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

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

1 Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Fig. 1 Overview of ICS materials

Fig. 2 Nanotex: an example of nanomaterials

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

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

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

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

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

Fig. 3 Examples of wood-based materials and applications

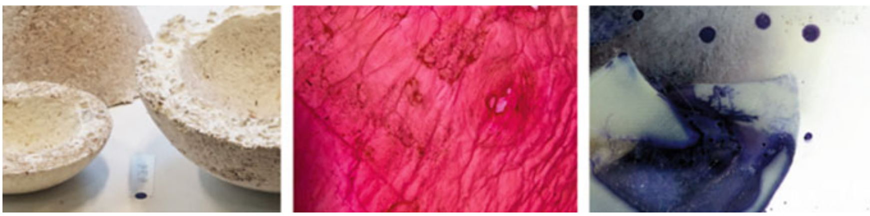


Fig. 4 Mycelium shapes, SCOBY leather, controlled fabric dyeing with Janthinobacterium lividum. Left image by Anke Pasold from KEA, centre, and right image by Alkymi

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

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

2 Methodology

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

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

2.1 Literature Review

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

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

Table 1 Sources identified for each keyword

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

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

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

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

3 Theoretical Findings

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4 Collaborative Workshop

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

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

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

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

Table 2 The four methods identified in the literature

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

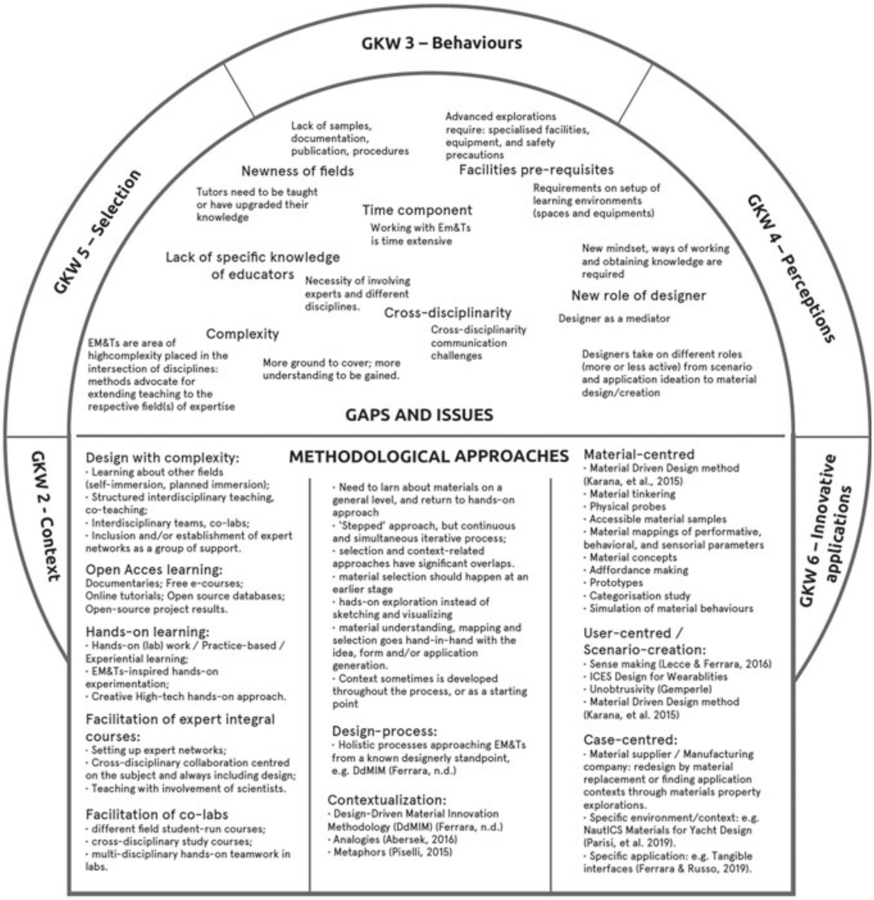


Fig. 5 Graphical result of the literature review

The session was organised in three steps:

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

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

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

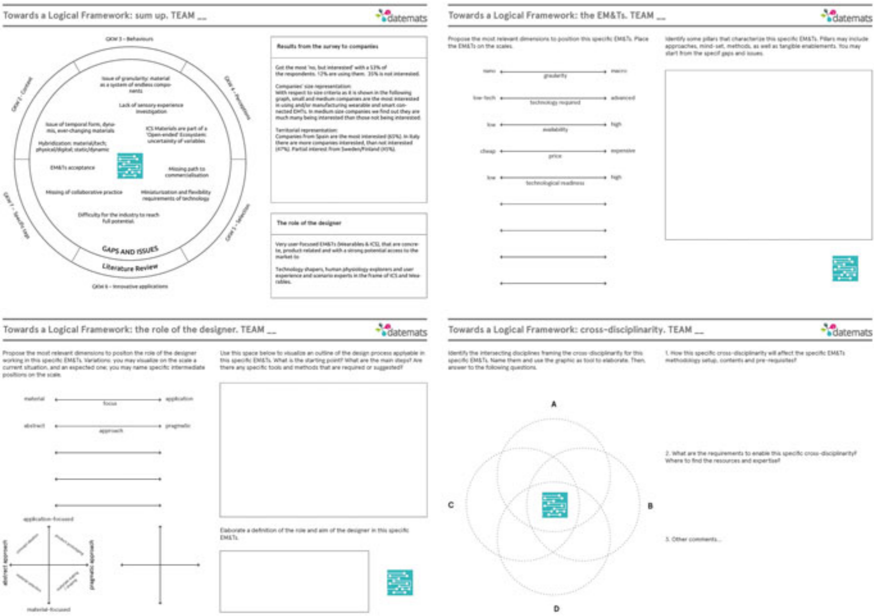


Fig. 6 The four canvases

Fig. 7 The collaborative workshop

1. Issues and Common Gaps for Each EM&Ts.
2. Potential Methods.
3. Potential Approaches to design for complexity.
4. The 5 W: what, why, where, with whom, who.

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

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

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

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

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

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

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

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

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

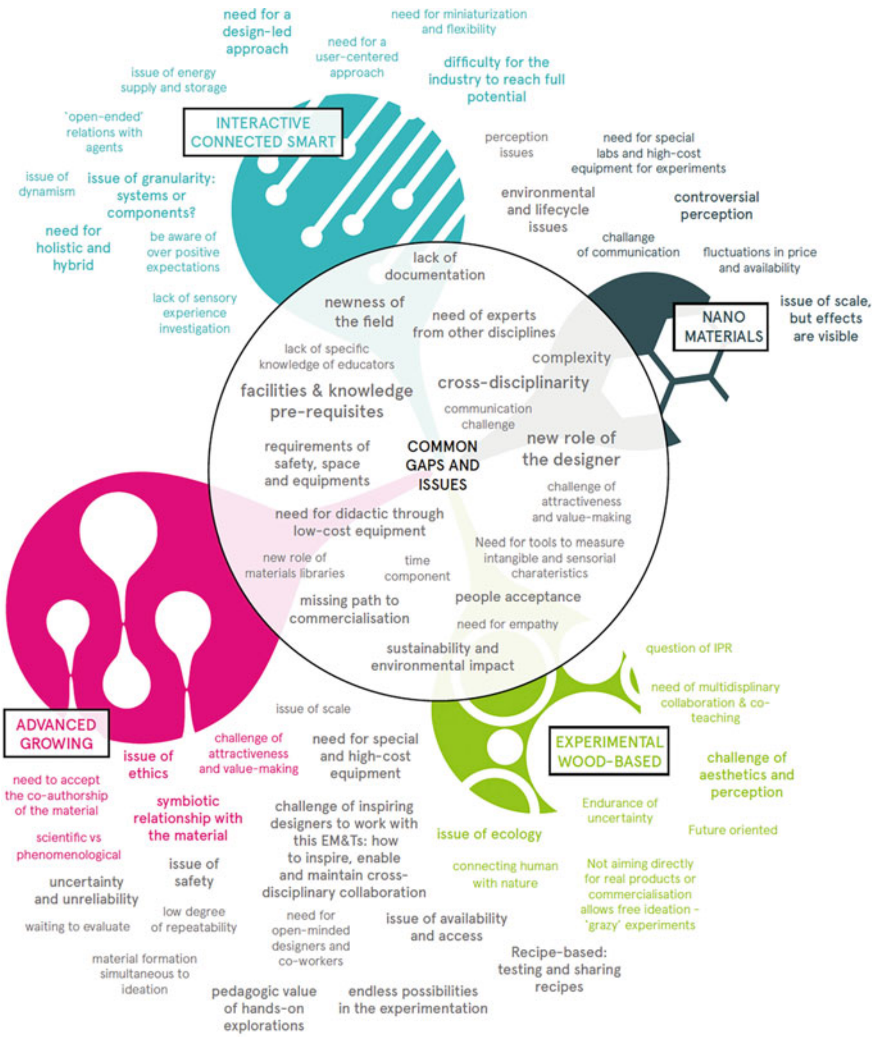


Fig. 8 Common gaps and issues

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).

In this regard, concerning the EM&Ts we can envision a holistic and 'stepped' but continuous and simultaneous iterative design process based on learning materials on a general level and returning to a hands-on approach. The method may place material selection at an earlier stage and context definition as a starting point or developed

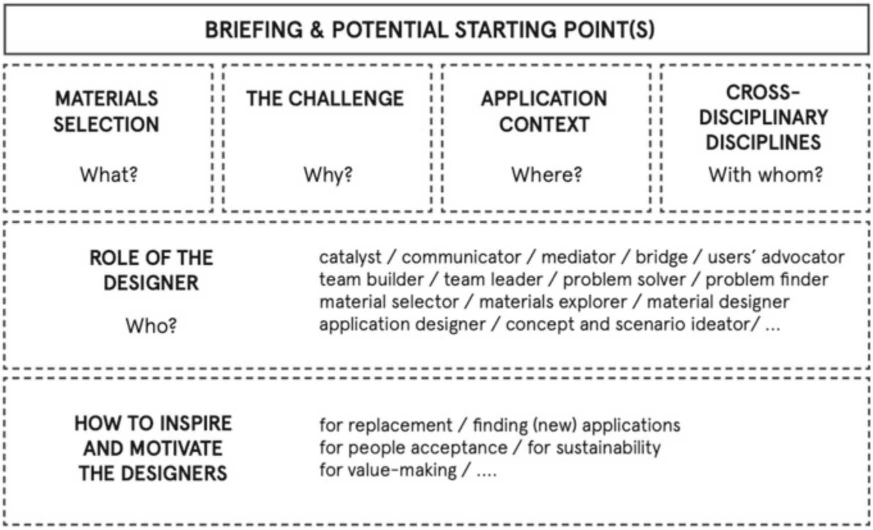


Fig. 9 The 5 W of the original design (teaching) method

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

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

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

5 Results: The Unique Design Method

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

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

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

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

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

Hereafter the three blocks are described:

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

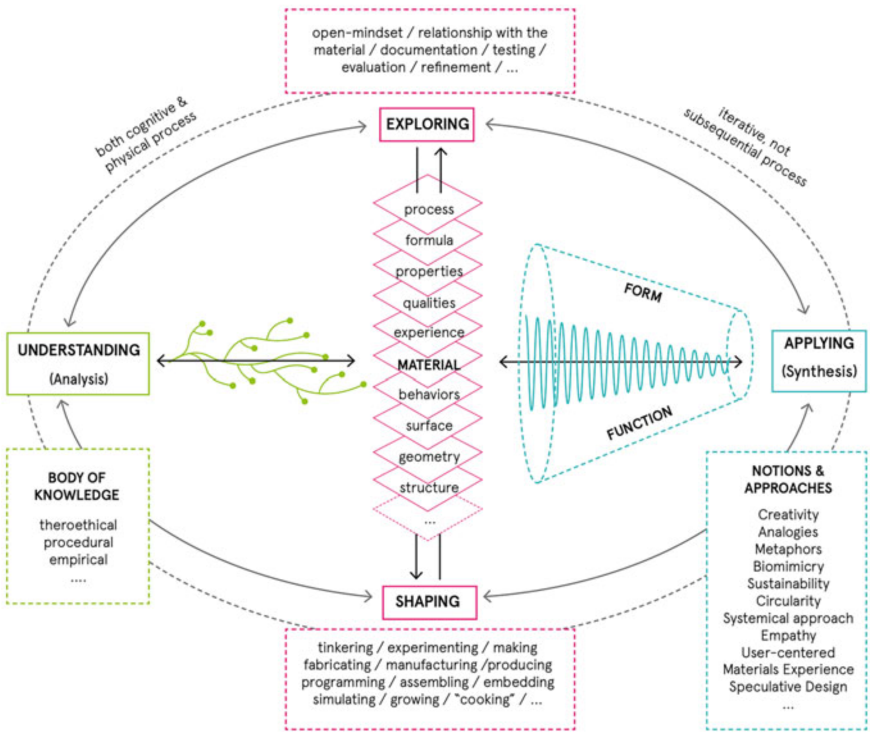


Fig. 10 The understanding, shaping/experimenting, and applying framework

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

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

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

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

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

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

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

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

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

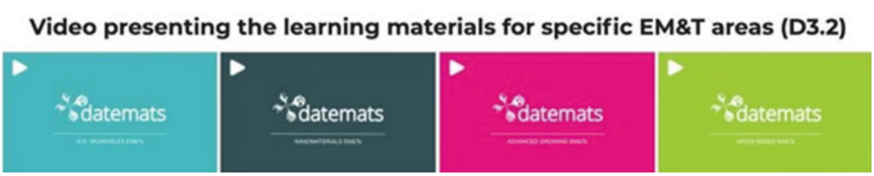


Fig. 11 Alternative source for understanding

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

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

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

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

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

Fig. 12 Material toolkit overview

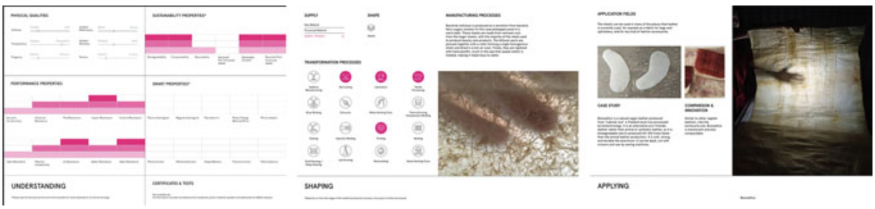


Fig. 13 Understanding, shaping, applying

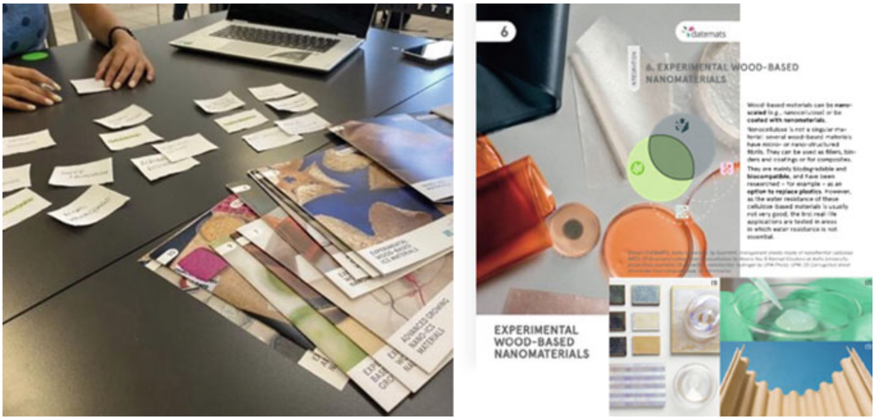


Fig. 14 The integration cards

Fig. 15 Exploring part in specific lab

6 The Teaching Method

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

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

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

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

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

The three module covers the three main blocks of the original framework: understanding, exploring/shaping, applying. Being the subject in the intersection of different disciplines, the modules can be carried out co-teaching, e.g., with experts in related disciplines.

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

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

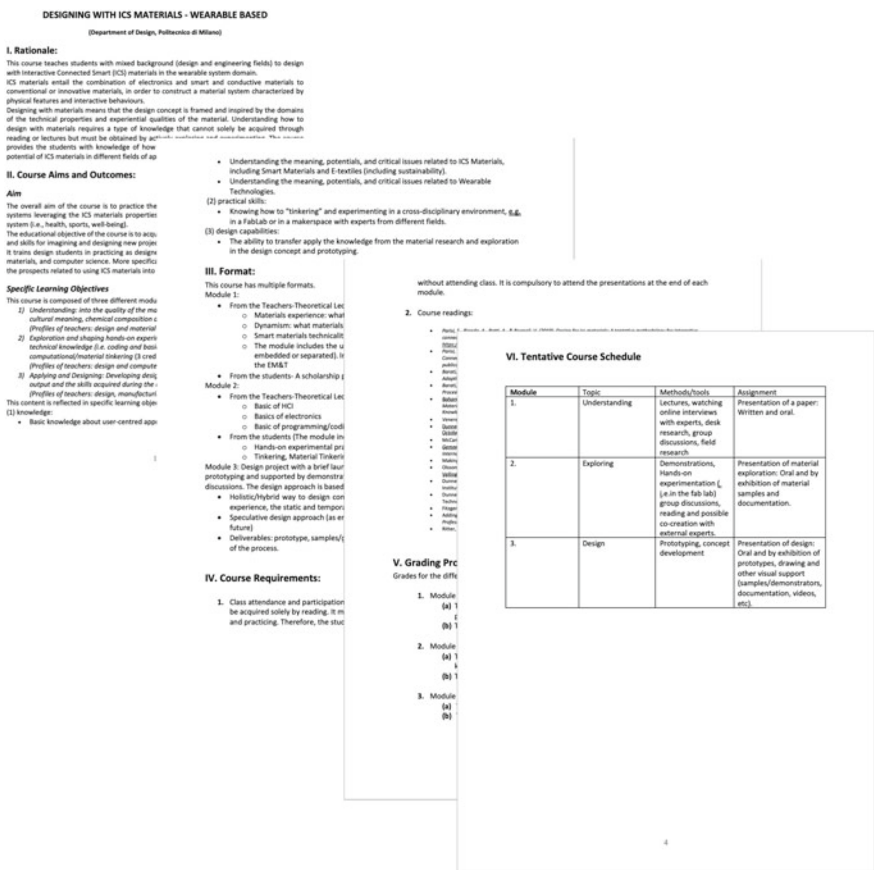
The template is divided into different sections:

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

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

7 Discussion

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



DESIGNING WITH ICS MATERIALS - WEARABLE BASED

(Department of Design, Politecnico di Milano)

I. Rationale:

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

VI. Tentative Course Schedule

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

Fig. 16 Example of the syllabus

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

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

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

We decided to perform the workshops within an education environment with students at the master's level (considered young designers) and companies launching a real market challenge to verify the efficacy of the design method at a professional level and at the teaching one.

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

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

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

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

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

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

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

8 Conclusions and Further Development

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

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

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

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

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

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

References

Abersek B (2016) Teaching with Analogies—examples of a self-healing porous material. Probl Educ 21st Century 70(1):4–7

Asbjorn Sorensen C (2017) A new approach to materials in Product Design Education—a shift from technical properties towards sensorial characteristics, pp 182–192

Ashby MF, Cebon D (1993) Materials selection in mechanical design. Le Journal De Physique IV 3(C7):C7-1

Ashby MF, Johnson K (2002) Materials and design: the art and science of materials selection in product design. Butterworth Heinemann, Oxford

Ashby MF, Johnson K (2013) Materials and design: the art and science of material selection in product design. Butterworth-Heinemann

Ashby MF, Cebon D, Silva A (2007) Teaching engineering materials: the CES EduPack. Cambridge University, Engineering Department, pp 1–13

Ayala-Garcia C, Quijano A, Ruge CM (2011) Los materiales como medio para estimular procesos de creación. Dearq (8):44–53

Barati B, Karana E, Hekkert P (2015) From way finding in the dark to interactive CPR trainer: designing with computational composites. In: Proceedings of the 9th conference on design and semantics of form and movement, May

Barati B, Giaccardi E, Karana E (2018) The making of performativity in designing [with] smart material composites, April, pp 1–11. https://doi.org/10.1145/3173574.3173579

BioHack Academy (2019) BioHack Academy. http://biohackacademy.github.io/. Accessed 20 May 2019

Chemarts (2019) CHEMARTS. https://chemarts.aalto.fi/

Cornish H (1987) Materials and the designer. Cambridge University Press, Cambridge

Dietza P, Guthmanna A, Kortea T (2006) Material-driven solution finding—functional materials in the design process. In Pham DT, Eldukhri EE, Soroka AJ (eds) Intelligent production machines and systems. Elsevier, Amsterdam, the Netherlands, pp 401–404

Ferrara MR, Lecce C (2016) The design-driven material innovation methodology. In: 6th International forum of design as a process-IFDP16 proceedings-systems & design: beyond processes and thinking. Universitat Politècnica de València, pp 431–448

Ferrara M, Lucibello S (2012) Teaching material design. Research on teaching methodology about materials in industrial design. Strateg Des Res J 5(2):75–83

Ferrara M, Russo AC (2019) Augmented materials for tangible interfaces: experimenting with young designers. Outcomes and analysis. *Adv Intell Syst Comput* 903(April 2017):667–672. https://doi.org/10.1007/978-3-030-11051-2_101

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

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

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