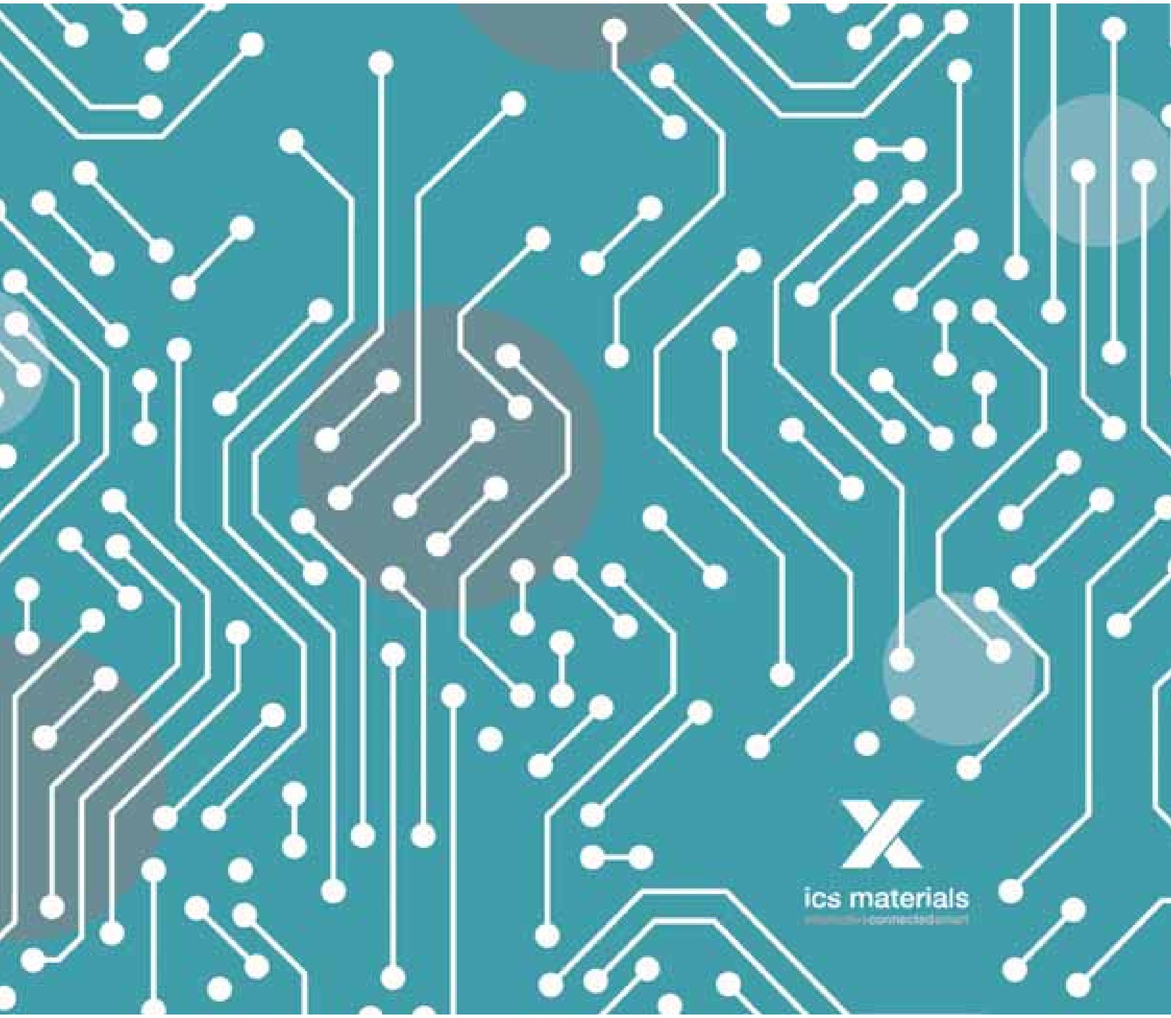
ICS MATERIALS

Interactive, connected, and smart materials

edited by Valentina Rognoli and Venere Ferraro



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1. ICS Materiality: the phenomenon of interactive, connected, and smart materials as enablers of new materials experiences

by *Valentina Rognoli* and *Stefano Parisi*
Politecnico di Milano, Department of Design

1. Living in an interactive, connected and smart world

In many areas of our private and social life, digital technologies are emerging with increasing strength and conviction. In the entrepreneurial and productive spheres, companies invest in digitalization following the guidelines of the new policies and riding the ever-increasing wave of financing aimed at new digital technologies. In front of such a promising context and an increasingly insistent demand, even the designers are invited to shape this umpteenth technological revolution. They have the responsibility to interpret this ambition for the miniaturization of information technologies and the diffusion of interdisciplinary environments that fuel cross-fertilization and the merging of previously isolated and distinctive practices. The ongoing direction we are increasingly witnessing is that the artefacts we use and wear in our everyday life are becoming more and more embedded with smartness. Smartness is the quality of an object to adapt to circumstances by reacting to different stimuli. While, at the level of designing interactive objects and systems for tangible interfaces, research and practice are already advanced, instead, at the level of the development and application of materials enabling smartness for purposeful and meaningful interactions, there are still significant progress to be done.

Indeed, the actuation of smartness will potentially evolve by instilling it in the matter itself thanks to miniaturization of technologies, instead then integrating it with interactive technologies. This will allow for seamless results avoiding the obtrusive presence of technology in the users' everyday life and promoting a more natural and sustainable approach to interactive objects, potentially enhancing novel and positive experiences. New materials with interactive and connective qualities that can be programmable and incorporated into intelligent systems are required to achieve this fully embedded degree of smartness.

As the products of our current time are and will increasingly be interactive and smart, designers and labs have also begun to work on developing connected and interactive materials, thanks to their hybridization with technology (Pandey, 2018). This reinforces an ongoing shift in the paradigm of relationship and agency between the designers, the design, and the materials: from being passive entities to choose from, materials have become active elements participating entirely in the design process, becoming the object of the design themselves. Indeed, these materials become able to sense and to communicate information, by performing behaviours by moving, changing colours, or by lighting up, and many other interactions. Thanks to this new agency and dynamism, starting from the shelves of the material library, where conventionally the samples are only stocked and catalogued, the material samples have gone on to be considered the main protagonists of the design process and the experimentation driven by design. This complex phenomenon revolutionizing materiality can be defined under the umbrella of Interactive Connected Smart (ICS) Materials and their implications in the design field.

In this chapter, we will propose a definition of Interactive Connected Smart (ICS) Materials, and we will identify the main elements constituting them. Finally, we will present the main experiences enabled and implied by these materials.

To define ICS Materials, we based on the results of the FARB 2015 project promoted and funded by the Design Department of the Politecnico di Milano (www.icsmaterials.polimi.it). In this extend, we consider all the relevant outcomes and findings from research and teaching experiences carried out by the authors.

2. What are ICS Materials

The concept of Interactive Connected Smart (ICS) Materials encompasses a broad range of materials that are defined by some of the following characteristics (Rognoli, Ferrara and Arquilla, 2016; Ferrara et al., 2018): be able to establish a two-way exchange of information with human or non-human entities; be 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; be 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; be programmable, for example - but not limited to - through software.

To have these interactive, connective and smart capabilities, ICS Materials are modelled as complex systems made by all or some of the following interdependent "building blocks" or "layers" (Parisi, 2020).

Conventional materials include materials such as plastic, paper and textiles that can be used as a support and structure in the system. Besides some mechanical and chemical interactions, such as performing flexibility and ageing, they do not perform dynamic and reversible behaviours. Therefore, they are latent materials with no evident interaction.

Smart materials are the ones that have changeable properties. They can reversibly change some features like shape, colour or light-emission in response to external chemical or physical influence, for example, light, temperature, electric or magnetic field, pressure and mechanical stress, chemical elements and compounds. The quality of the behaviour and the way these materials perform is programmable, i.e., they are engineered to respond in a predetermined way to the stimulus in a predetermined range. Frequent examples of these materials are shape-memory alloys (e.g., Nitinol, Flexinol, Muscle Wires), colour-changing (e.g., thermochromic, photochromic, electrochromic, halochromic pigments, inks and coatings), light-emitting (e.g., fluorescent, phosphorescent, and electroluminescent materials) materials (Addington and Schodek, 2004; Ritter, 2006; Ferrara and Bengisu, 2013; 2018)

Passive technologies include embedded sensing, such as sound, touch, and proximity sensors. Also, conductive materials can be used as sensing systems. They are mainly graphite, active carbon, and silver, and can be found in the shape of conductive fibres, threads, printed circuits, paints, and coating.

Active technologies include actuating technologies, e.g., LEDs, buzzers, or vibration actuators. Both passive and active technologies are connected with external or embedded computing technologies. Arduino or Flora boards are commonly used in prototype and experimental level applications.

Sources of energy can be external via wires and plugs or integrated with traditional batteries. Embeddable power supplies and harvesting systems can be alternative technologies and materials like flexible batteries, advanced solar panel systems, dynamo or electricity-generating materials, such as piezoelectric smart ceramics and polymers: on applying mechanical stress to piezoelectric materials, they generate an electric current.

Interconnection between components is supported and enabled by additional materials that can be found in the system wires, i.e. or conductive materials that can substitute traditional wires and cables.

If we combine one or more of these components - by layering or embedding -, we could achieve systems with different degrees of interaction, as presented in (Parisi et al., 2018 a) and in the next chapter (see chapter 2.2). Although having interesting functional implications, for example, tracking and adapting functions in different sectors and scenarios - which are described in the section III of this book -, ICS Materials present both material qualities and dynamic behaviours, enabling and implying complex and novel experiences that are worthy of understanding and enhancing. The lenses of the expressive-sensorial qualities and Materials experience are essential in the understanding and development of these materials, putting the sensory, emotional, and cultural relationships with the users in a pivotal point.

3. The lens of Materials Experience and expressive-sensorial qualities of materials

Nowadays, investigation on materials for design considers the expressive-sensorial and experiential qualities of artefacts as central, besides the technical properties of materials and their manufacturing characteristics (Ashby and Johnson, 2002; Rognoli, 2004; Rognoli, 2010; Karana, Hekkert and Kandachar, 2008 a; Veelaert et al., 2020). It is now acknowledged that materials require to have qualities that go beyond the fulfilling of practical and functional needs. They are qualitative aesthetic, expressive and sensorial characteristics eliciting intangible qualities related to cultural and personal meanings, perception, emotions and affectivity, that captivate the appreciation and acceptance by users and that affect the experience of an artefact beyond its functionality.

Rognoli, during her PhD research (2004), defined the sensorial, subjective, and qualitative profile of materials as their expressive-sensorial dimension. From this standpoint, materials have a role in characterising artefacts' perception, interpretation, and emotion, via their qualities. Examples of qualities are texture (smooth/rough), touch qualities (warm/cold, soft/hard, sliding/no sliding, light/heavy), brilliancy (glossy/matte), transparency (transparent/translucent/opaque). Designers are supported by flexible tools and methods for understanding, describing, and designing the material qualities of an object. Some relevant examples are the Expressive-Sensorial Atlas (Rognoli, 2010) mainly used in education (Pedgley et al., 2015), and the tools and methods used in the contemporary practice of Colours, Materials and Finishes (CMF) Design (Becerra, 2016). Therefore, designers can intentionally integrate, transfer or reinforce in an artefact some specifically "designed" qualities or references that all together trigger the desired material experience.

The concept of materials experience - introduced by Elvin Karana (Karana et al., 2008 a) and then further investigated, developed and extended (Karana, Pedgley et al., 2015; Giaccardi and Karana, 2015) - is defined as the experiences that people have with, and through, the materials embedded in a product. It describes a holistic view of materials for 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. This definition acknowledges and emphasises that, through shaping what we feel and think, materials have the agency to foster meaningful experiences.

The Materials Experience is modelled according to four experiential layers affecting each other (Karana et al., 2014; Karana et al., 2015):
1. the sensorial level (i.e., the aesthetics of materials) 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. The expressive-sensorial characterization of materials determines this level.
2. the interpretative level (i.e., meanings of materials) is related to the meanings evoked by the material and are associated to abstract concepts, e.g., materials are modern, natural, professional, cosy, etc. (Karana, Hekkert and Kandachar, 2008 b; 2010)
3. the affective level (i.e., emotions) is connected to how the materials make us feel and which emotions are elicited, e.g., feeling surprised, bored, excited, etc.
4. the performative level (Giaccardi and Karana, 2015) is related to the active role of materials on shaping our physical actions, ways of doing and practice. The materials can suggest us to interact in a precise manner, e.g., to scratch, finger, squeeze, etc.

It is evident now that scholars in the field of materials for design had then 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 relationship, and often contributes to give to products the features that are mediators of the quality of the interaction itself (Wiberg and Robles, 2010; Rognoli et al., 2011). Instead, the Human-Computer Interaction (HCI) and Tangible Embedded Interaction (TEI) community still considered only the functional properties of materials, and they did not believe their power as signifiers (Regier, 2007; Fernaeus and Sundström, 2012; Hornecker, 2010). We have to wait until the formalisation of the "material turn" (Robles and Wiberg, 2010) - and consequently "material move" (Fernaeus and Sundström, 2012) and "material lens" (Wiberg, 2014) - 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 concrete materials even in the HCI domain. 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 concerning the materiality of artefacts (Wiberg, 2018). Finally, HCI research shifted its attention from the materiality of information to materiality of interaction in the context of material-centred interaction design (Zhong et al., 2020). Therefore, the community around HCI and TEI has started to look at interaction and experience with materials as a complement to interaction with digital technology, bringing in novel computational properties of temporality, reversibility, computed causality, and connectivity (Vallgårda and Sokoler, 2010), and identifying aesthetic dimensions, namely pleasant, interesting, comfortable, playful, relaxing, special, and surprising (Petrelli et al., 2016).

4. Exploring ICS Materials as enablers of novel materials experiences: methods and results.

ICS Material may be enablers of novel and meaningful materials experience, as a combination of the expressive-sensorial characteristics, meanings, emotions, and actions elicited by their material components and interactive behaviours. In the last years, the authors of this chapter carried out workshops with students, professionals and colleagues to collect findings on the main experiential patterns emerging from the observation and interaction with these materials using samples (Parisi, Holzbach and Rognoli, 2021), developing prototypes and demonstrators (Parisi et al., 2021; Parisi, Holzbach and Rognoli, 2020), or observing pictures of best examples and visualized concepts (Parisi et al., 2019 a; 2019 b). Data were collected employing questionnaires and in-situ observation doing rapid ethnography and integrated with data resulted from the observation of best examples through pictures, videos and descriptions (Parisi et al., 2018 a; Parisi et al., 2018 b; Parisi and Shetty, 2020).

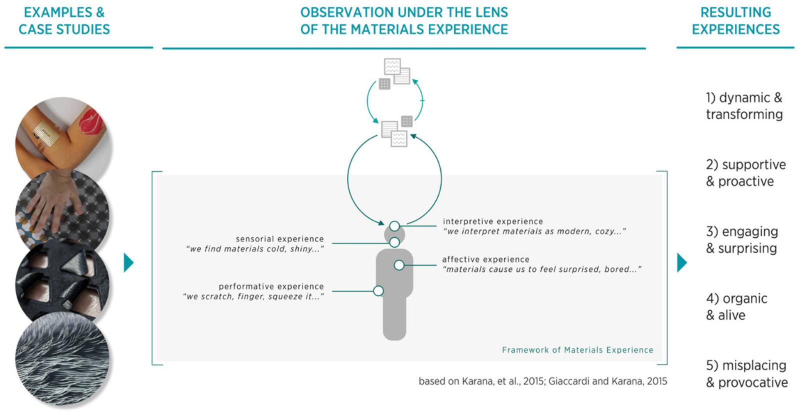

Fig. 1 - The model used for the observation of ICS Materials examples and case studies, using the lens of Materials Experience (Karana et al., 2015; Giaccardi and Karana, 2015). In the picture the following examples are shown: DuoSkin[1] (Kao et al., 2016), Recurring Patterns Project[2] (Nilsson et al., 2011), BioLogic fabric[3] (Yao et al., 2015), Transformative Paper[4] (Holzbach, 2015)

General considerations about experiencing ICS Materials

Among the results, prominent findings unfold the relationship between temporal and static expressions. From the observation of samples of best examples and case studies, the first reflection regards the three levels of the Materials Experience defined as Sensorial, Affective and Interpretive. At first, what emerges is a substantial similarity between ICS materials and traditional ones, when the material is latent, i.e., performing no behaviour. Therefore, they are perceived as traditional ones (e.g., paper, leather, concrete, fabrics, etc.), because at a sensorial level the impression is indeed given by the mate-

[1]DuoSkin by MIT Media Lab and Microsoft Research, 2016 (Kao, et al., 2016). Courtesy of Cindy Hsin-Liu Kao.

[2] Recurring Patterns Project by Smart Textiles Design Lab at the Swedish School of Textiles, 2011 (Nilsson et al., 2011). Courtesy of Linda Worbin and the Smart Textiles Design Lab at the Swedish School of Textiles.

[3] BioLogic by MIT Media Lab, Lining Yao, 2015 (Yao, et al., 2015). Courtesy of Lining Yao.

[4] Transformative Paper by Florian Hundt, a result of the cooperation "Intuitive brain" between Prof. Dr.-Ing. Markus Holzbach, Institute for Materialdesign IMD, HfG Offenbach and BMW AG, 2015 (Holzbach, 2015; Parisi, Holzbach and Rognoli, 2021). Courtesy of Markus Holzbach.

rial used as a support. This is due to the seamless integration of technology. The same implications regard the affective and interpretative levels that depend on the previous experience the user had with the material used as a support. While, in static conditions, the materials do not differ from traditional ones, instead they trigger different perceptions, emotions and interpretations while performing their programmed behaviour. Therefore, behaviours and dynamic expressions influence the experience modifying all the layers of experience.

Dynamic and transforming experience

In all the case studies observed, it is evident that, compared with traditional materials, the qualities of ICS materials are dynamic, reversible, and adapting in response to external stimuli. In other words, ICS materials are not latent; instead, they are constantly changing, modifying their qualities over time. A dynamic materials experience has 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 shape some experiences intentionally. 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 behaviours and practices, due to their ability to establish emotional and affective interactions (Minuto, Pittarello and Nijholt, 2014; Rognoli, 2015).

Supportive and proactive experience

To their best degree of smartness, interaction, and connectivity, such materials enable proactive experiences. Not only they sense and respond to input, but they can establish a relationship or a dialogue with the user or the environment, or even between the user and the environment. They respond to input from users or environment activity, making invisible data evident and, in a way, tangible to the users by means of movements, vibrations, sounds, colour-changes, or light-emission. Therefore, the users are encouraged to respond to the materials' feedback, changing their ways of doing or their habits for better. This can regard data about air or noise pollution. They can make information more accessible to the user, informing and enabling them to respond to it and act more aware - and proactively - in their daily life. Moreover, ICS materials can make objects, wearables, and spaces constantly monitoring biometrics and adapting to the users' needs for their wellbeing, with significant implications in health prevention and rehabilitation. Interacting with dynamic materials can lead to personalized relationships with the material. Personal and unique aspects of this relationship between the user and the material are derived from the interpretative component of the materials experience. This is especially the case in ICS Materials that change to suit different conditions.

Engaging and surprising experience

ICS materials enhance the aesthetic enjoyment by triggering the effect of surprise and by creating entertaining multi-sensory experiences. Much like for natural and biological organisms, dynamism and reactivity of ICS Materials offer an element of surprise and unpredictability which drives people curiosity. However, digital technology allows us to control such unpredictability. ICS Materials can 'integrate the unexpected' because they highlight the visual-touching incongruence as an underlying connection with the sense of surprise in materials (Ludden, Schifferstein and Hekkert, 2008; 2012). Often the incongruence is even improved by the contrast between the familiar look and feel of the material in its static form, and the surprising and dynamic expression in its temporal form. In many cases, users more likely interact with the material when static, while when reacting at first preferred to observe instead of touching. However, after some time, surprise and positive feedback may leave roam to neutral feedback. This issue can be addressed by creating complex dynamic interaction, by layers of temporal forms of different typology that may contribute to establishing a deeper emotional connection with the user. An example is combining programmed behaviour of actuators, with reversible behaviours of smart materials, with irreversible behaviours of the supporting material. The suggested combination will create diverse and ever-changing alterations, relations and behaviours in the material and its components keeping users' surprise and curiosity stimulated over time.

Organic and alive experience

Often, users express analogies between ICS materials and nature, because of their dynamic behaviours which emulate or resemble the ones of living organisms. Slow behaviours are considered more organic and nature-inspired and are perceived as more positive, evocative and emotional. Some case studies, in their latent dimension, suggested how the material would react, in an organic manner and by exposing a principle of accordance between shape, material, and behaviours. This evokes positive connections. In many cases, the inspiration to natural behaviours of animals or vegetal organisms is evident, and biomimicry arises as an approach to transfer the that natural feeling and to create more intuitive interaction.

Misplacing and provocative experience

While some people had a positive reception to the materials, mainly related to the feeling of surprise and wonder, for others the behaviours itself was considered as obtrusive or even aggressive. Although behaviours typical of nature and inspired by it are generally perceived as positive, evoking and relaxing the users, the 'living' behaviour provided by the digital components of these materials can cause emotional discomfort on the other hand. A material with an agency can be perceived as obtrusive, i.e., physically and sensory evident in an unwelcome and intrusive way, causing physical and emotional distress. To this extent, they have to be considered as uncertain and provocative. Out of their comfort zone, the users are challenged to find personal and unique ways to interact with the materials and objects. The observed cases reveal a tension between the sensorial and emotional comfort and enjoyment, and the possible feeling of discomfort and anxiety provoked by the behaviours.

5. Conclusions and remarks on ICS Materials and experience

In this chapter, we presented ICS Materials as a phenomenon enabling novel and meaningful materials experience, thanks to the leverage of material expressive-sensorial qualities and interactive behaviours. By observing ICS Materials examples through workshops, observations, questionnaires and qualitative studies through the lens of Materials experience, we presented some relevant findings of the main experiences they enable and imply. We clustered them into some emerging experiential patterns: 1) dynamic and transforming; 2) supportive and proactive; 3) engaging and surprising; 4) organic and alive; 5) misplacing and provocative experiences.

In these experiences, digital and material are not distinctive, but entangled elements of the same cognitive and design process. Digital, materials and design are no longer separated things but are porous elements of the same process of research, design and invention (Pink et al., 2016). 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. Indeed, ICS Materials are emerging materials with extraordinary characteristics unfolding new practices to shape and control them. They require a new set of approaches, tools, and techniques to be integrated into design practice and education.

Smart materials and interactive technologies entail new tasks and challenges for designers who have to ensure that - in achieving what is technically feasible - the well-being and sense-aesthetic engagement of people is preserved (Ritter, 2006). In particular, designers have to be careful about the risk to design something obtrusive - i.e., causing physical, emotional and affective distress - or meaningless for users. They can control it by tuning material qualities and practices, achieving meaningful materials experiences.

It is difficult to describe the qualities of ICS materials as they continue to change and transform themselves. This is also a limitation for the tools and models hypothesized for their understanding and characterization. These must be redesigned to provide the temporal perspective able to read the dynamic and changing experiences that ICS materials, as flexible and programmable elements, can create. Within ICS Materials, designers can also become programmers (Vallgårda et al., 2017) of the qualities of materials, designing interactions and responses as part of the expressive-sensory and experiential characterization of the material. In fact, ICS materials are incredibly flexible in providing countless qualities related to materials experience at different levels. The materials are, therefore, no longer chosen only for their properties but are programmed, designed, modified, processed to respond to specific needs or situations.

In this chapter, we have presented the definition of Interactive Connected Smart (ICS) Materials and have tried to identify their main constituent elements. Finally, we introduced the principal experiences enabled and suggested by these materials. Concluding, therefore, beyond the programming skills implicit in ICS materials, and their interactive, connected and intelligent nature, it was understood how these materials offer great opportunities in terms of tangible interaction. They are opening significant developments and new paradigms for product and interaction designers, which could act simultaneously on different levels of the design project. By adjusting the layers of experience to consciousness, designers play a decisive role by contributing to the creation of meaningful material experiences, meeting people's appreciation concerning specific materials and improving values and behaviours in society.

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This present book covers a series of outstanding reputation researchers' contributions on the topic of ICS Materials: a new class of emerging materials with properties and qualities concerning interactivity, connectivity and intelligence. In the general framework of **ICS Materials**' domain, each chapter deals with a specific aspect following the characteristic perspective of each researcher. As result, methods, tools, guidelines emerged that are relevant and applicable to several contexts such as product, interaction design, materials science and many more.

FrancoAngeli
La passione per le conoscenze