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Materials that Change Color

Smart Materials, Intelligent Design

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Chapter 1
Introduction

Abstract This chapter presents the subject and objectives of the book *Materials That Change Color* in the context of applied research and concept design. The implications of the techno-scientific research on theories and methods of design are outlined. Technical opportunities for new qualities given to objects of everyday life, like sensitivity, interactivity, communication skills and sustainability are analyzed from the perspective of design. In addition, the chapter discusses the implications of the extraordinary performance of the new materials on the broader meanings that new products present for users and on the visions of phenomenological reality in a cultural and socio-economic framework that characterizes the contemporary world. Some terms such as smart materials and smart systems are described and their role in design is shortly introduced. It is intended to provide designers the tools to develop skills necessary for innovative ways of thinking about materials and their relationship with technologies.

Keywords Smart materials • Smart systems • Design • Intelligent design • Nanoscale • Color

This book presents a design-driven investigation into *materials that change color*. These materials belong to the new class of high-performance materials, commonly known as *smart materials*, developed by chemists, physicists, materials engineers, and now available to be applied by designers to consumer products.

There is a vast variety of materials which make part of this new class of smart materials. In addition to materials that change color, treated in this book, there are those which change form, dimensions, temperature, those which transform one type of energy to another, and those which move; all in response to an external stimulus which induces a change in material properties according to the intrinsic nature of the materials, with a reversible effect.

This book introduces materials that change color with the aim of supplying basic information on them. Various categories of these materials are presented along with their behaviors in relation to the stimuli to which they react and other basic information, like characteristics, advantages, potentialities, production processes, and challenges for applications. This information will help to understand

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how materials that change color work, how they are applied to products and systems, and how their multi-faceted nature was put to use until today.

It is true that today's mode of techno-scientific operation allows the discovery, development, or replacement of smart materials continuously. Therefore, it is necessary to understand the properties of these materials and how they would behave under a certain energy input for new applications and for new directions in research in order to profit from them.

Another objective of this book is to develop a methodological approach for the use of these materials and related technologies, as well as a design vision, which is feasible and sustainable in the context of current problems. It is aimed to stimulate designers to take a more proactive attitude in the choice and application of these materials, in an efficient manner and as a strategy to realize innovations, which can contribute to social welfare and not merely aiming at commercial exploitation.

In order to aid these objectives, the book also presents a number of case studies: products, projects, concepts and experiments using smart materials, thus mapping out new design territories, roles and opportunities for these innovative materials. These case studies were chosen by the authors based on their capacity to represent state of the art projects and experiments in different fields of design, including product, interior, fashion and communication design. Unlike industrial patents, design case studies, by showing design methods and their results, are useful to understand both the functional and expressive nature of these materials. They show the new qualitative dimensions that smart materials bring into industrial and product design, the role that these new materials and technologies can play, and their influence in different areas of design.

The decision of treating a selection of case histories in a transverse manner in various fields of design has the intention of promoting a better understanding of opportunities offered by these technologies for designers. This approach derives from the typical mode of operation of Italian design, which utilizes tools such as design-driven innovation, cross-fertilization, and technology transfer, in order to develop creativity and facilitate innovation in products deriving from sectors with low capital investment. The whole of these case studies demonstrate the opportunities, which appear in projects with new scenarios for objects, environments, relations, and interactive systems, which satisfy new performance requirements. These case histories also form an ample range of scenarios of methodological approaches used by designers in various fields of smart material applications.

Within the context of rising sustainable and human-centered design agendas, this book will demonstrate the role and influence of these new materials and technologies on design, and discuss how they can implement and redefine our objects and spaces to encourage more resilient environments. The applications of smart materials are able to safeguard energy and material resources, to enrich product function, aesthetics, safety, and their communicative potential, and to contribute to a pleasurable user-product interaction. Once these potentials are put into action in a tangible project, it is possible to talk about *intelligent design*.

Smart materials provide new sources and perspectives for intelligent design. They are expected to be one of the key contributors to revolutionary products and systems of the near future. This book is meant to be a witness to the first steps toward a more human-centered, sustainable, and hopefully enjoyable future.

1.1 Smart Materials and Implications in Design

As it happens with all that is new, the widespread use of smart materials will also depend on their *acceptance* and *familiarity*. The acceptance may be facilitated through a comprehension, which is derived from correct information and from modes of communication, which must connect actors of innovation, namely materials scientists, engineers, designers, entrepreneurs, producers, distributors, and consumers/users. This is not an easy task but we want to try it at least for material scientists, engineers, and designers. This brief introduction intends to provide designers the tools to develop skills necessary for innovative ways of thinking about materials and their relationship with technologies.

Within the last five decades, materials became the true performers of change. One of the key innovations in that field has been the emergence of smart materials. This new class of high-performance materials is the highest expression of the *paradigm of tailor-made materials* (Manzini 1986; Ferrara 2004, 2005; Cardillo and Ferrara 2008) that has consolidated this contemporary third phase of the industrial revolution: the electronics and computer revolution. In other words, smart materials have been derived from the techno-scientific capability to intervene in the matter, not at the macro-scale, but at the molecular scale, and modify it[1] in relation to a project with predefined functions or performance. This model has given life to the electronic revolution, putting in action the potentials of artificial intelligence with an extremely reduced quantity of materials (miniaturization). As a matter of fact, working with materials at the electronic scale, the first transistor was realized, followed by all the electronic devices which we are using every day. Thus, the story of smart materials had started in the first 40 years of the 20th century when, thanks to the introduction of the electron microscope (1931), the study of materials at the electronic scale had amplified the understanding of the subatomic world, a dimension in which the laws of classical physics, where everything is measurable and predictable, was no more valid.[2] The study of

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[1] In a program solicitation of the National Science Foundation it was stated as follows (NSF 2000): "One nanometer (one billionth of a meter) is a magical point on the dimensional scale. Nanostructures are at the confluence of the smallest of human-made devices and the largest molecules of living systems… A revolution has begun in science, engineering, and technology based on the ability to organize, characterize, and manipulate matter systematically at the nanoscale. Far-reaching outcomes for the Twenty-first century are envisioned in both scientific knowledge and a wide range of technologies in most industries, healthcare, conservation of materials and energy, biology, environment, and education".

materials has helped to understand their organization and operation, opening up the doors to the Quantum Theory and quantum mechanics.[3]

Unlike classical physics, which is based on the concept of solid and indestructible particles (so-called *basic building blocks*), the concept of quanta, tiny energy packets with a double nature of wave (at subatomic level) and particle (at the moment of observation), made it possible to describe the dynamic properties of matter and the interaction of radiation with material.[4] It was thus concluded that the so-called building blocks are intangible energy waves, which appear like solid entity due to the great velocity at which they rotate.[5] A paradox of nature, which is

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[2] All classical physics was constructed around the mechanistic Newtonian model of the universe in which all physical phenomena took place. This was the three dimensional space of the classical Euclidian geometry: an absolute space, always steady and unchangeable. All the changes occurring in the physical world were described as a function of a separate dimension, called time. Also this was absolute, which did not have any link to the material world, which was flowing evenly from the past to the future, through the present. The elements of the Newtonian world, which were moving in this space and in this absolute time were material particles. In mathematical equations, these were treated as material points and Newton considered them as small, solid, indestructible objects from which all material was comprised. This model was very similar to the atomistic model of the ancient Greeks. Both were based on the distinction between empty and full and between material and space. In both of the models, the particles remained identical to themselves in mass and form and thus matter was always conserved and essentially inert.

[3] The formulation of the quantum theory began when Max Planck discovered that the energy of thermal radiation is not emitted in a continuous manner but in energy packages. Einstein called these energy packages *quanta* and postulated that light and all other forms of electromagnetic radiation can present themselves not only as electromagnetic waves but also in the form of quanta. Light quanta, which gave the name to quantum mechanics, were subsequently been accepted as real particles and are now called photons. However, these are special particles lacking mass and always, in motion at the speed of light. At subatomic level, matter is not situated at precise locations but they demonstrate a *tendency to be present* in a certain place while atomic events do not occur with certainty at a determined time but they show a *tendency to take place*.

[4] Hence the acceptance of the foundations of quantum mechanics:

- The objective state of matter is characterized by a superposition of several states.
- There is no objective reality of matter but only a reality that is determined by *observations* of a person from time to time.
- The fundamental dynamics of the micro-world are characterized by contingency.
- It is possible that, under certain conditions, matter can “communicate at a distance” or could “appear” from nothing.

[5] The current concept of atom is that of a complex dynamic system with the dimensions at the range of one tenth of a nanometer, composed of various types of neutral and charged particles. Negatively charged particles, i.e. electrons, orbit around a central nucleus, circa hundred thousand times smaller than the atom, in which almost all the mass is enclosed. Only those electrons less attached to the nucleus participate in complex processes of activation (during which the atom literally changes form), which give place to the stabilization of the chemical bond between atoms of condensed matter.

difficult to explain if our senses are involved[6]: how can something exist which is both intangible and tangible at the same time?

Well, matter appears ambivalent. This could be explained as a set of discrete atoms and particles where each of which have their own role and individuality or as a whole a space, a field which acts through waves, applying a force at an indefinite point (Heisenberg et al. 2002). Yet, even in today's techno-scientific era, quantum theory is science, which is *put up with*, rather than being *accepted*. Not because its implications have little interest, but because they are so discomforting with respect to past certainties, as to be incomprehensible if not directly unacceptable.

Similarly smart materials put our certainties in crisis. In fact, according to common sense, material is substance; the substance from which things are made, perceived by the senses, are characterized fundamentally by mass and volume. Even the terms material and substance, due to the strong philosophical connotation, remind something which exists in itself, in a permanent and stable fashion. With smart materials, this idea is not valid anymore, starting from the relationship between material consistency and its appearance, between stable characteristics and their possible variation with time.

But what is intended by the smartness of a material? The smartness in a material (or a system) is determined by the relationship between its properties, its state, and the energy applied directly to the material. If this relationship influences the internal energy of the material, altering both the molecular/crystal structure as well as the microstructure, then the input will cause a change in material properties: the material absorbs energy that enters and undergoes a change. The change of internal structure is a common property of smart materials. If the mechanism modifies the state of energy of the material but doesn't affect the material itself, in that case, the reaction consists of an energy exchange from one form to another: the material remains the same but the energy undergoes a change. Such materials are typically not considered smart materials.

Smart materials are sometimes used as a critical part of a *smart system*. Such systems are typically composed of a *sensor* which has the function of sensing a change in the environment, a *control* group which processes this data to decide on the type of action, and an *actuator* which performs the desired action. Smart systems do not necessarily contain smart materials, so the ones that do contain them are properly called *smart material systems* (Smith 2005; Varadan et al. 2006).

In the field of design, smart materials have challenged the rationalistic theory that is based on the truth of materials (Dunne 2005) to substitute it with the slogan "sincerity and ambiguity" (Paris 2009). In fact, smart materials, unlike common ones, have two or more appearances according to the dynamic behavior that varies with time in response to fields of energy. This is an important distinction that undermines both the user and the designer and challenges the suitability of

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[6] Up until 1982, scientists were not able to obtain an undistorted and direct image of atoms. In 1982, Binnig and Rohrer succeeded to get an atomic resolution image of the surface of silicon atoms with the scanning tunneling microscope (STM) that their team had developed (Wiesendanger 1994).

instruments used for design up to now (Addington and Schodek 2005). With smart materials, the objects and their immediate environments change, as do the ways in which they are conceptualized, tested, designed, and produced.

Another critical issue for design is the nanometer scale of some smart materials, which makes them very difficult to manipulate and process. Nanoscale features are difficult to analyze even with state of the art electron microscopes.[7]

Up until now, the application of smart materials at the nanoscale for the production of integrated components, miniaturized and incorporated into technical objects, increased the gap between the comprehension of the material and the function which it confers to electronic items. The gap between the electronic scale and the scale of objects (Dunne 2005) is primarily determined by the technical complexity, but also by the way of using smart materials. Manipulating materials at the electronic scale is even today a very difficult way for designers. This role is essentially delegated to scientists. In the field of materials for design, Manzini (1986) was the first one to explore the implications of design with innovative materials. He highlighted the opening of a new chapter in the history of design and the need to define a new framework, a vision, even a method, by which the designers could work with other actors of innovation to imagine a new interactive nature of products. As stated by Dunne (2005), Manzini has highlighted the potential of miniaturization, integration of multiple functions into a single object and aesthetic-decorative characterization deriving from new materials.

Many other important possibilities wait to be explored by designers. The potential presented by new materials to open new channels of communication between objects, electronic environments, and users need to be addressed. Furthermore, the advantage that smart materials offer in terms of energy savings and environmental sustainability are tremendously important today. Since most of the publications on smart materials are scientifically and technically oriented, the cultural, poetic, and practical aspects need much more exploration to do.

If scientists and engineers have been engaged in the development of these new materials for the past 20–30 years, designers have now the responsibility to find ways to develop applications, namely the appropriate adoption of technologies, to

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[7] The invention of STM represents, even if only partially, the breakage of barriers between the atomic (or nanoscopic) world and the everyday experience of people. Despite the fact that the atomic structure was described by theoretical physics since the 1930s, even today, most of the experimental data is of an indirect nature, provided mainly by techniques such as spectroscopy, X-ray diffraction, and electron microscopy. However, tools such as STM and atomic force microscopy, which have the ability to see and manipulate single atoms, are becoming more common. This permitted to understand that at the scale ranging between a few nanometers and the dimension of a single atom (0.1 nm), the properties of materials depend strongly on the dimension. Thus, a metallic particle can become transparent, a semiconductor particle can change color, another one can melt at a temperature significantly lower than the common counterpart, etc. All this without changing the chemical composition but only acting on the size. The wonderful performance of many smart materials are linked to this effect.

ensure that they become available for the improvement of our daily lives. In other words, design is a powerful process of adopting a technology of cultural appropriation[8] (Mosse 2010) that involves understanding, acceptance of the implications and consequences, and that operates by manipulating it so that it can improve the lives of users.

Today there are many arguments to support the use of smart materials. With regard to the intrinsic sustainability of smart materials, it can be pointed out that the advancement of knowledge (due to scientific discoveries and technological inventions) with the subsequent evolution of culture, has given rise to new questions and changing needs of the scientific, creative and productive approach.

Smart materials have been specifically engineered to accomplish a particular performance objective thanks to their capacity to respond dynamically to the environment (Addington and Schodek 2005). In fact, they are characterized by their ability to detect and respond to stimuli from the environment (such as stress, temperature, moisture, pH, electric or magnetic fields), by a specific change of behavior, as for instance a color or shape or form change. They are also able to detect the intensity of the specific stimulus and respond accordingly (Jiang and Feng 2010). Each type of smart material acts as if to have a “genetic” code, coinciding with the performance design, providing a specific and reversible reaction. It processes actual behavior in an analogous manner to biological systems.

Moreover, smart materials are ‘first law materials’, which means they adhere to the principle of conservation of energy, that is, they can “change an input energy into another form to produce an output energy in accordance with the first law of thermodynamics” (Addington and Schodek 2005).

Smart materials can be produced at the miniaturized dimension, even at nanometer-scale, because of their relatively homogeneous nature. The possibility of micro- or nanoscale processing of these materials encourage the invisible integration within other materials, to achieve sensors, actuators, and MEMS embedded into objects and our environment, extending the limits of where computation can operate, and enabling materials to interact with their surroundings (Manzini 1986; Cardillo and Ferrara 2008; Coelho and Maes 2007). This integration also allows a reduction of components and quantities of materials.

The integration of smart materials gives extraordinary performance and new qualities to the objects of everyday life: sensitivity, interactivity, and communication skills are just some of the new qualities. But the use of smart materials in a certain application does not necessarily lead to intelligent design. The intelligence depends on the type of project and on the vision of the designer.

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[8] Already in 1851, at the Great Exhibition in London, the architectural theorist Gottfried Semper affirmed the importance of design to “appropriate” the new tools that modern technology provides.

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