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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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 piezoelectric 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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