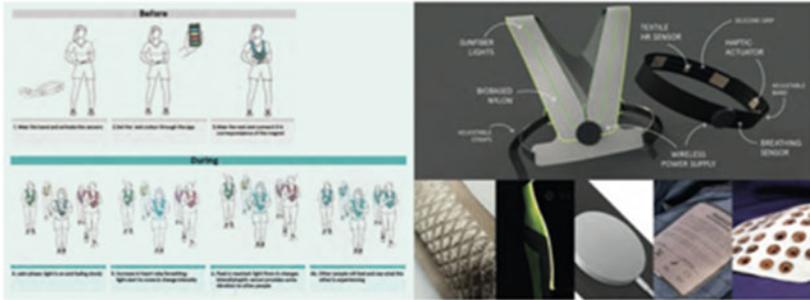
ADRENALIGHT

Smart garment for shared adrenaline experiences



A wearable system that allow to show and share your instant excitement in extreme, adrenaline group experiences, through multi-sensory stimulation.

The concept is thought to be used in any kind of adrenaline group activity to function at its best. The main purpose of this is because the product detects some body parameters (such as heart rate and breathing activity) that analyse the adrenaline experience and replicate all these feelings into a visual feedback. The goal is to involve all the people into an adrenaline situation and to use one person as a trigger for the others to regulate the level of adrenaline if it's too low for others.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Adriana González
Mechanics & Industrial
Design, TECNUN

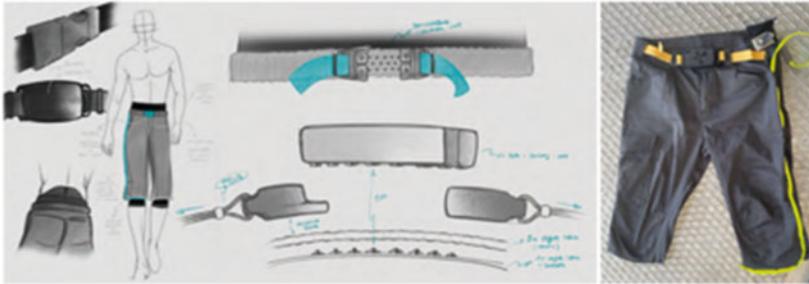
Giuseppe Fazio
Digital and Interaction
Design, Polimi

Martina Paramatti
Design & Engineering,
Polimi

Andrea Tremari
Digital and Interaction
Design, Polimi

SENSE-E WORKPANTS

Tech-wear for repetitive strain injuries prevention



Integrating SunFibre and ComTech sensors into the fabric of couriers' clothes to detect movement that may trigger Repetitive Strain Injury, while improving their visibility during shifts.

Repetitive Strain Injuries is a broad term to describe the pain felt in muscles, nerves and tendons caused by repetitive movement and overuse. Sense-e Workpants can help prevent RSI through early detection of strains, and anticipate needed therapy or rehabilitation by integrating strain gauge textile sensors in vulnerable areas of the body to measure movement. During the operational time of the device it collects data to share to the employer company. They can elaborate the data through AI systems and optimize the working hours of their staff and give feedback to employees.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Alice Ballestra
Design & Engineering,
Polimi

Ludovica Bonaldo
Digital and Interaction
Design, Polimi

Francesco Carlucci
Design & Engineering,
Polimi

Hanna Selim
Design & Business, Com-
munication & Media, KEA

A FOREST ARCHIVE

Collection of vases representing forest diversity



Collection of vases using different types of mycelium and tree residues to reflect on the diversity and uniqueness in forests.

This project is the result of an emerging materials explorations, with a speculative design approach and storytelling. A collection of vases representing a fascinating forest, merging the similarities between trees and mycelium: an infinite network of branches, each organism being unique in its own form and growth. The product is made of a substrate Dinesen's wood residues (saw dust and bark) with selected mycelium species (Pleurotus Ostreatus, Lentinula edodes, etc.). Moulded in two halves and later put together using mycelium bio-welding.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Alejandra Alarcón
Contemporary Design,
Aalto University

Jon Aranburu
Mechanics & Industrial
Design, TECNUN

Juraj Tomaic
Production Technology,
KEA

Marta Klyszejko
Jewellery, Technology &
Business, KEA

SKOVIT

Multisensory aquavit bottle to celebrate pine wood



Aquavit that through taste and touch transports you to the under-brush. Its second skin, fed off the tree's remnants, honours the pine in every part and keeps the liqueur fresh.

When a tree falls, nothing can be wasted. We started with Dienesen's desire to use every part of the tree and extended the concept not only to the woodworking residues, but also to the leaves, bark and roots. These parts provide a perfect substrate for the growth of mycelium, which thrives on the remains and gives them new life and use. Doing this, Skovit wants to embody the whole tree and offer its essence by making people taste it at 360°.



Areas of materials involved.



Feasibility of the idea.



Guillermo Ortiz
Industrial Design,
TECNUN

Irene Purasachit
Contemporary Design,
Aalto University

Pauline Rousseau
Jewellery, Technology
and Business, KEA

Sara Saccoccio
Digital and Interaction
Design, Polimi

RECOYSTEM

Mycelium hotel to shelter birds, insects and organisms



A tree is an ecosystem in itself, full of all kinds of living creatures. When a tree is removed from a forest, it leaves a empty place in the ecosystem. Could we replace the tree?

Recosystem is an insect hotel made of residue materials from the tree and mycelium. It hosts the ecosystem living on a tree, giving temporary shelter to insects, birds and other living organisms. Mycelium is an attractor for pollinator insects. Tree residues are great materials for insect hotels. This way the installation would also help to regenerate the ecosystem where the tree has been grown. It is also a potential product for gardens or public parks where pollinators could find a home.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Ana Apaolaza
Mechanics and Industrial
Design, TECNUN

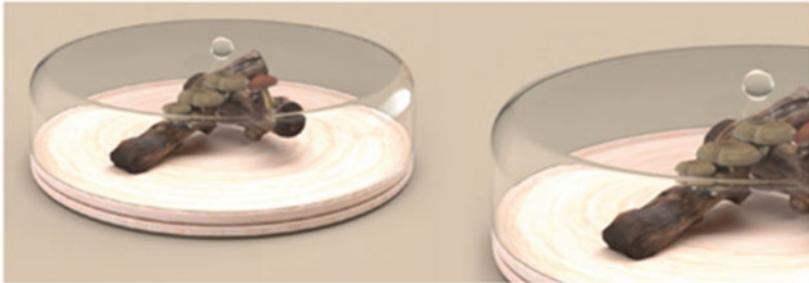
Niina Hyry
Contemporary Design,
Aalto University

Alessandra Sisti
Design & Engineering,
Polimi

Juliána Palková
Design & Business, Brand
Design, KEA

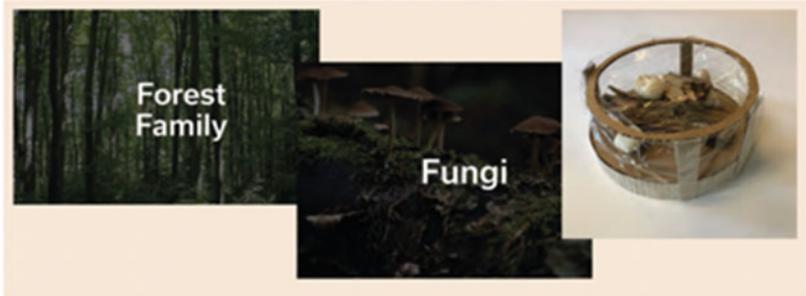
THE CENTERTABLE

Growing centrepiece for family home



Revisiting of the traditional centrepiece to become a celebration of the importance that mushrooms have in our existence, thanks to the exploitation of wood waste.

The Centertable provides an ideal structure to allow mushrooms and fungi to have controlled growth. The wood-base structure provides a constant and gentle airflow necessary for the growth, while the glass-top allows the light to pass through and also makes it possible to observe the mushrooms taking shape. Inspired by the conception of the forest as a huge family and according to the type and shape of the wood-waste, fungi will grow in different shapes creating unique compositions, as a symbol of the unique complex web of relations among a family.



Areas of materials involved.



Feasibility of the idea.



Andrea De Bernardi
Digital and Interaction
Design, Polimi

Anders Christian
Felsager
Sustainable Fashion, KEA

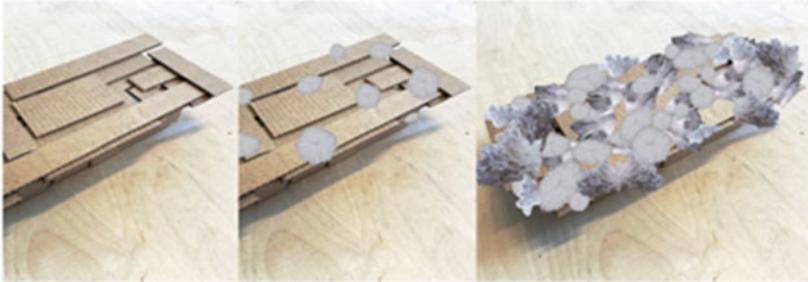
Ignacio Esnaola Garuza
Mechanics and Industrial
Design, TECNUN

Aino Ojala
Fashion, Clothing & Textile
Design, Aalto University

Lenka Loová
Design & Business, Brand
Design, KEA

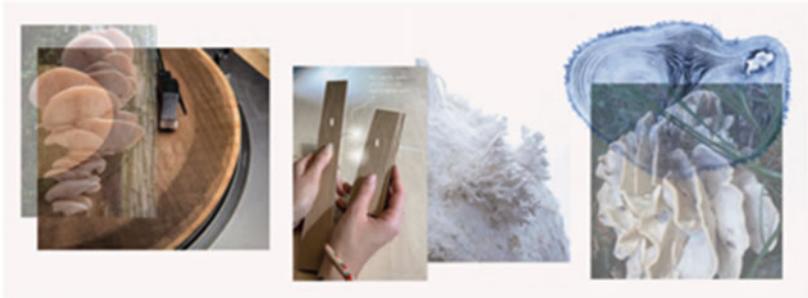
UNDER THE FOREST

Growing furniture with multisensory stimulation



Under the Forest is a growing furniture piece expanding the sensory horizon within the object itself is perceived: touch and sight are expanded in time, while the dimension of sound is introduced.

The idea is a furniture piece made out of wood residues, connected with mycelium, which will grow over time, covering the whole piece and forming a connection between wood and fungi. An even more natural cue is to let the table grow directly in the Black Forest, as mycelium is likely to spread much better in its natural habitat and surroundings. Every piece of furniture made will have its own soundtrack, as the bio-electrical sounds made along the fungus growing process will be recorded on a vinyl, made from wooden waste material and then carved with a laser cutter.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Luca Cappetti
Design & Engineering,
Polimi

Claudia Perez
Industrial Design,
TECNUN

Laura Rusanen
Fashion, Clothing & Textile
Design, Aalto University

Bea Braig
Jewellery, Technology &
Business, KEA

FLEXIROOM

Mobile fitting room



We aimed to create a flexible mobile fitting room that could be used in flea markets that are short on space using sustainable bio-based materials.

This fitting room consists of a long sheet of cellulose leather supported by Honext's panels on either sides. It is bendable; consists of wheels that can be moved at will, hangers made of MFC, and finally a compact stick on mirror. This product is ideal for vintage stores and flea markets that don't have enough space for fixed installations. It can also be customised (in terms of design and aesthetics) as per the needs of the customer. We primarily used wood based materials like cellulose for this project.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Aitor Juaristi Diez,
Mechanical and design engineering,
TECNUN

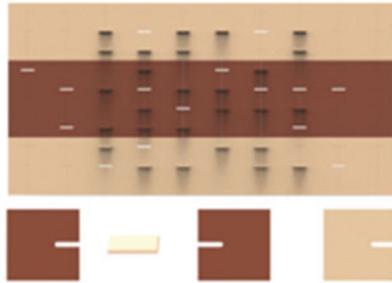
Pranava Sai Aravinda Pakala
Electronics and Nanotechnology,
Aalto

Martina Paramatti
Design & Engineering,
Polimi

Helena Troelsen
Sustainable fashion and tech,
KEA

HONEXT

Retail



A tile based on paper mill waste, with a slot for the attachment of modular wood dust and bers reinforced shelving units. The slots can be utilized for other wall textures like lights, hooks, etc.

Wall panels made of cellulose based waste have many benefits. However, they are not the best for continuous customisation and for load bearing activities. These properties would be beneficial at retail stores, where shelving, lighting needs etc are dynamically changing. Our panels, having a slot with scope of attachment of an assortment of objects, such as lights and projections to support merchandise on display, can make usage of these papermill waste panels a more viable option in the commercial space.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Nerea Fuentes
Industrial Design, TECNUN

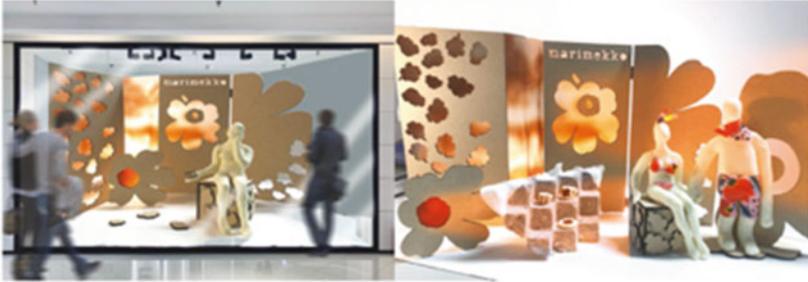
Pauline Rousseau
Jewellery design, KEA

Satyaki Roy
Creative Sustainability, Aalto

Shuai Liu
Design & Engineering, Polimi

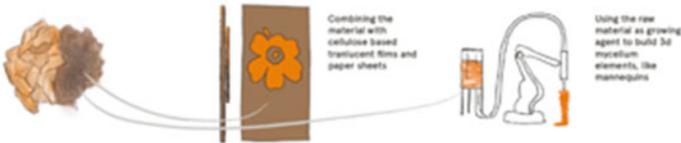
NATURAL DISPLAY

Retail window display system



Retail window display system made of recycled cellulose based panels. Personalized and modular elements for temporary and dynamic instore advertising applications.

Paper production waste is valorized through a circular process. We add value to recycled material with innovative material combination. The system is designed in a way that is versatile, scalable and replicable in different elements of the store or even in diverse markets and brands. The improvement of the based material gives the prospect of creating healthy and sustainable environments. At the same time, this product aims to create consumers awareness toward sustainable and carbon neutral products.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Javier Bereciartua
Mechanical Engineering & Product Design,
TECNUN

Clara Esteve
Design and Engineering,
Potimi

Marta Klyszejko
Jewellery, Technology and business,
KEA

Mira Niittymäki
Contemporary Design,
Aalto

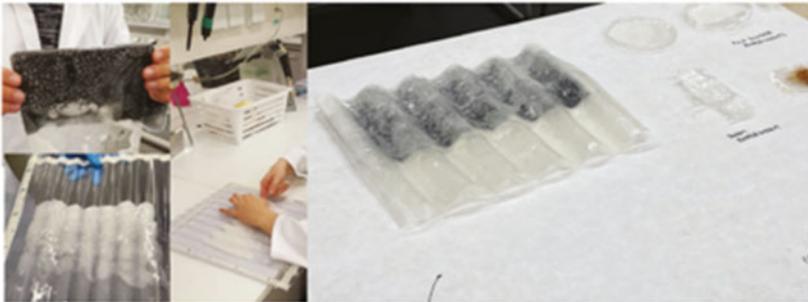
SPLIT AIR

Air filtration system



This is a functional and aesthetic divider that can be used in multiple locations. The dividers consist of biodegradable materials based on cellulose and carbon foam.

Split-air combines multiple innovative materials and technologies. The outer gradient panels are made of cellulose, which allows for a natural feel and touch. Due to its hydrophilic nature, it is coated with a superhydrophobic self-cleaning nano spray which will enable easy cleaning. The carbon foam is integrated on the upper part between these panels, which has the properties of filtering air, smoke and smell, especially advantageous for a clinical environment. The sides are closed with cellulose attachments, although the top is left open to allow for ventilation. The challenge may be how to attach these materials together sustainably to consider the disposal process.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Ena Naito
Contemporary Design,
Aalto

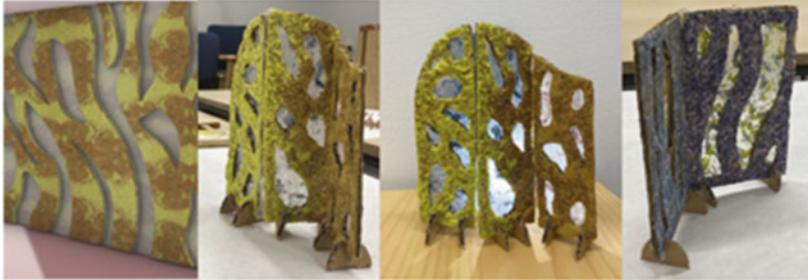
Ainara Alcain Iguñiz
Mechanics and Industrial Design,
TECNUN

Leonardo Cariga
Design&Engineering,
Polimi

Sofie Windfeld
Sustainable fashion tech,
KEA

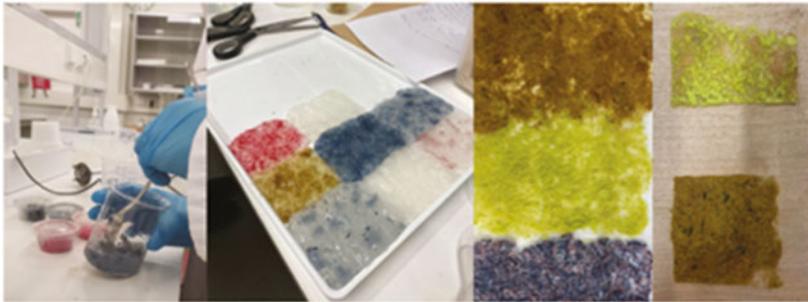
TEXTILE WASTE

Wallpaper



The wallpaper combines unwanted textile waste and the properties of the wood based materials and creates a new innovative and visual solution for Honext boards.

Apart from recycling waste textile, the main role of this material is to improve the aesthetics of the Honext boards. For that purpose, textile waste fabrics are used to get different patterns and colours, thus extending their life cycle. In addition to aesthetics, acoustic properties are also improved, as the low density of the textile fabrics strengthen the noise retention. To develop this material, four main ingredients have been used, glycerol, NFC, water and waste fabrics. To get different patterns and colours, different fibers and techniques can be used. The new material can be applied directly on the Honext boards with both water and MC once it has been produced.



Areas of materials involved.



Feasibility of the idea.

CONCEPTUAL



READY-TO-MARKET

Laura Rusanen
Fashion, Aalto

Andela Simunovic Pedersen
Jewelry, technology and Business, KEA

Borja Unanue
Mechanical and Design Engineering, TECNUN