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EMERGING MATERIALS & TECHNOLOGIES

New approaches in Design Teaching Methods
on four exemplified areas

edited by Venere Ferraro, Anke Pasold

D.I. FrancoAngeli
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New approaches in Design Teaching Methods on four exemplified areas

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DATEMATS project (Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach Agreement Number: 600777-EPP-1-2018-1-IT-EPPKA2-KA) has been Co-funded by the Erasmus+ programme of the European Union. The European Commission support for the production of this leaflet 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.

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Emerging Materials & Technologies: Meaning, Understanding and Issues

Venere Ferraro

Introduction

Currently, research in new emerging materials and technologies is one of the major drivers of this innovation and is also evolving at a rapid pace on many fronts in both industry and academia. This includes improved understanding and prediction of material properties and qualities, accelerated design and development of functional and multi-functional materials, the discovery of radical new materials and new materials processing technologies. The diversity and speed of change of this landscape provides great opportunity for an open innovation approach in which Knowledge Intensive SME's and Universities play a critical role in realizing the potential economic benefits. The interface between professionals with expertise in the field of design, engineer and material science has therefore assumed a new importance in the European Innovation agenda, both for accelerating the development of high value products and technologies and the delivery of solutions to major societal challenges (Innovation Material Project, 2013).

It is now understood that interdisciplinary collaboration and ***Emerging Materials and Technologies*** (EM&Ts) know-how in the design phase are essential elements in the way towards a circular economy.

Materials are key to technological advances in many fields, and particularly important for the success of the creative industries, one of the most promising fields of economic activity in highly developed economies. The materials industry has well established technological competences (technology push) whereas the creative industry is stronger in interpreting the context of using materials and the users' needs (design-driven).

A gap between the creative design of products that meet user needs, and the research and development of new materials by academia to be transferred to creative sectors has been identified (Commission Green Paper "Unlocking the potential of cultural and creative industries", 2010).

To do so there is a need in the academic landscape to ***educate future professionals*** in materials and technologies field and to involve enterprises (corporations and SMEs) to develop ideas towards commercial products and new business opportunities.

The present book contains the preliminary findings of an ongoing research project "DATEMATS"[1] funded by the European Commission – aimed at developing novel teaching methods for both design and engineering students in the field of Emerging Materials & Technologies (EM&Ts).

Particularly we will present a logical framework for four exemplified EM&Ts areas as results of the methods, gaps and issues related to their teaching methods.

We will first provide a summary of the four literature reviews conducted at respectively Aalto University on Experimental Wood-Based EM&Ts, Design Department of Politecnico di Milano on Interactive Connected Smart (ICS), Materials Wearable-based Tecnun University on Carbon-based & Nanotech EM&Ts and Copenhagen School of Design and Technology (KEA) on Advanced Growing. This to give a comprehensive overview of the overall findings, the four EM&Ts and their respective implications, the methodologies identified and the issues and gaps that were encountered.

Starting from the literature review an exhaustive explanation of each area will be given.

Precisely, the section one will be dedicated to definition, approaches and new teaching method related to a novel area of materials that is ***experimental wood-based materials***. Given, the novelty of the topic, the section will represent the area results of experimentation and activities developed inside ***Chemarts*** a long-term collaboration between two Aalto University schools, the School of Chemical Engineering (CHEM) and the School of Arts, Design and Architecture (ARTS).

The second section is instead dedicated to ***Nanotech materials*** by giving an overview related to materials meaning and potentialities of application, a synthesis of existing teaching methods and suggestion for new ones; this by using an in-depth literature review.

ICS Materials Wearable Based will be the focus of the third section; authors will give definition of wearable textile systems by highlighting potentialities and limits, they will stress the need of using ICS Materials,

1. 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.

define the meaning of ICS Materials and suggest new teaching methods in this regard.

Finally, the last section will describe ***Advanced Growing Materials*** by explaining meaning, the complexity of this open living system and suggestion for how to approach this topic in academia and teaching activities.

Each section has been cured and written by different authors belonging to the four different Universities, starting out from the literature review paving also emphasis on own experience.

Through the all book, different background, approaches and writing styles will be evident: this has been acknowledged as added value for dealing with the complex landscape of EM&Ts.

Needs, challenges related to the four EM&Ts areas

In the creative sector we are witnessing the need to support creativity-driven (e.g. design-driven) innovation by reducing the knowledge and communication gaps between the material scientists and engineers, the designers and creative communities and the producers. All actors capable of adding value to products and processes should be considered upstream in material development.

Innovative materials and emerging technologies are often thought as mainly related to a science (chemistry, physics, and engineering) in industry practice, as well as in the education field. Nevertheless, materials and technologies represent a key-factor not only to obtain better performances and innovative solutions but also to enhance the product language in term of new experiences and original expressive-sensorial dimensions. Materials can revitalise design, creating new business opportunities, transforming industrial activities and conceiving more sustainable solutions. ***Emergent materials and technologies (EM&Ts)*** are already at the leading edge in several sectors and are one of the key-elements through which industries can stimulate innovation processes and foster creativity. The new landscapes of EM&Ts require new interdisciplinary and transdisciplinary higher educational approaches in the field of design to provide unique competencies and skills to design students who will be asked to be able to exploit the innovative potentials of specific EM&Ts and simultaneously to adopt a more entrepreneurial attitude.

Nowadays, in the field of design, specific exploitation processes are required both into material and technology categories (how to design with and for them) and in the commercialisation of the resulting innovative products/demonstrators (be entrepreneurs/start-upper). All of these issues should be included in new educational approaches. EM&Ts need to be analysed and used also considering their no technological dimension: *expressive characteristics, potentials for new meanings, the end-user perspective, the socio-cultural and economic trends.*

In this regards, new competencies are today required: not just technical issues, but also *socio-cultural factors, entrepreneurial skills and market trends* that are typical of the design culture.

The Educators' goal is to train professionals in combining the cultural and social sides of design also with technical-engineering skills capable of generating innovations reducing the gap between Universities and Industrial Worlds.

In particular, speaking of knowledge connected to the field of EM&Ts education for industrial design, an *inter, multi and transdisciplinary didactic approach* is needed: to achieve that, educators are in need to investigate: (i) teaching models, (ii) how they could be useful to our idea of materials education.

We need to teach ***students with a mixed background (design & engineering***) to know how to exploit the innovative potentials of specific EM&T, ***generate innovation and to share this knowledge with companies*** in order to figure out what the real word require from a professional skilled in designing materials experiences; ***a professional that could be a manager, a start-upper, a new innovator***.

In this book we present the preliminary results of the ongoing research project "DATEMATS" aimed creating a transnational network among HEIs, Research Centres and Companies in order ***to develop and implement interdisciplinary and transdisciplinary methods for emerging materials and technologies education in the field of industrial design***.

The aim of the project is also to educate a designer able to deal with EM&Ts, taking into account the cultural and social aspect of the design process, developing demonstrators/products able to inspire new business.

The project deals with the wide area of emerging materials and technologies and to transfer knowledge about them both to students and industries. We present four exemplified EM&Ts Arear covered by four Universities with strong expertise in each area. In particular:

1. *Design Department, Politecnico di Milano_ICS Materials (Wearable-based) EM&Ts*
   - Educational method to design with ICS Materials and wearable technologies (currently developed with a technology driven one) into a multidisciplinary teamwork.
   - Knowledge about how to use ICS Materials (Interactive, connected materials) for wearable technologies.
   - Tools to teach entrepreneurial skills to students in order to master the exploitation of the design practice results (design thinking, co-design etc.).

2. *Material Design Lab, Copenhagen School of Design and Technology_ Advanced growing EM&Ts*
   - Methods for teaching material understanding, exploration and application in an interdisciplinary setting.
   - Knowledge from research to design and production.
   - Offering lab-residencies to designers working on new sustainable materials.
3. *Tecnun, Universidad de Navarra_NanoTech EM&Ts*
   - Evaluating the learning methodologies developed in the consortium.
   - Organizing and staging workshops/educational activities on the EM&Ts.
4. *Aalto University_Experimental Wood-Based EM&Ts*
   - Providing educational methods for interdisciplinary collaboration between design and chemical engineering in the field of biomaterials.
   - Collaboration models between science and design both in education and research.
   - Explorative hands-on sessions with biomaterials.
   - Integrating creative practices and design thinking in the education of chemical engineers.

The new landscape of EM&Ts between teaching and practice

Researchers in EM&Ts have to understand market needs and the competitive landscape, while designers and businesspeople have to know how new materials such as graphene can be implemented in their products. We are at a time of change in social and industrial eras, which is giving rise to a digital industrial revolution.

In this regard, several indications have been given by European Commission:

- integrate design and technological research and innovation;
- support creativity driven (e.g. design-driven);
- develop and promote platforms that support material development and innovation, involving designers, scientists, end-users but also societal stakeholders, anthropologists etc. and allow capturing and, when possible, making available unused knowledge and existing functional materials transfer;
- final user-oriented model should be adopted, and cross sectorial use of materials fully exploited.

Based on this ground Higher Education Institutions need to upgrade education models by means of innovative approaches targeted to:

- boosting new higher educational models where interdisciplinary (among universities with private and public organizations) and shared knowledge among different HEIs area key milestone;
- networking among design-HEIs highly specialized in specific fields of innovation in order to create a common, shared and new pedagogical approach framework laid down into specific "technology areas" (emerging material areas, also defined sub-sector, that is connected materials/wearable technologies, advanced smart materials, bio-materials, etc.) related to the expertise of each design-HEIs;
- reducing the gap in the higher education field related to EM&Ts providing novel education methods;
- developing new competences and skills into the design culture for "designing" with the EM&Ts (how to design with specific new technologies categories);
- educating professionals able to boost the new paradigms related to specific EM&Ts innovations (how to exploit their potentials).

The methodologies developed for each EM&T presented in each section of this book (from section one to section four) would represent ***an improvement in the education of new skills for industrial design engineering students***.

Final Remarks

Among Europe Policy priorities for University there is: encouraging *the creativity, the innovation, the entrepreneurial spirit* at all training and education levels.

If we specifically refer to new emerging material technologies it is largely recognized that a "creative approach in conceiving, developing, producing, using, and recycling materials can be effective in strengthening the competitiveness and success of all European industries, particularly of industries where technological advances are exploited in a creative way to increase the perceived value of a product or service" (European Commission 2012; European Commission 2010; Council of the European Union 2010).

Industry has continued to invest strongly in innovation despite recent economic uncertainties. 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 in product and process innovation and create competitive advantage.

In each section we will see how diversified and even complex are the four EM&Ts: they all stand 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.

ICS Materials EM&Ts area is situated in the intersection of Design (e.g., Human-centred design, Design for Disassembly, Interaction Design, Visual Design), Materials & Manufacturing (e.g., Textiles), and Computer Science (e.g., digital technologies). By the triangulation of these disciplines, the design practice about this EM&Ts is unfolded as 'Embedding & programming'. Other relevant disciplines and knowledge fields involved in the area are Ergonomics, Psychology & Perception, and Sustainability & Circular Economy. The definition of the application sector emerges as fundamental, e.g., health, sports, but not limited to wearables, e.g., automotive, architecture, furniture.

Nanomaterials EM&Ts area is situated in the intersection of Design (e.g., Creativity and Design Thinking for innovative application), Manufacturing Processes, and 'Hardcore' Science (e.g., Material science, Chemistry, Physics). By the interplay of these disciplines, the design practice in relation to this EM&T is unfolded as 'Super-empowering & Biomimicry'. Other relevant disciplines and knowledge fields involved in the area are Sustainability, Economics & Marketing, Psychology & Perception.

Experimental Wood-based EM&Ts area is situated in the intersection of Design (e.g., material exploration, User-centred design), Manufacturing (e.g., crafting, making, fabrication, and producing), and Chemistry (e.g., chemical engineering, material sciences). By the triangulation of these disciplines, the design practice concerning this EM&T is unfolded as 'experimental cooking'. 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.

Advanced Growing EM&Ts area is situated in the intersection of Design (e.g., material exploration), Manufacturing (e.g., crafting, making, producing), and Biology (e.g., biotechnological Science). By the triangulation of these disciplines, the design practice in relation to EM&Ts is unfolded as 'growing'. 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 lifecycles).

In this book we will present the synthesis of the four EM&Ts highlighting similarity, differences for all of them (see chapter The Four EM&Ts - A synthesis of a Literature Review), we will give an overview for each area in dedicated section presenting the meaning, the different approaches used and developed for each EM&Ts area, finally we will provide (see chapter "A Logical Framework for designing with and for Emerging Materials and Technologies") the setting up of a common and ***advanced methods to teaching EM&Ts within HEIs*, to create *new professional in young students, and to develop new guidelines and approach***.

Regarding the four EM&Ts several potential methods have been already 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); material-centred (e.g., material-driven design, material tinkering, experimental pedagogy, material mappings, material meanings, physical probes and material samples, material concepts, prototypes, simulation of material behaviours, affordance making); Design process.

This will be a holistic and 'stepped' but continuous and simultaneous iterative Design Process based on leaning materials on a general-level and returning to a hands-on approach. A process that may place material selection at an earlier stage, and context definition as a starting point or developed throughout the process. The process would prioritize hands-on exploration over sketching and visualizing. Material understanding, mapping, and selection would go hand-in-hand with the idea, form and application generation.

We will see how this will be implemented and merged into a **unique design teaching method for students with a mixed background** (design&engineering) in the field of EM&Ts.

The creation of the unique design teaching methods will and has having been possible thanks to:

- *Permitting to integrate the different HEIs approaches in an international coherent body of knowledge expandable to all EM&Ts*. Integrating the different EM&Ts teaching and exploiting methods through an inter-disciplinary approach, that goes beyond the simple coordination, and involves different stakeholders, increases the knowledge-exchange of different cognitive approaches and methodologies to EM&Ts and collectively redefines a new common method. Only through an interdisciplinary approach (design/creative, engineering/technology) together with inter-competencies methods (different EM&Ts specialization) into an international cooperation on interconnected topics (different methods about EM&Ts) can create a crossbreed methodology and a consistent and common body of knowledge on the teaching and exploitation of EM&Ts.
- Enhancing the development of *human capital through modernised higher education system*, *improving entrepreneurship skills* and

providing to student's *new methods to manage and exploit EM&Ts and their innovation potentials*, is a constantly increasing EU challenge, which can be solved by implementing coherent active strategies. An EU based approach is needed, focusing at exploiting new innovative skills in a learner-centred and problem-based way. This issue cannot be faced univocally, but needs to be jointly defined by different actors, calibrating opportunities that derive from a collaboration of organizations across national borders.

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The Four EM&Ts - A synthesis of a literature review

Anke Pasold

Introduction

To map the state of the art, four literature reviews were conducted, one on each of the Emerging materials and technology themes framing specific core competences of the respective educational institution.

These were forming the base for a comparative reading leading up to a summarising paper synthesising the findings on the four EM&T areas. Apart from their obvious differences, they displayed a number of common denominators in the areas of focus with regards to overall set up, approach and methodologies but also in terms of detected challenges, issues and gaps. These constitute beneficial findings for the logical framework and will be laid out in comparative settings below.

Most important findings

The four presented reviews span from (1) very user-focused EM&Ts (ICS), that are concrete, product-related and with a strong potential access to the market to (2) material-property focused EM&Ts (Advanced Growing and Experimental wood-based) that place a focus on exploring materials and their respective potentials for the use within products or on substituting existing harmful or 'endangered' materials through parameter tweaking for newly developed, designed matter to (3) application-ideation focused EM&Ts where the designers are part of shaping the capabilities of the prospective applications (Carbon-based and Nanomaterials).

Out of the four, ICS is the area that is most explored. It is also the area closest to the 'traditional' design process, most easily applied, accessed, understood and the most direct way into a marketable application. Carbon-based, nanotech and Advanced Growing EM&Ts require the descend to the microscale. Whereas the first 'rethinks' the designer's role to the ideation of the prospective applications, new solutions and framework for the implementation of the materials the last requires the in-depth understanding of the biological agent for the development and eventual co-creation of material and product.

Experimental wood-based materials require the in-depth understanding of the material on a chemical level to understand and create possible areas of application and prospective products.

Probably most notable was the overall lack of documented, published didactic material within the HEIs EM&Ts. Most generally the lack of documented processes of how to didactically work with these EM&Ts, especially with a designerly approach and the therewith-connected lack of didactic methods. For parts of the original structural division that formed the frame of the literature reviews and looked at 'Didactic approaches on how to (1) select (2) context-specific EM&Ts through their (3) behaviours and (4) perceptions towards (5) innovative applications', there was very little to no material found, some areas could not be covered at all. The reviews therefore (also) displayed accounts of general discussions, critical viewpoints and developments when working with (emergent) materials (All), own practice (Aalto) and deductions from case studies/product samples/ design projects (KEA).

This is, in part, due to the relative newness, the emerging nature of the materials and technologies, in part due to the challenges that are further elaborated within the later sections of the document.

Pre-requisites for working with the EM&Ts

It became apparent that working with these EM&Ts not only places new requirements on the methodological approach but also on the general setup of the learning environments, on the type of spaces available, the type of spaces the learning and teaching is conducted within and the equipment that is made accessible.

Requirements concerning the general setup for exploring, experimenting and working to be able to approach the field, analyse and understand its areas and conduct and test the work are essential pre-requisites within the didactic frames. Though a number of 'low-level' explorations are possible and can be run on respectively low-tech or with little equipment, more expert explorations, that eventually can relate to a industrial context, require specialised facilities, specialised equipment and related safety precautions.

All HEIs furthermore mentioned the benefit and necessity of expert networks being connected to the respective areas to support the complexity, the field-specific areas of the project and to ensure and enable the cross-disciplinarity through subject expertise.

Designers role in EM&Ts

Designers have a less or more active role in the process and in the actual shaping of the materials - From creating the material to ideating application areas, they *can conceive products* with improved performance, usefulness and aesthetic value rather than achieving some exotic new functionalities (Karana et al., 2013), *explore the contexts* within which these emerging materials might be used and can help evaluate and weigh claims that are often competing such as safety vs. performance. They can *bridge the gap between theoretical knowledge and practical applications* to develop new products, services and experiences and *work in multi-disciplinary teams* to explore the materials technical aspects, manufacturing processes, economies of scale as well as ecological and sensory domains or material experiences.

They thereby take on essentially different roles within projects conducted within the EM&Ts areas. They turn idea, scenario and application generator in the frame of Carbon-based & Nanotech, technology shapers, human physiology explorers and user experience and scenario experts in the frame of ICS and, to a big part, material designers in the frame of Advanced Growing and Experimental wood-based materials. Furthermore, within the interdisciplinary setup of the EM&Ts, their role as mediator and communicator is inevitably heightened even more.

Methodological Approach

Overall

All four reviews display a strong focus on hands-on, experimental and explorative methods throughout all stages of the projects and as a continuous strategy within the process. These are combined with theoretical input to, both, approach and understand the EM&Ts. This, consequently, encompasses the need for mapping and documentation as an analytical, comparative and validation tool.

All of the represented EM&Ts are of high complexity, placed at the intersection of several disciplines and therefore require knowledge and methods of those, to a certain extent: Material research, Chemistry and Design (Experimental wood-based, Aalto), Material science, Biology, Chemistry and Design and Engineering (Advanced Growing KEA), Material science, Chemistry and Design (Carbon-based and Nanomaterials, Tecnun) and Design and Technology (ICS, Polimi).

Most recorded methods therefore advocate for one or all of the following; *extending teaching to the respective other field(s) of expertise*, *expert involvement*, *cross-fertilisation* and an *overall promotion of the cross-disciplinary* nature of the EM&Ts respective areas. This, inevitably, results in a necessary establishing of a focal area within the projects complexities, which poses a number of challenges in itself and substantially broadens the area to be covered. It furthermore contributes to the time-extensive nature of the projects. Teaching modules are therefore either run in shorter, reasonably compact and very guided workshop formats or, if more freely structured, over longer periods to allow for in-depth study and output that is closer to concepts that can be implemented.

Either framing relies on 'stepped' approaches to tackle the complexity and to learn about the respective non-design field allowing for experts to come in where relevant.

Introduction to respective other field - dealing with complexity

All four, in the project encompassed, EM&Ts display an interdisciplinary nature. They are placed at the intersection of different fields, all of which contain their own expert knowledge, own, different approaches and mind-sets. This meeting of different disciplines inevitably poses didactic challenges, which are tackled in three main models; *learning about the respective other field* (self-immersion, planned immersion) as a separate discipline to be able to operate within it, *structured interdisciplinary teachings and co-teaching* to have expert input within the different areas and phases (Chemarts, 2019) (Bahar Barati et al., 2015) *and interdisciplinary teams and co-labs* to have field expertise from each area. (Biobuilders, 2019; Chieza, 2018) (Chemarts, 2019).

In several combinations and with different degrees of intensity and level of integration or respective steering, they also encompass the inclusion and/or establishment of expert networks as a more or less active support group.

The overall didactic methods aim at inspiring, informing and instructing, thereby creating a base knowledge, an entry, to the subject or complete understanding of the respective other.

Within the three aforementioned categories they include:

Open access learning; specialised social media channels, online portals and platforms are employed with the aim of sourcing existing up-to date and easily accessible knowledge and expertise as a necessary foundation and a general supporting pool. Those can be used in the preparation phase and are furthermore valued for their promotion of collective exchange, the identification with a shared cause, encouraging decentralisation of knowledge, democratisation from established structures. (Kretzer, 2017). Concretely they can comprise *cutting edge documentaries* via e.g. YouTube to learn about and comprehend the concepts related to respective field(s) faster and more efficiently (Sebastian & Gimenez, 2016), *free e-courses* for more in-depth teaching and learning experiences (de la Rosa, 2012), *online tutorials*, *open source databases* for openly sharing information and respective democratisation of scientific content (BioHack Academy, 2019) (Materiability, 2017) (Materiom, 2018) (http://openmaterials.org), *open-source project results* for continuous learning cycle (NANOLAB, 2019).

Hands-on learning is part of most reviews as a way to understand the behavioural and perception-based properties, familiarising with specific characteristics and processes and enable the experiencing of the material through our senses, feeling the properties, the potential and its agency. (Groth, 2017). They are also an entry to the field and used as memorable experiences that increase students' interest and understanding and point to exploration paths to potential applications. They are executed in a number of different ways, such as hands-on (lab) work, practice-based, experiential learning, observation and experimentation (IRRESISTIBLE, 2019) (BioHack Academy, 2019) (Pirjo Kääriäinen et al., 2017; Rueda Mejía, 2019); EM&T-inspired hands-on experimental work (NANOLAB, 2019) (BioHack Academy, 2019) (Pirjo Kääriäinen et al., 2017; Rueda Mejía, 2019); creative high-tech hands-on approach using low-cost, sensitive multipurpose lab tools (NANOLAB, 2019) (BioHack Academy, 2019).

Facilitation of expert integral courses comprising the setting up of expert networks, general didactic formats that are cross-disciplinary collaborations centred on the subject and always including design as well as teaching with involvement of scientists (Chemarts, 2019).

Facilitation of co-labs through the setting up *ECTS giving student-run courses* with active student involvement from different fields (*DTU Biobuilders - a new student-run project*, 2019) with each student contributing with the field-specific knowledge resulting in setups very close to practice, *setting up of cross-disciplinary study courses* (Fabricademy, 2019), *familiarising students with methods and design approaches through multi-disciplinary hands-on teamwork in labs* (Itälä, 2014; P. Kääriäinen et al., 2017; Karana et al., 2010).

The didactic formats range from traditional lectures and presentations for establishing theoretical frameworks, giving insights into materials and contemporary applications to assisted hands-on work in form of introductory workshops of shorter and longer nature, study and occasional courses (Aalto) and exhibitions (Aalto, KEA) to supervision of individual BA & MA projects (Aalto, KEA).

Key factors of documentation are further supported by regular presentations and feedback fore.

All such approaches place particular requirements on the instructors that need to be experts within the respective fields and/or experts on the new didactic approaches.

Designing with the four EM&Ts

The reviews showed that the original categorisation laid out as a frame for the search for the didactic methods was difficult to identify within the published materials. With the limited literature that could be found, categories 1-4 merged, for the biggest part, into one integrative process. With the exception of ICS, where there were examples within all categories, the HEIs advocated for combining the areas into category 1 as context, behaviour and perception, in most cases, were found to be selection integrate and all needed continuous exploring and mapping in an interdependent manner. In the frame of the researched EM&Ts, the material selection is therefore not so much of a starting point for possible applications (Pedgley, 2013) but rather a simultaneous process of idea, form and/or application generation through material understanding, mapping and selection.

Rather than the originally suggested categorisation for the reviews, the attempted application context that guided the arrangement of methodologies made repeated occurrences throughout the reviews and has therefore become the basis for the comparison of findings.

Contextualisation

Creating a relevant context to tackle the abstract nature when first getting in contact with the field. Recorded methods are the *Design-Driven Material Innovation Methodology* (DdMIM) that aims at the development of one or more materials to identify applicative scenarios, characterise product lines and develop specific products, *the creation of analogies* (Abersek, 2016) and *Metaphors* (Piselli, 2015).

Material-centred

When the material becomes the driver of the creative finding process by evoking ideas and opens the path to discover opportunities of a given material and the therewith-connected development of the application context. This approach is in parts or as a whole seen in ICS, Biomaterials and Advanced Growing. Most of the explorations follow the Material Driven Design process (Karana et al., 2015) to resolve the uncertainty in relation to the material knowledge and involve *Various tinkering activities* (Garcia et al., 2017; Parisi et al., 2017a; Rognoli et al., 2016; Rognoli & Parisi, 2018), *Physical probes* (Garcia et al., 2017; Parisi et al., 2017a; Rognoli et al., 2016; Rognoli & Parisi, 2018), *Material samples* that support experimental processes, e.g. MdL at Sapienza (Ferrara & Lucibello, 2012), *Accessible material samples* for experiments and aesthetic processes and different manufacturing processes, *Material mappings* of performative, behavioural and sensorial parameters, of properties (Bahar Barati et al., 2015) properties and applications (Bahareh Barati, Elvin Karana, Paul Hekkert, 2015), *Sensorial mapping* (Rognoli, 2011; Asbjorn Sörensen, 2017; Parisi, Rognoli & Sonneveld, 2017), *Material experience* (Bahareh Barati, Elvin Karana, Paul Hekkert, 2015), *Material concepts, Affordance making* (Bahareh Barati et al., 2018), *Prototypes, Categorisation study* to find out what associations people have with the material concepts (Karana et al., 2018), *Simulation of material behaviours* through small tangible library (Barati, Karana & Hekkert, 2015), *Digital models* within Biobuilders Mycelium for Mars project (*DTU Biobuilders - a new student-run project*, 2019) experience pro-totyping in real-time hybrid simulator (Barati et al., 2017).

User-centred

Ideating ideas around a specific user and the therewith connected scenario-creation gives clear indications of the involved parameters and limits and aims at an actual application, thereby making the process more real. Methodologies involve a.o. *Sense making*: human pleasures and consumer needs (Lecce & Ferrara, 2016), *ICES Design for Wearabilities, Human body in motion, Unobtrusivity* (Gemperle), *MDD* (Karana et al., 2010).

Case-centred

Creating closeness to new industrial challenges by linking to material suppliers or manufacturers is a beneficial approach for both universities and companies. It is a way to give clear indications of material properties or environmental factors, especially for the more technical, application focused EM&Ts (ICS and Carbon-based and Nano-tech), it seemed valuable to start from a particular material or specific material properties to therefrom redesign a part or a whole by e.g. material replacement or by finding possible application contexts through material property exploration (Piselli et al., 2018) as trialled within a specific environment through the ICS for Yacht Design (Parisi et al., 2019) or specific application in the context of Tangible interfaces (Ferrara & Russo, 2019).

Issues & Gaps Related To EM&Ts

There are a number of common gaps and issues that apply to all four EM&Ts. They are comprising the aforementioned *complexit*y as a consequence to the cross-disciplinary nature of the areas and the involvement of experts and different disciplines, leading to substantially more ground to cover and more understanding to be gained but also an inevitable communication challenge between professional fields, the *designer's new role* requires a new mind-set and new ways of obtaining knowledge and new ways of working, the *'newness' of fields* and the therewith related lack of samples, lack of documentation, lack of procedure that make it additionally difficult to start up, the *time component*, the *lack of design expertise within the respective* other that increases above mentioned challenges of cooperation and communication, the level of *specific knowledge of educators*, that results in tutors needing to be taught or have upgraded their knowledge before teaching students (IRRESISTIBLE, 2019) leading to a related training on two levels: first, for teachers that will train design students and second for the students themselves.

Equally there are gaps and issues that relate to some of the areas, where they are found to have overlaps.

Experimental wood-based materials, Advanced growing, Carbon-based and Nanomaterials

The *issue of scale*: 'Difficult to understand what you don't see' (Schulz, M., Zhangzhang, Y., Alvarez, N., Shanov, V., Pai, D., Pixley, S. & Kim, 2013) (Olteanu et al., 2017), the *need for special laboratories and (high-cost) equipment* that are needed to conduct experiments and explorations with the related safety precautions and safety instructions, which, as an undesired side effect, can create a threshold upon first contact, the importance of a *complete preview and knowledge regarding the lifecycles of emerging materials* in coherence with economies of scope and scale which are ecologically and economically sustainable, the need for *structured analytical tools* to quantify and compare intangible and sensorial characteristics of materials.

Experimental wood-based materials, Advanced growing

When an artefact designer finds themselves in the role of Material designer there needs to be gained a new understanding not only on the approach but the different nature of the process that entails the *lack of clear boundaries* throughout the experimental phase, the handling of *endless combinations* of ingredients, environmental factors, production means give a sense of uncertainty (Daalhuizen, Badke-Schaub & Batill, 2009), the *delay through growth and processing time* in the context of evaluating the outcome which is *disconnected from the moment of crafting*, the need to *accept the co-authorship* of materials and the therewith connected *unpredictability*, the *accepting of accidents* as enhancers, instead of forcing the material to achieve a predesigned shape, the value of finding a *balanced dialogue* with the material where both guide each other, the *change of mindset* in a process where materiality is simultaneous with and intrinsic to the creative process itself (Mäkelä & Löytönen, 2015) (Chieza, 2018) (Collet, 2017), the *material acceptance of unknown materials* and materials out of context or materials with 'bad reference' (Karana et al., 2018), the big *gap between the material explorations and finished product* and the therewith connected, necessary switch from experimentation to careful planning and realisation of the selected idea (Mäkelä & Löytönen, 2015) and the resulting *missing path to commercialisation*.

ICS Materials Wearable based

Also within ICS there is a recorded *missing path to commercialisation* with explorations often stopping at concept stage related to materials manufacturing (Barfield & Caudell, 2001). There are *issues with miniaturization and flexibility*. Full potential can only be reached once industry can level up to the full potentials. In the process itself there is a *lack of sensory experience investigation*: Designers must consider the user's cognitive load, sensory and cognitive bandwidth (Baker et al., 2015) and the *contradiction of the R&D vs. designerly approach*, which in turn could lead to more collaborative practice and bridge the *gap existing between design and science* to more fully realise the opportunities and contexts of ICS (Fairburn et al., 2016).

Conclusions

The conducted reviews within the HEIs focus areas show a relevance for not only furthering and expanding the didactic landscape throughout DATEMATS but, for a large part, the need for establishing the very same, especially with view to the missing path to commercialisation and the gap to the industry.

The Literature reviews gave an overview of the rather poor selection of didactic methods within the aforementioned areas and therewith lay a good groundwork for the required take on didactic developments and the logical framework.

There is an overall agreement on the cross-disciplinarity being the biggest potential for innovation whilst at the same time posing the biggest challenge due to its consequential complexity as well as the difficulties that sustain at the intersection of different expert areas in terms of approach, methods and communication.

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1. Experimental Wood-based Materials

1.1. Experimental Wood-based Materials: Towards a sustainable material world

Pirjo Kääriäinen, Sara Lucía Rueda Mejía

Introduction

This section frames Experimental Wood-based Materials and explores the potential of these materials to change the existing fossil-based material environment and discusses the role of design and designers in this process. In this context, wood-based materials refer to ***materials that are processed either chemically or mechanically from trees for innovative applications***. The materials include cellulose fibres, fibrils (micro- or nano-structured) and derivatives, lignin, bark extractives, and novel combinations of these (Kääriäinen et al., 2020).

The ongoing overuse and waste of natural resources is totally intolerable and makes no sense from any perspective. Circular economy specialists Ernesto Hartikainen, Nani Pajunen and Riitta Silvennoinen from The Finnish Innovation Fund Sitra stated in 2017: 'The world is being shaped by global megatrends such as the rapid development of digital technologies, the growing scarcity of natural resources due to increasing consumption and unpredictable political turbulence caused by the aftermath of globalization' (Kääriäinen & Tervinen, 2017). The increased amount of knowledge about environmental problems and the ongoing climate change calls for urgent actions, articulated also in the United Nations Sustainable Development Goals (UNESCO, n.d.). People are becoming increasingly conscious of the need for change, and at the same time, science and technology are developing faster than ever, enabling us to tackle the existing problems and to create new, more sustainable way of living. Although we urgently need to find ways to reduce global consumption in general, the need for materials will not disappear.

Materials derived from trees and plants have been used throughout human history for various purposes: for building, textiles, everyday utensils, nutrition and medicine. In the industrial era chemical pulp and paper industries have been developed along with the more traditional mechanical wood processing. These processes have caused serious environmental problems related specially to harvesting and manufacturing. However, this paper does not focus on the existing forest industry as such or discuss the broader role of the forests in the climate change. The focus is on how these precious raw materials can be used for innovative, high value-added applications by combining material engineering and technical know-how with creative design and sustainability. An example of this is CHEMARTS, a long-term strategic collaboration between two Aalto University schools, the School of Chemical Engineering (CHEM) and the School of Arts, Design and Architecture (ARTS). CHEMARTS collaboration started in 2011 as an Aalto University initiative looking at possible ways to integrate design and material research. Since the beginning, the objective of CHEMARTS activities has been to inspire students and researchers to explore bio-based materials together, and to create new concepts for a sustainable material future. CHEMARTS acts as an umbrella for various activities, such as cross-disciplinary study courses, the Summer School, and externally funded research projects (CHEMARTS, n.d.).

As the collaborative approach to this research field is quite new, and not many academic publications are available, most references of this chapter come from our own edited publications where various writers have been sharing their expertise and research.

Why Wood-based materials?

Bio-based materials are often considered the best option to replace dominating fossil-based materials. For example, Hartikainen, Pajunen and Silvennoinen (2017) consider cellulose-based materials as a future substitute for fossil oil-based materials such as plastics and resource-intensive materials such as cotton or aluminium. They do not only see the renewability, recyclability and biodegradability of cellulose-based biomaterials as properties that make them interesting as substitute materials; they also consider these materials as having their own special qualities. 'The organic nature of biomaterials also involves unique properties and allows for previously unimaginable applications' (Kääriäinen & Tervinen, 2017).

Wood has three main components: cellulose, lignin and hemicellulose, and ***cellulose is the most abundant organic biopolymer in the earth and***

can be found in all plants and algae. It is already a common material in everyday consumer products such as paper, packaging and cardboard, films (cellophane) and textiles (viscose, lyocell). Researcher Heli Kangas from VTT, The Technical Research Centre of Finland, explains how cellulose in its various forms is used also in chemicals and additives used in cosmetics and food, whereas lignin is currently mostly used for energy (Kääriäinen & Tervinen, 2017). In addition to these three main components, trees contain rich array of other components for example for UV-protection or antibacterial properties.

Fig. 1 - In Finland, forests are a source of well-being, as well as a source of renewable raw materials. Photo Eeva Suorlahti, Aalto University

Wood can be processed either mechanically (for example, sawn timber and plywood) or chemically (for example, kraft pulp and its derivatives). About 70% of Finland is covered by forests, and the forest industry has played a substantial role in the Finnish economy since the 1900s. The forest industry is well known for its high-quality wood which is used in the production of multiple merchandises such as lumber, pulp (name for processed cellulose), paper, and packaging materials, as well as cellulose derivatives such as food supplements and pharmaceuticals. Pulp, paper, cardboard and sawn timber have been the main export products of Finland for decades. The use of traditional paper products is declining as digitalization moves forward, and the two main product categories are currently packaging and pulp. Constantly expanding e-commerce needs more and more packaging solutions and pulp is needed to produce bulk materials such as tissue paper for fast developing markets. In recent years, the traditional forest industry in Finland has started a renewal process, to transform pulp and paper mills into biorefineries, and to explore new and possibly higher added-value applications for wood. At the same time, a new start-up scene for wood-based materials has emerged (mmm.fi; Finnish Forest Industries; Uusi puu, n.d.). A new approach to wood-based materials, especially those that are cellulose-based, is one of the strategic points defined by The Finnish Innovation Fund Sitra, for the vision of Finland and the future of the planet as a 'society built on organic materials' (Kääriäinen & Tervinen, 2017). To make this happen, the use of all material resources (virgin, recycled, side streams and residues) has to be efficient, and all the loops need to be closed for ***the circular economy***. According to the Ellen McArthur Foundation (n.d.), a pioneering circular economy facilitator, the circular economy 'is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems'. These need to be the guidelines for the future material developments.

Fig. 2 - Wood cellulose in its various forms. Photo Eeva Suorlahti, Aalto University

The role of design(er) in Wood-based Materials development

Finland is not the only place where wood cellulose and other wood-derived advanced materials are currently researched and developed. For example, Sweden, Canada and Japan have well-established scientific research teams and ambitious research programmes on these materials. However, the whole field is very technology centred and design driven approach is still rare. Some examples where designers are working together with material researchers exist, but in most cases, designers are involved only when a new material is ready to be applied for products or needs to be communicated. In some cases, designers and artists might be working with these materials in the context of speculative design, not material engineering. An effort to test and implement a ***design driven approach*** in the context of wood-based material research was conducted in Finland through 'Design Driven Value Chains in the World of Cellulose (DWoC)' project 2013-2018. Three main roles for designers were identified: idea generating, prototyping and communication (see chapter 1.2; cellulosefromfinland.fi). Several other research projects with similar approach have followed.

Design researcher in DWoC project and material design pioneer Tiina Härkäsalmi explains what ***sustainable design with a holistic approach*** means in the context of material development: 'Sustainable design is based on a human-centred design strategy from a systemic perspective, with a key goal of balancing economic, environmental and socio-cultural aspects in the creation of concepts, products and systems in the long term.' Design has to link environmental life cycle considerations with material development by focusing on the multifaceted qualities of objects, processes, services and their systems in whole life cycles. Härkäsalmi emphasizes a holistic system approach to creating alternative production and consumption models 'by closing material cycles including both forward and backward flows in integrated supply chains, creating alternative scenarios of product use and dematerialization of systems in ways that meet consumer needs but are less resource intensive' (Härkäsalmi, n.d.).

Designers will play a key role in emerging ***ecodesign***, a product design method in which products are designed for several life cycles. Ecodesign can be defined as a design procedure aiming to reduce the overall environmental impact of a product or service to a minimum (Ecodesign Circle, n.d.). As materials are one of the main elements of any product, designers and other experts involved in product design will need in-depth knowledge of material properties, their production and reuse processes, and material flows. However, even this is not enough: to maximize the design impact, designers should be involved in early-stage material development. Sitra experts Hartikainen, Pajunen and Silvennoinen consider materials know-how in the material development and product design phase to be the key element, which enables the transition towards a circular economy (Kääriäinen & Tervinen, 2017). Material design expert Tiina Härkäsalmi clarifies the ***difference between the integration of the design approach into materials research and development and the conventional product design process*** in which the design requirements commonly outline the materials selection from existing materials (Kääriäinen & Tervinen, 2017).

Fig. 3 - Bio-based material experiments by CHEMARTS Students in 2018. Photo Eeva Suorlahti, Aalto University

Conclusion

Wood-based materials come from renewable sources, can be modified on the chemical level, and can be used for recyclable and/or biodegradable products. When utilized wisely for added-value applications, they have the capacity to replace fossil-based materials such as some plastics or synthetic textiles, cotton with its several sustainability issues, or some harmful chemicals used in, for example, in dyeing or finishing. However, the sustainable use of biomass is continuously debated in Finland, with the discussion focusing especially on carbon sinks, nature protection and economical aspects (LUKE, n.d.). Growing forests are carbon sinks, and there is no doubt that biodiversity has to be ensured and the value of nature as such has be promoted. On the other hand, wood acts as carbon storage in long-lasting products such as wood construction, and wood-based material solutions might help us solve some of the serious problems we face today.

On the global scale, Experimental Wood-based Materials and their potential for future applications can also be found in the development of new interactions and integrations between the materials and forms through new technological processes. By focusing on both new materials and new technological processes we can reinforce the capabilities and functions of the human body, improve health conditions, and even create a new type of relation between products/buildings and their existing environment (Oxman, 2013).

To create and implement a sustainable material world, we need to know the origin and processing of materials, and to understand their whole lifecycle and impact. A holistic approach enabled by interdisciplinary collaboration is needed already in the early stage of the material development. This is where designers can play an important role. Matilda McQuaid, curator at Cooper-Hewitt Smithsonian Design Museum writes: ‘The challenges to our planet are so complex that they cannot be solved by one discipline. Design is a bridge. It translates scientific ideas and discoveries into real-world applications. (Lipps, Condell & McQuaid, 2019).

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1.2. Collaborative strategies in education and research

Pirjo Kääriäinen, Sara Lucía Rueda Mejía,
Tarja-Kaarina Laamanen

Introduction

Design discipline has started to move from industry-based expertise towards an approach and attitude that can contribute to all programmes across the university system: this to meet the several prevailing challenges. (Welch & Loy, 2013).

Design courses around the world have been reviewed and revised so that design can have broader implications for the environment and societies (Loy, 2012). Design has more intangible immaterial uses, as well as more detailed understanding of materials. Complex problems require interdisciplinary knowledge and the ability to work across disciplines (see Self, 2019). Thereby, the definition of interdisciplinarity by Julie Thompson Klein and William H. Newell (1998) also fits this context: 'a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession and drawing on disciplinary perspectives and integrating their insights by producing a more comprehensive understanding'.

Interdisciplinary design pedagogy approaches have become central in higher education (Loy, 2012); isolated knowledge alone can no longer provide a basis for innovations. Future professionals need flexibility, the ability to think and act in interdisciplinary, intercultural contexts; they need to have capability to bridge different spheres of thinking, cross borders, and question existing intellectual as well as behavioural habits in order to create new scenarios and cultivate visionary results (Bast, 2015).

The pedagogy developed for the education of the emerging wood-based materials is based on these ideas and principles. Through playful material explorations, firstly in a non-commercial framework, Aalto University CHEMARTS aims to ***inspire and educate future professionals with creativity, knowledge and skills to work in the interdisciplinary environment for material development***. This chapter presents the background of CHEMARTS collaboration and its three main pillars for education.

Fig. 1 - Design students working at CHEMARTS lab 2017. Photo Eeva Suorlahti, Aalto University

The birth of the CHEMARTS collaboration for Wood-based Materials

Interdisciplinarity has been at the core of Aalto University strategy and CHEMARTS collaboration from the beginning. Aalto University was formed in 2010 by merging three traditional universities: technology, business and design/art, and aiming to enable innovations through cross- and interdisciplinary collaboration. CHEMARTS collaboration was initiated soon after, when staff from the two schools met in internal events and recognized a shared interest in bio-based materials, wood chemistry and textile design. In the summer of 2012, an interdisciplinary student team (three from CHEM, three from ARTS) was hired to complete two tasks: 1) to familiarize itself with the latest cellulose-related applications and to explore the potential of cellulose in the future and 2) to figure out how design and wood-based material sciences could collaborate in practice. The student team, supported by a recently graduated tutor, spent three months familiarizing themselves with materials and production processes as well as with each other's working methods. They set the foundation for the CHEMARTS collaboration: they established ***the practice-based working methods*** and made a proposal on how the collaboration should be organized and what kind of courses it could include. They also created the 'World of Cellulose' and 'Luxury Cellulose Finland', concepts, which were afterwards used as an inspiration for a significant strategic research opening (Kääriäinen, Niinimäki & Lindberg, 2017). During the following two years interdisciplinary student teams created and tested joint activities, with financial support from the University. Since then, collaboration over disciplinary borders has been embedded in all CHEMARTS activities. The general idea is to explore wood-based materials and their applications for innovative uses through an experimental and hands-on approach. (Kääriäinen & Tervinen, 2017).

In 2013, the experimental collaboration in education expanded into a large strategic research opening, 'Design Driven Value Chains in the World of Cellulose' (DWoC) project. DWoC aimed to generate new cellulose-based product and service concepts in Finland. The idea was to inspire a new ecosystem through design and novel technologies to create viable alternatives for fossil-based synthetic materials. The DWoC project was based on the ***unique combination of design-driven prototyping and strong technology development competence*** (cellulosefromfinland.fi, n.d.). The design team consisted of four design experts and couple of design students, each having a different role. Design researcher Carlos Peralta focused on the interdisciplinary interaction between material engineers and scientists, designers and business researchers in the DWoC research project. He listed the key elements of successful collaboration as developing a common language to 'overcome the limitations of disciplinary jargon', finding a clear common purpose, and cherishing mutual trust. These are relevant points for any collaborative activities, but in the DWoC project the experience of shared activities (working together in practice) was found especially valuable. 'Interdisciplinary collaborators need to develop mechanisms to integrate their disciplinary methods and approaches. This will not happen by itself, it takes time and effort', Peralta concludes (Kääriäinen & Tervinen, 2017).

Dialogue between research and education

The experiences from the DWoC and also from other ongoing research projects on bio-based materials at Aalto University have had a substantial impact on working methods and ways of collaboration and communication in the educational context. The dialogue between education and research, and the knowledge transfer between design and material science is continuous, bringing together scientific methods of material research and creative practices under the topic of bio-based materials and enhancing a new kind of shared expertise. This enables deeper problem solving and opens up a complex phenomenon through shared expertise (different knowledge and disciplines) and collectively gathering information (Muukkonen, Hakkarainen & Lakkala, 1999). However, company collaboration and knowledge transfer from academia to industry have not been in the focus of these educational activities so far.

Three core pillars of CHEMARTS

The general idea of this wood-based EM&Ts is to explore wood-based materials and their applications for innovative uses through an experimental and hands-on approach. CHEMARTS collaboration has been developing organically for years in the intersection of chemical engineering and design, enabling the testing of various pedagogical approaches. It has not been strictly part of any specific study programme. The CHEMARTS approach to Experimental Wood-based Materials EM&Ts is based on three pillars: bio-based materials, interdisciplinary collaboration and experimental pedagogy for educating 'future professionals with a multidisciplinary mindset and skills' (Kääriäinen, Niinimäki & Lindberg, 2017).

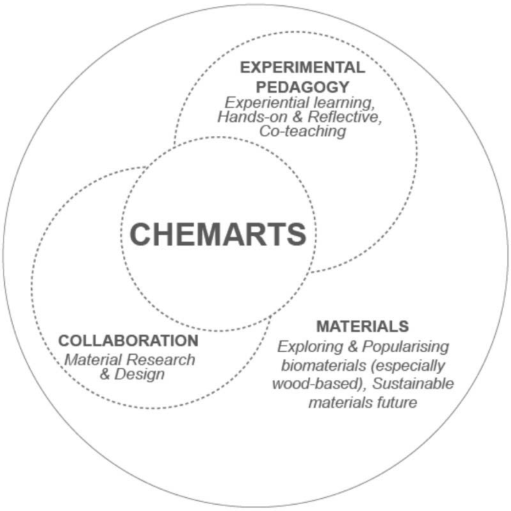

Fig. 2 - The three core pillars of the CHEMARTS approach to Experimental Wood-based Materials EM&Ts (2019)

Pillar 1: Materials (Wood-based Materials) provide the medium and context for the learning process based on exploring and popularizing bio-based materials and developing ***alternatives for sustainable materials futures***. Students are encouraged to search information according to their interests, to conduct creative material experiments, and to develop concepts for the future use of these materials.

Pillar 2: All activities are planned to enhance and enable ***collaboration between design and material research***. The students work in mixed teams in an interdisciplinary environment, they are tutored by experts from different disciplines, and the research methods are adapted from both disciplines: from scientific material research and design practice and research (*e.g.* constructive design research, Koskinen et al., 2011; Kääriäinen et al., 2020).

Pillar 3: In this case experimental pedagogy consists of an ***experiential learning process, practice-based working methods and co-teaching***, all in connection with bio-based materials. The focus is on a natural learning process, a 'growth mindset' – a learning experience that works for different purposes and ages (Dweck, 2017) – rather than aiming for specific results, for example, solving of given problems. The inquiry-based learning process can start before the problem is clarified or framed (Muukkonen, Hakkarainen & Lakkala, 1999), and the problem is framed through a process that includes information mapping (from different disciplines), creative hands-on experimentation and teamwork (Kääriäinen, Niinimäki & Lindberg, 2017). Co-teaching has proven to be the key for truly interdisciplinary education: it enables bringing in-depth expertise from various disciplines and achieving the targeted learning outcomes. However, co-teaching is challenging it requires joint planning, good coordination, open dialogue and mutual respect between teachers themselves, as well as between teachers and students.

Fig. 3 - Students sharing their gained knowledge through presentations and exhibitions. Photo Eeva Suorlahti, Aalto University

Conclusions

The learning process for Wood-based EM&T's is mainly designer/student-driven, and the role of the supervisors and tutors is to act as facilitators. They provide background information on wood-based materials, discuss the most relevant ongoing research related to the students' projects, and open up the most applicable design methods for their purposes. Students are encouraged to step out of their comfort zones: design and art students to learn and apply methods from engineering students and vice versa.

Currently the pedagogy in CHEMARTS for Wood-based EM&T's can be described not only as co-teaching but at its best as co-learning: the staff also learn from the students. According to Professor Tapani Vuorinen, one of the CHEMARTS initiators and an expert in wood chemistry, design students have enhanced scientific research through their explorative approach to materials. Common understanding and new knowledge have been gained by doing things together and openly sharing processes and results (Kääriäinen, Niinimäki & Lindberg, 2017).

As no clear design tasks or strict guidelines are given (except safety rules), students need to be highly motivated and work actively with their own projects (Kääriäinen & Tervinen, 2017). This kind of pedagogy is demanding not only for students but also for supervisors and tutors and does not suit all learners. Finding a balance between freedom and guidance can be challenging (Kääriäinen, Niinimäki & Lindberg, 2017).

The most interesting material recipes since 2015 were collected and 'The CHEMARTS Cookbook' was published in 2020 (Kääriäinen, Tervinen, Riutta & Vuorinen, 2020). The book enables students to learn the basics of wood-based materials and working methods according to their own rhythm, even outside the courses. This provides a space for new innovative approaches and leaves time for in-depth discussions during the contact teaching.

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1.3. The hands-on approach to Wood-based Materials

Pirjo Kääriäinen, Sara Lucía Rueda Mejía, Tarja-Kaarina Laamanen

Introduction

The main idea behind the courses for Wood-based Materials is to inspire students from different disciplines to gain knowledge of materials and their origins, to work together over disciplines to learn from each other, to experience hands-on material research and to find new ways to communicate in the intersections between design and science. This chapter describes the practice-based learning process of Wood-based Materials and discusses the meanings of the experimental hands-on working with the materials.

The learning processes

In the case of wood-based EM&Ts, a hands-on approach means practice-based and iterative material experimentations combined with theoretical studies and personal reflection throughout the process. The whole learning process is supported by experts and tutors with a versatile background in design, engineering or material science. Depending of the course, students work in teams or individually, and share their ideas and results with peer students and tutors regularly. The learning process can be divided in three main steps.

The first step in the process of building an understanding of wood-based materials is to interact with materials and recognize the different features through personal observations. Parallel to material experiments, students attend to lectures and familiarize with relevant literature. At this stage, students do not aim directly for any specific applications: the main focus is on ***finding opportunities through playing, experimenting and observing*** the material's behaviour and its properties. This allows free ideation and even 'greasy' experiments. It also provides ***space for failures and unexpected findings*** during the process.

When technical and tacit knowledge increases, students ***narrow down their ideas and move towards a more systematic phase***. They define their specific focus area and targets and create their own design concept and research plan for further experiments. The supervisors provide background information on the materials and related material research projects, tutor the workflow, and support the design process (Kääriäinen & Tervinen, 2017).

The last part – intertwined with the continuous exploration process – is about applying. Based on their findings and interaction with tutors and peers, students ***create prototypes and prepare to communicate their processes and results*** in a final presentation and/or learning diary and exhibitions. Developments to enhance physical material characteristics such as strength or stability, or to test production processes like moulding, are undertaken in tandem with the exploration of some of the perceptual material characteristics such as feel and texture.

Fig. 1 - Working hands-on with materials. Photo Eeva Suorlahti, Aalto University

Meaning of the hands-on approach

The experimental and hands-on approach has specific advantages. Action or material change serves as a mediator for thinking – acting as steppingstones for thoughts to evolve (Kirsch, 2010). Externalization is a way of making sense of one's own thoughts as well as sharing a common focus with others (Kirsch, 2010). Material constructions assist verbal communication towards a shared understanding (Garner & Evans, 2015). Thus, hands-on work is both social and individual by nature and involves materialized meanings that are shared ideas, beliefs, knowledge, emotions, and even cultural associations (Moran & John-Steiner, 2003).

Touching and giving shape to materials with one's hands is one of the common ways of understanding and making sense of the world we live in. ***In addition to gaining individual and shared understanding of tangible materials, their properties and their feel, the hands-on approach enhances human experiences***. Researcher Camilla Groth describes the act of making something with one's hands in a material as a way of participating in the world, as an interaction and negotiation between the person and her environment. The manipulation of materials is a means to affect and experience the world. 'What we make either stays or vanishes, but the experience has changed us, maybe in little ways, maybe in great ways.' Hands are a contact point between humans and the surroundings, bridging the physical and material worlds. 'Through our sense of touch, we feel the material and its properties, its potential and its agency' (Groth, 2017).

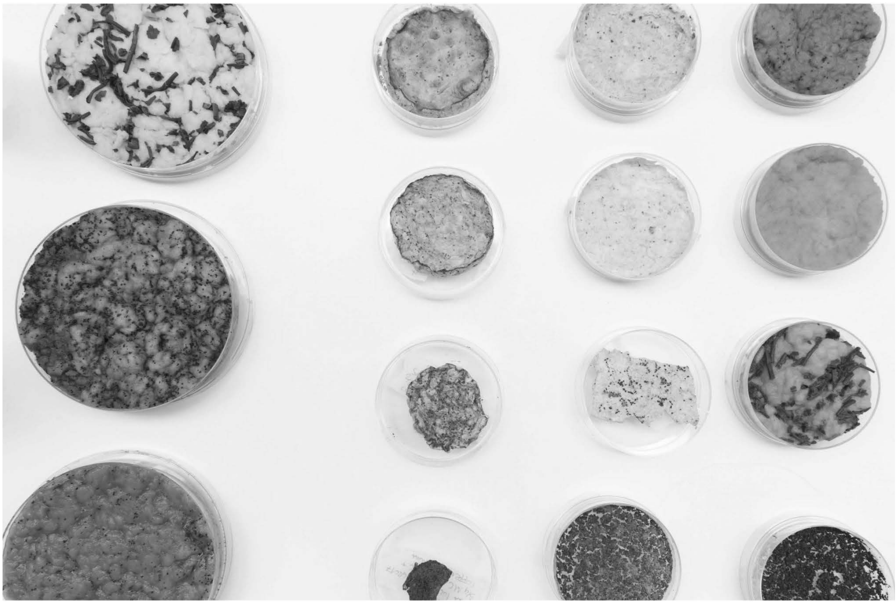

Fig. 2 - Material experiments by Sara Lucía Rueda Mejía 2017. Photo Eeva Suorlahti, Aalto University

Furthermore, the constant manipulation of bio-based materials with our hands can also become ***a bridge between a human and nature***. The industrial era with its complicated production processes and global commerce systems, together with ongoing urbanization has created a huge gap between humans and materials. Engaging in hands-on working is a counterbalance for screen-based activity, providing authentic sensory experiences and a tangible connection to the real world (Blakey, 2015). In her master's thesis, former CHEMARTS student Sara Lucía Rueda Mejía sees biomaterials as a medium that connects the human body and nature. She describes her experiences of the CHEMARTS courses accordingly: 'Some key insights I obtained while manipulating biomaterials were the enhanced sense of touch, the type of emotions that arise while working with biomaterials, and the increasing sense of closeness and oneness with nature'. The more she experimented with materials, the more her perception of materials widened, and the closer she got to nature. For example, while working with berries and extracting their colour, the link between the original sources of inks and nature was enhanced. 'The more I interacted with berries to get their colours, and with wood celluloses to give cohesion to structures, the more I understood materials as being more than individual sources. An invisible relation between materials, nature and me began to form' (Rueda Mejía, 2019).

Going deeper, another explored meaning in the student's projects while sensing materials with the hands is the meaning of ***material interactions for wellbeing and professional development***. Interacting and working hands-on with materials, in particular biomaterials, allow students to experience different types of emotions such as joy or calmness. When students play with the materials in order to find the appropriate mixture to build the desired properties and outcome, they often feel joy and the excitement of new findings and conducting successful experiments. Based on her own and her classmates' experiences, Sara Lucía Rueda Mejía explains how handling bio-based materials, for example natural inks and wood celluloses, helps to understand the versatility of these materials. When playing with these versatile materials, students felt the possibility to embrace emotions, like curiosity and joy, and got the opportunity to use their imagination. According to Sara Lucía Rueda Mejía these emotions arouse mainly during the tactile exploration of bio-based materials, which opens a space for students' expression and enhances their creative skills by giving freedom to their imagination and fantasy (Rueda Mejía, 2019). The meaning of these aspects should not be underestimated in our hectic world in which climate change and other problems burden our minds, and ***increased digitalization impoverishes our sensory experiences***. This aspect has also been highlighted by Hartikainen, Pajunen and Silvennoinen from Sitra: 'As our understanding of human wellbeing grows, we uncover new advantages of biomaterials such as health benefits. On a rapidly urbanizing planet with people becoming unhealthier in densely packed cities made of concrete and asphalt, a future society built on organic materials is a vision truly worth striving towards' (Kääriäinen & Tervinen, 2017).

Fig. 3 - Experiencing nature through all the senses. Photo Maija Järviniemi, Aalto University

Conclusions

In addition to learning about Wood-based Materials and material interactions, students learn skills they can use in their future careers, regardless of the field in which they work. For example, they learn not only problem solving but also problem framing, as they need to define their own projects. They also learn to ***endure uncertainty***. When students learn to find their own ways of managing an open problem, they also learn to become independent in their learning (Winters, 2011; Sawyer, 2018). This is an essential skill from the working life perspective that has moved beyond traditional industry practice.

Through their experiments with challenging materials and interaction with people with different mind-set, students also learn creativity, persistence and resilience. They learn to analyse and accept failures, and to ***use their creativity to find new opportunities and solutions***. Experimenting often leads to unexpected results or dead ends, which call for further reflection and articulation. When these processes are properly facilitated, they advance students' abilities to think about their creativity (Schön, 1987; Sawyer, 2018). In addition, doing something new and unfamiliar may prevent the creation of the most obvious ideas (Ramdyny-Ellis et al., 2010;

Kosonen & Mäkelä, 2012). Thus, an explorative orientation, which includes reflecting on and articulating the emerging embedded knowledge, helps students in acquire better integrated academic skills and understand how to sustain creativity in their future practices (see also Winters, 2011).

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1.4. From ideas to innovations: sharing and scaling up

Pirjo Kääriäinen, Jari Laine, Sara Lucía Rueda Mejía

Introduction

When it comes to the design process it is important to recognize that ***ideas or inventions are not yet innovations***. The idea is often the first step, and the invention is usually described as a new concept, method, process, product, etc. resulting from research, but not yet applied. Innovation means that the idea is turned into realization, it is an invention that has already been applied. An invention becomes an innovation just after the first attempt to carry it out in practice, i.e. implementation of the new idea (Fagerberg et al., 2005).

Consequently, experimental courses and workshops focusing on Wood-based Materials can be seen merely as pre-innovation activities, generating ideas and setting the ground for further research. The lack of industry collaboration can be seen as a gap; on the other hand, it has enabled completely free experimentation phase. However, in the future it is important to create pathways for taking the best ideas towards real-life applications. This chapter ends with a case study of a recently established start-up with focus on bio-based materials.

Fig. 1 - Biodegradable dish from willow bark fibres by Eveliina Juuri, Sanna-Liisa Järvelä & Jinze Dou CHEMARTS 2017. Photo Eeva Suorlahti, Aalto University

The complex path from ideas to innovations

The ongoing development of scientific and technical innovations in the field of wood-based materials (for example micro- and nanostructured cellulose) are opening up pathways for totally new applications for bio-based materials. However, the path from the idea – or even from the first prototype – to real applications is long and complicated. Typically, the ***development of new material takes 5-15 years*** and proceeds from laboratories to proof of concept and piloting stage before possible upscaling. It requires not only scientific material research and manufacturing process development (and funding for those) but also user and market understanding parallel to business development. To facilitate innovation and commercialization processes, broad collaboration and multifaceted expertise are needed in different phases of the process. Design (and designers) can have an important role in these processes: strategic design, co-creation and design methods and tools could be valuable assets in this context. For example, based on the findings from the DWoC research project, design (and designers) can play three main roles in material research. Firstly, designers can provide new approaches or directions for technology development; secondly, they can enhance and speed up material development through iterative hands-on prototyping and find user-centred ideas for material applications; and finally, design provides good tools for co-creation, knowledge sharing and communication (Kataja & Kääriäinen, 2018).

Each discipline has its own research traditions and ways of working and documenting process and results. In the case of innovations and commercialization processes in an interdisciplinary material research context, systematic process documentation is also crucial for designers. IPR (Intellectual property rights) must be discussed and agreed within teams as early as possible, and all team members should be included. As the world is full of ideas and experiments, it is very important to find out what has already been done and what kind of aspects need to be considered if aiming to scale up an idea. For example, if the idea relates to nutrition or medicine, there are very specific regulations for commercialization. In many cases the best way to make an impact is through sharing the ideas in the spirit of open innovation (Chesbrough et al., 2006), especially if there is no specific interest to take the idea forward – perhaps somebody else can develop it further. Universities and research institutes have usually established systems to evaluate ideas and inventions, and to provide advice if they have the potential to be scaled up and commercialized.

Entrepreneurial approach to experimental Wood-based materials

One of the key questions is how to educate future professionals with a vision, proper skills and braveness to act. The main challenge of experimental Wood-based Materials courses and workshops is to find proper ways to include entrepreneurial thinking and business aspects without restricting the experimentation process too early. These issues have not been included in CHEMARTS courses so far; the focus has been on the students' learning process and collaboration skills. The outcome has mainly consisted of very early-stage material samples, and even the best ideas have remained on pre-innovation level. To open up the potential and possible role of experimental Wood-based Materials courses, we interviewed the owner of Havu Cosmetics, a recently established start-up.

Fig. 2 - Natural cosmetics with biodegradable packaging, Lumi Maunuvaara 2017. Photo Kaisa Syrjänen, Havu Cosmetics

Case example: Havu Cosmetics

Havu Cosmetics is a start-up company located in Helsinki, Finland, co-founded by CHEMARTS Summer School alumnus Lumi Maunuvaara. She was interviewed in March 2020 to share her experiences as a student who became an entrepreneur.

Back in 2017, Lumi Maunuvaara was a first-year bachelor's student at the School of Chemical Engineering at the Aalto University. She decided to join the CHEMARTS Summer School because she found the teachers inspiring and was driven by the opportunity to combine two of her interests: chemistry and creativity. When asked of her motivation, she explains: 'The course was a great platform to study materials, to get into the materials, to make some benchmarks, and to learn about cosmetics. Since the course was mostly about experimenting, there was no barrier to trying something completely new'.

Lumi Maunuvaaras's main focus during the CHEMARTS Summer School was on designing wooden packaging for cosmetics. After three months of experiments, the first prototypes were presented publicly at the Habitare fair in Helsinki in 2017. The feedback was positive. Soon after the fair, one of her peer students from chemical engineering, Tatu Fontell, suggested collaboration. As Lumi had always dreamed of being able to combine design and chemistry, and Tatu had always dreamed of a company of his own, they agreed to start a joint company. 'It was a spontaneous thing to do with another 19-year-old guy. We were kind of crazy. It was only later, when we began the process of building the company, that we truly felt the pressure of all the steps that had to be taken getting all the files ready, creating a strategy, and so on'. Eventually, the company was founded in October 2017.

When asked about the role of the University, Lumi Maunuvaara says that her process was merely an independent one. However, she did receive some support: she received extra credits in another study course for setting up the company, and Aalto staff shared some contacts in the areas of chemistry and business. She continues: 'Support from the school wasn't necessary; if you start a company you can't rely on anything, you need to do it yourself, you learn by doing and not by overthinking. Support is available when necessary. However, I got a lot of ideas during the CHEMARTS course. For me, it was perfect'. The 2017 Summer School included one lecture on bio-based business, given by a senior business advisor and investor. Based on the course feedback, the lecture was inspiring and useful to enhance the students' entrepreneurial thinking, not only for Lumi Maunuvaara but also other students.

When asked about the challenges in the process of establishing a start-up in this field, the young entrepreneur mentioned a heavy workload in general. It is demanding to develop the final product, to find the right manufacturers and to raise funding at the same time – and to make the wrong choices. In the end, Lumi Maunuvaara states that 'It's all about doing and working'. However, she also described some things easy and inspiring. 'When you do something on your own, your heart is beating fast, and everything is simple at the end of the day – and you've accomplished something cool… It's nice to see something that you've done on your own'. She also said that collaboration with her partner has been smooth, and they complement each other. They both major in chemical engineering, and Tatu has business studies and Lumi design studies as their minor subject.

At the moment, Havu Cosmetics sells beauty products such as masks and lipsticks. All the products are based on natural plant oils and waxes, and the packaging is mainly made of wood. At the beginning, they used also plastics and metal parts, but now they produce 100% biodegradable products using certified biodegradable and bio-based PLA (polylactic acid) and wood (black alder & aspen). 'I wanted the cosmetics to look like wood. Our formula only has natural waxes and oils'. The products are sold online and at the Aalto University Shop. Havu Cosmetics is still in its start-up phase but is growing in addition to the co-founders, the company has two marketing employees and a cosmetics chemist senior advisor (2020). It also has a board, of which three people are investors and advisors, and had just received a private investment worth €110K. They have also built collaboration with a venture course at the Aalto University. At the end of the interview, Lumi Maunuvaara concluded: 'I am still very motivated to continue with this company'.

Conclusions

The courses for experimental Wood-based Materials are focusing on pre-innovation activities and aiming to inspire not only the students and faculty but also broader audience. Thus, sharing of processes and results openly has been one of the key elements of these activities (Kääriäinen et al., 2020). In the future, the most promising ideas generated and tested by the students could be further developed towards innovations, either into advanced research projects, or together with selected partner companies. The story of Havu Cosmetics is only an individual case, but it reflects the role and meaning of the experimental courses and workshops focusing on Wood-based Materials. Consequently, it is important to keep the explorative and spontaneous approach that is identified as strength of the study courses. One option is to dedicate some of the courses or workshops for closer collaboration with a certain company. This will require setting up clear roles and responsibilities and defining guidelines for IPR.

After all, a good method for creating an entrepreneurial mindset for the emerging field of Wood-based Materials is to provide understanding of the mechanisms of this specific field, and to encourage students to learn to trust in their own decision-making processes while offering support and guidance when required.

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2. Nanomaterials

2.1. Carbon-based & Nanomaterials and its relevance to Design Practice

Paz Morer, Aitor Cazón, María Isabel Fernández, Robert Thomson

Introduction

Nanomaterials is the sector of materials research and applications industry involving materials at nanoscopic scale and is no small matter. As one of the emerging materials, it has captured broad interest in the science community for decades. In 2005, the European Centre for the Development of Vocational Training (Cedefop, 2005) in a report entitled "Identification of skill needs in nanotechnology" said that nanotechnology was set to play a key role worldwide in the 21st century since it was a cross-sector technology which was increasingly relevant to economic areas such as chemistry, medical technology, automobile and the food industry. Before going deeper about educational methods for this type of EM&T, this chapter will cover the main benefits and applications that nanomaterials have nowadays and will also present the existing barriers to reap the benefits of its use.

Benefits of nanomaterials

Nano means essentially all material whose arrangement expresses at least one dimension in the range of 1 to 100 nanometres (European Comission, 2011). Proportionality of nano structures then dictates the various arrangements of the material in its form, for instance a nano particle, or fibre verses a nano crystal. This arena of research and design creativity has opened up dimensions upon which the production of material patterns can be exploited to produce an "effect" or property, which is relatively stable over time, can be reproduced precisely through available industrial processes at an affordable expense, be it economical or biological in nature. The advent of nano has also blurred the boundaries between the hard logic of classical sciences and the creative affluence of the arts and design thus catapulting forward the potential for innovation in ways which could not have been foreseen, and opening doorways into new fields of industry in lifestyle, communication, space travel and the environment to say a few. The versatility and variety of engineered nanomaterials (ENMs) thus naturally awaken tremendous interest and inspire practical applications of all types moving nano into the fuzzy-front-end of the design and planning process (Bandala & Berli, 2019; Halada & Orlov, 2018). Nano technologies dissolve the clear-cut boundaries between materials and their native differences and throw into the mix opportunities for blended identities, a sort of cross dressing between material families and the synthesis of design practices into the realms of pure information. Material identities can morph to fit the new pressures of materials selection, designed upon demand, engineered into systems rather than selected by them.

The use, development and testing of nanomaterials in a market environment resets the expectations of consumers with respect to what is considered now desirable, possible, or even taboo. On the one hand, it opens up a landscape for new approaches and refinements in creative methodologies and industrial practices. On the other, it promotes the development of totally new economies, lifestyles, methods of communicating and in some cases new biological lifeforms (Saphira & Youtie, 2015; Crawford, 2016). The newfound options for material upgrades simply democratise the processes of materials selection, migrating away from the approach of search-and-match to fit requirements within a window of fixed sets of material classes and their rankings. Instead it proports a future of materiality tending towards the customization of features; a bottom-up approach in which materials become the means for embodying the very innovative aspects of the products they form. Scientifically born materials can shatter our preconceived notions regarding our ontological associations to material heritages. In a world where polymers can be made to be a strong as metals but lighter and parts can be grown directly in moulds using bacterial clusters, one is compelled let go of their material prejudice and instead embrace the newly found alternative raided by possibilities.

The simple advantage of upgradability has the effect of relaxing the tension between competing material sectors, granting the lesser performing materials a chance to compete within a traditionally terse and demanding market. It becomes self-evident that, when even the simplest of conventional materials has the potential be elevated beyond its associated value to embody and perform in high tech applications by virtue of its own individual merits rather than its historical legacy, we too will have transcended our own attitudes towards what we consider as a "fixed material quality", the meaning of luxury, or disposable or intelligent. Perhaps it is in this sense that nanotech leaves its deepest yet subtle imprint; on the dismantling of material stereotypes and invitation towards an a-la-carte approach where materiality is a consequence of design requirements and planning and not vice versa.

Nanomaterials touch every single aspect of economies in potentially beneficial ways. Not only can they provide a means for materials to outperform, but also to extend that performance over longer spans of time to provide a higher service, dependability, savings, and sustainability. For instance, a nano-reinforced material might perform to the point of infinite life cycle expectancy or even offset eventual performance losses accumulated through numerous recycling efforts (Fenner & Daniel, 2014). When we make something better performing, the user is merely and only the primary beneficiary. Things which break less need less replacing and fixing as there is more margin for the inclusion of safety factors which traditionally are omitted to over costing constraints. Higher quality also infers longer lasting finishes, tighter tolerancing and lesser malfunctioning. These advantages allow brands to produce all around better products which can justify premiums at a fraction of the cost. Materials become amortized by the invested research and technologies verses the physicality of the resource itself.

Nano coatings can minimize the need for the labour some and highly contaminating task of cleaning and disinfecting household objects, public spaces and hospital environments or reduce the cost of infectious outbursts worldwide via intelligent use of antimicrobial/bacterial/fungal nano-coatings (Deshmukh et al., 2019). Specialized mineral ceramic compounds can provide means for fireproofing building materials while offering photo-catalysing pigments for cleaner air in interiors. Along similar lines, intelligent materials possess the ability to monitor their individual and shared status or the health of their environments and users. They can perform self-diagnostic operations and provide live feed integration with surrounding network systems regarding safety parameters or material identification, useful for effective materials recovery and recycling protocols. By embedding intelligence, one can improve material-environment incompatibilities, for instance reducing chemical reactivity, or even take advantage of complexity to regulate the rate of drug release into and from a substrate using complex chemical pathways.

Material systems can be customized interstitially, with property gradients via intelligent chemistry allowing to mitigate object-environment relationships and focus them towards adopting synergies rather than resistances. Controlling smaller scales of biology is also a field of research. Here, materials are grown, assembled, and shaped into non-random molecular structures. The variety here too may range drastically. Particles can be deposited epitaxially into layers or chemically interconnected as a web of bound matrices. Alternatively, compounds can take the form of molecular chains combining into nano-fibrils which reinforce substrates or act as fillers to provide hyper uniform, porosity free surfaces. Fibres may also aggregate into non-woven textiles to prevent water vapour permeation or offer sub-micron filtering and thermal insulation.

One can immediately see how rapidly the options queue into creative landscapes limited mostly by our ideas. Materials evolve towards higher functions and perhaps, on a more ontological level, in-line with expressions of meta conscious behaviour. The logic behind a scaled-based advantage resides in that if material property arises and differentiates in proportion to the degree, shape and complexity of its interconnected pattern, then really small materials can bear more information by virtue of their scalar advantage alone. Distended over larger spans yet, the nano-scalar advantage accumulates, grows in accuracy, efficiency while remaining substantially hidden, unperceived by our senses. In other words, unless one is aware of its presence, nanomaterials behave in totally unintuitive and magical ways. It is logical to see why then they present themselves as solutions to otherwise cumbersome and conflicting problems, attracting much attention in all fields of potential application.

Some nanomaterials applications

Material manipulation at the nanoscale finds its way towards applications in engineering, industrial fabrication and across diverse fields of design, birthing in its wake a new form of functional design opportunity, at a much smaller scale. Materials under this scalar domain behave differently. They can encapsulate layers of invested functional intelligence within, thus when applied onto otherwise inert materials they can endow them with extra functionality, desirable properties like environmental resistances or alter their aesthetic qualities. Nanomaterials have gathered much interest and support because of the versatility and compactness of their applications. At times, they may provide the means to streamline a number of complex functions which would otherwise require costly multi-tiered industrial processes into simpler, integrated ones. At others, they may provide dopant structures to drastically alter sub-performing material behaviours, bringing them up to speed with design requirements and specifications. This is the domain in which transformative chemistry and integrated industrial techniques take the front row seats and set the stage for future material expressions having quasi alchemical traits.

Examples in the real world today in fact range broadly often in subtle ways unbeknownst to the observer. Nano worlds seep into all domains of physicality, from particle-sized additives which enhance electrical conductivity in fabrics to 3D printed polymer scaffolding structures, for stem cell culturing (Akbarpour et al., 2019). Nano can both breach and/or bridge the senses with encapsulations of nano fragrance impregnated printable pigments or even grant us the illusion of colour via light refraction of structured colour particles. Nano compounds can alter the surface chemistry of a hydrophilic substrate whereby polarizing and complicating surfaces with intricate topographies and transform it into an ultra-hydrophobic layer (Zakerzadeh et al., 2019). In a similar way, materials used in medical applications can provide a seamless symbiosis with bodily organs as they are functionalized with aminoacidic coatings capable of rejection free bonding.

Simultaneously, another clear and present advantage of nanomaterials, beyond their size is the fact that a plethora of methods exist for its application. In some cases, surface-based nano layering can be applied as a paint (sol-gel technique), by brushing it directly onto a substrate. In other cases, nano fragments can combine autonomously into self-assembling crystals structures by chemical manipulations of charge. Nano materials can be an agglutinant, an additive, a reinforcement for composites, a surface finish, or a molecular sized chemical robot actionable by fluctuations in electro-magnetic fields. Building on the variety of molecular recipes and their properties are the numerous and ever-growing industrial techniques for effective applications onto or within host materials. Some may include a super fine deposition of chemical vapours, or water-born infiltrations. The combinatorial potential which arises from the variety of chemical elements, their structural design and the methods in which distinct industrial techniques apply them both individually and as an ensemble begins to boggle the minds' capacity to focus, take decisions and tame the sense which arises from unbridled possibility, becoming inherently overwhelming.

Green chemistry proports alternative manufacturing techniques involving the manipulation of biologically derived compounds, both bacterial or plant based, using enzymes as catalyst enablers for material synthesis at lower temperatures (room temperature in some cases). Its contributions lie in the lowered toxicity of chemicals and pre-emptive approach towards recyclability of nature based on the “material is food” point of view. More efficient efforts are systems invested not only in the materials but the pre-cycling of the manufacturing processes and solvents which produce them. Green chemistry is biochemically based nano manufacturing leveraging and emulating the self-assembling systems of nature be this by chemical pathways or growing biological matter. Ultimately, its focus is to deliver no-harm materials which not only provide adequate substitutes to the plethora of existing synthetically derived materials, may provide food and nutrients to the systems which degrade them.

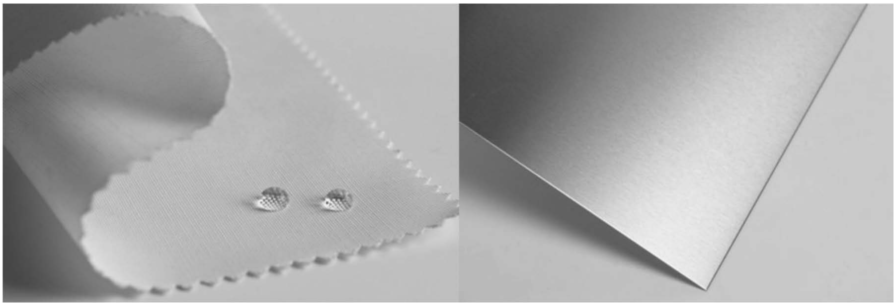

Fig. 1 - Self-cleaning tissue treatment (left) and Nanoscale anti-fingerprint coating for stainless steels (right). Courtesy of Materfad

Surface applications of nanotechnologies include surface chemistry alterations via high definition industrial processes (i.e. Chemical vapour depositions) or applications of surface finishes (ultra-hydrophobic waxes, silica-based enamels) the one providing a complete barrier to the passage of water vapour, the other providing scratch resistance) (Figure 1). Other examples may include nano reinforcements, usually nano fibres, crystals, and fillers. Examples include graphene-polymer composites, which display both high elastic modulus and electrical conductivity due to the inclusion graphene nano fibres. In medical applications, nanomaterials may allow self-healing ceramics to bond with bodily protein for seamless, low rejection bodily assimilation of a prosthetic component.

Barriers to spread the use of nanomaterials

However, materiality at this scale concurrently promotes a series of difficult challenges, which are to be addressed and solved if we are to reap the benefits of its use, favourably in time.

One lies in the inherent difficulties and intricacies of its manufacturing, which has been, and still is to this day, reliant on lengthy development and costly investments in effective physical processing techniques. It is ironic that such large machinery is required to have a productive control and monitoring over such minute assemblies and molecular compositions and that such stringent controls must be satisfied over time for adequate and scalable production. Concurrently, as the threshold of material size decreases and possibilities are explored, the more probable and threatening become their autonomous and random interactions with surrounding chemicals, bacterial life, cellular clusters, and ecosystems. Some compounds indeed may be easily absorbed into cell walls, interact, substitute, and interfere with endogenous biochemical pathways. Nano thus presents an over looming and imposing health threat factor towards organisms. For this reason, despite the impetus and phenomenal potential, nanotechnology is still met with contrasting public opinion. Beyond laboratory-based advancements and speculation, nanotechnology is found to be fundamentally lacking in historical perspectives, a solid logistical infrastructure, and educational co-adjuvants, for establishing a well-rounded and tested maturity. Even within educational institutions, advancements in nanomaterials are quarantined from public disclosure by the hyper specialized proprietary patent pending technologies which produce them. Therefore, knowledge is scarce, thwarted by the few adequately trained personnel across the many fields of industrial application. Fragmentation breeds inefficiencies and the inability to access unilateral agreement. Consequently, most nanotechnology research, fabrication and exploitation remain polarized and circumscribed within a small niche of industrial producers, uncommunicated and unbeknownst to key industry influencers, such as designers, final users like you and me. A growing opportunity gap between education, creative industry and economies awaits.

Yet another barrier is rooted in the perceptual discontinuity which nanomaterials cast. The very minute nature of nanomaterials indeed conceals the way they work as well as the logic and standards by which they should be measured and selected. In fact, to a large degree, their properties remain rather mysterious to most users. Most adopters are fundamentally ignorant about basic information regarding both the opportunistic advantages and underlying perils of this field. Often, a great deal of specific knowledge in physics and chemistry is needed to fully grasp the underlying factors behind the structural and chemical behaviours of the material, let alone the capacity to predict its future impacts upon ecosystems. Contrary to the more traditional bulk materials, nano families have not benefited from general diffusion in traditional educational curriculums. To fully unlock the gradient of realistic opportunities and threats across all benefiting disciplines, a proper method for educationally specific transmission is necessary. This ultimately boils down to the adoption of a proper language which may enable different fields of creativity and analytical resolution to act, collaborate, specify, understand, and plan. Working under the auspices of incomplete information and guess work is likely to yield short term, low resolution, stop gap solutions while, in the long run, may divert compounding problems further down the timeline. The alternative is a slower growth rate with more emphasis on education and responsible approaches whereas to integrate and allow informed planning strategies more in line with preventive design practices and sustainability. Certainly, unregulated adoption is easy and quick to blur the line between useful tool and recipe for disaster.

Ahead of us further lies the need and opportunity for developing the infrastructures and safety protocols for the integration of nanomaterials into circular economies. On the one hand, this could inspire new economies dedicated towards reverse logistics of nano materials through their identification, classification, recovery, recycling and/or reuse (Austrian Society for Environment and Technology, 2020). On the other is the category of biologically degradable nano nutrients with programmable lifecycles. Partially responsible for this is very nature of their scale which is unperceived to humans. It is improbable to know by visual tactile textural or auditive inspection if a material has been nanotechnologically enhanced. This aspect is at least in part responsible for the attitudes we have and will have in the future regarding our decisions about their responsible use. In fact, nanomaterials often display effects which are difficult for users to understand. Nanomaterials often act autonomously without revealing the mechanisms through which they operate. They simply perform functions often not associated with the host material thus endowing them with contrasting, new abilities, in other words they can alter our standard associations to the material they inhabit. As counterintuitive properties are granted to materials which are well known to not possess, our abilities to evaluate them and thus make selections decreases. This by effect causes a sort of cognitive dissonance and casts doubt upon what could verse should be done. The combination of its undetectable nanometric scale in conjunction with the non-intuitive emerging properties it grants, obscures the insights necessary for proper and responsible adoption of responsible and effective adoptions in creativity and innovation.

Conclusions

The perception and identification of materials and its associated characteristics are fundamental tools for navigating for cognitive connection between a user and the object being used. Nanomaterials grant us added dimensions of association with objects without being fully understood, an element of ignorance which may cast us into danger. With the advent of the nano opportunity a paralleling concerted effort is being made to insert design principles into the mix. Prevention through Design principles are practices which breed discussions regarding sustainability, material health, and alternative forms of manufacturing the things which make other things, for instance green chemistry which ultimately relate to nanotechnology or bio-manufacturing. Prevention through Design is a set of principles that includes solutions to design out potential hazards in nanomanufacturing including the design of nanomaterials, and strategies to eliminate exposures and minimize risks that may be related to the manufacturing processes and equipment at various stages of the lifecycle of an engineered nanomaterial.

The interest is nowadays trying to be transferred to industries so they can apply these nanomaterials in new industrial products with improved properties (anti-graffiti, anti-corrosion, fire-resistant, anti-fungal, anti-friction, anti-grease and oils, anti-bacterial, self-cleaning, dry lubricants, self-releasing, polishing, photocatalytic applications, etc.). In the development of a new industrial product that emphasizes innovation, developers shall possess experience in a variety of fields like product life-cycle management, materials knowledge, manufacturing processes and economies of scale as well as the ecological and sensory domains of material experience, etc. The role of designers as developers of new products should be to explore the context in which these emerging materials might be used, that is, they should be the catalyst that translate the nanomaterials' theory into real-world application incorporated within products. Although this transfer is happening with more or less success to real applications, the disruptive potential for unusual or novel applications drive designers and companies alike to seek and implement breakthrough innovations in products. Among other factors, the origin of this fear is the lack of an appropriate strategy that shows HOW TO transfer this nanomaterial knowledge from theory to practice. In other words, industry demands a growing need for experts (designers) that can bridge the gap between theoretical knowledge and practical applications for nanomaterials in order to develop new products, services and experiences. Cedefop reports was in the same line and asked for new demands for qualification in nanotechnology and the need to improve training and higher education, since the lack of qualified personnel lead become an obstacle in the development and the application of nanotechnologies.

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2.2. The selection of Didactic Methods in Design Process

Paz Morer, Aitor Cazón, María Isabel Fernández, Robert Thomson

Introduction

Despite an increasing spectrum of applications with nanomaterials, it is necessary to have a big picture about how these nanomaterials are actually learnt by future designers. Indeed, as future developers of products, designers need to be at the front end of knowledge about nanomaterials if they want to look for disruptive applications or products. The next sections will present a brief review of the literature related to didactic methods developed around these materials. Moreover, it also covers how to transmit that knowledge to more practical levels, considering not only those methods developed for nanomaterials but also other didactic methods used in the transmission of knowledge about new or smart materials.

How are students learning about nanonametrials?

Few references were found from previous research experiences about didactic methods for the training of students about nanomaterials. Sebastian and Jimenez (2016) in their article "Teaching nanoscience and thinking nano at the macroscale" said that one of the major challenges for nanotechnology is education. To overcome this issue, they said that cutting-edge documentaries via YouTube make the learning and comprehension of concepts related to Nanotechnology faster and more efficient. In a similar manner, De la Rosa (2007) presented a learning experience in nanoelectronics based on free e-courses and some of them specifically for carbon nanotubes. His conclusions pointed out that e-courses contributed to a more in-depth teaching and learning methodology. Ferrara and Lucibello (2012) from Polytechnic de Milano proposed a detailed methodology to teach material design to students. Although traditional lectures are important, they put especial emphasis in the practical experimentation (Ferrara et al., 2015), where students can observe, analyse and understand the material with the goal of carrying out several workshops so students can "bring out the characteristics of materials and experiment with new expressive languages, assessing the potential in the usability of the products". In Tecnológico de Monterrey, Tamez and VegaCantú (2019) used a hybrid approach to teach applications of nanotechnology through product development. They are not using nanomaterials materials but biomaterial, but the approach they follow must be considered. Students create new products, applying knowledge about nanostructured materials properties and methods of production that were learnt during the format of 16 lecture sessions and 6 laboratory practices. In this sense, they remark the importance of instructor's expertise and guidance were critical to encourage students to analyse the properties and advantages of nanomaterials and to use them to generate a new product. So, instructors should be experts or received in depth training before the course.

The seed for learning methods about nanomaterials

Past experiences about teaching nanomaterials were the base for several projects that wanted to establish more formal methodologies to learn skills about nanomaterials. Two projects are going to me mentioned. The first project is named IRRESISTIBLE (FP-7 project number 612367). It is a project on teaching, training and combining formal and informal learning focused on Responsible Research and Innovation. It is a coordination and support action under FP7-SCIENCE-IN-SOCIETY-2013-1, ACTIVITY 5.2.2. Young people and science: Topic SiS.2013.2.2.1-1 raising youth awareness to Responsible Research and Innovation through Inquiry Based Science Education. Five of the ten training modules developed in this project are focused on nanomaterials.

The didactic materials developed in the framework of this project are free shared through their webpage[2]. Concerning the results achieved by this project, a relevant conclusion was that the training activities in which students took part actively, like observation or experimentation, and that exemplified the manner in which these materials can be valorised in their everyday life increased students' interest for learning in this subject and represent a fundament for sustainable education. The second project is NANOLAB[3]. It is an open project by FIM Department of Modena and Reggio E. University in Italy, which aims at including nano-inspired hands-on activities in high schools. It consists of simple, cheap, robust, and safe experimental protocols, currently covering four areas of nanoscience: smart metals, nanoparticles, conductive polymers, nanostructured surfaces, each linked to one of Nanoscience "big ideas". The experimental activities range from manual to digital data collection and elaboration. A very innovative point of this project is the idea of including the use of pupils' own mobile devices (cell and smart phones, tablets) which turn out to be powerful, low-cost, sensitive multi-purpose lab tools, with an added

2. http://www.irresistible-project.eu/index.php/en/resources/teaching-modules.
3. http://www.nanolab.unimore.it/it/formazione-e-kit/il-kit-formativo.

impact on students' motivation and active involvement in what they call a high-tech hands-on approach. All materials generated in this project are published under Creative Commons license but most of them are written in Italian (Lisotti et al., 2014).

Conclusions

After analysing the most important references in the literature, all instructors agree that the area of nanomaterials is hard to be understood by the students mainly due to the fact that nanoparticles cannot be seen without high-cost special optical devices, which are unaffordable for students in many educational institutions. Most of them remarks that traditional lectures in classrooms are still necessary, for some aspects, but new approaches are necessary (Figure 1).

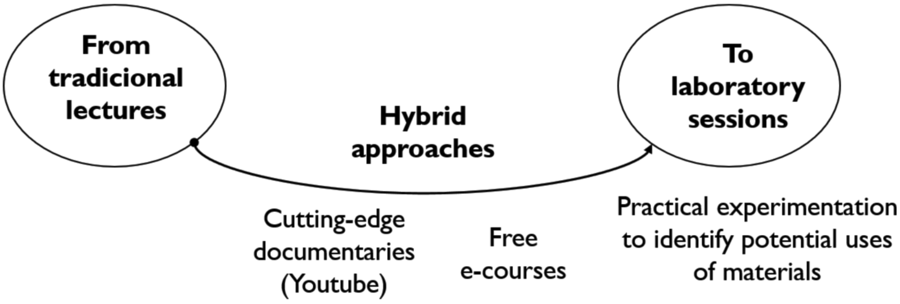

Fig. 1 - Approaches to learn about nanomaterials

Due to the nanoscale nature of nanomaterials, it seems that when dealing with how to transfer nanomaterial skills to students, the education approach must range from traditional lectures to laboratory sessions by laboratory sessions where students can learn the material and its application through experimentation. Therefore, when training students through experimental activities in which they took part actively using low-cost tools (such as their mobile phones) oriented to understand the impact that these emerging materials can have for improving their daily life, the researchers achieved memorable experiences that increased students' interest and their understanding on nanomaterials properties and their potential applications.

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2.3. The need for a holistic approach

Paz Morer, Aitor Cazón, María Isabel Fernández, Robert Thomson

Introduction

Although those methodologies presented in the last chapter can be valid and applied for design students, it must not be forgotten the special nature of design students since, when developing a new product, they must consider many different aspects to succeed in the process. Theses aspects cover more formal requirements form the client, like aesthetics and ergonomics, but also more technological points like performance or the manufacturing material of the product. In this chapter, this last topic is discussed.

Where to select materials in a design process?

The designer needs to face a previous step before applying nanomaterial knowledge to real world practices. The question to answer is: how does the material selection need to be carried out? Concerning this, a first interesting insight achieved from the literature review is related to the concept of selection of materials in the design process. Bezooyen in chapter 19 of Karana et al. (2013) raised a new point of view of materials in the double diamond design process (Design Council, 2005)[4] (Figure 3). This author explained that in the traditional design process, material selection took parts in the "develop" stage (the second diamond) where material selection criteria are defined by context of manufacturing and cost to realize an already mature product concept. However, when designers consider materials in the "discover" phase of the design process a new relationship emerge where materials can be used to broaden the idea generation by using a specific material as starting point to explore possible applications. This perspective is also shared by Pedgley in chapter 24 of Karana et al. (2013) that highlights the responsibility of industrial designers to avoid a classic material selection process and open doors to play with unusual and untested emerging materials that might revolutionize a product sector or at least provide new opportunities to differentiate a product from their competitors.

4. https://www.designcouncil.org.uk/news-opinion/double-diamond-15-years.

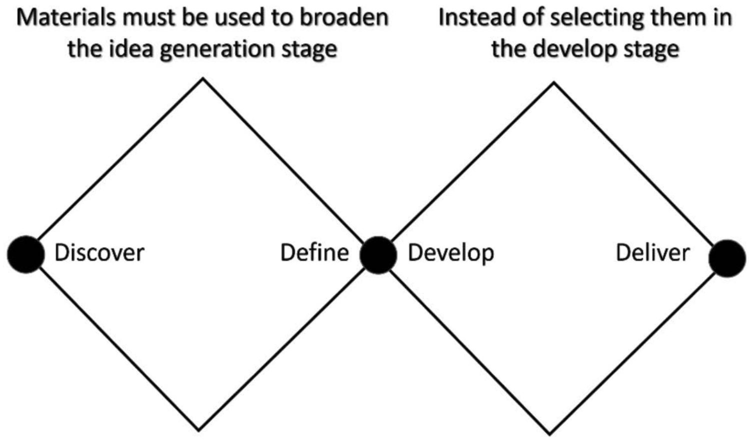

Fig. 1 - Where to select material in a design process? [Adapted from Karana et al. (2013)]

Moving the materials to the fuzzy frontend of design process drives to the need of a change from previous design methodologies, such as sketching or visualizing, to more hands-on exploration and prototyping methods. As noted by Karana et al. (2015), physical encounters with materials can positively influence the creative process. The use of materials then become a driver of the creative "finding" process by evoking ideas and the "discover" stage opens the path to discover opportunities of a given material.

Specifically, in the field of nanomaterials, Piselli et al. (2018a) designed a practical experience for graduate students to combine the traditional theoretical framework of materials selection with industrial case studies application. These authors exploited the potentiality of "materials selection workshops" that last 5-days and were conducted in collaboration with international nanomaterials and product manufacturers. Depending on the profile of the company involved, the workshops followed two typologies:

- Type A. Manufacturing Company: The objective is the redesign of a product, or its components, based on material replacement.
- Type B. Material producer/supplier: In this type of workshop students were called to explore the properties of a specific material and the possible contexts of application.

These authors state that the excellent concepts elaborated by students participating in their workshops testify that their approach help students in producing a "more aware design", which is closer to new industrial challenges and represents a win-win strategy for both university and industry.

How to select materials in a design process?

The criteria that the designer must use for selection of emerging materials is another relevant subject identified in the literature review. Most articles collect more generalist methods to select new materials: some focus on the search in digital databases trying to answer a few important questions, such as: What kind of digital tools exist?, How do they work?, What properties determine the selection? or What kind of information results from the selection? (Ramalhete et al., 2010); while others emphasize the selection of material for its meaning and its relation to design simultaneously with the material characteristics that are related to manufacturing processes (Asbjørn, 2016). However, Veelaert et al. (2016) provides one of the wider visions about this subject because these emerging materials growth makes the selection of a material for a specific application a lengthy and expensive process that combines social, economic, and environmental domains.

Nowadays, from a disciplinary point of view, engineers commonly addressed material selection process analytically, looking for matching between the objectives and constraints related to the product requirements and an existing material and its properties that are found through screening databases available in the market in the form of several software tools. At this point, product designers are disappointed because they do not have equivalent support and tools for selecting materials specially in their materials selection activities at early stages of the design process considering all the product life cycle phases, specifically with a view to environmental impact. Hence, Veelaert et al. (2016) classify the characteristic of materials that can be used as selection criteria in four groups and enforced the idea that different types of information are needed for designers at the different phases of the design process:

- Technical (mechanical, thermal, electronic…).
- Intangible characteristics (product personality, user-interaction, meanings, emotions, appearance, and perceptions through the material of a product).
- Sensorial (feeling, smell, texture, sound, hardness…).
- Product life cycle cost including environmental impact.

From the sensorial point of view, Piselli et al. (2018b) proposed a method based on mapping test for materials selection that allows to choose raw materials and finishes that will provide designers with measurable data to support and explain materials sensorial and intangible decisions.

The need of a Material library

Other relevant insight achieved in this literature review is that of the changing role of material libraries from a place of information and hyper choice to places opened to students, professionals, researchers, teachers and visitors where experimental processes can be activated to create, plan and design product innovation (Bianchi & Lucibello, 2018). These authors presented the experience developed at the MdL of the Sapienza University of Rome where material samples can be accessed and used, while, at the same time, small experiments and aesthetic processes can be tried out (scratching, engraving, embossing, various surface treatment, etc.) and the materials can be experimented using different manufacturing processes such as 3D printing, moulding, etc.

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2.4. New perspective and suggestions for teaching with and for NanoTech

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Introduction

Despite the growing number of applications about nanomaterials and the educational efforts in Academia to bring to "understandable" language what nanomaterials are and can do, the truth is that there is still much room for improvements in this matter. This chapter has been written to present the intrinsic difficulty of nanomaterials to be understood by students – who are more used to Newtonian world – and the different opportunities that we must consider when dealing with them.

NanoTech: a mind-bending matter

Nanotechnological advancements in materials tend to result from integrating embedded structures and functionalized arrangements of matter into patterns over fractally larger scales of space. A by-product of these complex molecular interactions is the phenomenon of emerging properties or "material intelligence" modulated by the internal material equilibriums reacting to external stimuli, at such small scales. Although all matter, structured or not, embodies varying degrees of material intelligence, it is the patterns resulting from specific scales, which we harness into designer properties. In fact, we observe that at such extreme size reduction, certain molecular structures verses others can evoke differentiated material traits (i.e. water or UV repelling abilities), while concurrently enjoying incremental benefits in efficiency, speed, and precision. It is clear to see how these features present ideal applications for innovative design intent and systemically tailored applications. Among the practical advantages, nanomaterials can distil material excesses, increase versatility, and tailor functional values over tiny material spans using minimal material quantities. Systemic applications further yet benefit from the compounding effects of various spin-off phenomena, which can be harnessed into ecosystems of concrescing synergies and intelligence. At this level, materials begin to manifest degrees of autonomous agency over their surroundings manifesting new ontological expressions in the more intangible qualities of energy.

Not surprisingly, a bilateral divergence is brought into existence, between the ever-growing list of technologically available superpowers and the cognitive abilities of people to understand them. Unveiling the functional nature of such minutely structured materials boggles the mind, yet beyond this, lies a more obscure intellectual barrier, namely our limited capacity to understand and transfer this knowledge via adequate explanatory models. In fact, as advancements push onward, they often tend to become less accessible to our comprehension, behaving in progressively less intuitive manner. In other words, there is a growing cognitive disconnect between our ontological expectations of materials as we know them and the new and surprising behaviours they can possess once they are nanometrically altered. This, difficulty is understandable. Any hard science requires an ability to visualize abstract, counter-intuitive concepts, integrate non-common logic and learn to not take "face value" for what is being observed. Creative intuition or natural instincts here provide very little insight into predictive assumptions regarding nanomaterials because what you see is not necessarily what you will get. For designers this can be a handicap since they rely heavily on assumptions and learnt patterns typical of the Newtonian world, but nano is fundamentally the quantum world, it plays a different game. In this sense, the nano domain challenges our capacities and intuitions for making profoundly wise decisions, casting us into realms of doubt. It has changed the way we think and feel about solutions both long term and short, how we weigh benefits and the level of implied responsibility we deem necessary to uphold. Alike engineers, designers share both the spoils and the burdens of materiality along with the implications of broader choice parameters, the advantages and costs of new features and the balancing act between the power of innovation and its caveats.

As of late, the range of contending options has grown exponentially and disproportionately to one's ability to know, chose, apply, and satisfy counteracting points of view in real time, having a paralyzing effect. This becomes self-evident upon scrutiny of the grotesque misuse of technologies and the rampant examples of poorly solved stop-gap solutions which make their way to landfills and resource exhaustion. We require new and updated didactic methods with a holistic and impartial focus, from which to structure knowledge and creativity so that they may coalesce together. Informational content should be accurate and available in a variety of flavours, catering to a broader audience with diverse learning abilities and backgrounds so that the creative impetus can reap the benefits of a holistic material approach and extend beyond the objects they compose to further include their lifecycles, logistic systems, economies and ecologies. It is within this framework that value can settle into its own specific niche while still contribute and relate to the greater whole. This is no small matter.

Challenges and opportunities for teaching with and for NanoTech

Perhaps the prevailing methods of industrialized education is a model no longer suited for rapidly evolving creative and technological humans. Afterall, they emerge from a trade focused mentality, designed to output invariability, and fulfil internal efficiencies, often times at the cost of the student. In a system of constant technological acceleration, inflexible systems can quickly become self-limiting and obsolete while in turn, the gaps in knowledge are like fragmented puzzle pieces, difficult for individuals to piece together, incomplete in their resolution and potentially disastrous on the environment. For instance:

- Industrialized education is based on the segmentation of labour and know-how through specialization. This fragmentation however becomes self-limiting and error prone as it relies incrementally on the intercommunicational abilities of individual departments. Achieving wholeness is a communications-based task and we do not all agree on the same issues.
- Time here is not to our advantage. Learning by failure, despite its effectiveness, requires a significant chunk of time and its pace is easily surpassed by the sheer speed of cutting-edge technological advancements. By the time a task is completed, a product is designed, and a system is patterned, it is likely to be outdated.
- Designers and teachers share this component of emotional distress. After all, if current solutions are doomed to be soon outdated, how can they be integrated into a waste-free industry?
- An opposing model is to transfer technology in a way which is adapted to the receiver, taught in a hybrid, multifaceted manner and bridging forms of individual intelligence and insight, into customized flexibility. Although facts are non-negotiable, the way they are delivered and understood might be fundamentally a personal one.
- Developing critical thinking abilities is vital and shaped by a high acumen in nanotechnical know-how. On the other, they must retain a well-rounded diplomatic sense while developing artistic freedom, so that future trends may also evolve, entertain, and express their technological onthos.
- Institutions of higher learning are compelled to revisit their methodologies and upgrade them to reflect a flexible model, which can integrate precise nanotechnological know-how and cushion it within a more stable dimension of classical value-added common sense.

Several experimental approaches from different schools of thought are emphasizing the different outcomes between learning seen as knowing or "knowledge by description" and the felt domain of experience or "knowledge by acquaintance". Knowledge by description is an explanatory model for information transfer heavily based on concepts described by language-specific terminologies. This method deals with complexity by combining symbols, meaning and actions into a chronological framework. Phenomena are described and unpacked through storytelling techniques, having a beginning an end and conclusions. Knowing is a memory-based activity, building gradually upon levels of prior knowledge, therefore ultimately it is subject to memory, as it does not necessarily imply a true understanding of the mechanisms which constitute the phenomena, nor does it require an activity. To consolidate knowledge into a deeper sense of understanding is to identify with it on an experiential level, whereby you develop an active level of intimacy and failure with the process. In experimentation, the individual becomes subjectively part of the process of discovery. Information here is felt through the sensitivity of conscious effort and therefore more distinctly memorable and proprietary. One also has the sensation of accomplishment or failure. What is learnt here is the variability of the outcome and the emotional content is ubiquitous.

Several external factors also contribute to the overall discontinuity and inefficiency of nanotechnological knowledge transfer. Beyond the academic limitations above mentioned, are the ineptitudes and general bureaucratic procedures through which the information is kept for long periods of time. Often the very technologies being developed are proprietary and fall under the protection of non-disclosure agreements and patent pending applications, which can isolate the information from public view for several years.

Practical applications of nanotechnology are often made public after they have been launched onto the market through products and are no longer cutting edge. Once the intellectual property documentation is made public, it can be studied and taught in universities, but the underlying information remains undeciphered. Corporations, however, are not the only culprits. Universities also fund and develop research projects under clauses of secrecy and thus reserve the proprietary information to limited groups of their student body.

Educators vary enormously in their degrees of intellectual capacity, teaching experience and their ability to connect to students in ways that favour a learning environment. This becomes more evident in emerging fields of study. However, the difficulty which lies behind educational efforts extends beyond the activity of actual content delivery, testing and grading. Teaching curriculums require a high level of planning, selecting and investing in relevant topics suitable to the student body. These topics require the support of a laboratory with necessary tools and safety protocols for teaching and testing. Hence, a large component of the curricular planning efforts must also be invested in the continuing education activities of the teachers themselves and the development of a team. Moreover, since nanoscience and nanotechnology are rooted in chemistry, materials science, computer science and biotechnology, schools must possess a multidisciplinary team of scientific educators.

Finally, online videos are being considered useful as educational support tools given that physical/chemical phenomena might be more effectively communicated from a visual standpoint rather than verbal descriptions because it can be used to show students' things that would be otherwise hard to transfer in a limited period of time.

Conclusions

The issues related with training of design students in nanomaterials found in the literature can be bulleted in the following list:

- Difficulties to communicate the materials' characteristics to students due to their small dimensions (difficult to understand what you do not see) (Schulz et al., 2013; Olteanu et al., 2017).
- The expensive equipment (special optical devices) needed to work with these dimensions render difficult a cognitive and experiential strategy of understanding through classic communication (Schulz et al., 2013; Lisotti et al., 2014).
- Controversial about safety of nanomaterials coming from cosmetic and food sector negatively affect the perception of these emerging materials (Henkler, F. and all, 2012).
- Difficulties for teachers to comfortably conduct such a multidisciplinary subject (Lisotti et al., 2014).
- The level of implication of companies that will develop products with nanomaterials in the existing didactic methods is restricted to launch the challenges, provide information about their existing products and their requirements (Piselli et al., 2018a).
- Material libraries do not fulfil the needs to advance innovation in this material class because they miss relevant information and multidisciplinary experience (Bianchi & Lucibello, 2018).
- "Materials used in designs are subject to ongoing fluctuations in availability, limiting processing methods, price, attributed meaning on the one hand, and the rapid pace at which new, competing materials are constantly being developed" (Haug, 2019). From an educator's perspective, a detailed classification of materials knowledge acquisition method could constitute a solid point of departure when teaching design students on this topic.

The following suggestions were identified through this literature research:

- The need of training on two levels. First, for teachers that will train design students and second for the students themselves.
- Importance of a complete preview and knowledge regarding the lifecycles of emerging materials in coherence with economies of scope and scale which are ecologically and economically sustainable
- The need for structured analytical tools to quantify and compare intangible and sensorial characteristics of materials.
- Acquire in depth information about materials providing didactic experiences and knowledge though low-cost equipment of analysis.

To conclude, although few references were found from previous research experiences about didactic methods for the training of students about nanomaterials, some interesting conclusions were obtained. A first result from this review is the identification of previous experiences coming from other European projects oriented to teach students from high school on this emerging material helps us to identify some didactic strategies that are already tested and that provided positive results. These strategies ranges from traditional lectures to laboratory sessions, which include some online training, so as to overcome the difficulties to communicate this materials' characteristics to students due to their small dimensions. Those studies indicate the importance of the need of training on two levels: first, for teachers that will train design students and second for the students. A second key subject resulting from this review is the need for a holistic point of view of the characteristic of these materials for their selection processes. This subject has evolved in the last decade raising to an agreement in the design community about the need of four different types of criteria (technical or behavioural, intangible, sensorial or perception and material life-cycle including their environmental impact) to be used in the design process for selecting these emerging materials. Finally, the analysis of the selection process enforced the idea that different types of information are needed for designers at the different phases of the design process. Also, researchers stated that the role of the material changes along the process, from being a driver of the creative "finding" process by evoking ideas in the fuzzy-front-end stage, to the development stage where material selection are defined by context of manufacturing and cost to realize an already mature product concept.

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3. ICS Materials, Wearable Based

3.1. Wearable Textile Systems: design layered intelligence materials

Venere Ferraro

Introduction

Wearables, initially stated as "wearable computing" can be considered as "the study or practice of inventing, designing, building, or using miniature body borne computational and sensory devices. Wearable computers may be worn under, over, or in clothing, or may also be themselves clothes" (Mann, 2012).

Starting from their born back into 1960, wearables have been at centre of huge interest both in academia and in industry field. Placed in between the digital and human world wearables have the potentialities to change the way we live and interact with each other's thanks to the enhanced functionality of sensing, reacting, and/or adapting to stimuli in the environments to which they are exposed.

Wearables fall in many different categories: glasses, jewels, headgear, belts, arm wear, wrist wear, leg wear and footwear are taking on new forms and functions but also skin patches and e-textiles.

There is a major trend towards human hybridization, and wearables represent a generation of hyper-connected products that allow for exploring new design fields between human and advanced technology.

The vision behind wearable computing foresees future electronic systems to be an integral part of our everyday outfits. In twenty years, many applications have been explored in fitness, healthcare, military, automotive areas but the original and still good target for wearables is in some way ubiquity: these electronic devices have to meet special requirements concerning wearability, usability. Wearable systems will be characterized by their ability to automatically recognize the activity and the behavioural status of their own user as well as of the situation around them, and accordingly to use this information to change and modify the system. In this regard, being wearables comparable to the clothes, we can envision clothes provided with a third dimension and becoming "portable informative infrastructure".

The dress is, indeed, the only element able to follow the user in a non-intrusive way, in a natural harmony with the human body: it is a natural and universal interface. To do so, wearable need to be thought, designed and developed by using smart textiles. We consider the new class of ***smart textiles***, the ***active ones***: they contain built in actuators and sensors, they are dynamic and allow new functionality and experiences.

The use of smart textile in field like wearable technologies poses several questions and challenge to meet and solve. How can we design smart "wearable" textiles with no traditional materials but manufactured and shaped within a platform that embraces the electronics features? How can a designer shape smart textile into a clothing/wearable by considering both aesthetics and functionality? Do we need new approaches?

In this chapter, author explores the realm of smart textiles, their application, potentialities and weaknesses by proposing approaches and solutions for a designer working in the field of smart textiles applied in wearable domain.

Smart textiles: from a simple material to a working platform

Smart textiles are defined as textiles (in the shape of shirts, socks, shorts, belts, etc.) that can sense and react to environmental conditions or stimuli, from mechanical, thermal, magnetic, chemical, electrical, or other sources to provide functions such as health monitoring and activity tracking. They are able to sense and respond to external conditions (stimuli) in a predetermined way.

Given, the diversified panorama of smart textiles, a clarification about the meaning of smart textiles is here needed. They can be classified as passive or active smart textiles: the first ones are materials to which a specific function is added by means of material, composition, construction, and/or finishing (e.g., by applying additives or coatings) (Cherenack & van Pieterson, 2012). On the contrary, active smart textiles, are those capable of sensing, reacting, and adapting to the environment or stimuli and integrate actuators and sensors (Vagott & Parachuru, 2018).

We call this category: ***wearable textile system***.

The basic concept of a “wearable” textile system consists of a textile structure that senses and reacts to different stimuli from its environment. In a wide range, a smart textile system has a very simple structure thanks to which it’ s possible to wear a technological apparatus with common clothes.

The sector is heterogeneous and growing it has been estimated that the market for wearable technologies will grow from $20 billion estimated in 2015 to almost $70 billion by 2025.

Wearable textile systems have been mainly designed and developed in health management and sports applications to collect data such as heart rate, sweat rate, breathing rate, muscle tension, posture status, location, and temperature. For instance, they can sense the temperature outside and consequently warm up or cool down, based on the measured temperature (Figure 1).

Fig. 1 - Example of wearable textile systems applied into healthcare and sport

In ***sportswear*** a wearable textile system promises to offer effective solutions for wearers who seek more detailed data about their fitness and performance. Smart textiles can also increase the comfort level of the user and eliminate the use of bulky equipment such as chest straps. Since athletes and major league players constantly strive to improve their performance, an opportunity of storing data for analysis by lightweight devices that can be embedded in their sportswear offers a high potential for further performance enhancement.

Specifically, technology-enhanced sportswear, including compression garments designed for muscle recovery, can provide an appropriate medium for carrying large numbers of sensors close enough to the wearer's skin, to pick up the weak electrical signals generated by physical effort. Multiple extra data types, in addition to heart-rate electrocardiogram (ECG) signals, can be collected today, including electromyography (EMG) for analysing muscle activity. Furthermore, accurate body-temperature monitoring can be useful for monitoring fitness and can also protect the wearer against the dangers of over exercising.

Close-fitting sportswear represents an ideal base for embedding sensors such as MEMS inertial modules, to accurately monitor the wearer's movements. Smart textiles allow accurate sensing by helping eliminate noise that looser-fitting garments could introduce by moving relative to the wearer's body. Sensing motion enables applications allowing to identify areas where technique could be improved, such as running stride or arm action.

Medical applications of wearable textile systems include the monitoring of patients' vitals such as temperature, hearth rate, respiration, stress and sleep levels and so on.

For the ***medical*** and ***healthcare sector*** the main driver for innovation remains the added value in terms of better functionality and performance, but also total cost, compared to established approaches, the continuous integration of new technologies in the development of new products while adapting to new challenges placed by the ageing society – for integrated ICT (Information and Communications Technologies) tools that enable remote monitoring of patients – the enhancement of barrier and comfort properties for professional medical garments. Moreover, in the medical field, the wearable smart textiles integrated with could monitor vitals such as body temperature and heart rate. It would wirelessly transmit the data to the professionals' station. Simplifying the process to gather patient data would streamline the healthcare.

Electrodes manufactured and directly integrated into the wearing surface such as Piezoresistive fabric sensors can be used to monitor the posture and movement of the wearer. These electrodes allow for the monitoring of medical patients over extended periods of time, as the fabric electrodes are reporting the data while the electrode-infused clothing is being worn (Figure 2).

Smart textiles application in wearable domain appears to be very diversified and based on research, which has its foundation in different research disciplines: textile design and technology, chemistry, physics, material science and computer science and technology.

Significant for this research is the ***interdisciplinary approach*** and the interaction between basic research and design activities.

Fig. 2 - Piezoresistive sensors manufactured into flexible textile

According to applications, functionalists, end-user and degree of intelligence smart textile are then also classified according to the design paradigm chosen to integrate electronic functions into the textile architecture. Indeed, in the huge panorama we can find a case in which the textile act as a base for the attachment of sensors, output devices, and printed circuit boards (garment and fabric level integration). Such textiles becoming the actual wearable integrate the desired functionalities "disappearingly" inside a textile sensing/working platform.

Designing wearable that embrace smart textiles means to consider the material per se as a designed/shaped form/object having ***a hybrid layer*** that combine various functional fibres (with differing degrees of complexity) with attached integrated circuit components and off-the-shelf sensors.

This is for sure possible thanks to three main technological drivers: the first is the introduction of new type of textile fibres and structures for example conductive materials; the second is the miniaturisation of electronics, which makes possible to integrate electronics into textile structures and products; the third is different kind of wireless technologies enabling the technology to be wearable and at the same time communicating with other devices such as computers or mobile phones (Cherenack & van Pieterson, 2012).

Besides the above listed drivers, we also need to consider design approaches and tools addressed to the aesthetic/user-oriented and experiential aspects.

Approaches and tools for wearable textile systems

The hybrid layer system required for the wearable textile system needs to meet both technological and aesthetic/acceptance requirement.

This class of materials as all the different recent technologies change the way people behave and interact defining also the behaviour of artefacts, environments and systems (Forlizzi et al., 2004). It is therefore crucial to design them, as they uncover new modes of interaction as well as new ways to engage, entertain and inform people. This approach to applying new technologies to the real world is very much linked with the idea of designing experiences, which means to design not only functional elements (realm of engineers), but also the features needed to involve users at an emotional level.

Based on this ground, a user centred approach (UCD) is required. In an UCD approach, users appear as the ultimate experts, those who can properly assess design prototypes, propose changes, and ultimately, integrate end products within their routines (Assis, 2009).

When it comes to wearable textile system a practitioner needs to design the all layered system by considering human factors and skin requirements by having: a moisture 'base-layer' or the so-called 'second skin', a middle insulation layer, for breathability reason and a protective outer layer (McCann, Bryson, 2009).

A user-needs driven design methodology is here proposed to promote collaborative design with users. It addresses a breadth of technical, functional, physiological, social, cultural and aesthetic considerations that impinge on the design of clothing with embedded technologies, that is intended to be attractive, comfortable and fit for purpose for identified customers. If a product does not look good or work, the user will not be satisfied. Form embraces aesthetic concerns and the importance of respecting the culture of the end-user, and function embraces the generic demands of human body and the particular demands of the end user or activity. In order to aid decision-making, the design process requires an overview of the profile of the target customer in terms of gender, age group, and an indication of the proposed category of smart textile product to be developed. For example, design features that constitute a wearable acceptable and useable garment with embedded smart wearable attributes far a child playing sport will be different tram the needs of a fireman subjected to extreme hazardous environments or from the demands of everyday clothing far an older wearer. Successful wearable system design is the result of designers becoming thoroughly conversant with the culture, history and tradition associated with the particular end-use or range of activities. A design that is considered attractive for a wearer from one community or age group may be totally unacceptable for another.

The designer will benefit from gaining an overview of human physiological issues that impinge on the design of the functional garment layering system. It is necessary to consider practical issues to do with the demands of the body that may be addressed in everyday clothing in terms of comfort. The psychological feel good factor is directly related to appearance and style as well as to the reliability, or the perception of reliability, of the garment system. Designers should carry out primary research observing and obtaining feedback from wearers to identify their needs far the chosen activity or task. An appreciation of the functional needs of the end-user will impact on a breadth of design considerations with regard to comfort, protection, durability, weight, ease of movement, identification and aftercare. The designer's challenge is to engage with the end-user(s) to uncover, understand and priorities a range of issues that set the scene for the specified activity, or range of activities, and inform the development of products that are attractive and fit for purpose in relation to the culture and lifestyle of the intended wearer(s) (McCann, Bryson, 2009).

From the design perspective we are also required to understand and have the knowledge related to the way to translate the user needs into a real wearable textile system meaning to know the fabrication and the possibility to shape the hybrid system.

In this regard, a schematic wearable textile system can be identified through various hierarchical components through a new category of material called ICS Materials (see chapter 2 of this section)

ICS Materials are defined as systems combining inactive materials, active stimuli-responsive smart materials, and proactive materials (Parisi et al., 2018) and shaped exactly as the layered system that answers user demands and acceptance (Figure 3).

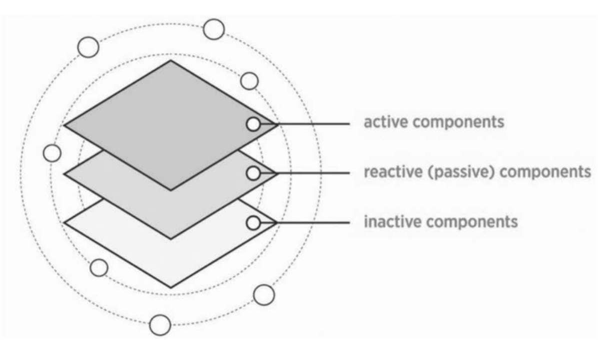

Fig. 3 - ICS Materials layered system

Conclusions and final remarks

Wearable smart textiles are becoming increasingly advanced and helpful in increasing the functionality of both everyday clothing and work wear. They have applications in health management, sportswear, industrial work wear, temperature control, safety, and entertainment. The technologies developed for wearable smart textiles are still being improved and developed. Many designs can still be streamlined to decrease bulkiness and improve the overall integrated feel of the technology.

Textile-based smart wearables have a broad range of potential application markets such as sports, health, personal protection or entertainment. Smart clothes that reveal information on our posture, heart rate or body temperature are being developed. However, while many functioning wearable textile system prototypes have been developed over the last 10-15 years and some niche products have been launched on the market, real wearable textile system seems to be largely absent. Factors combined with a lack of must-have functionality which would persuade users to accept shortcomings, are mainly to blame for the fact that textile-based smart wearables are not more widely in use.

There is a related missing path to commercialization since explorations often stop at concept stage related to materials manufacturing (Barfield & Caudell, 2001). The main problems could be summarized as follow:

- Lack of miniaturization: Limited size and thickness requirements for components in wearable devices, smaller components -more design flexibility, ability to make technology invisible.
- Lack of Flexibility: Flexible mobiles and increasing integration into all wearables increase requirements for flexing/stretching.
- The need for materials and embedded sensors to be lighter and more flexible.

Design and developing wearable textile systems means to take into account not only functional elements (realm of engineers), but also the features needed to involve users. For instance, for sports, fitness and health purpose social acceptability will be enhanced if they enhance an individual's social status as well as providing the functionality needed.

By considering smart materials as a working platform that generate the end product (wearable) a set of requirements need to be met:

- Responsiveness to end-user.
- User centric ergonomic functionality: a new term – 'wearer ware' – may be needed to fill a gap in terminology.
- Ease of use.
- Wearer comfort (weight, bulkiness, flexibility, skin-friendliness).
- Ease of care & maintenance (wash-ability, repairability).

- Connectivity to and from the platform.
- Support for a diversity of sensors.

In order for the industry to start developing such class of products in a massive way we also need to train new professionals having a complementary education that embrace knowledge from design to materials to computer science. Following this, a new curriculum is needed that should overcome the following barriers:

- **Lack of Sensory experience investigation**: Designers must consider the user's cognitive load, sensory and cognitive bandwidth.
- **Missing of collaborative practice**: Need to develop collaboration strategy between design and science, to more fully realize both the opportunities and contexts that Wearable offer (Fairburn et al., 2016).
- **Material/ Technology acceptance** of unknown materials, materials out of context, materials with 'bad reference'.

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3.2. Towards the definition of ICS Materials in Design Education: Approaches in specific teaching methods

Stefano Parisi

Introduction

Novel materials with interactive, dynamic, and hybrid qualities are emerging under the influence of miniaturization of information technologies and the diffusion of interdisciplinary environments fuelling the cross-fertilization and blending of previously isolated and distinctive practices, namely materials fabrication and technologies programming and embedding. We refer to this wide and hybrid family of materials as *Interactive Connected Smart Materials*, also known as the acronym *ICS Materials*. As presented in the previous chapter, such materials arise as one of the principal options to be applied in the Wearable sector, allowing the seamless integration of technologies. Indeed, the most successful examples of ICS Materials which are feasible and ready to be applied today belong to the smart textiles and e-textiles area.

In this chapter, a definition of ICS Materials will be provided, presenting their ontology – *what they are* –, anatomy – *what are their parts* –, and taxonomy – *how they are classified*.

In design and engineering universities and schools, some teaching activities have been already carried out to explore and apply these materials in many sectors. Although these workshops and courses are still quite recent and experimental, it is possible to recognize very specific teaching methods, approaches and tools that have been applied, after being selected from closer or intersecting areas or developed on purpose. In this chapter, the approaches used by these teaching methods are presented and discussed.

What are ICS Materials?

The materiality of artefacts and built environment is shifting towards a novel dimension: one characterized by hybridization, dynamism, and interactivity. Indeed, new materials with extraordinary characteristics are emerging and new practices to shape and control them are unfolded, requiring a new set of approaches, tools, and techniques to be integrated in design practice and education (see chapter IV).

Evident examples of manifestation of this unfolding hybrid, interactive, dynamic materiality are smart materials and systems based on the integration of reactive materials and electronics. The phenomenon has been observed 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) elaborates the concept of *expanded matter* or *x-matter*, i.e., materials effectively enhanced with additional capacities such as tracking, sensing, responding, interacting, by the integration of information technologies. Similarly, *Augmented Materials* (Razzaque et al., 2013) refers to materials with generic physical and computational properties, in which electronics are seamless and embedded during the fabrication of the material. *Computational Composites* (Vallgårda, 2009) identifies composite materials in which at least one of the components has computational capabilities. *Smart Material Composites* (Barati, 2019) highlights how smart materials can work together in a system, as also affirmed by Ritter (2006) about the potential of Smart Materials to be combined to create complex interactions.

Interactive Connected Smart Materials, also known as *ICS Materials* (Parisi et al., 2018; Ferrara et al., 2018) is a recent and inclusive definition, where smartness, interactivity, and connective capability are enabled by the combination and interdependence of different material components into complex and hybrid material-based systems.

Ontology – what ICS Materials are: the inclusive concept of Interactive Connected Smart (ICS) Materials encompasses a broad range of materials that have some of the following characteristics:

- being able to establish a two-way exchange of information with human or non-human entities;
- being able to respond simultaneously and reversibly to external stimuli, by changing their properties and qualities, for example – but not limited to – colour-changing. light-emitting, shape-shifting behaviours.
- being linked to an external or integrated source of energy and communicating with a source of information, for example – but not limited to – through cables or digital networks;
- being programmable, for example – but not limited to – through software.

Anatomy – what are their parts. To have a clearer understanding of what ICS Materials, it is necessary to consider such materials as hybrid and complex systems, made up of several interdependent elements and belonging to different domains. To gain and play out their smart, interactive, and connective capabilities, ICS Materials are hybrid systems that can be made of all or some of the following components "building blocks" or "layers":

- ***Inactive components*** are conventional and latent materials with no evident interaction, such as paper, plastic, and textiles. Their only dynamic behaviors are limited to conventional mechanical and chemical characteristics, such as ageing over time and performing flexibility. For example, copper reacts to the oxygen in the air producing its very characteristic green patina changing the material aesthetics and perception. They can be used as a support and structure in the system.
- ***Reactive components*** include smart materials, the ones that have changeable properties. They can reversibly change some features like shape, colour or light-emission in response to physical or chemical influence from the environment or the users' body, for example temperature, light, pressure and mechanical stress, electric or magnetic fields, chemical elements and compounds. Usually, the behaviour is programmable, meaning that such materials are engineered to respond to the stimuli in a predetermined range. There is a wide range of smart materials. They can be classified according to their behaviours. Shape-memory alloys are metal alloys commonly mentioned as Nititol, Flexinol and muscle wires. After a deformation, they can return to their original shape, when triggered by heat or electric current. They are frequently available in the shape of sheets, springs, or wires that can be integrated into textiles by interweaving them with traditional fibers. Colour-changing or *chromogenic* smart materials change their colour in response to external stimuli. Thermochromic responds to changes in temperature; photochromic responds to changes in light conditions; electrochromic responds to electric field; halochromic responds to change in the pH. They are frequently available in the format of pigments, inks, and coating that may be applied to any surface, from polymers to glass, from paper to textile. Light-emitting smart materials emit lights due to the excitement of their molecules. These are classified as fluorescent, phosphorescent, and electroluminescent materials.
- ***Active components*** include embedded sensing and actuating technologies, such as sound, touch, and proximity sensors, and LEDs, buzzers or vibration actuators. They are connected with external or embedded computing technologies, such as Arduino or Flora boards.
- ***Interconnection*** between components is supported and enabled by additional materials that can be found in the system. Conductive materials can substitute traditional wires and cables. They are mainly graphite, active carbon, and silver, and can be found in the shape of conductive fibres, threads, printed circuits, paints, and coating.
- ***Alternative sources of energy*** can be integrated as additional components. They are embeddable power supplies, like flexible batteries,

or electricity-generating materials, such as piezoelectric ceramics and polymers. On applying mechanical stress to piezoelectric materials, they generate an electric current.

Taxonomy – how they are classified: if we combine one or more of these components – by layering or embedding –, we could achieve three categories with different degrees of interaction (Parisi et al., 2018):

1. inactive materials: made only of inactive components, they can change over time – e.g., ageing – but they do not own any smart or interactive quality. This is the least significant category in terms of integration into wearable technologies, due to their lack of smartness in their sensing and communication capabilities.
2. reactive materials: made of the combination of inactive and reactive components, they respond to external stimuli by changing their qualities reversibly.
3. proactive materials: made of the combination of inactive and active components, often with the addition or reactive components, not only they respond to stimuli, but they are active and adapting in a mutual relationship and dialogue with the user and the environment. They can make invisible data evident and tangible to the users, enabling them to be more aware in their daily life.

Methods, tools and approaches for teaching ICS Materials: State of the Art

In Design and Engineering schools and universities, courses and experimental workshops have been carried out on the application of smart, interactive, and connected materials in different sectors and using distinctive methodologies supported by tools and procedures – whether they are borrowed from nearby areas, or originally developed on purpose. Here the main teaching methods and approaches used in the design area to transfer knowledge about interactive, connected, and smart materials are described, the ones specifically designed to deal with such materials, and the ones dealing with emerging materials in general, embracing ICS Materials, but not limited to.

One premise is that the most widespread approach to teaching design materials is the mixed approach, with a principal emphasis on direct experimentation and application, through exercises, design challenges and project briefs. As Haug (2018) states different approaches and methods for teaching materials exist and are applied in design High Education Institutions (HEIs): these involve multiple and intertwined sources of learning, such as 'Material-produced' information – for example, direct experimentation with materials –, ‘Interpreter-produced’ ones – for example, discussion and confrontation with instructors, experts, and peers –, and ‘Representation-produced’ ones – for example, texts, videos, and pictures. In this framework, *Active Learning* (Bonwell & Eison, 1991) and *Experiential Learning* (Kolb, 1984) are fundamental approaches to teaching and learning materials in a design context, in particular, engaging students in a design challenge with companies (Piselli et al., 2018) and *learning through making* (Pedgley, 2010). Schön and Bennet (1996), described how the design and creative practice itself could be observed as a conversation with materials, through which the practitioner gets to know materials. Teaching with physical materials and product samples emerges as an efficient method for gaining knowledge about materials and for stimulating the creative process though direct exploration, as many sources argue (Haug, 2018; Rognoli, 2010; Pedgley, 2010; Ayala Garcia, Quijiano & Ruge, 2011).

Along these lines, we collected a selection of teaching experiences from literature review and based on our experience as educators. Here the selected experiences are briefly described pointing out at the most relevant observations on the methods and tools that have been used. In the conclusions of this chapter, you would find a summary of the main approaches that have been retrieved from these experiences.

The ***Design-driven Material Innovation Methodology (DdMIM)*** (Lecce & Ferrara, 2016) is described as a systematic approach for research centers, design schools, practitioners and small medium enterprises. It is based on the understanding of the wider socio-cultural scenario before selecting advanced materials – including smart materials – as a technology platform to set up and place the design concept. It allows the development of one or more materials starting from scientific discoveries, material patents or production processes, to identify applicative scenarios and to develop specific products and create value for them for the market launch. DdMIM has been applied in the application of smart materials and interactive technologies in the development of tangible interfaces for products and interiors in a series of design workshops at the School of Design of the Politecnico di Milano (Ferrara & Russo, 2019).

In the scope of the research about ICS Materials at the Department of Design at Politecnico di Milano, Parisi et al. (2019a; 2019b) developed a tentative methodology definined as ***Design for ICS Materials*** that has been applied in the pilot experience of the workshop “NautICS Materials”. The workshop used the context of the nautical sectors and related environmental inputs and triggers – for example, moisture, light, movement and sound – as the starting point for a multidisciplinary design workshop on ICS Materials using a novel methodology and a supporting toolkit to design in the absence of physical materials, including inspirational scenario boards, informative materials cards, and ideational concept canvases. The workshop approached the topic with a speculative perspective, acknowledging that such materials are quite advanced for the current yacht sector, but could be potentially applied in in concepts of future yachts.

Dystopian Thinking is a tentative methodology based on Speculative Design aiming at ideating and envisioning innovative ideas for the application of advanced materials and technologies in a fictional future context inspired by Sci-Fi scenarios. It has been used specifically on smart materials to be applied in wearables, in the workshop "El Futuro de los Wearables Dinamicos / the Future of Dynamic Wearables" (http://blog.materfad.com/2018/02/materfad-organiza-un-workshop-sobre-wearables-en-la-mobile-week-barcelona-2018; https://www.piscolabisdesigners.org/workshop-future-of-wearables-from-dystopian-thinking-x-jessica-fernandez-cano). The methodology and related toolkit based on inspirational cards and canvases facilitate the creation of concept ideas as diegetic prototypes with a great disruptive potential from the vision of future scenarios defined by a technological context.

Similarly, other teaching activities used educational tools in the form of cards and canvases – for example, a ***sensory map*** for understanding and ideating smart material-based artefacts (Colombo, 2014) – and databases – for example, a digital database collecting cases of ***Shape-Changing Material Systems (SCMSs)*** (Hölter et al., 2019). Other learning materials supporting students that are specifically focused on smart and interactive materials are Open-access tutorials and platforms to inspire about making techniques and potential applications, for example the online platforms ***Openmaterials*** by Catarina Mota (http://openmaterials.org) and ***Materiability*** (http://materiability.com).

Kretzer (2017) argues that designers and architects need to learn using and qualifying the potential of active materials. This forms the foundation of ***Materiability*** as a pedagogical attempt based on multi-disciplinarity, hands-on explorations and speculative and critical applications. It focuses on providing open access to information and encouraging information material literacy, rather than prescribing a specific method; encouraging students to learn "how-to-do" instead of teaching "what-to-do"; prioritizing independent self-development, rather than instructing about specific techniques and skills. Similarly, the ***FabricAdemy*** (https://textile-academy.org) programs support learning and experimentation with smart materials and textiles for the development of wearables, encouraging hands-on experimentation, the use of open-source technologies, digital fabrication, and multi-disciplinarity.

Using the environment of Polifactory, the Fab Lab of the Politecnico di Milano, to encourage and enable making, tinkering and prototyping, ***InDATA projects*** at the Design Department of the Politecnico di Milano (http://www.indata.polimi.it) carried out a hands-on experimental educational activity in the format of the 2-day Hackathon "DATA < > Materials" focusing on developing interactive devices and wearables by using a methodology combining speculative design, bioplastic making, electronics programming and embedding, digital fabrication. Future scenarios involving the use of technology were provided as a starting point. Students were supported with tutorials, recipes and learning and design tools to carry out materials experimentation and ideate and prototype concept ideas. In this process, ***material tinkering*** (Parisi, Rognoli & Sonneveld, 2017) is used as a goal-free and playful exploration with physical components – both materials and technologies – for understanding their potentials and lead further developments.

The teaching activities at the Institute for ***MaterialDesign IMD*** at the Offenbach University of Arts and Design (http://imd-materialdesign.com) deal with materials charged with digital, adaptive or interactive elements. The applied methods are fundamentally based on hands-on exploration and materials making, working in a hybrid space where form, material, and technology overlap, characterized by elements of different and often contrasting nature: traditional materials and crafting techniques, mixed with smart technologies and advanced fabrication processes. The result of the activities are prototypes that encourage the discussion about *material authenticity* and *speculative applications* (Parisi, Holzbach & Rognoli, 2020).

The ***Material Driven Design (MDD) Method*** by Karana, Barati, Rognoli and Zeeuw van der Lann (2015) facilitates designing for materials experience, namely an intended experience that is conveyed by the materials of a product due to their physical qualities, emotional and cultural values. The methods teach "how to design for experiences with and for a particular material at hand". In particular, it addresses emerging materials, including smart materials. The method aims at facilitating reaching materials acceptance to users and the market, by identifying meaningful materials experiences to enhance or transfer to the material in its development. The starting point of the method is the material which needs to be first understood by tinkering, user studies, and benchmarking. From that understanding, a materials experience vision is created and manifested into patterns to transfer or enhance into the materials to achieve the intended materials experience. Finally, the material is applied into a product concept, consistently with the intended vision.

Using the MDD method, a body of research and experimentation involving students was carried out on ***designing with and for smart material composites***, specifically a particular light-emitting and piezo-electric composite material (Barati, Giaccardi & Karana, 2018; Barati, Karana & Foole, 2017; Barati, Karana & Hekkert, 2015; Barati et al., 2015), at the Faculty of Industrial Design Engineering at Delft University of Technology. It focuses on the fact that smart material composites like this are underdeveloped, open-ended, and often difficult to have physically on hands, causing uncertainty in terms of sensory experiences, performances and interaction qualities. Therefore activities and explorations with students focus on identifying ways to ideate, simulate, manifest and assess the performative qualities of the smart material, by *affordance-making* – "a making process in which both the designer and the material perform in response to the skillful exploration of not-yet actualized affordances" – and *experience prototyping* using a real-time hybrid tool to support design students.

An educational workshop by Schmid, Rümelin & Richter (2013) focuses on the development of ***glass-based tangible user interface***, starting from the suggestions provided by the inactive material itself which is then implemented with electronics. The combination of the *multi-disciplinary expertise* of the teaching staff and the use of *metaphors and analogies* to inspire forms and behaviours in the ideation process were key. Similarly, metaphors have been used as a device for conceptualization of smart materials-based projects in a lighting design workshop (Piselli et al., 2015) and a product design workshop (Russo & Ferrara, 2017) at the School of Design of the Politecnico di Milano. In the latter workshop the role of the *whole-body experience* and *somaesthetics* was central (Richard Shusterman's Full Body Thinking Approach). The role of user experience in dealing with material-based interactive products is emphasized in the use of tools for Enhancing product sensory experience in design workshops (Colombo, 2014).

Conclusions

In this chapter, we provided a definition of ICS Materials and we argued how they represent an optimal solution for responsive and seamless wearable technologies. A broad survey about teaching methods used in design schools and universities has been carried out and presented. They used methods and supporting tools, techniques, procedures and guidelines that are carried out from other design areas or even from other disciplines. The main approaches can be resumed as follow:

- **Mix-methods**. The most widespread approaches to teaching design materials often use mixed learning sources, including the use of frontal lectures, reading of texts, videos, and pictures; laboratorial experiences with direct experimentation with materials; discussion and confrontation with instructors, experts, and peers (Haug, 2018). Open access platforms, tutorials and databases are equally principal sources for gaining and exchanging information, considering the novelty of ICS Materials (Kretzer, 2017). Most of the methods used in design prioritize a principal emphasis on direct experimentation and application, through exercises, design challenges and project briefs.
- **Multi-disciplinary approach**. In a considerable number of presented cases, the urgency for creating a multi-disciplinary environment to learn, test, experiment and develop applications of ICS Materials is expressed. Indeed, ICS Materials area is situated in the intersection between design, material, interaction, but not limited to this, fundamentally involving also electronics engineering, traditional crafting, material science, sustainability, and the related application fields, specifically wearable design. Since only a few cases report to actually operate in this multi-disciplinary field with co-teaching and collaboration with experts, this is a gap.
- **Hands-on and material-centred**. The majority of the presented cases argue the centrality of having a specific material or a selection of materials at hand and starting the design process from this point. This is the key idea of the MDD and other methods. Tinkering, physical making and hands-on manipulation of materials are crucial in the learning process. As it often occurs with advanced materials, physical samples may not be available, or spaces or equipment are not available. In this case, it is necessary to replace them with other learning material – for example cards, canvases, and online databases.
- **Simulation**. One of the problematic issues related to ICS Materials may be that with scarce access to materials, facilities, equipment, and multi-disciplinary learning environment, the student won't be able to produce the ultimate material, but produce or collect different material samples to mimic or exemplify the sensorial qualities or the physical behaviours (Karana et al., 2015). Some of the presented methods use metaphors and analogies, to inspire and communicate the performance and behaviours of smart and interactive materials. This arises as a successful approach in capturing, prototyping and communicating the performative and dynamic qualities of advanced materials, through simulation. *Experience prototyping* and *bodystorming* are methods that can be used to physically explore, test and define functionality and behaviours of ICS Materials in the first stages of the development process or in absence of physical materials.

- **Application-oriented**. Most of the methods are based on the application of the materials into a product, to challenge materials potentials and limits, and encourage new product development and innovation based on the unique characteristics of the materials. They can involve companies and stakeholders in order to contextualize the materials and create a link between the world of Academia and Industry. Some of the described methodologies – for example, the MmDID – fundamentally embrace partnership with design-oriented companies. "The novel technological landscape implies indeed this sort of collaborations, as Design Schools can effectively assist companies in making evidence-based decisions" (Ferrara & Russo, 2019). In this case, the knowledge transfer target is twofold addressing both students and people from companies.
- **Context-driven**, also defined as *case-specific*. The context – whether it is an environment, a situation, an application field, a wider social scenario – is defined as a starting point of the design brief. Indeed, the context provides restrictions to the limitless possibilities of emerging materials. Therefore, the material and its resulting application is situated in a discourse with industry and society involving not only technological opportunities and limitations, but also social necessities coming from a community of actors. Indeed, one challenge arises from a higher risk of designing a product integrating a novel smart material without creating a real value for society.
- **Speculative approach**. Some methods rely on a speculative approach detaching materials application from a current context or situation and imagining narrative scenarios based on alternative futures. This is in consideration of the current technological limitations and scarce availability of ICS Materials, that will be overcome in the future, due to technological development. The produced prototypes have a diegetic and critical role in delivering a narrative and questioning about complex ethical implications related to the materials and their applications. In addition, "designer's naïve perspective with respect to every technical detail of a technology allows them to see new applications" (Barati et al., 2015).
- **User-centred**. The majority of the cases that have been presented in this chapter are fundamentally user-centred, considering the user as an active stakeholder and participant to the discussion, since the initial phases of the learning and design process, for example through user studies. The user interaction and expectations in relation to the material aesthetics and performance are key. Some of the methods focus more on the physical human body interaction with materials, while others extend to the experiential dimension, whether it is psychological, affective, or interpretative.

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3.3. Dynamism as an emerging materials experience for ICS Materials

Valentina Rognoli

Introduction

The world of contemporary materials presents a great variety of choice for material solutions. The materials, from passive entities to choose from, have become active elements that participate entirely in the design process, becoming objects of the project themselves. Starting from the shelves of the material library, where the samples are only closed and catalogued, the samples of the materials have gone on to be considered the main protagonists of the design process and the experimentation guided by design. Besides, the designers have shown that they want to be more and more independent in the design and prototyping of self-produced material solutions. They no longer want to depend totally on other professional figures such as engineers and chemists mainly, to get their hands-on and experiment with the materials. The phenomenon of self-production of materials by designers that have appeared in recent years has been formalized in the DIY-Materials approach which today leads to the development of original and innovative material solutions to which companies also look with interest (Rognoli et al., 2015). The materiality of the world where we live is changing under the influence of technological advancement and social requirements. The diffusion of the Open source and the spreading of fab labs, workshops, and platforms for experimentation and prototyping, the democratization of technological practices is conducting to easier access to data and technologies both owned, through cheap and flexible tools, and shared, also for non-specialized users. As a result, the design is becoming computational and interactive, exploring trans-disciplinary approaches, and merging with computer engineering and biology (Parisi et al., 2018).

The designers, therefore, want to actively participate using their creative skills in shaping the material of which the objects will then be made and are aware of how the material is the principal element in determining the user experience of the artefact. As the products of our time are and will increasingly be interactive and smart, the designers have also begun to work on connected and interactive materials and on their hybridization with technology (Pandey, 2018).

In the panorama of contemporary design, we have increasingly faced with design needs strongly influenced by the technological system characterised by the ubiquity and connectivity of everyday artefacts that give rise to increasingly Intelligent, Connected and Smart systems. The designers are called to imagine new material experiences in daily life, through communicating and interactive devices that will be future everyday objects (Giaccardi, 2015). Even the multidisciplinary HCI community, after projecting research towards the dematerialisation of technologies, is re-evaluating the value attributed to sensory/perceptual involvement with physical matter, promoting the role of materials as a material lens through which to look to the future of dynamics of interaction.

Due the fact that digital and material are not separate but entangled elements of the same process, the chapter aims to contextualize the interactive, connected and smart materials in the theoretical framework of materials experience, presenting the possible and designable dynamism of materials as an emerging materials experience.

From technical properties to expressive-sensorial qualities

In the last 30 years, the domain of design research converging on Materials and Design has turned its focus from technical and engineering properties of materials to their expressive-sensorial qualities that define and affect the users' experiences of artefacts (Ashby & Johnson, 2002; Rognoli, 2004; Rognoli, 2010; Karana et al., 2008).

In a recent publication, where the authors built a literature review study on experiential characterization in product design, in which they described the current state of the art and identified gaps or opportunities for further research in this domain (Veelaert et al., 2020), it is clear that there is still much to be done and investigated in this domain. Therefore, it is now acknowledged that materials need to have qualities that go beyond the fulfilling of practical needs. They must have intangible qualities that captivate appreciation and that affect the experience of an artefact beyond its functional value. These qualities were firstly named, expressive-sensorial qualities of materials and then Intangible Characteristic of Materials (ICM) (Karana, Hekkert & Kandachar, 2010; Karana, Hekkert & Kandachar, 2007), and later intangible sparks of materials (Karana, Pedgley & Rognoli, 2015); they are qualitative, non-technical, and intangible characteristics related to emotions, personality, and cultural meanings.

Rognoli defined the sensorial, subjective, qualitative, and unquantifiable, profile of materials as their expressive-sensorial dimension. This notion looked at design materials as instruments to characterize a product from the points of view of perception, interpretation and emotion. By means of the expressive-sensorial qualities of materials, designers can embody in the product sensorial emotional references that trigger a particular material experience. The Expressive-Sensorial Atlas (Rognoli, 2010) supports designers in their understanding of the material qualities and unfolds their relations with engineering properties. It is a mapping of the technical, objective and measurable profile of materials, into a sensorial, subjective and qualitative one. The atlas is a collection of charts or tables, which report information in a structured yet flexible manner, without grading or privileging material. The atlas has a purposeful 'work in progress' format, rather than a completed entity – intended to grow according to the users' requirements and experiences.

Examples of the qualities are texture (smooth/uneven), touch qualities (warm/cold, soft/hard, flowing/stilted, light/heavy), brilliancy (gloss/matte), transparency (transparent/translucent/opaque).

At the didactic level, the atlas is an interactive tool used to teach future designers about the existence of a sensory dimension of materials, consisting in tactile and photometric sensations that people perceive because of interaction with (sensorial exploration of) materials. These aspects are divided into top-level parameters (texture and touch for tactile sensations; brilliancy and transparency for photometric sensations), which in turn are divided into qualities (texture: smooth/engraved; touch: warm/cold, soft/hard, light/heavy, sliding/sticky; transparency: transparent, translucent, opaque; brilliancy: gloss/matte). These characteristics may be also used to describe the sensorial level of materials experience.

From expressive-sensorial qualities to the materials experience concept

Elvin Karana introduced the concept of materials experience in 2008 (Karana et al., 2008) and then it was further investigated and developed. In general, the term 'materials experience' describes a holistic view of materials in design, emphasising the role of materials as simultaneously technical and experiential. Taking materials experience as an entry point, it is possible to understand and describe how people experience materials and how physical, biological, social, and cultural conditions constitute these experiences. Furthermore, it is possible to inspire innovative material applications as well as new materials and design research trajectories.

The concept of materials experience describes the experiences that people have with, and through, the materials embedded in a product. This definition acknowledges and emphasises that, through shaping what we feel and think, materials have the power to foster meaningful experiences.

In comparison with the expressive-sensorial dimension of the materials, the concept of experience includes the interaction between user and materials possibly incorporated in an artefact. Experience is an episode, it is a time-lapse, it is a story that emerges from the dialogue that a human being establishes with his world through action (Hassenzahl, 2010).

The materials experience framework at the beginning was composed of three different levels affecting each other. The first one is the sensorial level (i.e. the aesthetics of materials) that is the experience that originates from perceiving and noticing material sensorial information by senses. The sensorial experience of a material is related to sensorial information, such as softness, warmth, smoothness, sound, weight, stickiness and so forth. This level is very linked with the expressive-sensorial characterization of materials. Then, the designer has to reflect on what the material may represents, its meanings (interpretative level). The interpretive experience, related to the meanings evoked by the material and are associated to abstract concepts, e.g. materials are modern, cozy, etc. Meaning is linked to judgment: about what the material represents to us, and emotion is connected with how the material makes us feel (emotions). The affective level is related to emotions elicited by the material, e.g. feeling surprised, bored, etc. (Karana et al., 2014; Karana et al., 2015).

In HCI community Giaccardi and Karana explored how the framework of materials experience exhibited the active role of materials play in shaping people's interactions and practices. In fact, to complete the previous framework it was necessary for the designer to include also "the active role of materials on shaping our ways of doing and ultimately, practice: the performative level" (Giaccardi & Karana, 2015). Sensorial perception, emotions and meanings significantly influenced the performances the human beings establish around material objects. The unique and peculiar ways of doing are mediated and affected by the material character and their qualities. For that reason, he performative experience, acknowledges the active role of materials in shaping ways of doing, physical actions and practices, e.g. to scratch, finger, squeeze, etc.

When the scholars in the field of materials for design had already stressed the central role of materials in shaping meanings, sensorial and emotional interactions, highlighting how the right choice for material and process affects the user-product interaction, and often contributes to give to products the features that are mediators of the quality of the interaction itself (Wiberg & Robles, 2010; Rognoli et al., 2011), the HCI community still considered only the functional properties of materials, and they didn't believe their power as signifiers (Regier, 2007; Fernaeus & Sundström, 2012). We have to wait until the formalization of the "material turn" (Robles & Wiberg, 2010) for HCI to put a particular emphasis on the methodological importance of closeness to the materials-at-hand and on underlining the importance of actively working with materials. In fact, it was established that thanks to the material interaction, it is possible to activate "a knowledge-generating process inseparably intertwined with, and enabled by, a material discovery process" (Wiberg, 2014). Wiberg stated that materiality could be a framework to understand computational artefacts and their social impacts, which describe how the interactivity of digital computing manifests itself in a material form. The key feature of this notion is the dynamic relationship between people and interactive systems in relation to the materiality of artefacts (Wiberg, 2018). Finally, HCI research shifted its attention from materiality of information to materiality of interaction in the context of material-centered interaction design (Zhong et al., 2020).

Dynamism of materials as an emerging materials experience

The materials themselves are dynamic entities because they always change. This change can be slow or fast, reversible or irreversible, it can involve the material whole body, or it surface, it could be supported by chemical or mechanical properties of the components of materials or it can be related to its shape. Anyway, it is always synonymous of dynamism. This can be enhanced by the use of different kinds of materials (ICS Materials) that change over time or interactive with which the user interacts dynamically, creating meaningful, with a high symbolic and emotional value. The key issue of dynamism is fundamental because we consider the temporal dimension that influences the material experience. The sample of material is no longer considered as something static and immutable that can be closed in a closet or attached to a table, but it is a dynamic entity that interacts with the external conditions influencing the properties and qualities of materials, and then the materials experience.

In the New Penguin English Dictionary, the word *Dynamic* is defined as "something pertaining to or characterized by energy or effective action; vigorously active or forceful; energetic; … something marked by continuous activity or change; something related to variation". Taking into account the above definition, it is easy to realize that there are a lot of shades of meaning for the concept of dynamic, above all if we decide to associate it to the world of materials for design.

There is a particular class of materials that are dynamic and changeable thanks to their intrinsic properties; that is the smart materials. The smart materials are well known by scientists and also by the designers. They are generally defined as highly engineered materials that respond intelligently to their environment (Addington & Schodek, 2004). These materials "have changeable properties and are able to reversibly change their shape or colour in response to physical and/or chemical influence, e.g. light, temperature or the application of electrical field" (Ritter, 2007). The smartness is referred to their ability to sense the environment and at the same time transforming themselves in a controlled way. These materials are fundamentally different from traditional materials since they are dynamic and active. The distinctive qualities can generate unique interfaces supporting a new way of interacting with the users. They can also create a new form of physical interactions based on new affordances and communication languages. If we think to apply these unique material qualities applied to everyday objects, play a big role in people's social behaviour and practices, thanks to their ability to build affective and emotional interactions (Minuto et al., 2014).

Many researchers from different disciplines have studied smart materials from different perspectives and points of view, finding original names that each time highlight the qualities of this class of materials which is able to create many different material experiences. Not only these materials are considered as reconfigurable and dynamically respondent to use or context, but smart materials can change their identities over time. To highlight the dynamism of smart materials over time, some scholars in HCI defined them as *becoming materials* (Bergström et al., 2010). The quality of dynamism is obviously in progress and develops in a temporal dimension. Dynamic materials can also be called "becoming" because they are fundamentally temporal and can assume multiple states of expression that can be repeatedly and minutely controlled over time. As Bergstom et al. (2010) affirmed, the world of materials where the designer chooses the right combinations of features to concretize the intended experience, can be described in terms of being (what is the material?), doing (what does it do?) and also becoming.

Other scholars in their studies highlighted different aspects of smart materials class and decided to call them as *information materials* (Kretzer, 2017). This name is mainly due to their inherently dynamic nature, thus not only carry and visualize information but are also based on information, being artificially created from pure intellect. "Information materials, wants to establish an awareness of a new materiality that can actively change its properties over time, that can be produced and programmed to display a particular performance, and that emerges across multiple disciplines, including nanotechnology, materials science, genetic engineering, or synthetic biology. Most of all, however, it aims at mediating an understanding that these materials are fundamentally distinct from traditional ones. Therefore, they should not only be contemplated in isolation but also lead to profoundly new concepts in terms of architecture and spatial design, attributing value to processes, temporality, and transience". The dynamism of the information materials is linked with the possibility the have to change and transform themselves.

The investigation around dynamic materials continued and also led to the formulation of the concept of *ICS materials*, defined as materials or even hybrid material systems or composites with sensitive, smart or gradually varying properties lead to new and complex ways to design. This opens up new possibilities on the level of concept, form, structure and surface, and paves the way to consider material properties and qualities as dynamic and ever-changing. Materials become the dialogical carriers of a wide variety of information – they become informative and intuitive (Parisi et al., 2020). ICS Materials are not limited to computational, electronic, and digital. Indeed, this definition also encompasses interactive materials using chemical, mechanical, and biological means. It is possible to enrich the ICS Materials definition telling that they are hybrid material systems that work by establishing interactions among their constituting components, and with people, objects, and environments, through the combined use of electronic, chemical, mechanical, and biological components (Parisi et al., 2018). In this case, the dynamism is included in the concept of interaction at the basis of the design of this kind of material or hybrid system.

At least, the dynamism as an emerging materials experience that can change the users' experiences of everyday objects is presented also in the recent publication edited by Skylar Tibbits titled Active Matter (2017) as a result of the Active matter Summit held at MIT in April 2014. In the summit participated researchers from seemingly unrelated disciplines but with the same aim, create active, intelligent and dynamic materials. "Active Matter is a newly emerging field focused on physical materials that can assemble themselves, transform autonomously, and sense, react, or compute based and external information" (Tibbits, 2017). From the collection of case-studies contained in the book, it possible to realize how the dynamism of the materials can take many different physical and concrete forms, going from microrobotics to programmable bacteria, to computational skins. This list of dynamic materials provides evidence, which then turns into awareness, of how the user experience with these materials is dynamic and how dynamism passes through the four levels of materials experience listed above. These are the materials with which the designer will have to deal soon and with which she/he will have to give shape to our future the world.

Conclusion

In this chapter, we talked about how materials are evolving and how the research of materials for design evolved consequently.

From an engineering approach, that only considered the properties and performances of the materials, we moved towards a more user-centred approach considering perceptions and feelings, up to the focus on the quality and the experience of the materials. The concept of materials experience was presented by relating it to an emerging experience: dynamism. Since digital and material are not separate but entangled elements of the same process, the chapter aimed to contextualize the interactive, connected and smart materials in the theoretical framework of materials experience, presenting the possible and designable dynamism of materials as an emerging materials experience.

The materials that will shape the world of our future will be different from those to which design has shaped so far. Technology is hybridizing all physical media and therefore, also traditional materials will have to become more interactive, connected and intelligent. Digital, materials and design are no longer specific and distinct and separate things but are porous elements of the same process of research, design and invention (Pink et al., 2016). These evolving, informative, ICS, active, digital and dynamic materials lead to new expressions and a new sensuality in design. The work of blending the technology and materials, which are elements with different properties, qualities and also affordances, for creating new emerging materials experiences, becomes the task of the designer.

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3.4. What do we need to design innovative teaching methods for ICS Materials in wearable domain?

Venere Ferraro, Stefano Parisi

Introduction

In chapter (I) the domain of Wearable Technologies was presented and articulated as a platform where the combination of traditional materials, reactive ones and active technologies can be seamlessly integrated to satisfy functional and aesthetical requirements. In chapter (II) we provided a definition of Interactive Connected Smart (ICS) Materials, as breakthrough materials that are particularly indicated for the application into the wearable technologies' context. Dealing with such innovative and novel materials in Design & Engineering practice and – particularly – in didactic requires very specific approaches in accessing information, acquiring knowledge and skills, and implement them into solutions. A broad survey on the teaching methods and approaches is carried out and presented to definite the State of the Art. The main approaches emerged as: mix-methods, multi-disciplinary, hands-on and material-centred, simulation-focused, application-oriented, context-driven, user-centred, and speculative.

In chapter (III) the central role or the expressive-sensorial qualities and materials experience in didactic approaches in materials for design are presented. The dynamic dimension of ICS Materials highlights the challenge of understanding and manipulating their aesthetic qualities to define intended meaningful experiences for the use. As the existence of these complex materials is coming to light, and their presence in some conceptual applications and in limited industrial sectors is getting to be acknowledged, it is crucial for Design and Engineering Education to introduce them in theoretical and experimental teaching activities. With the proper tools and methods, students would acquire interest and an organized set of knowledge, skills and competences about such materials. As young professionals, they will be ready to manage these materials from a creative and executive dimension to respond to the demand of the industrial sector about having knowledge to understand and skills to manage this class of emerging materials and technologies.

According to the gaps and issues emerged in the previous chapters, in this chapter we will propose a framework of contents, approaches and techniques to be integrated into innovative teaching methods for ICS Materials.

Gaps and issues related to ICS Materials

The previous chapters and related literature review on educational methods and tools to design with these EM&Ts revealed the main gaps and issues related to the application of ICS Materials in Design Education.

Generic gaps and issues in common with other Emerging Materials and Technologies areas are listed as follows:

- Complexity, requiring more ground to cover and more understanding to be gained.
- Cross-disciplinarily, requiring the involvement of experts and different disciplines.
- New role of designer in the project, requiring new mindset and new ways of working and obtaining knowledge.
- Novelty of the field, causing related lack of samples, documentation and procedures.

Regarding the very specific issues related to ICS Materials we can cluster them into six main categories:

Commercial and technological issues. There is a missing path to commercialisation, since explorations often stop at the concept stage related to materials manufacturing (Barfield & Caudell, 2001). One crucial gap is the current lack of miniaturized technologies in smaller size and thickness allowing the seamless integration in the materials. Another gap is the one of flexible technologies, allowing flexing and stretching when integrated into wearables. Another issue is the need for materials and embedded sensors to be lighter and more flexible. Due to these gaps, it is difficult for the industry to reach the full potential of ICS Materials and Wearables.

Missing of collaborative practice. ICS Materials and wearables are developed at the intersection between design, materials, and interaction. There's the need to develop collaboration strategies between design and science, to more fully realize both the opportunity and the contexts that Wearables and ICS Materials offer (Fairburn et al., 2016). These include the integration of enablers (technicians and instructors, cooperation with computer scientists and Human Computer Interaction practitioners) and enablements (equipped lab, electronics components, and coding), in particular for advanced experimentations.

People acceptance. Besides technological aspects, one emerging and crucial challenge is identifying meaningful and purposeful ways for designing with and for ICS Materials. This is especially true for Material and Technology acceptance of unknown materials, or when materials are out of context, or the materials have a 'bad reference' or negative connotations. In achieving what is technically feasible with this EM&T, designers have the new task of considering the well-being of users to avoid frustrations, nuisance and discomfort (Ritter, 2006). Besides technical and functional issues, User-Centered Design and understanding and designing for Materials Experience arise a critical issue to meet users' acceptance and appreciation (Karana, Pedgley & Rognoli, 2015; Karana et al., 2015).

Lack of Sensory experience investigation. Designers must consider the user's cognitive load, sensory and cognitive bandwidth. ICS Materials change over time in a reversible manner. This adds the issue of understanding and designing with and for dynamic and ever-changing matter. Dynamism makes the sensory and experiential dimension more difficult to capture. A holistic approach considering static and temporal expression is required.

Material granularity. ICS Materials are characterized by granularity; they can be considered as a material assemblage or system: ICS Materials and Wearables can be both seen as a finished material, or as an assembly component that can be combined in a system with limitless possibilities. What is provided to students (finished material to apply or components to combine and shape) will impact on the format and methodology of the teaching activities.

The need for a Holistic Approach. From these gaps a urgency is emerging: the one to develop and apply a unique and systematic learning and teaching methodology encompassing competencies on materials, design and interaction technologies, the hybridization of physical and digital, the interplay of dynamic and static expressions of the materials and technologies, the capability to combine knowledge on technical properties and fabrication processes with the understanding of the sensorial and experiential qualities of materials.

ICS Materials EM&Ts area is indeed situated in the intersection of Design, Materials & Manufacturing, and Computer Science. Other complementing and supporting disciplines involved in the area are Ergonomics, Psychology & Perception, and Sustainability. Therefore, an innovative methodology to teach ICS Materials, covering theoretical knowledge – based on materials and design –, practical knowledge through a learning by doing approach – coding skills and manufacturing processes – and skills about how to design successful products by involving companies is needed.

In this chapter, we propose a systematic framework of approaches, methods, and tools to overcome them in design education. The aim of the framework is to:

- Provide a body of knowledge regarding ICS Materials – including Smart Materials and E-textiles – and their meaning, potentials, and critical issues in relation to the Wearable domain; knowledge on related

subjects, e.g. basic knowledge about user-centred approach in HCI and sustainability.
- Introduce students to new skills: "tinkering" and experimenting in a cross-disciplinary environment, for example in a FabLab or in a maker-space with experts from different fields.
- Practice students' design capabilities in transferring and applying knowledge from material research and exploration in the design concept and prototyping; managing the complexity and designing new interactive systems leveraging ICS Materials properties and qualities, considering the context of application, for example wearable.

Understanding ICS Materials: what do we need to discover ICS Materials and apply/Use into wearable textile systems?

Designing, teaching and learning with and for ICS Materials would require a unique and innovative mindset open to complexity, temporality, and interdependence. To understand ICS Materials, we could use a combination of theoretical lectures and online interviews with experts covering different subjects, e.g., Materials experience, Dynamism, Smart materials technicalities, to frame materials-related aspects such as historical use, cultural meaning, chemical composition and technical qualities. The use of physical samples (with materials and technology embedded or separated) is beneficial to the activities. In alternative, teachers can provide cards or other tools representing ICS Materials. Students can be assessed by the production of a scholarly paper to be presented to the rest of the class, developed doing desk research, field research and group discussions. The teachers' profile is based on design and material engineering.

Besides introducing materials technicalities – what is possible to do with materials – as shown in chapter I and chapter II, and materials experience – what materials do and how we feel it –, as shown in chapter III, it is fundamental to understand ICS Materials as hybrid, dynamic, and interactive entities.

- ***Understanding ICS Materials as Hybrid entities***. The term 'hybrid' identifies complex entities constructed with a combination of components and substances belonging to different domains and characterized by very diversified, even contrasting, nature: the natural and the synthetic; the analog and the electronics; the latent and the mutating; just to mention some of the most exemplary assembly defining a new materiality. One that is blurring between different territories, sharing borders of different disciplines, and intersecting in novel spaces for designers to explore (Antonelli, 2008). One where manipulating physical matter by making and prototyping blends with embedding electronic components and programming their digital apparatus, and even with synthetic biology and growing living organisms. Hybridization is enabled by multidisciplinary environments where multi-disciplinary collaborations are encouraged to be experimented allowing a continuous flow of cross-fertilized inspirations and redefining the practice of material design (Parisi, Holzbach, Rognoli, 2020).

- ***Understanding ICS Materials as dynamic entities***. The term 'dynamic' is generally applied to all materials, since they are not to be considered as static entities. Indeed, some of their attributes and characteristics fluctuate over time, for example availability, price, manufacturing processes, but also cultural associations, meanings, and attached emotions. Dynamism is also the capability of a material to physically change over time. Traditional materials are subjected to contamination from the environments and the users, which produce alterations and new expressiveness over time, e.g., copper reacts to the oxygen in the air producing its very characteristic green patina changing the material aesthetics and perception. Dynamism can be capitalized for aesthetic and functional aims with the application of smart materials, also known as reactive, or functional ones (Ritter, 2006) or with the embedment of micro-electronics, in the form of sensors, actuators, and micro-computing technologies. Smartness is defined as the capability of a non-living entity to adapt to circumstances. Smart materials indeed are the ones that respond to external stimuli by reversibly modifying their qualities, performing mainly shape-shifting, color-changing, light-emitting, and electricity-generating behaviors. Dynamic materials have both a transforming and transformative nature. The transforming nature is described and articulated by the concept of *becoming materials* (Bergström et al., 2010), focusing on smart materials as fundamentally temporal entities that can have multiple states of expression over time that can be controlled by designers to intentionally shape some experiences. The transformational quality of these materials produces new affordances, stimulates new communication languages, and triggers new way of interacting with the user, playing a big role in shaping people's social behavior and practices, due to their ability to establish emotional and affective interactions (Minuto, Pittarello, Nijholt, 2014).
- ***Understanding ICS Materials as Interactive entities***. The term 'interactive' stands for the ability of materials to establish mutual relationships with other entities, non-living ones, e.g. the environment or objects, and living ones, e.g., people or other living organisms. This relationship is conveyed by the exchange of data and information through the material qualities and behaviors. The concept of *informa-*

tion materials (Kretzer, 2017) "(…) wants to establish an awareness of a new materiality that can actively change its properties over time, that can be produced and programmed to display a particular performance, and that emerges across multiple disciplines, (…) attributing value to processes, temporality, and transience". The book *Active Matter* collects examples of materials based on a diversity of interactive components, including microrobotics. Active Matter is defined as "a newly emerging field focused on physical materials that can assemble themselves, transform autonomously, and sense, react, or compute based and external information" (Tibbits, 2017). Interaction can be both considered as a quality strictly related to technologies, in particular the digital and electronics domain – 'Technology-Centered view'–, or a generic quality of establishing relationship – 'behavioristic view' of Interaction (Saffer, 2009). In addition, the material itself invites and encourages the user to perform and establish actions, ways of doing, and practices (Giaccardi & Karana, 2015).

Exploring and shaping ICS Materials: what do we need to experiment and fabricate?

This area of knowledge and skills can focus on hands-on experimentation with ICS materials leveraging technical knowledge (i.e., basics of coding, electronics, and Human-Computer Interaction provided through theoretical lectures, tutorials and exercises) and design approach in computational/material tinkering, i.e., creative experimentation with physical and digital. Through this process students will produce samples and process documentation on which they will be given assessment. Exploring and shaping ICS Materials can involve teachers from the design area and teachers from computer science. The design practice is adapting to the integration of such materials, unfolding novel and hybrid approaches and techniques, taking in consideration the material physical qualities, the dynamic behaviours, and the material form and structure, working on the making of the material itself and on the smart components programming and embedding.

- *Material Tinkering.* When it comes to materials exploration, Material Tinkering is applied. It means hacking and manipulating physical elements – both materials and technologies – in a playful, creative, and purposeless way to get familiar with the material characteristics and find opportunities (Parisi, Sonneveld & Rognoli, 2017).
- *Collaborations and Open-source environments.* The spreading of workshops, fab labs, maker spaces facilitate this kind of experimentation and

support inter-disciplinary collaborations. Open-source material databases and tutorials in online platforms enable the access to knowledge.

- *Fabrication*. The fabrication of ICS Materials combines traditional materials with innovative ones, low-tech crafting techniques with advanced technology, creating a new design space to explore; one in which the capability of designers to modify the characteristics of the materials can be made by both physical manipulation and digital technology, including digital fabrication processes and generative and parametric design. Different techniques to fabricate ICS Materials are about creating multi-layered surfaces and embedding technologies into a material composite (Ferrara & Pasetti, 2020).
- *Material programming*. Material programming envisions a future practice for designing the tangible and temporal forms of ICS Materials, blurring the boundaries between programming and crafting these new smart and computational materials (Vallgarda et al., 2017).

Applying ICS Material to Wearable textile system: what do we need to ideate ICS Materials?

The ideation of ICS Materials can be done by the execution of a design project with a brief launched by a company. The project work can be realized by developing design and prototype(s) based on the output derived and the skills acquired from understanding and exploring the materials. The design techniques that can be used are drawing, concept development, and prototyping, supported by demonstrations of making techniques and combined with group discussions. The design method is based on the combination of speculative design and a holistic and hybrid approach to design considering different layers of the artefact (e.g., digital and physical, product and experience, static and temporal). The expected deliverables on which students can be assessed are prototypes, samples and demonstrators, videos, presentations, and documentation of the process. The teaching staff involved need expertise in design, manufacturing, and computer science.

- *Systemic Design: Open and Complex System*. ICS Materials can be considered as complex systems interacting with other living or non-living agents as part of a physical and socio-technical ecosystem. Interdependency with other entities, first of all people, and within the components constituting ICS Materials, requires a design approach to ideate ICS Materials are based on Systemic Design considering ICS Materials as an Open and Complex system interacting with other entities.

- *Speculative Design.* Technological limitations related to the seamless integration of components in the materials still exist, but in a future perspective are going to be solved with the increasing miniaturization of technologies even into "intelligent grains of dust"– namely, Smart Dust (Warneke et al., 2001) – and alternative energy supplies, such as flexible batteries and piezoelectric materials. Sensing and communication capabilities will be embedded at the level of the material manufacturing itself as opposed to the level of the object design, as it is today. For this reason, a speculative approach may be applied, as it addresses looking toward the future, and creating products and scenarios for those fictional scenarios. Speculative design tries to imagine what it would be like to design without the current limitations of technology, culture, and politics in mind (Dunne & Raby, 2013).
- *Creativity, metaphors and analogies*. In the Ideation phase, finding metaphors and analogies support the generation of positive and meaningful experiences for the users. In particular, a successful strategy is the one to simulate qualities, shapes and behaviours inspired by nature, through Biomimicry (Benyus, 1997), wich uses Nature as a model.
- *Sustainable design*. One of the main challenges regarding the development and application of ICS Materials is the one of delivering an environment-friendly final product, using non-toxic, easy to disassemble, update and repair, long-lasting and recyclable components. The integration of interactive technologies with renewable and biodegradable materials and fibers may allow the separation of components, as in the pulp-based computing by Coelho et al. (2009), in the mycelium-based interactive object by Lazaro & Vega (2019) and in transient electronics, e.g., biodegradable electronic devices and dissolvable circuit boards made of silk proteins (Tao, Kaplan & Omenetto, 2012). To this extent, the integration and partial substitution of traditional electronic components and energy supplies with smart materials lead to the optimization and reduction of energy flows. This is the case of piezoelectric materials as an alternative for batteries, or thermochromic coating as an alternative to technological interfaces. Also, conductive materials support and enable the interconnection between the components of the system substituting traditional wires and cables. As shown in chapter (II), the framework of ICS Materials is totally inclusive, prioritizing electronic based materials, but opening up also to the interactive qualities of bio-based and living materials. Indeed, in the near future, substituting electronic and traditional smart components with bio-based ones is a plausible scenario, as experimentations and prototypes developed by labs, universities and designers all around the world demonstrate.

- *User Centred Design and Unobtrusivity.* ICS materials can be applied in a range of design sectors, up to wearable technologies. The application of such materials into wearables unfolds many opportunities both from an aesthetic and functional perspective. ICS materials enhance the 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 wellbeing. By introducing smart materials and interactive technologies into wearable, new tasks and challenges for designers emerge. Designers must ensure that – in achieving what is technically feasible – the well-being (Ritter, 2006) of people is preserved, and the requirements of wearability, human movement, unobtrusivity (Gemperle et al., 1998), comfort, warmth, softness, flexibility, and maintenance – including washability – are respected (Luprano, 2006; Ferraro, 2012). In particular, the designer should avoid the wearable device to be obtrusive, meaning causing emotional and physical distress, both by identifying the proper body areas, and identifying the right combination of material sensory qualities, dynamic behaviors, and form to be in contact with the human body.

Conclusions

In this chapter, we argued the urgency for Academia to develop teaching methods to transfer knowledge and skills about ICS Materials so that young designers could be updated and could respond to the demand of the industry. We presented the main gaps and issues related to the area and we proposed a systematic framework of approaches, methods, and tools to overcome them in design education. The aim of the framework is to provide a body of knowledge, skills and capabilities regarding ICS Materials, so they could be able to face the challenges represented by the integration of these materials in purposeful and feasible applications and new products development. Design educators, students and young designers are encouraged to take part on the challenge of their sustainable and smart inclusion into everyday practice as a catalyser for change. We are confident that this will positively contribute to fulfilling technological challenges, and mitigating and solving societal and environmental issues, today and in the nearest future.

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4. Advanced Growing Materials

4.1. Advanced Growing Materials - Designing with Living Matter

Anke Pasold

Introduction

The act of growing materials has gone hand in hand with our development as a civilisation.

Humans have cultivated, harvested and effectively used grown materials since their very first attempts as farmers. And since the very beginning, the grown has not only been harnessed as food source but also as a means for creating useful artefacts in a necessary pursuit of economically sourcing everything there was.

Over the last decades, we have advanced to growing materials in laboratories with the aid of synthetic biology and through experiments with microbes allowing us to engineer specific material properties and to design with a view to manufacturing both form and function within one step.

However, the specific creative process connected to designing with living matter has had a substantial influence on how we conduct the work and when we want to design with advanced growing materials a number of expertise and a pool of knowledge of different disciplines have to meet challenging our hereto employed approaches and the conventional understanding of design processes.

The following four chapters explore this field from the perspectives of the relevance in the design field, the didactics in the bigger range of complex, open systems, the current didactic takes and a framing for possible future teaching within this field.

Advanced Growing materials in the context of the project

Advanced Growing materials and technologies is a research field of cross-disciplinary material research that is defined by the cross-fertilization between the science among others biology, chemistry and material science, design and engineering for diverse forms of material expression and performance (Karana et al., 2018). It is an area that bears obvious links to nature in origin, inspiration, understanding and formation, but in contrast to a lot of other design approaches using these references, it directly and actively employs natural systems in the form of living matter.

It is a discipline that emerged at the turn of the millennium and that has especially grown over the last decade with a rising number of investigations, projects, innovations, companies, academic journals, conferences, as well as the establishment of online communities and information hubs and an ever growing number of bio- and wetlabs around the world as well as first attempts at partial or whole educations on the topic.

The project results span from conceptual ideas to material innovations and implemented product solutions and have created a very vibrant and constantly evolving field with an ever-growing community, on both professional and more DIY-based levels.

More specifically, advanced growing materials are those created from and through a controlled cultivation of living matter that can be directly grown and/or manufactured into the subsequent matter formation, function and performance by tapping into the organism's natural growth behaviour.

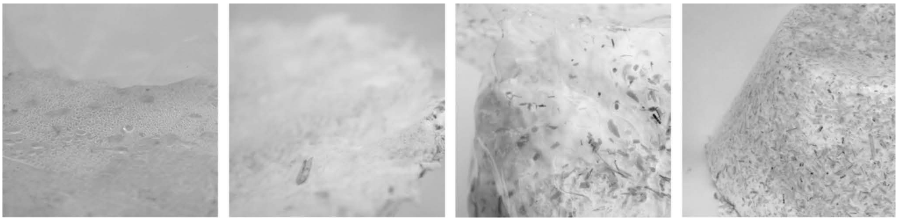

Fig. 1 - Recording mycelium's growth behaviour. Photos by alkymi

Designing with them is often named 'Growing Design', 'Biodesign' or Biofabrication. Though slightly different in their definition, all three constitute approaches, where designers collaborate with biological organisms, forging favourable conditions and constitutions for guiding their growth towards the respective creation of material and product applications. These emerging new design practices are stimulated through the convergence of biotechnological and design tools utilising the natural mechanisms, the living matter, in a bottom-up approach (Attias et al., 2020).

Relevance for Design Practice

Advanced growing materials bear a significant role in the current search for substitutes and are therefore often seen in the role as surrogates for harmful, conventional materials in the context of packaging, building and insulation materials, substitute for leather, active agents for fabric dyeing.

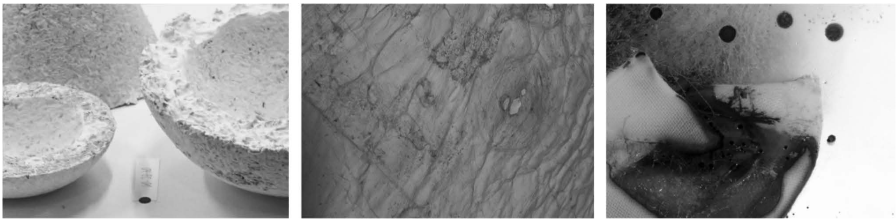

Fig. 2 - Mycelium shapes, SCOBY leather, Controlled fabric dyeing with janthinobacterium lividum. Left image by the author, centre and right image by alkymi

In that sense, their area of exploration can be seen as a source of inspiration for alternative materials, processes and approaches within an interdisciplinary field of operation. They support a general focus on a different material attitude within design projects and the physical constitution of the same within the real world. They advocate for a design process that starts with the creation of the material and the inclusion of relevant material parameters right from the start to therefrom lead to an applied solution that is fit for circular processes.

They can challenge convention and inspire new practices through their applied processes, in particular with sight to the current material selection, performance and perception practice vs. the acute awareness of resource scarcity and circular economy agendas, which ultimately means they can play a role in facilitating our transition to a more sustainable way of life by targeting contemporary challenges such as climate change, low energy manufacturing, natural resources depletion, human and environmental health (Diniz, 2019).

In terms of innovation, their entry point to a new thinking about materials, the way they come about, are sourced and applied but especially the specific role they play in the discussion about the material selection's role and approach within the project.

They are also displaying and in singular project samples manifesting the potential to facilitate novel product ideas and the eventual creation of market-ready product solutions (Camere & Karana, 2017; Karana, 2018).

In their very nature as a growable resource with high efficiency due to a (compared to conventional materials) relatively high growth rate and little energy input, they can positively contribute to sustainable and circular material solutions with a world of new material composites, that, if ideated in the right way and through the use of renewable or revived organic resources as feeding elements for the living organism, can be biodegradable. They are easily reproducible (though with small variants in the results, which is something that can and should be designed for) and they can be developed to a respective (performative) finish (Camere & Karana, 2017).

They furthermore enable new ways of creating, forming and joining materials as well as the inclusive eventual shaping of ideated products.

On a wider scope, and in their referenced similarities to Do It Yourself (DIY) materials (Garcia et al., 2017; Parisi et al., 2016; Rognoli et al., 2015; Rognoli, Ayala-Garcia et al., 2016; Rognoli, Parisi, et al., 2016) they are, furthermore, loosening the boundaries between disciplines, and are thereby, furthering intense collaborations of among others Material science, design, engineering and the social science as stated by Karana for a common purpose of designing for meaningful material experiences and the common endeavour to find meaningful applications (Brownell, 2015) in a time and age where the material discussions need to be taken to a new level.

Designing with Living Matter

The designer's role shifts to being a co-creator of the materials in a co-working manner (Collet, 2017), where both the matter, its specific environment and conditions (both during and after growth) and the designer influence the eventual shape and constitution and therefore the expected function and performance. This in turn leads to a complex, open project setup that concurrently handles more parameters than design processes in the more traditional sense of understanding.

Examples of experimenting and designing with living matter are found on all layers from actual research laboratories to academic institutions and professionals that experiment within and develop the field of Advanced grown projects. In many cases this is done via collaborations between research institutes, design and architectural and engineering schools, DIY-driven creators and professional designers or via cross-disciplinary project setups in the attempt to triangulate the designers work with that of expert individuals, representative key institutions and key sector of industry as the required very broad expertise cannot be located in design alone, making cross-disciplinary working a valuable asset (Chieza, 2018).

The approaches towards designing with living matter are, however, not consolidated and therefore widely lack proper documentation or inclusion in curricula. There are found a lot of DIY initiatives that take inspiration from the informal Maker culture with connected open sharing of knowledge and democratized access to technologies and outcomes. Paired with the opening of previously closed-off knowledge spheres such as biology via e.g. DIYBio (DIYBiologist, 2008) or WAAG (Stikker, 2018) and similar biohacking portals such as the exploration of intersections between traditionally separate domains and ways of working is further encouraged. (Sharples, de Roock, Ferguson, Gaved, Herodotou, Koh, Kukulska-Hulme, Looi, McAndrew, Rienties, Weller & Wong, 2016).

The fundamentally different nature of the projects means a change in approach to designing that starts with an innate material understanding to be able to successfully integrate that knowledge into projects. And whilst there are approaches trialled within that field, the particularity of a necessary descent to the microscale to create influence and change the material's variables in accordance with the conditions and therewith achieve pre-intended qualities for the resulting or co-created tangible products and applications need a further look at a wider scope of possibilities through a hybrid method approach.

In order to sufficiently source and apply living matter in the context of design, we need to learn about and with them. Approaches can be found anywhere between a DIY approach, where one learns from others through open source knowledge to partial curriculum inclusion to the establishing of cross-disciplinary pedagogical zones, where students can freely inquire, discuss, conduct experiments and take actions with the aim of a positive impact (Meyers, 2018).

Fig. 3 - Designing with Living matter requires the designer to gain a material understanding for an eventual material formation within the material's ecosystem. Illustration by the author

Issues & Gaps

Designing with living matter is, however, still a reasonably young discipline and therefore poses a number of challenges. It is a field of high complexity spread across a number of disparate disciplines, with consequentially more ground to cover and more understanding needing to be gained. The Cross-disciplinarity encompasses the involvement of expertise and possibly even experts from different disciplines, which comes with related communication challenges in terms of vocabulary and terming.

This combined with the relative newness of the field results in a lack of related samples, lack of procedure and documentation, despite singular attempts, on the general field of advanced growing. The ones created are either incomplete or more often than not from open source environments, on githubs, through DIY sources and therefore still pose obstacles for access and have an inherent risk in terms of validation. It is difficult to source details on important elements such as precise material compositions, incubation conditions, and fabrication methods (Attias et al., 2020) and little research can been found, in which all the significant variables are systematically tested (Attias et al., 2017) and sufficiently documented as a validated base for further exploration towards a possible market implementation. These documentations are equally essential in the process of understanding the material and constituting a base knowledge for constructing a foundation from which to design from as this will give inherent knowledge about structure, aesthetics and potential form.

The designer themselves has a new role (artefact designer turns material designer) in the process, which requires above stated as a prerequisite for working within the field including the establishing of successful and appropriate processes, methods and tools which to a big extent need to be (re-) learned whilst yet others need to be established. This applies especially to above named complexity which creates additional challenges related to complex systems, which should be taken into account in the development of support tools and methods for Growing design and are covered in more detail in chapter 2. But it relates equally much to the designer's struggle with the time-consuming nature (at least in the initial material understanding phase) of living material projects and the inevitable separation of the moment of crafting from the evaluation of the outcome due to the delay through growth and processing time, which makes for a very intangible parameter in a process that reclaims hands-on to experience materials (Ayala-Garcia, 2014; Groth, 2016; Mäkelä & Löytönen, 2015; Rognoli, Ayala-Garcia et al., 2016; Sonneveld & Schifferstein, 2009) through a hands-on approach methods as its premises.

At the same time, the material formation does not come after the ideation as a separate phase of giving form to the emergent idea. In fact, the materiality is simultaneous with and intrinsic to the creative process itself: the materiality does not only exist or impose challenges and constraints on the designer's idea (Gherardi & Perrotta, 2014), ways of working and attitudes but it guides them to a big degree, giving the feeling of a disconnectedness between process and result.

With living matter that extends to the necessary acceptance of the co-authorship of the materials and the therewith connected unpredictability (Ginsberg & Chieza, 2018; Mäkelä & Löytönen, 2015) which inevitably leads into needing to accept accidents as enhancers (Mäkelä & Löytönen, 2015), instead of forcing the material to achieve a predesigned shape, finding a balanced dialogue with the material where both guide each other to a successful result. The result itself bears challenges with regards to new aesthetics (Karana et al., 2018) and the ethical parameters linked to designing with living matter. Especially for project endeavours that make it past the exploration phase. More often than not designers get caught in the exploration stopping several steps short of the realisation into an actual product application, let alone a path to commercialisation, which is the constituted big gap between material exploration and finished products (Mäkelä & Löytönen, 2015) is often missing.

In conclusion, designing with Living Matter does need both, a new overall approach to the projects, a new way of working, a new way of understanding the outcomes and possibly a new way to approach the consumer product market. It needs to acknowledge the processes as complex and look for inspiration on how to approach that complexity (further explored in Chapter 2), it needs resourcing of hands-on, experimental and experiential methods (highlighted in Chapter 3) and it needs looking at the educational setup and frame (further elaborated on in Chapter 4).

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4.2. Didactics for designing in Complex, Open Systems

Anke Pasold

Introduction

Designing with living matter is, by its very nature, designing with complex, open systems.

Any living system is a self-regulating system that is cognitively connected to its bigger ecosystem in form of a dynamic, networked structure (Capra & Luisi, 2014).

The complexity of such natured projects has been addressed within the systems thinking or systemic design (Jones, 2014) that looks at ways of understanding and tackling the interconnected, cross-disciplinary nature of processes that are placed across a number of different fields with no clear boundaries. Lending didactic approaches from a more generalized systemic approach, therefore seems a logical step towards adequate ways of looking at working with Advanced growing materials to be able to apply findings from that domain. Especially in view to the characteristics rooted in the complexity of working with living matter that impose considerable challenges for designers, such as the lack of control in the process, the connected uncertainty, the lack of boundaries, the unpredictability of reactions to induced actions and the parameters interdepencies, some of which there exist attempts to solving within the realm of systemic design approaches.

In theory, designers are to a certain degree equipped for complexity through the wicked problem solving (Rittel & Webber, 1973) that has become part of their practice as many of today's design challenges can, in fact, be described as complex due to their cross-disciplinary systems that behave in unpredictable ways and which have multiple stakeholders from different domains and with differing objectives, different ways of framing or characterizing the challenge and description in domain-specific terms. And there are a number of approaches that work with the framing of the very same (Dorst, 2015).

However, in the light of Advanced growing materials, designers are not only faced with yet another new discipline and with a terrain where the usual methodological approaches don't suffice and expertise, skills and knowledge from other research fields are indispensable but also with a new type of collaborator, the living matter itself.

Advanced Growing Materials as complex-open system

Designing with Advanced Growing Materials inevitably places ones project into a complex-open system category that the creative needs to operate within.

The matter itself is part of the bigger ecosystem, whose interdependencies need to be understood and respected to be able to structure explorations accordingly in the process of the co-creation.

The intent of creating and successfully designing with living systems places such project endeavours at three levels of complexity: firstly, the complexity that lies in the very placement at the intersection of disparate disciplines, secondly, the complexity at the material level as there is an inherent need of understanding the living matter, the specie, before embarking on exploratively co-creating with it and thereby consequentially employing it into a purposed use and, lastly, the complexity at the application level, where the two first are important requisites. This means that the material has to be understood in terms of fluxes, its matter-energy and information, amongst its parts and with its ecosystem to be able to relate those findings to a respective forming possibility. This further implies the understanding of actuators and reactions, which will give an approximated understanding of the space of possibilities for interaction, manipulation, effective use and application.

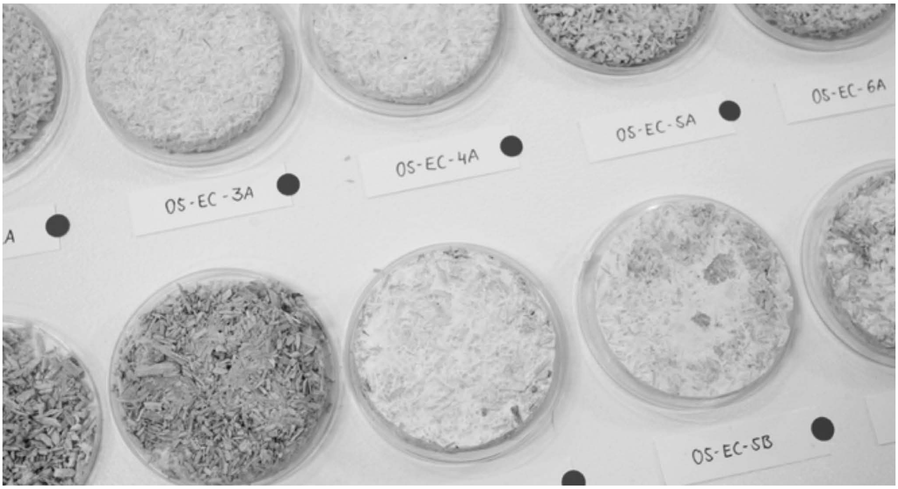

Fig. 1 - Mycelium: Studies of different nutrition and grain in substrate. Photo by alkymi

Just as any other complex system living matter is characterised by dynamically organising and intricately balancing their interconnected entities that are parts of a vaster pattern that connects and evolves by discernible principles (Capra & Luisi, 2014).

The first task for the designer is to understand and effectively map those very correlations and the therewith connected discovery of the pattern to be able to creatively guide and employ the creation of the material for the purpose of the design process. Within this process the designer will need to tackle the eleven (partially overlapping) characterisations of complexity that have been established: the system's unpredictability, context dependency, noise, emergence, stochasticity, non-linearity, cross-talk, open systems, overlapping hierarchies, incomplete understanding and possible multiple characterizations (Chen & Crilly, 2016).

Particularly open systems bear the challenge of boundary definition, a definition of where they start and end and their therewith connected invariances.

Living matter is categorized as an open system since it is difficult to define a start and end in terms of definition and boundaries, which are in flux with the environment and elements can appear to be (at the same time) part of the material system and part of the system's environment allowing for a variety of states that arise from interactive currents of matter-energy and information. This interplay is synergistic, generating "emergent properties" and new possibilities, which are not predictable from the character of the separate parts. This can be considered a challenge or an opportunity (Sevaldons, 2014) but needs to be addressed either way.

The need for boundaries

For being able to design with advanced growing materials, it is, however, imparable to establish boundaries within which to create the design space and to understand both details and totalities (Roshko, 2010) that guide a path to understanding outcomes of certain experimental actions.

A basic understanding of how the material behaves biologically is an imperative for applying technical and experiential consequences when shaping and respectively growing it into a usable form and function. This understanding, however, can only be reached by an initial understanding followed by explorations into form and growth simultaneously.

To handle the complexity that arises between the possibilities within this interconnected network of relations and dependencies, a number of strategies that reach beyond traditional approaches, and therefore help acquiring a good understanding of how the system works need to be employed to make the non-straightforward relationship between the biological entities being engineered and the systemic behaviours those entities are designed to exhibit (form, function, performance) explicit.

Understanding and controlling complexity

Two main approaches can be applied to gain this initial understanding and establish a sense of control to effectively design within the network of parameters at hand: Rational design approaches and Black box design approaches (Chen & Crilly, 2016), both aiming at making the complexity more digestable.

The first include simplifying principles such as the reduction to certain conditions that are explored individually first to establish certain patterns, learning through designing and making experimentation integral to the process of designing or constructing the system, which is modelled on nature's trial and error way of evolution and can be consolidated in experiential and experimental learning approaches (*that are elaborated upon in chapter 3*), and integrating multiple characterizations so that information about the system and its elements from different sources and domains are integrated and can be searched when designing, which points to the actual setup of the work as being structured in cross-disciplinary teams or co-laborations with different disciplines experts inclusion and input.

The second, the Black box design approaches, aim at making things more concrete. They can be employed with well-defined requirements e.g. maximising growth speed and poorly defined requirements e.g. improving quality.

Defining the field of exploration

This practice of isolating parts for explorations in the context of living matter e.g. only working on the influence humidity is going to have in a given context will give a more comprehensive understanding of those individual influencing factors. It is effectictively restraining the search space to only explore certain parameters or certain matter or certain apects of a certain matter to gain a first understanding and reach a level of certain concreteness.

This aligns well with observations from educational contexts, that advocate for a more defined and limited field of exploration (Pugliese & Pinto, 2017) to within those restraints allow for real depth that can create novelties and prevent students from stranding in the pool of sheer endless posssibilities.

Tackling and working with complexity

Whilst these approaches allow for a more managable working setup, they should still consider that the singular parts react in unity once taken out of isolation.

Complex design is often represented not as a single unified approach but as a set of related perspectives and activities. The three identified aspects of complex design are the constructing of a certain characterisation of complexity, adopting a certain objective with respect to that complexity and exercising a certain design approach with respect to that objective. This is strongly linked to the awareness that the objectives within the design process are different. Whereas artefact designers in the traditional sense commonly have a specific list of requirements with regards to the object's future use and thereby have very tangible objectives for the process outcome, the actions here are moved towards three high-level design objectives that of designing to avoid complexity, designing to compensate for complexity or designing to exploit the systems complexity (Chen & Crilly, 2016) thereby redefining the complexity into a necessary agent within the project.

Need for tractability

When trying to understand the system, we are therefore probing for the correlation of certain action to reactions to uncover ways of interacting and manipulating the system and its constituent parts and in consequence being able to record and **map behavioural patterns** that give a bigger, more predictable outline of entry points. It is a way of addressing complexity by tractably searching the vast solution space and recording findings, overlaying, synthesising and mapping them through the designerly skill of visualising content in form of design schemata (Lawson, 1996; Speaks, 2002) or gigamaps (Sevaldson, 2011) structured in the form of systems-thinking methods to capture complexity on the path to an understanding that will enable designing within the laid-out, defined frames.

Learning as an inherent part of the process

The most important conclusion from the working with complexity, however, is the recorded manifestation that only by working and therefore designing with the system, at whatever level of complexity or isolation, will we gain a better understanding of the very same (Chen & Crilly, 2016).

This is aligned with a general advocation for more hands-on, experimental and experiential ways of working within the context of material-based explorations in general and living matter in particular. This emphasis on trial and error and essentially learning by doing, through experiments, through the hands will be covered in more detail in Chapter 3 that is looking into the experimental-experiential approaches. It is the probing and recording the system's given feedback that loops to the next iteration of probing and recording to establish patterns through informed alterations.

Simulation

Essentially the objective of understanding the system is to get some predictability through the recognition of patterns, connections, leverage points and feedback loops (Meadows, 2009).

Once recognised these structural, formal and behavioural patterns can be simulated. In a more advanced step, this could be done through computation making for a wider, more advanced search space.

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4.3. Experimental-Experiential Approaches to Designing With Advanced Growing Materials

Anke Pasold

Introduction

The challenge of working within a field of high complexity, in between a number of disparate disciplines and with the different expertise required for this systemic project nature necessarily requires the use of a number of different strategies once the complexity has been broken down into smaller, more manageable 'pieces'. Each of these 'pieces' can then be explored through a resp. scientific or designerly approach of their own accord.

For the biggest part, these constitute as singular experimental and experiential approaches rather than overall strategized research designs or complete curricula. They can be seen in the few established teaching projects, most of which submit to reduction in complexity to tackle the new field of exploration.

So, really it seems that in order to grasp the initial working tools and methods, they are enjoying an exclusive viewing.

Experiments in theoretical framing

Although the need for formal input in form of lectures and tutorials is not excluded from the syllabus and is in fact seen as a way of building a base level of understanding, subject placement, general introduction and introduction of the respective other, there is an inevitable rise in hybrid methods and a heightened and necessary focus on experimental and experiential methods to qualify the knowledge and expertise grounded in the cross-fertilised setup of design and science. The methods furthermore emphasise the role of hands-on approaches (Ayala-Garcia, 2014; Groth, 2016; Mäkelä & Löytönen, 2015; Rognoli, Ayala-Garcia et al., 2016; Sonneveld & Schifferstein, 2009) to get an in-depth understanding of the material (Bak-Andersen, 2018; Groth, 2017; Karana et al., 2015) which is an indispensable foundation for establishing the almost concurrent search for applications, formations and consolidated physical design results.

For most parts this is undertaken in form of phasing models with an initial phase for understanding the advanced growing material and a general initiation of a base understanding of biological systems, which includes the uncovering and appointing of initial issues of e.g. time component and aesthetics, a second phase to experiment with those in application spaces that work towards the establishment of bioinformed design strategies and missions in an active, goal-oriented manner, a possible third phase to address specific issues that were discovered in the two previous phases and might need further elaboration in form of additional experimentation, feedback and analysis and a final to create the outcome (Diniz, 2019; Pugliese & Pinto, 2017).

Phase models

The initial understanding creating **first phase** (so adequately named 'Seed' in the MA Biodesign) is typically built up as a series of experimental and experiential methods conducted in both laboratories and studio workshops that enable the how to learn about materials to then dive into the learning about the material with the related mastering of tools and methods and the understanding of strategies. They comprise *Methods for exploring the material itself* in form of induction to relevant, related fields, knowledge and skills (Diniz, 2019; Pugliese & Pinto, 2017), experimentation, related observations and recording and analysis and lab-based explorations that employ scientific methods to uncover basic needs of the living matter as well as favourable and unfavourable conditions for their growth (Stikker, 2018), *Methods for understanding the overall context, formation strategies etc. of living organisms* in form of established hybrids that combine lab and studio work and cover initial investigatory experiments with form studies to understand and catalogue bio strategies, studio workshops to introduce form giving, experimental approaches, material ways, fabrication means (Diniz, 2019), explorations of existing biodesign strategies, field trips for observations of living systems with the aim of recording and analysing natural principles to in the next step being able to understand natural principles as well as spontaneous activities that have impact on form giving (Pugliese & Pinto, 2017). These are combined with *Methods for obtaining and recording the new knowledge* which are conveyed in form of a series of knowledge-gathering and mapping workshops (Diniz, 2019) *Methods for initial forming and ideations* in form of diverse experimental and experiential approaches for design enquiry and a necessary *Theoretical framing that is covering* relevant theoretical, scientific and cultural references, ethical issues related to sustainability & biodesign practice to enable the students to integrate and discuss relevant theoretical and contextual references and conduct their respective research.

They are structured as hybrid methods in terms of theoretical input and own observations, experimental exercises and explorations to create a basic formation potential as well as a repertoire both with regards to matter formation and vocabulary within the field.

There is an additional exploration into relevant Form creation aspects as contextual observations.

Experiential studies need formal contexts for formal explorations which include learning about and getting inspiration from and subsequent information gathering about nature's strategy through biomimicry (Benyus, 2020; Institute, 2018) with special focus on six specific aspects comprising morphological studies regarding the form in its dimensional and geometrical configuration and the structure in terms of what elements are used and how they are arranged amongst themselves (Thompson & Bonner, 2014), physiological studies that explore the way in which a living organism or bodily part functions, anatomy studies that look at the physical structure of an organism, behavioural studies that explore and document form and constitution of repeated reactions in response to a particular situation or stimulus, and exploration relating to the origin, the point, place and phenomena that gave rise to the event as well as distribution of the event and how it is shared out among a group or over an area (Pugliese & Pinto, 2017).

The more application-focused **next phase** (Grow & Diniz, 2019), aims at a goal-oriented, 'informed' experimenting. A lot of the previously mentioned methods that were covered in the context of the initial understanding phase will be sourced in a more strategic design setup with employing of (nature's) principles and strategies to advance to more concrete advanced grown material design enquiries. The material is actively employed as a co-creator, for form experiments and for creating a hybridisation where ideas are materialised and materials idealised (Gherardi & Perrotta, 2014) in a design space of opportunities that affords the creation of material-design scenarios (Karana et al., 2015) which can lead to the **final phase** (Harvest & Diniz, 2019) where the previously explored are being merged into consolidated project outcomes and validations.

The explorations shift between hands-on, experiential methods and the implementation of experiments and lab tools, between enquiries of scientific and phenomenological nature.

The aim is to understand the role of experiments and explorations, the processes definition as complex, the natural biological agents as displaying spontaneous reactions to their environments, typical for open systems, and the significant impact these factors have on form giving leading to the deduction of possible alterations, manipulations, focused use and applications.

The practice should lead to the building up of detailed, illustrated process documentations in form of lab journals (Pasold et al., 2018) and design catalogues and the formulation of respective mappings through initial sketches, photographs and writings (Pugliese & Pinto, 2017) of both creative and scientific character that highlight contextual aspects as well as structural options that emerge within living matter through biological and formal actuators. It is essentially a path to understanding the in-the-process-of-being-created as actuator/reactor in an overall ecosystem.

Methods and Tools

There are number of recorded methods and tools that are useful within this exploration, such as *various tinkering activities* (Garcia et al., 2017; Parisi et al., 2017a; Rognoli, Garcia, et al., 2016; Rognoli & Parisi, 2018) for material explorations where small interventions and tweaking have impacts on the constitution of the results, the creation of physical probes for tangible comparison on the physically constituted material properties (Garcia et al., 2017; Parisi et al., 2017a; Rognoli, Garcia et al., 2016; Rognoli & Parisi, 2018) as the use and creation of material samples is seen as highly supportive within experimental and experiential processes (Ferrara & Lucibello, 2012) with the importance of accessible material samples for experiments and aesthetic processes and eventual manufacturing processes being an essential part of a foundational understanding.

To fully understand the potentials of the material explorations and have a basis for creating a mapping that can lead to a pattern understanding of influencing factors and resulting constitutions and as an invaluable way of comparing material mappings of performative, behavioural and sensorial parameters are employed.

These can be looking at properties (Barati et al., 2015) and applications (Barati, Karana & Hekkert, 2015) the sensorial aspects through sensorial mapping (Rognoli, 2011; Asbjorn Sorensen, n.d.; Parisi, Rognoli & Sonneveld, 2017), recordings of material experiences (Barati, Karana & Hekkert, 2015), Categorisation study to find out what associations people have with the material concepts (Karana et al., 2018) and an eventual depiction of the same.

Once these parameters have been identified simulation studies in both analogue and digital fashion are helpful for faster scenario generation. These can be done through small tangible libraries that simulate material behaviours (Barati, Karana & Hekkert, 2015) or digital models (DTU Biobuilders - a new student-run project, 2019).

Most methods can find application throughout the whole process but will need an initially created understanding at the very beginning as that is regarded as the most effective way of implementation throughout the project. Most important is the familiarisation with methods from both fields to fluently being able to switch and apply, mix and match.

Experimenting in the real world

Common to all phases is the invaluable continuous inclusion of expert assistance and feedback on the exploration of both detail and whole and the respective findings relevance to the interdependent relationship by either direct expert integration or expert sourcing at important stages of the project to help identify and internalize the findings and therefore continue with a well-informed understanding of causes and outcomes. These include experts from the science such as biology, chemistry as well as material science from both academia and industry. The experiments can therefore be run in an informed iteration where the designers understand implications and outcomes.

Those feedback sessions are held in a number of different formats some native to the design field such as frequent presentations, pin ups and input sessions, some more discussion, debate and proof based. They are to enable the monitoring of the process as well as the built-up of a professional vocabulary.

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4.4. Enabling for Designing with Advanced Growing Materials

Anke Pasold

Introduction

Having defined the sphere and placement of practices involving Advanced Growing Materials and established that they constitute a field of complex, open systems, which lead to the establishing of the possibility of sourcing didactic methods not only from material practices of the same or similar nature but also more generalised degrees of systemic approaches, a number of focus areas can be outlined for the definition of didactic frames.

The following will therefore look at how to enable for designing with Advanced Growing Materials.

Because even though there is a collective number of experimental and experiential approaches mentioned in the previous chapter, they can only fully unfold in the proper framing for both teaching and conduction of the work and the therewith connected explorations.

It has been established that there is an inherent need for cross-disciplinary knowledge, communication and engagement.

Now there will be cast a look at how this can be facilitated, what requirements there are to the spaces and the conveying of the appropriate skills and competences.

Three levels of enabling frames

Working with Advanced Growing Design as an emerging material practice with limited established conventions needs the definition of enabling frames, on three predominant levels: (1) the level of the student, the creative, the instigator in terms of their mindset for being able to operate within this new design domain and its respective new way of approaching an appropriate design process, (2) the outer in terms of setup of facilities, networks and possible eventual co-labs and finally (3) the inner in terms of skills and competences in the creative through new sets of processes, methods and tools.

These three are not to be seen as independent or being setup in subsequence of each other but much rather as co-developing and co-existing within an overall strategy of full and successful implementation.

Enabling new ways of thinking

Mindset

The basis for learning and effectively working and creating within this new frame, is a changed mindset in the designer. It is understanding the projects nature of being open and complex, its placement at the cross-section of disparate disciplines that are playing a role in the development of the same, and the appreciation of entering into a new way of designing; Material first, product synchronously after. It means enabling the scientific as well as the artistically creative and phenomenological approaches and the respective tools and methods related to them. But it also requires the appreciation of the time issue, the tackling of lack of control both with regards to the subject but also with regards to the conduction of the experiments and the knowledge entities, it means subduing to external pools of expertise of knowledge and dependency on other disciplines and the implicit knowledge distribution across different collaborators with respective awareness of language and vocabulary.

It requires the willingness to unlearn part of the learnt and the motivation to acquire different, new ways of working, getting insights and creating. It means entering the space of hybridisation within an area of design, where it is not only the materialisation of ideas but much more the idealisation of materials that is at the forefront. (Gherardi & Perrotta, 2014)

And all this has to be undertaken with a deep appreciation of the need for cross-disciplinary knowledge and its accompanying cross-disciplinary communication and engagement.

Role

Working with Advanced Growing Materials changes the designer's role from designing artefacts in the learned fashion by means of certain tools and methods following a pre-established process to designing materials and either appropriating their properties or establishing applications for the already constituted performance values.

On the one hand, it leads back to the knowing the material by experiencing it through our senses, feeling the properties, the potential and its agency (Groth, 2017). On the other it is the awareness of the organism's reaction to its environment; whose interdependent influencing conditions need studying in parallel with the formal constitution as the designer is entering into the co-creation with the same. It furthermore places the designer into an ambassadorial role of such areas as the possibly conceived ethical issues and to the user yet unknown and therefore unusual aesthetic properties of the outcome.

Enabling new ways of working

Frame

Seeing that operating within this field puts cross-disciplinary working methods at the forefront, there is a heightened demand on the proper setup.

The constitution of which comprises both, *the physical spaces* in form of design experimentation as well as lab spaces with the appropriate equipment, setup, safety procurements and related safety instructions and the *establishment and facilitation of expert network(s)* in different, new formats to meet the needs for operating within the complexity of the field and thereby enable both, the scientific and the creative approach to the subject in a deep level of immersion allowing for a high level of innovation to source the full potential of working in the in-between.

The former needs a designated space that inspires, supports and enables experiments, design explorations, prototyping and ideation in a proper manner conducing to safety for primary and secondary users and conducive to the species worked with.

The latter, the platform for cross-disciplinarity, on the other hand, requires the proper establishing of a support network of experts for input and guidance, as development partners and partners for debates and continuous feedback and exchange. Such a network can exist in a number of different forms from advisors that are external or internal to virtual experts or the reliance on open-source materials but are preferably a combination of them all weighing the importance of time vs. facilitation aspects and level of expertise and the point in time within the project those are required, such as the consulting of scientific experts in the analysis and validation phases. The initial aim of such a setup would be the faster progression, deeper immersion, better validation and consequently greater innovations depending on the varying degrees of involvement in the field of study. The eventual aim being the development of a consolidated knowledge platform that makes the learnt available within a field that is currently heavily relying on access to open-source knowledge.

Collaborative learning

Part of the systemic didactic approach is that complex and new knowledge is learnt in collaboration and co-teaching sessions that enable peer-review as well as external analysis and criticism; together with the material and one another (material, peers and experts).

Feedback and expert input make the process not only faster and more effective but can also validate the results. This can be facilitated by means of cross-disciplinary project setups or project-internal periods of exchange and mutual discussions or the integration of teaching staff from other areas into the curriculum. There are several models pursued which each in their own right contribute to the process in dependence of means and possibilities. Setting up of co-labs and co-teaching as a path away from different curriculums for the greater good with the incentive of getting people out of their professional silos and thereby get them to actively contribute to a certain case are just as a relevant as the establishing of peer-learning where students are encouraged to articulate and discuss amongst each other to create a more open space of shared knowledge and ideas that contributes to the overall pool for furthering the overall progress in fluid field of collaborative efforts and self-study for team contribution.

There are furthermore a small number of examples of facilitation of student-driven activities, such as DTUs Bluedot project (DTU Biobuilders - a new student-run project, 2019) that collaborate on curriculum external ECTS-giving projects that from the very start support these cross-disciplinary undertakings to enable cross-fertilisation.

Communication

In the context of cross-disciplinary setups, an appropriate glossary is of major importance. Agreements on terms and definitions and a practice of discipline-independent ways of communicating is one of the two main components that should be considered within these cross-disciplinary setups. It is important that different knowledge domains and the designers working in them are able to share knowledge and collectively harness insights; failure to identity such common ground leads to duplicated efforts and missed opportunities for building upon established bodies of knowledge. However, only by describing complex design activities in domain-neutral terms can such potential commonalities be identified which pre-supposes an initial awareness and identification of the disparities in practice.

Complex design activities involve constructing a certain characterization of complexity, adopting a certain objective with respect to that complexity and exercising a certain design approach with respect to that objective. By having a domain-neutral representation of complex design problems (Chen & Crilly, 2016), it becomes possible to identify commonalities between problems that at first sight appear unrelated and hence share knowledge, insights and methods.

Coordination

When control is distributed rather than centralised as would be the case in many of the collaboration projects but especially with cross-disciplinary team building unless brought together in one physical location, there is an inherent need for checking in and following along the same plan (Chen & Crilly, 2016) to reach a united goal. Here above-mentioned communication plays a very essential role, especially in light of the aforementioned difficulty of planning out an accurate project timeline within the context of working with living matter.

Enabling new ways of designing

When an artefact designer turns material designer there are a number of new sets of skills, competences and tools they need to master. Some of these can be sourced in the respective other disciplines and their way of working whilst others evolve along the lines of design enquiries into living matter. Equipping with these means a number of changes to didactic approaches but also an extension into fields of previously unnecessary. Instead of contributing solely to transmitting knowledge and skills, *the teacher's role then is to create conditions for the emergent and evolving learning* – and to be prepared to learn herself, alongside the students (Mäkelä & Löytönen, 2015), facilitate and plan projects in a way that they prepare for the two path exploration and an understanding that the project work is not about the material study but that it can't be ideated without, so that the designer can operate and ideate within the set up frame.

The initiation phase is extensive, especially for newcomers, and the knowledge ground to be covered equally vast. Adding a microscope, a laboratory suit and a lab attitude of miniatous recording is just the first step towards understanding the value of a scientific working method, where one builds on previously learned, explored and recorded of self and others, works in the lines of hypothesis and proofs, observes, analyses, interprets and finds patterns.

Designers will also need to learn to source the other disciplines knowledge at the right points throughout the project and they will need to learn how to validate and appropriately employ it. They need to gain an understanding of how best to merge discipline-innate skills and own hands-on explorations; which skills they will need to master and where it is sufficient to gain a basic appreciation of and general insight into approaches.

In this context the systematic approach to working that is part of being able to handle the complex nature of the setup is just as important as building the basis for balanced dialogues (Mäkelä & Löytönen, 2015) between the designer and the material, the scientist and the material and above all between the different experts.

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A Logical Framework for designing with and for Emerging Materials and Technologies (EM&Ts)

Stefano Parisi, Venere Ferraro

Introduction

This book aimed at giving an overview of the four exemplified areas of EM&Ts in term of meaning (what the four areas are), applications, teaching methods, gaps and potential solutions to be implemented in each EM&TS.

We presented the synthesis of the four EM&Ts highlighting similarities, differences for all of them, we gave an overview for each area in dedicated sections. We will now provide the setting up of a common and advanced method to teaching EM&Ts within HEIs, to create new professionals in young students, and to develop new guidelines and approach.

In this chapter authors will present the results of a hands-on Workshop held on October 2019 at Copenhagen School of Design and Technology (KEA) as part of DATEMATS project meeting.

The objective of the workshop was to detect all the information about the different EM&Ts approaches and methods used by each Higher Education Institutions as well as the European SMEs' needs in terms of issues and gaps related to EM&Ts knowledge transfers.

Experts coming from both Academia and SMEs shared the knowledge related to the literature review in current methods about EM&Ts, a survey to identify the gaps regarding EM&Ts between Academia and Industry, the identification of gaps, limits, and constraints related to EM&Ts teaching methods.

Through participatory sessions, participants carried out a proactive exchange of thoughts and knowledge to set the ground for the definition of the Contents of the new Design teaching Methods.

This chapter introduces the context of participatory workshops as a research method. Then, it describes the methodology applied for the setup and execution of the activities, the development of the toolkit based on canvases and frameworks, and for the collection and analysis of data.

Finally, the document presents the resulting Logical Framework as a universal and concise systematization of the items retrieved from the triangulation of the results emerged into the previous chapters, the use of the tools, and the participants' discussion in the workshop. In conclusion, limitations, implications, and further development of the Logical Framework and the related Transnational Workshop are discussed.

Participatory Workshop in Research

This chapter reports an Interdisciplinary Knowledge Sharing activity that took place during the Transnational meeting of the research project DATEMATS in Copenhagen, involving all the partners of the project and led by Design Department of Politecnico di Milano. The knowledge sharing activity consisted of the setting up of specific activities, such as co-design creative sessions for the sharing of the results related to company surveys, reports, best practices, methods and findings presented in the previous sections of the book.

The main findings have been formalized in a Logical Framework for an original teaching method that is used as a blueprint for setting the unique teaching method in the four EM&Ts area. To do so, a participatory workshop was carried out.

Participatory methods have been used from years in the context of Academic research (Creswell, 2012; MacDonald & Headlam, 2016), Educational Research (Creswell, 2009; Cohen, Manion, & Morrison, 2017), and specifically in Design Research and Practice (Sanders & Stappers, 2012).

In the landscape of Design Research (Sanders, 2006), a participatory mindset characterizes design researchers that are not only working and collaborating with people (i.e., users of a product or service), but involving them in all stages of the design development process, by co-creation practices, to help ensure that the designed product or service meets their needs (Sanders & Simons, 2009). A participatory approach to design research is characterized by the use of physical artefacts and tools, i.e., rationally designed devices that produce both tangible commodities and productive systems for intangible commodities (e.g., education, knowledge, or decisions) (Illich, 1973-75, via Sanders & Stappers, 2012). An example of the use of tools for participatory design applied in the educational context is the guidebook 'Design Thinking for Educators' (IDEO, 2012). In a participatory framework, tools and methods are used to stimulate creativity, and problem-definition and -solving capabilities, as a scaffold for collective creativity (Sanders & Stappers, 2012). Collective creativity is crucial to solve wicked problems (Buchanan, 1992), i.e., the ones that are "difficult or impossible to solve because of incomplete, contradictory, complex interdependencies" (Rittel & Webber, 1973).

In the setting of participatory research, the format of the workshop arises as a method for qualitative research (Ahmed & Asraf, 2018; Ørngreen & Levinsen, 2017). Workshops provide an opportunity for researchers to identify and explore relevant factors in a domain, which are not evident to participants or researchers before the workshop process. Workshops are characterized by being events of a limited duration targeted to a group of participants, aiming to an outcome both for the organizers and the participants. Workshops are specifically designed to fulfil a pre-defined, though not predictable, purpose. Workshops encourage engagement through collaborative discussions and feedback between the facilitator and the participants (Ahmed & Asraf, 2018). Strategies and guidelines to organize and carry on a workshop properly are suggested by the literature (Chambers, 2002; MacDonald & Headlam, 2016).

Generally, workshops involve as participants a small group of people selected accordingly by a common domain, expertise, or interest, e.g., experts in the research field, users of products, or students. In particular, a workshop involving colleagues and project partners has the threefold aim of fulfilling participants' expectations to achieve something related to their interests, fulfil a research purpose (Ørngreen & Levinsen, 2017), and knowledge sharing and alignment between the partners. In this particular type of workshop, the participation is characterized by a collaborative and collegiate modality. The researcher plays the complementary roles of the 'clinician', who focuses on participant needs, and the ethnographer', who focuses on the research (Ørngreen & Levinsen, 2017). In the analysis of the results, the Design researcher works as a translator that translates insights, ideas, thoughts into a framework that inspires new design directions.

Based on this ground, a hands-on Workshop was set accordingly. Participants were divided into small teams (four participants per group), to encourage interaction and discussion. Groups had a heterogeneous composition of the members, i.e., from different organization involved in the project and countries, combining academic partners with non-academic ones (i.e. SMEs). A facilitator was in charge of introducing, explaining the activity and moved around the working tables to support the groups.

The hands-on Workshop

The setting and the performance of the participatory workshop needed an organized and clear synthesis of both literature review and the overview of each area; in order to move forward the logical framework embracing them all, a poster named 'Shared Ground' describing and organizing in a graphical and concise way the common issues and aspects of the four EM&Ts was realized (Figure 1).

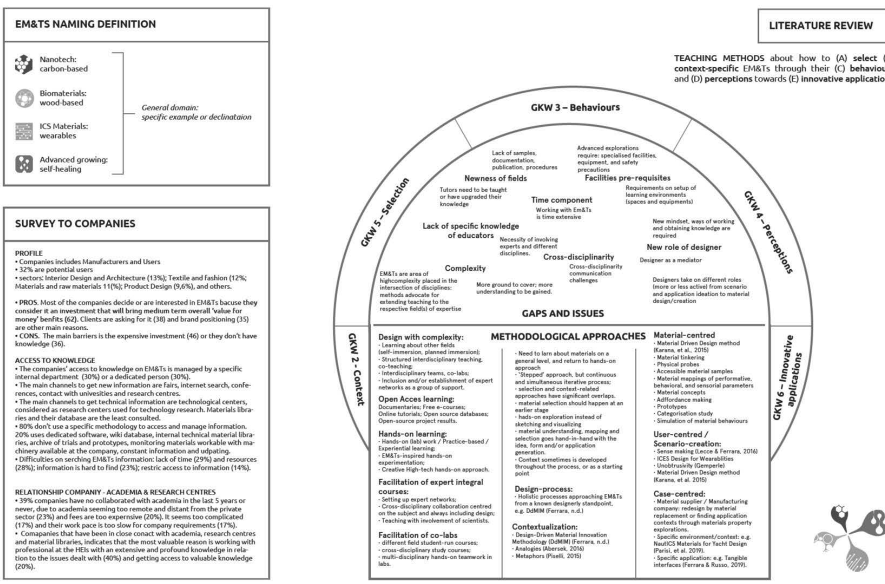

Fig. 1 - The 'shared ground' poster. Designed by Stefano Parisi, Politecnico di Milano

The poster has been designed by Design Department of Politecnico di Milano; structured on one page divided into different sections: one introductory section about the EM&Ts naming; one section about the highlights from the Survey to Companies interested in each EM&T; one section about the results from the Literature Review: common Gaps & Issues, and Methodological approaches, shared among the EM&Ts.

The poster was the starting point for discussion and setting of the canvases designed for the execution of the workshop and needed to be filled out by participants.

Indeed, after a discussion on the Shared Ground Canvas, separated canvases for each EM&Ts were elaborated: each canvas was provided with graphical elements, schemes, charts, and blank boxes to complete, supported by instructions and suggestions for each section. Rather than modules to complete in each section, the canvases were chosen for being a flexible tool to facilitate thinking and debating; participants could decide to focus more on one canvas they found more significant than others, or to move from one canvas to another with no specific logical sequence. Also, participants were welcome to use any techniques to work on the canvases, e.g., writing notes, keywords, sentences, drawings, sketches, mapping. For each EM&T, four Canvases were produced for a total of sixteen having an identical structure and distribution of the contents:

1. 'Sum up canvas': a list of the single EM&T-specific gaps & issues from the literature review and the survey to companies (Figure 2). Also, it describes the role of the designer dealing with the EM&T area, as described in the literature review.

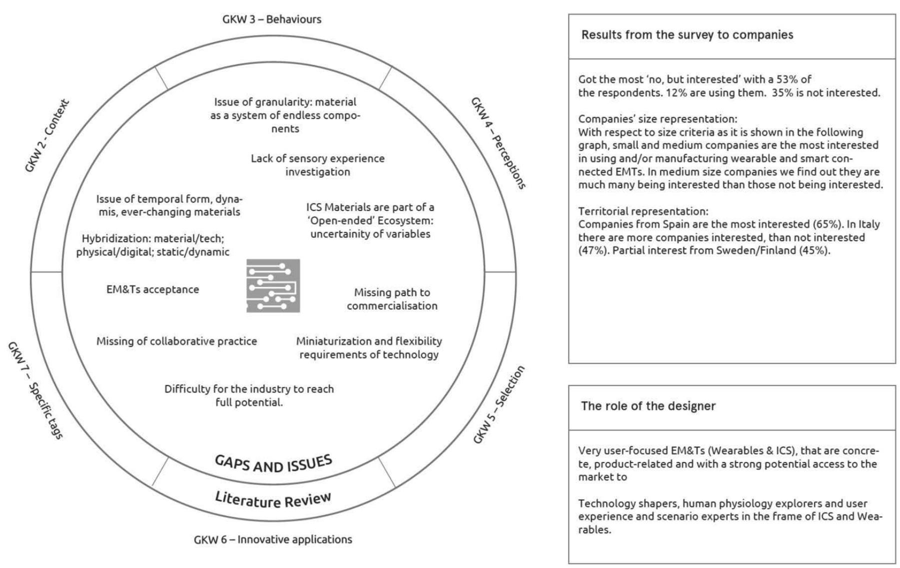

Fig. 2 - Example of The Sum Up Canvas for ICS Materials EM&Ts. Designed by Stefano Parisi, Politecnico di Milano

2. 'The EM&T canvas'. The aim of this section was to identify the most relevant dimensions to describe the specific EM&T and position it on such aspects. This helps in characterizing the specific EM&T under a variety of lenses and perspectives, from the most technical and objective (e.g., price, performances, availability) to the most qualitative (e.g., self-communication, aesthetic values, authenticity). Also, it allows identifying criteria to compare and relate the different EM&Ts. In the canvas, participants were asked to identify some dimensions to posi-

tion the EM&T, using a set of scales (1-axes parallel charts): they were welcomed to propose values, polarities and optional intermediate positions on the scale, place the EM&T; but also visualize on the scale the current position, and the future or expected one. Some example scales with given values and polarities have been provided, e.g., the granularity of the EM&T (from nano to macro), the required technology (from low-tech to advanced), the availability (from low to high), the price (from cheap and expensive), technological readiness (from low to high). A blank box was also provided with the request to identify pillars that characterize the specific EM&Ts. Pillars might include approaches, mindset, methods, as well as tangible elements (Figure 3).

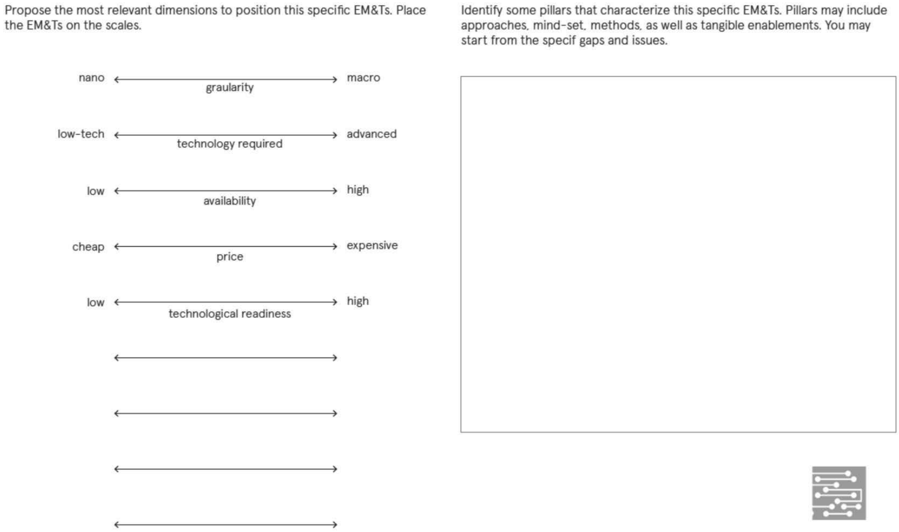

Fig. 3 - The EM&Ts Canvas. Designed by Stefano Parisi, Politecnico di Milano

3. 'The role of the designer canvas.' The aim of the section was to define the role of designers working in the specific EM&T and the kind of design process they apply (Figure 4).

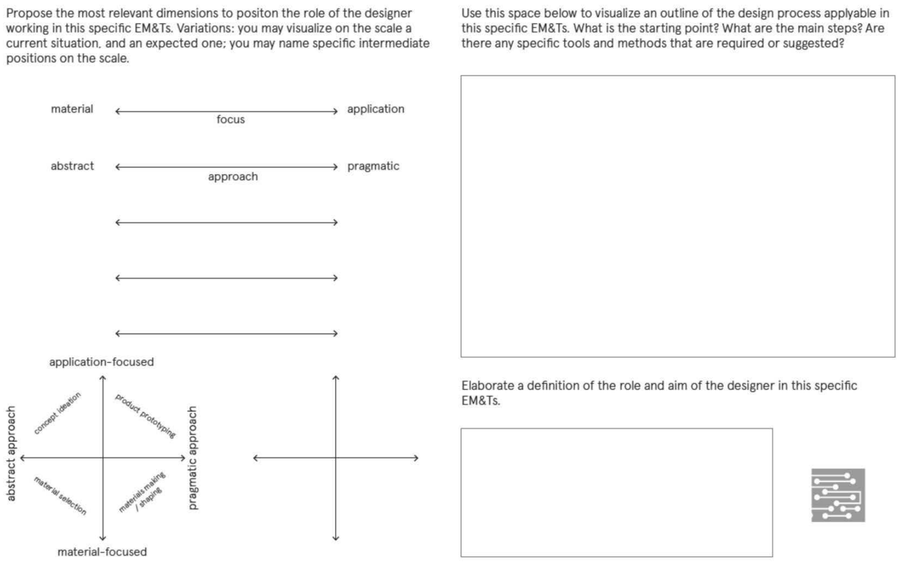

Fig. 4 - The role of the designer Canvas. Designed by Stefano Parisi, Politecnico di Milano

This plays a crucial role in determining the contents and formats of the DATEMATS unique teaching method. This can be achieved by identifying the most relevant dimensions to describe the role of the designer for the specific EM&T and position it on such aspects. Indeed, from the Literature Review a variety of roles and design tasks emerged in different EM&T (e.g., materials exploration, concept creator). This helps to characterize the designer activity and role under a variety of lenses and perspectives and to identify criteria to compare and relate the designers working in the different EM&Ts. A set of scales (1-axis charts) and cross-maps (double-axes charts) have been provided in order for participants to propose the most relevant dimensions to position the role of the designer working in this specific EM&Ts. Some example scales were presented, with given values and polarities, e.g., the focus (from the material to the application), the approach (from abstract to pragmatic). These example scales were intersected in an example cross-map, i.e., the value abstract/pragmatic approach crossing with the value application-/material-focuses identifying four areas in the quadrants: material selection, materials making, concept ideation, product prototyping. In addition, a blank box was provided with the request to visualize an outline of the design process to apply in this specific EM&T,

focusing on the starting point, the main steps, the required tools, and methods. Another blank box was added with the request to elaborate a definition of the role and aim of the designer in this specific EM&T.
4. 'Cross-disciplinarity canvas' (Figure 5). The aim of this canvas was to identify and name the intersecting disciplines framing the cross-disciplinarity for this specific EM&Ts. This activity will have a crucial role in determining contents, modules, teaching staff profiles, and other requisites in the formulation of the Datemats teaching method. The canvas provides a graphical scheme with intersecting bubbles representing the crossing disciplines working in the area, vaguely inspired by the Krebs Cycle of Creativity (Oxman, 2016). Participants were asked to identify the subjects and related practices and contents by filling the scheme. Then, they were asked to answer the following questions: how the cross-disciplinarity would affect the EM&T methodology set up, materials, and pre-requisites; What are the requirements to enable the cross-disciplinarity; Where to find resources and expertise.

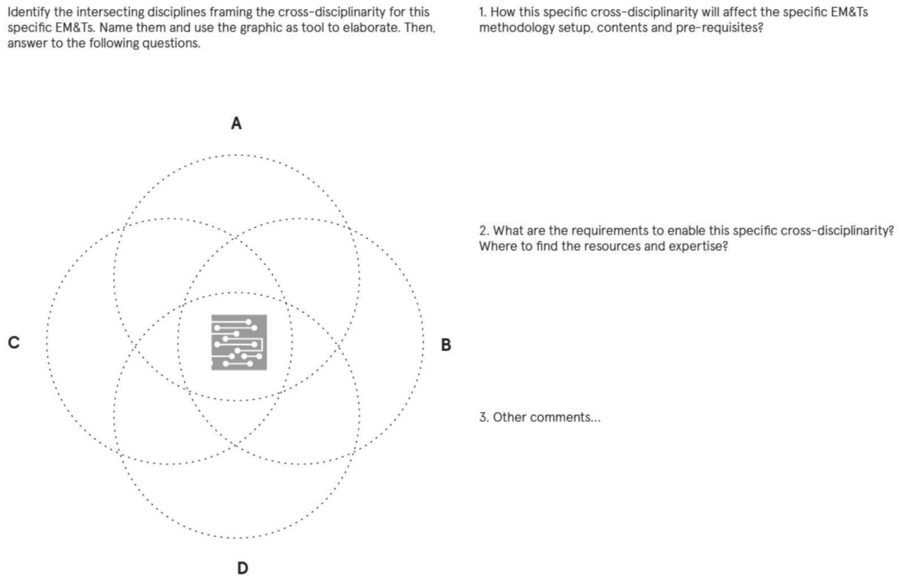

Fig. 5 - The cross disciplinarity Canvas. Designed by Stefano Parisi, Politecnico di Milano

The tools and activities were managed by researchers from Design Department of Politecnico di Milano (Figure 6). Participants were divided into small teams of four participants per group and the room was organized, exhibiting a set of samples of materials from each EM&T provided by the partners on four different tables. Therefore, each table was assigned to a specific EM&T.

Fig. 6 - Pictures portraying the workshop phases, from the explanation of the activities and tools, the use of the toolkit in small groups with the support of physical samples, the presentation of the results, followed by the collective discussion and the organization of the findings on a whiteboard. Pictures by Daniela Amandolese, Materially

Four copies (1 per group) of all the four canvases regarding each EM&T were displayed on the related table. In rotation, groups had to move from one table to another, discuss and fill empty canvases on 25 minutes turn, and then leave the filled canvases on the table and move to the next one. At the end of the activity, participants were asked to verbalize their insights and opinions by presenting the results for each EM&Ts, 6 minutes for each EM&Ts. A 15 minutes collective discussion followed. A white-board was used by a facilitator to keep records and organize the most relevant points of the debate systematically. The activity took around 2 hours and a half, in total. One facilitator, from Design Department introduced the activity and moved around the working tables to support the groups. In addition, the facilitator had the role of checking the time and guarantee that the scheduling of the activity was respected.

Data collection was done by Politecnico di Milano by keeping all the filled canvases as a record, a tool for data collection and analysis. They were filled with notes, sketches, schemes containing opinions, and data generated by the groups' discussions on each EM&T. Also, audio-recording was used to collect data and opinions during the collective discussion and presentation for the results. The whiteboard used to record and organize the main relevant points of the debate was photographed and used for data collection. In addition, the facilitator took notes during the activity.

Collected data from all these sources have been analysed by Politecnico di Milano, producing transcripts of the audio tracks, and clustering relevant data on a digital wall. The obtained information has been organized in a graphical representation of the Logical Framework, considered as a blue-print for the development and implementation of the ***unique teaching method***.

Towards the logical Framework

The Logical framework presents the common gaps and issues as well as the ones for the distinctive EM&Ts. In particular, it is worthy of mentioning the issues and gaps that might have a direct implication into the formulation of didactic contents and definition of the course structure such as the complexity and cross-disciplinarity of the field that leads to the need of experts from other disciplines and opening up a challenge about communication and languages to use; the newness of the field causing a lack of documentation and specific knowledge of educators; the need to identify and provide facilities and knowledge pre-requisites, and in particular guarantee safety and use low-cost equipment for didactic; the need to integrate tools and contents about the experience, intangible and sensorial qualities of materials, sustainability and environmental impact, commercialization and entrepreneurship.

Specifically, the ICS Materials EM&Ts area is characterized by the need for a holistic and hybrid approach considering material qualities & interactive behaviours, the physical & the digital, the system & the individual components, the technicalities & the experience. 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 perception, and fluctuation in price and availability of the materials and techniques.

The Experimental Wood-based EM&Ts area is characterized by not aiming directly for real products or commercialization, which allows free ideation and 'grazy' 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 areas share the issue of time needed for the material to grow and dry, which brings detachment from the intervention of the designer and the observation of the result. They share a recipe-based and hands-on approach that leads to endless possibilities in the experimentation with a low degree of repeatability and high-rate uncertainty and unreliability. Both are involved in the interplay between a scientific approach versus a phenomenological approach (Figure 7).

The clear and strong understanding from the literature review and the hands-on workshop is summarized into two words: ***cross-disciplinarity*** and ***co-teaching***. 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. Cross-disciplinary teaching is characterized by Open Access learning (e.g., open-source project results, open-source databases, documentaries, free e-courses, online tutorials), Hands-on learning (e.g., lab work, practice-based, experiential learning), Facilitation of expert integral courses (setting up expert networks, cross-disciplinary collaboration, teaching with the involvement of scientists), and Facilitation of co-labs (e.g., diverse field students-run courses, cross-disciplinary study courses, multi-disciplinary hands-on teamwork in labs).

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.

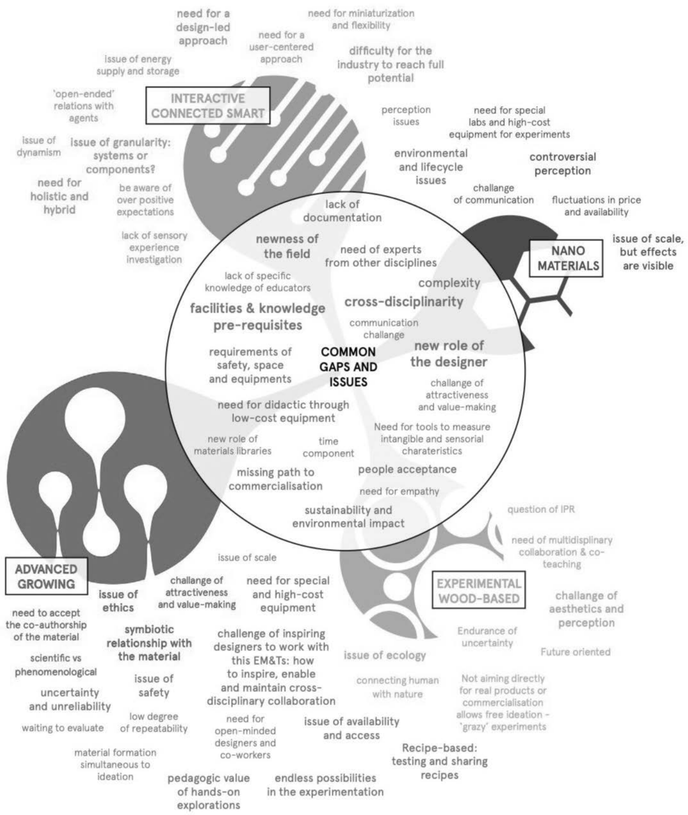

Fig. 7 - An overview of the four EM&Ts complexity. Designed by Stefano Parisi, Politecnico di Milano

Original Framework for Teaching

The last section outlines an original framework for teaching.

The application context definition and materials identification could be the starting point of the process. Indeed, the briefing and potential starting point(s) for the design didactics on EM&Ts are presented using the 5 Ws (i.e., What, Why, Where, With whom, and Who) and one How questions (Figure 8):

- Selection of the material (i.e., What?)
- A Design challenge (i.e., Why?)
- Application Context (i.e., Where?)
- Cross-disciplinary disciplines (i.e., With whom?)
- The role of the designer as: catalyst, communicator, mediator, bridge, users' advocator, team builder, team leader, problem solver, problem

finder, material selector, material explorer, material designer, application designer, concept and scenario ideator, etc. (i.e., Who?)
- And finally, how to inspire and motivate designers for: replacement, finding (new) applications, for people acceptance, for sustainability, for value-making, etc. (i.e., How?)

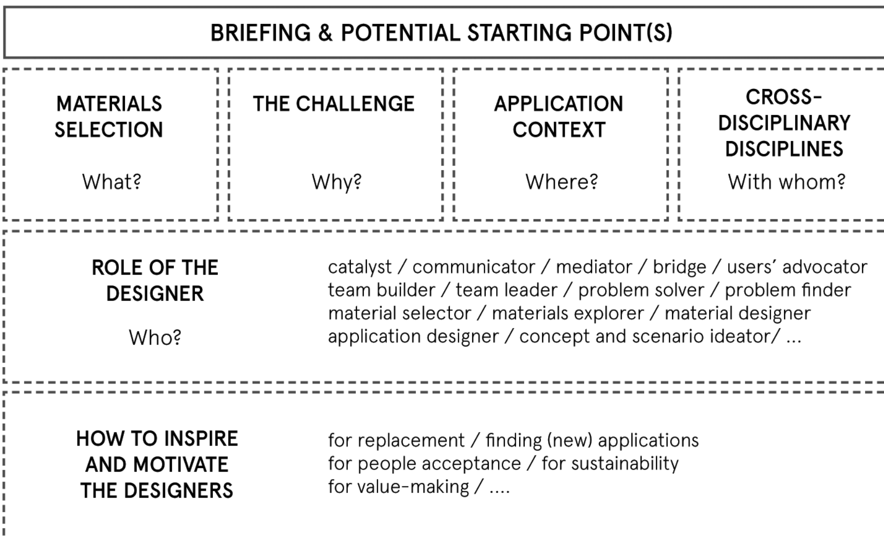

Fig. 8 - The 5 Ws of the original teaching method. Designed by Stefano Parisi, Politecnico di Milano

The teaching and learning process is both cognitive and physical and is based on the identification of three main didactic blocks: Understanding, Shaping/Experimenting, and Applying (Figure 9). Although the description of the process establishes a chronological succession of the three blocks, they are profoundly intertwined, iterating, and often simultaneous and overlapping in their definition.

'Understanding' is a module where the fundamental knowledge is given to students. It is based on a varied body of knowledge (e.g., explicit, tacit, theoretical, procedural, empirical) and the sources for acquiring knowledge can be a mix of material-produced (e.g., interaction with material samples), interpreter-produced (e.g., discussion with instructors, experts, and peers), and representation-produced (e.g., studying on texts and videos).

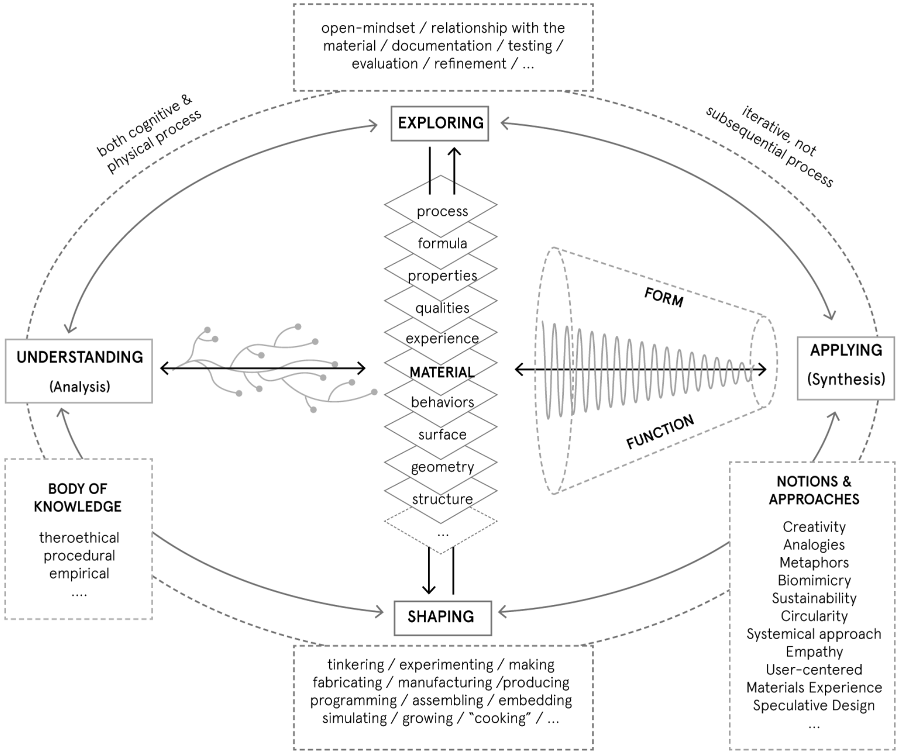

Fig. 9 - The Understanding, Shaping/Experimenting, and Applying Framework. Designed by Stefano Parisi, Politecnico di Milano

'Shaping/Exploring' is the connecting block between 'Understanding' and 'Applying'. This is the block where tacit knowledge is mainly acquired. Exploring and Shaping represent two sides of the same block. While Exploring put emphasis on the designer getting knowledge on the materials and processes by iterating, documenting and evaluating, Shaping is focused on the material being manipulated in many ways, e.g., tinkering, making, fabricating, manufacturing, producing, programming, assembling, embedding, simulating, growing, 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. Multiple directions or 'branches' are identified, outlining a divergent 'branch-like' process. In this block, the material is experimented and shaped on its multiple dimensions, namely the process, the formula, the properties, the qualities, the experience, the behaviours, the surface, the geometry, the structure, etc. Approaching the 'Applying' block, only one direction – or 'branch' – for material development is selected, and a converging and iterative process is applied, targeting the definition of form and function.

'Applying' block represents the synthesis of the process when the material is embedded and encoded into a project. In this block, the main strategies and approaches that are applied are: creativity, analogies, metaphors, biomimicry, sustainability, circularity, systemic approach, empathy, user-centred design, materials experience, speculative design, etc.

Discussion and further development

The present book contains the preliminary findings of the ongoing research project "DATEMATS[5]" funded by the European Commission - aimed at developing novel teaching methods for both design and engineering students in the field of Emerging Materials & Technologies (EM&Ts).

Particularly, we presented a logical framework for four exemplified EM&Ts areas as results of the methods, gaps and issues related to their teaching methods.

In this chapter the logical framework was presented as output of a hands-on workshop aimed at sharing knowledge and creating a consensus and clarification among the researchers around the four EM&Ts areas.

Moreover, the Workshop supported the implementation at a Transnational level of all the key information collected via desk research and already implemented at each National level; according to the specific needs, the partners have brought a more in-depth national view.

The framework here presented was based on the literature review and collective discussion on a participatory activity in order to obtain the highest agreement between partners and a proper degree of scientific referencing to academic sources.

The framework has an inclusive nature, which tends to accommodate every definition and elements. However, it is evident that each area and institution have its own specific needs and characteristics. In order to create a universal and common framework for all areas and institutions, it may happen that some aspects are banalized in the process of universalization. Efforts have been made to avoid banalization, e.g., avoid creating the

5. 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.

neat distinction between explicit knowledge delegated to learning theory in a traditional classroom and tacit knowledge destined only to practical activities in workshops, which separation is outdated and characteristic of a surpassed way of teaching design.

Another challenge was faced when some concepts that are typical of an area have been extended to other areas, with the risk to become irrelevant. Efforts have been made to highlight when elements are distinctive of one EM&T area, when elements are belonging to two or more EM&Ts, and when shared by all, creating distinctions.

Attention was dedicated to preserving and reporting definitions and categories already identified in previous deliverables, enriching and updating them with new information, instead of altering them.

The Logical Framework arises as one pillar of the challenge posed by European Agenda that is to support creativity-driven (e.g. design-driven) innovation by reducing the knowledge and communication gaps between the material scientists and engineers, the designers and creative communities and the producers.

It will have direct implications in the definition of new four syllabus developed and further applied in the curricula of the four European University: School of Design, Politecnico di Milano, Copenhagen School of Design and Technology, Tecnun, Universidad de Navarra and Aalto University.

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The present book contains the preliminary findings of an ongoing research project "DATEMATS" (Knowledge & Technology Transfer of Emerging Materials & Technologies through a Design-Driven Approach Agreement Number: 600777-EPP-1-2018-1-IT-EPPKA2-KA) funded by the the Erasmus+ programme of the European Union aimed at developing novel teaching methods for both design and engineering students in the field of Emerging Materials & Technologies (EM&Ts).

It focuses on four exemplified EM&Ts areas as results of the methods, gaps and issues related to their teaching methods.

It provides a summary of the four literature reviews conducted at respectively Aalto University on Experimental Wood-Based EM&Ts, Design Department of Politecnico di Milano on Interactive Connected Smart (ICS) Materials Wearable-based, Tecnun University on Carbon-based & Nanotech EM&Ts and Copenhagen School of Design and Technology (KEA) on Advanced Growing.

It will present the synthesis of the four EM&Ts highlighting similarity, differences for all of them; it will give an overview for each area in dedicated section presenting the meaning, the different approaches used and developed for each EM&Ts area, finally it will provide the setting up of a common and advanced methods to teaching EM&Ts within HEIs, to create new professional in young students, and to develop new guidelines and approach.

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