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Toward designing new sensoaesthetic materials*

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Abstract: In ancient societies, there was no arts/science split. The development of materials was driven both by aesthetic and technological goals. At the end of the 19th century, things changed dramatically. Scientists started being able to analyze composition, detect structure, and make a link between structure and properties. The subsequent 20th-century revolution in new materials changed almost all aspects of human activity. However, it was not without serious side-effects, the first of which has been that the materials science community has willingly marginalized itself. The second is the eradication of interest in the sensual and aesthetic properties of materials, and thus the banishment of the creative urges that arrive via the senses. This paper discusses these issues, and suggests that collaboration with the materials arts community offers exciting new challenges and could create an intellectual community that is not just more culturally and ethically aware, but also nurtures more innovative science.

Keywords: materials science; arts; culture and materials; senoaesthetic; materials art.

INTRODUCTION

The relationship between culture and materials is most obviously demonstrated in the naming of ages of civilizations after materials, such as the Stone, Bronze, and Iron Ages. In ancient societies, there was no arts/science split. This was because there was no science, or at least not in the sense in which we mean it today. Nevertheless, without the laws of thermodynamics, crystal structures, or phase diagrams, our ancestors discovered most of the materials we have today: metals, cements, pigments, ceramics, composites, and glasses [1].

Although each ancient civilization pushed forward materials technologies, the development of a structure of materials knowledge, a deductive theory of materials, was not fully developed until the 20th century. The roots of this approach are to be found in the Renaissance of Europe in the 15th and 16th centuries. The practice of alchemy grew, and, although shrouded in the occult, it instilled a thirst in its adherents to discover the hidden principles behind the transformative nature of some materials, and the apparent immutability of others such as mercury and sulfur. Amongst other things, these experiments yielded new pigments, mordents, and binders, which were then used by Michaelangelo, Titian, and other Renaissance artists. Thus, the development of materials was driven both by aesthetic and technological goals [2].

The openness to new modes of thought about the natural world, which was initiated in the Renaissance, ultimately led to the destruction of the Aristotelian principles of intuition and dogma. By doing so, natural philosophers discovered a huge wealth of new phenomena, such as electricity. It was an extremely fruitful period in which the concept of a "scientist" was born (although the term "scientist" was coined much later). This new approach is encapsulated by Santiago Ramón y Cajal [3]:

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> The intellect is presented with phenomena marching in review before the sensory organs. It can be truly useful and productive only when limiting itself to the modest tasks of observation, description, and comparison, and of classification that is based on analogies and differences. A knowledge of underlying causes and empirical laws will then come slowly through the use of inductive methods. Another commonplace worth repeating is that science cannot hope to solve Ultimate Causes. In other words, science can never understand the foundation hidden below the appearance of phenomena in the universe. As Claude Bernard has pointed out, researchers cannot transcend the determinism of phenomena; instead, their mission is limited to demonstrating the how, never the why, of observed changes. This is a modest goal in the eyes of philosophy, yet an imposing challenge in actual practice.

But the discoveries of the Enlightenment period, and the new attitude of taking apart the natural world, in order to discover its mechanisms, provoked strong reactions by various parts of Western society. In particular, a Romantic movement grew up, which in its most extreme form was opposed to the active deconstruction of Nature. This attitude is typified in the following passage from the poem *Lamia* by Keats:

> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule and line,
> Empty the haunted air, and gnomed mine —
> Unweave a rainbow, as it erewhile made
> The tender-person'd Lamia melt into a shade

In this poem, Keats comments on Newton's theory of light, which he regards as "unweaving" the poetry of a rainbow and so as an attack on the fundamental mysteries of the universe. In the same period, Mary Shelley wrote *Frankenstein*, which was a reaction to the newly discovered phenomenon of static electricity which Galvini had recently showed could provoke a severed frog leg to twitch. This Frankenstein theme, in which scientific discoveries are viewed as leading to the downfall and degradation of the human spirit, is another Romantic theme, and continues to modern times (e.g., the film *Terminator*).

The philosophical split between the Romantics and Rationalists deepened in the 19th century, as the Industrial Revolution took hold. The defining material of that century, steel, allowed engineers to give full rein to their dreams of creating suspension bridges, railways, steam engines, and passenger liners. In doing so, engineers used steel as a material manifesto to transform the landscape and to sow the seeds of modernism. The industrialization of the countryside, towns, and cities showed that science had the power to transform society, but more than that it gave status to scientists and engineers as powerful architects of change.

The scientific project of cataloging of the phenomena of world led also to the development of a large body of deductive theory, which not only yielded new understanding about observed phenomena, but predicted new phenomena. This was particularly important for materials technology. As the discipline of chemistry progressed in the 19th century, it became possible to systematically explore materials properties. The establishment of the periodic table was a good example of this: it predicted the existence of certain elements, which were then discovered. This caused, amongst other things, new pigments to be discovered such as cobalt blue and cadmium yellow, which ultimately gave rise to artistic movements such as Impressionism and to the Color Theorists. But while it might be supposed that the discovery of new pigments might have initiated a new closer relationship between the arts and sciences, in practice it heralded an end to the collaborative exploration of materials. After this, materials discovery and development was largely to become a scientific activity.

The 20th century is often referred to as the age of silicon, in reference to the materials breakthrough that gave rise to the silicon chip and digital computing. But this is to overlook the kaleidoscope of new materials that revolutionized 20th-century living. Architects took the new mass-produced sheet glass and combined it with structural steel to produce skyscrapers that invented a new type of city life [4]. Product designers and fashion designers took the new plastics and transformed the home and fashion [5]. Polymers were used to produce celluloid and in doing so ushered in the biggest change in visual culture for 1000 years, the cinema. The development of aluminum alloys and nickel superalloys allowed us to fly cheaply and changed the rate at which cultures collided. Medical and dental ceramics allowed us to rebuild ourselves and change the social context of disability and age [6]. New composite materials, such as fiberglass and carbon fiber-reinforced plastics, literally changed the shape of all sporting equipment [7].

Thus, the 20th century witnessed a materials revolution in which the new discipline of materials science played a central role in transforming architecture, product design, urban design, fashion, transport technology, medicine, and the visual and performing arts. However, the arts/science split in materials has led to a situation where now the scientists, technologists, and industrialists (the materials science community) involved in the development of new materials, move in both academic and social circles widely separated from designers, architects, media, crafts people, and artists (the materials arts community).

This status quo may not be desirable for a number of reasons. Firstly, the materials arts community are not playing their full role in determining the focus of publicly funded materials research (at the moment it is the military and industrial sectors that collaborate most closely with materials science departments). Secondly, the cultural sector has a long history of posing interesting problems which benefit the arts and push science forward. A contemporary example could be the need in the digital media community for haptic materials that transform their properties in response to digital stimuli so that virtual touch and haptic feedback can become a (virtual) reality. Such new materials could also have impact on architecture, jewelery, product design, the special effects industry, as well as art [8]. Thirdly, materials have an immense cultural significance, and the further introduction of new materials by an isolated science community holds the prospect of a further deepening of the rift between scientists and society.

TOWARD THE DEVELOPMENT OF NEW SENSOAESTHETIC MATERIALS

Materials science as a discipline is the study of the structure of materials. It is a central tenet of materials science that a particular structure will always yield a particular set of properties, so control of structure yields the control of properties (e.g., strength, toughness, etc.). Materials science became possible because scientific instruments were developed to enable the observation of structure at different scales, firstly through the optical microscope, then through electron microscopes, atomic force microscopes, and a myriad of other techniques. These observations then give rise to a body of theory which can predict how to improve properties. Thus, theory, simulation, and experiment all inform each other to provide a framework of the systematic development of new materials.

The close relationship between materials science and engineering promotes this innovation. The disciplines share a common language in mathematics and have agreed-upon standards. Materials testing and the establishment of mathematical definitions of properties such as strength and toughness were developed precisely because engineers wanted quantitative information about the materials they were using to build. The Kirkaldy mechanical testing laboratories in London were the first such foray into developing this common language, which is now standard practice. Large databases have now been developed which are an effective translation between the language of crystal structure, chemical bonding, nanostructure, and microstructures that materials scientists study, and the language of fracture toughness and elasticity that engineers need to design buildings and machines.

The relationship is particularly strong in sectors where performance improvement is the only key to commercial survival, such as the electronic and aerospace industries. The design of a jet engine, for instance, involves engineers and materials scientists working at all length scales to deliver the required increase in performance. The ability to hand information up and down the scales in a form useful to each practitioner has been the key to innovation, the reduction of the cost of flying, and the increase in safety. This separation of approach and profession, as a function of the scale of structures, is illustrated in Fig. 1.

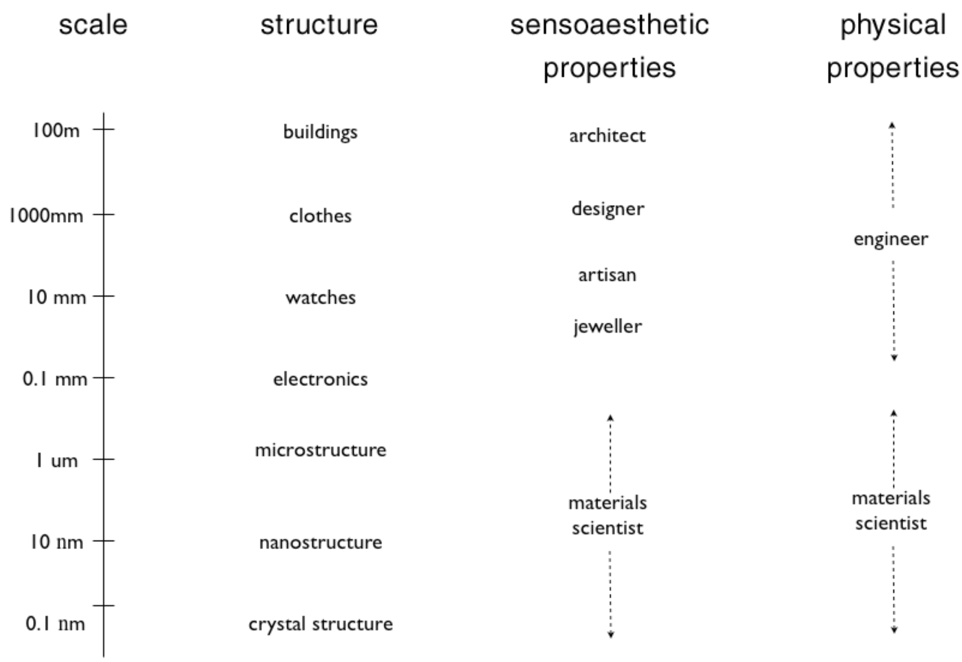

Fig. 1 A schematic of how the sensoaesthetic and physical properties of structures are designed and used by different professions and at different scales.

The situation is very different for structures whose performance is not based solely on the physical parameters but also by sensoaesthetic (sensual, aesthetic, and psychological) properties of materials. These structures include buildings, interiors, urban spaces, clothes; in other words, structures in which human comfort, inspiration, and satisfaction are important. These structures tend to be designed by the materials art community, because of their expertise in understanding needs and desires of people. Unlike the aerospace industry, however, there is no systematic methodology for development of materials with such sensoaesthetic properties. There is no body of research linking structure to sensoaesthetic properties of materials, except in the case of pigment design.

Part of the reason for this is that many of the sensoaesthetic properties of materials are clearly subjective, and so are outside the realms of materials science. The aesthetic appeal of wood interiors, for instance, is by definition a matter of taste, which depends on the culture of the person as well and the intended role of the structures. Nevertheless, some materials are considered warm (woods) and others cold (metals). These generalizations do not just have their origin in a shared cultural outlook but rather in our shared biology. Metals are good conductors of heat and so conduct heat away from the way quickly, making them seem cold to the touch. Woods are thermal insulators, so the reverse is true. Thus, the interface between humans and the material environment is mediated by the senses, the color, smell, sound, touch, and taste of materials. These sensoaesthetic properties are also unusual because they have a psychological component. For instance, the color blue is not perceived as a fixed hue in the brain, the perception of blue is relative to the color context [9]. Similarly, the taste of a material depends on action and association of the context of eating: a potato can taste like an apple, in the absence of smell [10].

ROLE OF MATERIALS LIBRARIES

The materials that clothe us and define our homes and cities are chosen by product designers, fashion designers, and architects from the vast array of materials in production. There is a growing recognition of the sheer enormity and difficulty of this task, requiring as it does an encyclopedic knowledge and understanding of all types of materials technologies. Individual materials arts experts tend to have specialized areas of expertise of particular materials and processes, for example, a knowledge of silicone rubbers; their properties, processing, advantages, disadvantages, suppliers, etc. But it is becoming simply impossible for individuals, and indeed organizations, to have such in-depth knowledge across the spectrum of materials [11].

The materials arts solution to this problem has been to develop materials libraries. Like a library of books, these are repositories of knowledge, but instead of books, they contain materials. Physical access to samples of materials is the crucial aspect of these libraries, because the sensoaesthetic properties of materials are largely unquantifiable, and so a hands-on sensory interface is vital. Materials libraries are a new phenomenon and have only been in existence since 1997. There are now materials libraries in New York [12], Amsterdam [13], Berlin [14], Paris [15], and London [16,17]. Also, many design and architecture companies have recognized the importance of materials libraries, such as IDEO, Foster and Partners, and have developed in-house facilities.

Apart from a commonality of purpose, materials libraries share very little else. Unlike libraries of books, which have had hundreds of years in which to refine and agree on standards, formats, and taxonomy, the materials library as a formal concept is barely 10 years old. Some libraries exist primarily as a searchable database, with a much smaller physical archive of samples. Others exist as a specialized reference library on a particular topic: Kingston University's materials library [16] specializes in renewable and recyclable materials; Materials ConnXion [12] exists to serve the design and architecture community; the King's College London materials library [17] exists as a materials science portal for the materials arts community. The further development of materials libraries is certain to continue, both as an interface between the arts and science, but also as an interface between materials producers and materials users. They provide a solution to an increasing problem, that of increased specialization and complexity, and the need for central repository to access information about existing materials.

This materials arts innovation has much to offer materials science. Firstly, a materials library provides a repository of materials which allows the systematic investigation of both the quantitative and nonquantitative aspects of sensoaesthetic materials properties. Secondly, the materials themselves provide language to interface with the materials arts community and the public, since generating physical encounters with matter provides an often forgotten way into technical discourse and interdisciplinary discussion. For instance, allowing a materials library user to cut ice using simply a wafer of aluminum nitride, provides a nonmathematical sensual way to discuss the thermal conductivity of materials. In other words, the sheer extraordinariness of some materials demands explanation of the science that underpins them [18]. The materials library also provides a natural interface to discuss the ethical and cultural impact of new materials technologies, such as nanotechnology and rapid prototyping. The presence in the library of samples of materials produced using these technologies, immediately showcases the present state of the technology and removes the mathematical barrier to discussion between the materials art and materials science communities. The resource also provides students and the public with a similarly nonmathematical introduction to materials science [19].

SENSOAESTHETIC STRUCTURE–PROPERTY RELATIONSHIPS

Another materials selection approach to sensoaesthetic properties has been developed by Ashby and Johnson [5] and is based on the principal of property mapping. For instance, the acoustic properties of materials may be characterized as a combination of pitch and brightness—the former being defined by the physical parameters, modulus, and density, the latter being defined by the damping coefficients of the material. Using these attributes, a property map is built up which clearly clusters materials that will sound "bright" if struck, like glass or bronze, or muffled, like lead and rubbers. The usefulness of such an approach to the materials arts community is clear, in that it becomes a way to categorize and select materials for their acoustic properties using existing materials science databases.

This approach also provides an insight into how to modify sensoaesthetic properties. The modern designer, artisan, or architect no longer has to rely on empirical methods to develop new materials with particular combinations of physical and sensoaesthetic properties. While a musical instrument maker in the 17th century had no choice but to rely largely on trial and error, a materials scientist can use the wide range of analytical tools to determine the internal structures of the materials and so correlate them with the sensoaesthetic properties—thus mirroring the approach employed so successfully to understand the physical properties of materials (see Fig. 1). An example of the successful application of such an approach is the work by Derby and Ferguson to develop new mokame gane techniques [20,21].

CONCLUSIONS

The underlying assumption with the current materials paradigm is that materials scientists need microscopes and sophisticated analytical equipment to develop new materials with novel physical properties because they know that without this, little progress could be made. The situation is no different for developing new sensoaesthetic properties of materials. There is very little activity in this area for a number of reasons. Firstly, due to the historical development of materials science as a discipline, it as been estranged from the materials arts community who are expert in the sensoaesthetic properties. Secondly, because many of these properties though real, are not measurable in a quantitative manner, their study is perceived to fall outside the remit of materials science. Nevertheless, the investigation of structure property–relationship for sensoaesthetic properties, shown schematically Fig. 1, seems to be an exciting challenge for the materials science community. As the great materials scientist, Cyril Stanley Smith, commented:

> The great success of the logical analytical reductionist approach to understanding over the last four centuries and the utility of the application of its principles has not negated the evidence of history that the sensual-emotional-aesthetic capabilities of the human being also have validity. The problem is to find the proper nonexclusive role for each [22].

Materials science can benefit from the materials arts community by following their use and development of materials libraries. These provide an archive of materials with which to systematically investigate the sensoaesthetic properties. They also provide an instinctive, aesthetic, and tactile interface between materials science and the materials arts community.

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