The Sound and Taste of Materials

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The question of what a material *is*, and how it is defined, lies at the heart of all materials disciplines. In broad terms, these questions encompass the processes of materials research, identification, selection and utilization, and thus impact on our studying, gathering, organizing and interactions with all *stuff*. However, much of the literature that discusses specific aspects of materials, from both scientific and artistic stances, does not directly address the question of exactly what a material is, and how it is defined.

Dictionary and encyclopedia definitions focus their attention on the role of materials as the stuff that comprises things, for example, "the matter from which a thing is or can be made" (OED, 1999). In the arts, what often occurs is a form of definition by default, where the word "material(s)" is used descriptively to denote the components of a work, product, or building. In these cases, the material is being referred to, understood, and in turn defined as the matter or substance used to create objects or products. A material becomes the input in the process of physical construction that influences the properties of that which is constructed as a result of the material's embedded materiality. This materiality is associated with classifications ranging from a qualitative aesthetic, sensorial, and behavioral appreciation of a material, to the specific cultural resonance of a material and its ability to connote *meaning*.

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Materials science and engineering are disciplines that revolve around the development, testing, and utilization of materials. The process of materials selection brings into focus the nature of this relationship, as the structure, properties, and behaviors of materials are researched and quantified in order to predict how a material will perform in a given scenario. The establishment of well-defined terminology ensures that information about a material is communicated in an exact manner: to talk of strength versus stiffness, for example, is not a semantic exercise but a precise quantitative description of mechanical behavior, as strength is defined as a resistance to crack propagation, while stiffness is the resistance to shape deformation (Callister, 2005). These concepts of strength and stiffness are also divorced from the scale of material sample, so the stiffness of a paper clip is defined to the same degree as the stiffness of a girder if they are made from exactly the same material, and is referred to as an intrinsic material property (although there is now a growing appreciation that there are size effects at the nanoscale).

The experimental tests that provide the terminology of materials and their mechanical behaviors are carried out for two main reasons: to simulate the conditions in which a material will be used and therefore "predict its service performance", and to gather "engineering design data" to check that the material meets its specifications (Martin, 2002). Information on the properties of materials, which is generated in these processes, is collected in databases. One such database is the Cambridge Engineering Selector, which offers the user the opportunity for the "rational selection of engineering materials and processes" through computational methods (GrantaDesign, 2012), a system developed within Cambridge University by Michael Ashby and his colleagues.

Processes of materials selection, appreciation, and interaction are very different for structures whose performance is not based solely on the physical scientific parameters, but also on sensual, tactile, aesthetic, and cultural factors. Creations such as buildings, interiors, clothes, pens, computers, vacuum cleaners, and mugs are structures in which human comfort, inspiration, and sensual satisfaction (for example) are important. Notions of how a material might function are not simply to do with scientific values of performance but notions of meaning and more qualitative attributes. Such structures we tend to call objects, and these are often designed by members of the arts community whose relationship with materials selection is very different to that of the engineer. It is in fact very diverse, with each type of practitioner having different methodologies and traditions.

There comes a point, however, when the type of question being asked of a material by an artist or designer requires an answer that involves something of the science of materials. The design of a successful product, for example, relies upon more than materials desire and approximation. Design training does not generally provide an in-depth scientific knowledge of materials, but more and more designers are taking it upon themselves to gain a greater understanding of the broader materials picture. Wishing to discover "how plastic is made" or "which metals are good for you to eat with and which are not" leads many product designers to ask "many materials science questions, and set out to answer them in the only way we know how: Google" (Berger and Hawthorne, 2008). The materials science and engineering model of materials selection, with formal terminology and mathematics, is often difficult to access and assimilate into projects by many designers and those coming to materials from an arts background (Ashby and Johnson, 2002). With this in mind, Michael Ashby and Kara Johnson wrote *Materials and Design: the Art and Science of Materials Selection in Product Design* (2002) in an attempt to bridge the gap between the approach of designers and engineers in relation to materials. Throughout their book, Ashby and Johnson bring quantitative analysis and qualitative attributes together for the designer to make informed materials selection decisions. They generate accessible graphical information that plots technical attributes and offers the opportunity of visual comprehension of scientific data sets. For example, a multidimensional scaling (MDS) plot of acoustic properties (acoustic pitch versus acoustic brightness) for a wide variety of material families is provided on p. 72 of Ashby and Johnson (2002).

Despite the diverse approaches used by arts practitioners—from potters to painters, product designers to jewelers—a qualitative, tactile, and hands-on approach to materials is often favored as a way of getting to grips with what a material is like (Esslinger, 2006). Specific materials expertise, encapsulated through experience and highly technical knowledge, is often key to arts practices. However, such methods are rarely generalized or accompanied by use of the structure–property paradigm of materials science. While quantitative analysis, testing, and microscopy are on the increase within the arts as engagement with scientific technologies increases (Ede, 2005 and Hauser, 2008), the practitioner's relationship with materials is still largely driven by use, manipulation, and appreciation of them on the macro level, from encounters with haptic and aesthetic analysis at the human scale.

This presents a problem, for, although there is a large amount of technical information about materials available for scientists, engineers, technologists, and industrialists to use in the making of objects, these quantitative data reveal little of their aesthetic properties, and these are the properties that are of predominant interest to the materials–arts communities. Indeed, there has been little work looking at how the physical properties of materials relate to their sensual and aesthetic properties. Within the world of materials, there can exist a split between the materials science community, those scientists, technologists, and industrialists who are interested in the physicality of materials, and those in the materials–arts community who are interested in the sensoaesthetic properties of materials. The two sides often do not speak a common language. The question is then this: how do we create a methodology that brings them together in a coherent, collaborative, and productive fashion?

SENSOAESTHETICS

Our work in developing a sensoaesthetic theory of materials attempts to shed light upon the aesthetic and perceptual side of materials through psychophysical and materials science methodologies. Although it may initially appear that a hard scientific discipline might not marry up well to the softer side of materials, upon closer inspection it is revealed that the way we interact with, and the emotion we feel from, all materials is rooted in their fundamental physical properties. We can consider the sense of touch as an example. The major factors that we use in the identification of materials by touch are warmth, softness, and roughness. If you feel something that is hard and cold to the touch, then you know it is going to be something like metal, glass, or stone. If you feel the surface texture, then you are more than likely to be able to identify exactly what material it is. All your senses are used to pick up on the physical properties of a material, and it is those physical properties that materials scientists define and measure. For example, metals generally feel cool to the touch because they conduct heat away from your skin very quickly. So we can say that, in general, materials with high thermal conductivity will be perceived as feeling cool to the touch. Or if an object is soft to the touch, then we can look at physical variables such as elastic modulus or plasticity to characterize the interaction.

The overall aim of our research is to attempt to fill in this gap by using scientific methods to study those properties of materials that are largely ignored by materials scientists, yet are vitally important to material art and design communities and coming under an increasing amount of scrutiny by those interested in the sensorial aspects of materials (Karana et al., 2009; Rognoli, 2010). The sensoaesthetic properties are strongly dependent on perception, and the study of perception falls within the realm of psychology. This work therefore combines psychophysics, the science of the senses, with materials science, a discipline driven by physical characterization. The result is a body of work that is moving toward the development of a sensoaesthetic theory of materials (Howes and Laughlin, 2011, 2012; Laughlin, 2010; Miodownik, 2007).

A material–object methodology

The experiments undertaken at The Materials Library (Laughlin, 2010) were designed to study the links between the aesthetic perception of materiality and the measurable physical properties of the materials themselves. A core concept of this research was to study these sides of materiality by staging *encounters* with sets of material–objects (Laughlin, 2010), rather than simply with materials. The deployment of the term "encounter" is used to describe the framed coming together of materials and people and aims to underline the role of the unexpected in such a meeting, and the possibility of a confronting experience. Confrontation should be considered here in terms of an arrestment of the senses, a moment that makes one notice, realize, or consider something outside of the usual, a moment or scenario where an unexpected occurrence, discovery, or experience punctuates our existence and results in a conscious noticing of matter. To facilitate this, we introduced the idea of the swatch. This is something familiar to us when choosing materials for certain applications, for example, swatches of textiles used by tailors and paints by home décor retailers. We moved beyond this material swatches to material–object swatches, an isometric set where form was kept constant and materiality was changed. This allowed for the study of perception of materials as a direct function of their physical properties.

THE SOUND OF MATERIALS

Sounds and music can have striking emotional effects on us, from joy and elation to the depths of despair. Sounds and their cultural resonances are in fact built upon the materiality of the objects used to create them. In the same way that the feeling of a surface through touch is rooted in our perception of the physical properties of that surface, the aesthetic and emotional connotations of sound can be linked to well-defined physical parameters. In this work, we set out to explore how changes in materiality affect changes in perception of sound using a set of custom-made objects. The two primary methods used to analyze the objects were participatory observation and acoustic testing.

The objects

To test the comparative acoustic properties of different materials and how these were experienced through perception, a swatch of tuning forks was made (Figure 4.1). In this way, the form was kept constant but

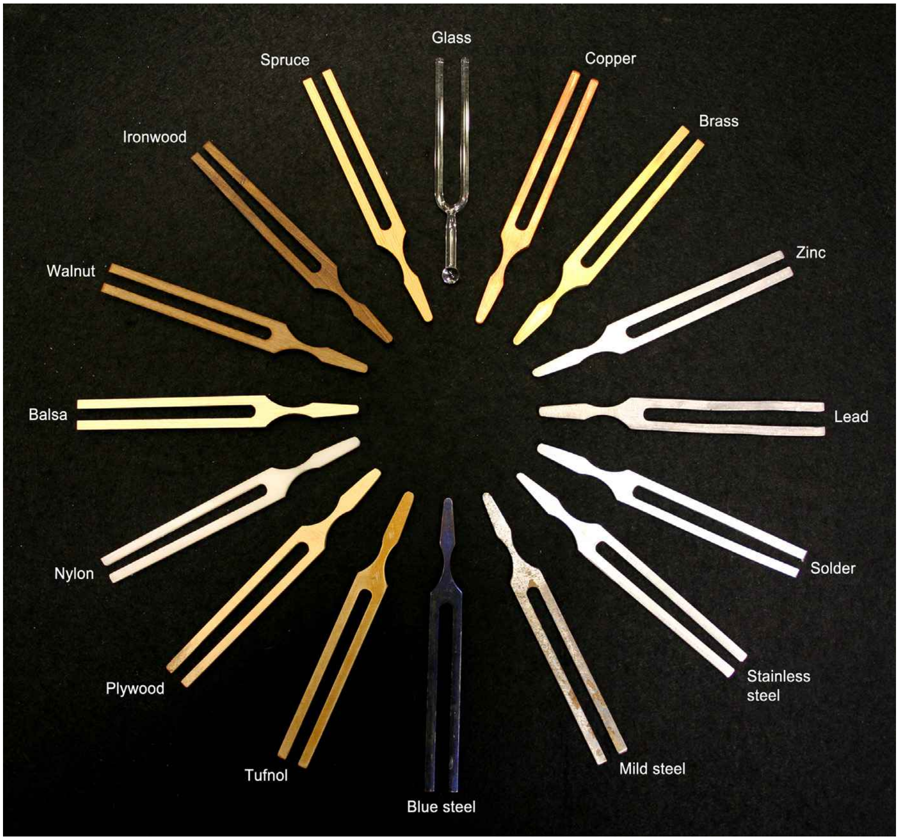

FIGURE 4.1
Sixteen tuning forks of varying materials made to render the micro performance of a materials structure as a macro experience.
Laughlin, 2010.

the material was changed. Given their status as an object with a specific use, their position on the material–object continuum is elevated above the metals from which they are composed. Changes in material enabled the resultant differences in the performance of the forks to be judged in relation two well-defined physical parameters: density and elastic modulus. Any shift in the frequency of sound produced by each fork would be a direct result of the materiality, rather than the form of the material.

The principle factors that influence the production of sound by a tuning fork are the shape of the fork (form), and then the density (materiality) and elastic modulus (materiality) of the material. The pitch of the note that a tuning fork produces is expressed as

$$f \infty \frac{1}{l^2}\sqrt{\frac{AE}{\rho}}$$

where f is the frequency of the fork, A is the cross-sectional area of the tuning fork (form), l is the length of the forks prongs (form), E is the elastic modulus of the material (materiality), and ρ is the density of the material (materiality). The creation of a set of tuning forks that keeps form constant and employs materiality as the variable enables the exploration of the density and elastic modulus, values that are not varied in commercially available tuning forks.

The quantitative evaluation of form is accessible and comprehensible at the human macro level of scale, whereas the materiality values are derived from a structural scale invisible to the eye. For instance, in the case of metals, the density is typically determined by the atomic mass, which determines the weight, and the crystal structure, which determines how closely the atoms pack together. The elastic modulus (stiffness) of metals is determined by the electronic structure of the atoms and the type of bonding present. Overall, the tuning forks were used to explore these invisible structures and properties in a way that rendered their effect as a macro, experiential phenomena that users could encounter through physically playing the tuning forks.

The results

The concept of the encounter was primarily defined by the haptic exploration of the material—object by the participants. For the tuning forks, this haptic exploration takes the form of the handling and physical playing of a tuning fork by a participant and the experiencing of the phenomena that occur. The qualities of the sound produced by a tuning fork are experienced as a note of a specific pitch (frequency), with a particular brightness (a combinatory factor of duration and amplitude). We used the tuning forks to investigate the effects of materiality on sound, with the exact frequency produced by each fork measured and the shift in pitch attributed to the change in materials.

The commercially made blue steel tuning fork, when struck, rang with a bright and sustained note. In contrast, the fork made of copper emitted a tone of low pitch and volume, and of a short duration, while brass emitted a tone of intermediate pitch but very long duration. An extreme example was that of zinc, which made no audible sound and the prongs deformed if struck forcibly. The wooden forks did not "ring" like the metals forks, but produced a single note of very little duration when pinched instead of struck. The range of notes produced is not insignificant, with obeche, walnut, and bass woods all producing tones higher than spruce, closer to the blued steel, while plywood, balsa, and iron wood all produce notes lower than spruce with both balsa and plywood emitting tones lower in pitch than the copper fork. The polymer forks (nylon and acrylic) produced no audible sound upon striking, but when pinched produced a low note with a dull thudding quality. With regard to the encountering of the tuning forks, all three aspects of performative agency were embraced, that of the doing participant, the functioning form, and the behaving material. These three elements of the encounter affect and depend upon one another, working toward the enactment of the material—object as a representation of acoustic phenomena that can be physically experienced.

The tuning forks were played and assessed by a group of musicians whose perceptions of pitch and brightness were judged against those of Ashby's and Johnson's MDS map for acoustic properties, mentioned earlier in the chapter. In terms of the frequencies produced by the tuning forks, we found broad agreement with the theoretical predictions, apart from a few anomalies. We also found that judgments of pitch made by musicians were also in agreement with the frequency measurements. The greatest surprise was that the pitch of disparate materials could be very similar, while the brightness of the note varies dramatically, due to variations in the material's coefficient of loss. Changes in material enabled the resultant differences in the performance of the forks to be judged in relation to density and elastic modulus. Any shift in the frequency of sound produced by each fork was a direct result of the material from which it was made and as a result, the isomorphic set of tuning forks went some way to practically demonstrating and conceptually representing the science of their materials.

Within the act of encounter, the set of tuning forks becomes a physical manifestation of both the frequency equation and the MDS map of acoustic properties mentioned earlier in the chapter. The tuning forks, the frequency equation, and the MDS map are in fact three versions of the same thing, three ways of representing the relationship between materials and acoustic properties. The effects of density and elastic modulus are not explained by the tuning forks themselves: this is part of the role of the librarian in discussing the encounter with the visitor. The effects of density and elastic modulus are experienced in the act of playing the tuning forks. As a result of the existence of the set of tuning forks, density and elastic modulus are "performed" by the tuning forks and enabled as a physical experience of acoustic properties.

THE TASTE OF MATERIALS

Similar to the way we related the aesthetic qualities of tuning forks to their underlying physical characteristics, we conducted an experiment to correlate taste characteristics of solid materials with their physical properties. The specific focus was on the differences in how "metallic" tasting a set of metal objects were in relation to well-defined physical variables.

Tastes are received through taste buds on the tongue. There are five generally accepted basic tastes: bitter, salty, sour, sweet, and umami (Ikeda, 2002). The perception of flavor and more general oral sensations are dependent on further factors such as smell, texture, and temperature (Lindemann, 2001). The concept of taste is generally associated with substances that we place in the mouth in order to consume. However, the experience of taste in relation to inedible matter is much less appreciated and understood. Although "metallic" is not commonly considered a basic taste, there is growing evidence that metal ions act as chemosensory stimuli in the mouth (Lawless et al., 2006). Lawless et al. (2006) showed that ferrous sulfate produces a distinctly different sensation from the traditional basic taste descriptors, all of which are thought to have unique receptors (Chandrashekar et al., 2006).

The chemical aspects of the taste of inedible materials are commonly discussed in terms of their standard electrode potential, which defines the susceptibility of a particular material to being oxidized (Bartoshuk, 1978). These potentials have been measured for most metals, and are believed to confirm broad trends of taste: metals that are highly susceptible to oxidization such as copper and aluminum have a noticeably metallic taste, whereas gold and silver are almost tasteless (Lawless et al., 2006). However, previous to our work there had been no systematic investigation into the relation between the physical or chemical properties of solid materials and their taste.

The objects

As an object, the spoon is at the heart of life, feeding us from infancy and accompanying us in both the preparation, sharing, and eating of food the world over, making it a culturally significant artifact experienced by a truly vast number of people (Petroski, 1992). We chose the spoon as an isomorphic form because of its high object status, being extremely recognizable and readily associated with eating and tasting, thus providing a material form that people would be conceptually and physically comfortable with having in their mouths. Teaspoons were identified as the ideal type of spoon for this study as the bowl of the spoon would be small enough to fit into any adult mouth with ease.

In making the spoons, a number of practical factors had to be taken into consideration. The sensitivity of mechanoreceptors in the mouth means that the tongue would instantly feel any differences in size and texture, no matter how slight. If the eye, hand, or mouth were to detect such differences, the isomorphic nature of the spoons set would be placed in jeopardy. It was therefore important to use a technique to make spoons that were both repeatable and exact. It was decided that preexisting teaspoons made from stainless steel would be coated in a number of different metals, and the final swatch is shown in Figure 4.2. Six stainless steel teaspoons were electroplated with copper, gold, silver, tin, zinc, and chrome. Each metal was selected on the basis of its nontoxic status, suitability for contact with human skin and mucous membranes, its ability to be electroplated, and the ease with which it could be sterilized.

The experiments

Unlike the tuning fork encounters, the spoons investigation was staged as a formal scientific study (Laughlin et al., 2011). The spoons were presented for encounter in order to gather data on the human experience of the taste of materials that could be mapped against the standard electrode potential of the same materials. We recruited 32 participants of mixed ages and both genders. Participants were blindfolded and asked to taste each spoon sequentially, rating each one on scales of 1–7 for the adjectives cool, hard, salty, bitter, metallic, strong, sweet, and unpleasant. The subjective experiential data were analyzed using standard statistical techniques. In brief, repeated measures one-way analysis of variance (ANOVA) with Tukey's Multiple Comparison Test was performed. For testing the order effect, which was considered undesirable (and therefore was sought with greatest power possible) in

FIGURE 4.2

The swatch of spoons used in the experiments. From left to right: copper, gold, silver, tin, zinc, chrome, and stainless steel. *Laughlin, 2010.*

addition to the Tukey comparisons from the ANOVA, the planned analysis included individual participant's paired t tests comparing the first spoon, which was always stainless steel, to the other stainless steel spoon, which was randomized in the order (Laughlin et al., 2011).

The results

Plots investigating the correlation between the perceptions and the relevant physical or chemical property of the pure metals (Laughlin, 2010; Laughlin et al., 2011) were obtained using standard physical and chemical data sources (Atkins and Jones, 2005; Latimer, 1952; Vanysek, 2009). For copper and gold, the electrode potential of two oxidation states were plotted since both could be formed in the mouth. For the adjective metallic, an inverse correlation between the electrode potentials of metal ions and perceived metallic taste of the metals was observed. An identical pattern was observed for the adjective strong. For this reason, zinc and copper were considered as strong tasting, while the other metals were considered mild tasting. A near-identical pattern was seen with the adjective unpleasant, with the minor exception that the difference between silver and either copper or zinc was not as significant: silver was not significantly more unpleasant than the other mild-tasting metals. None of the metals differed significantly in saltiness or sweetness.

The experiment revealed that more negative standard electrode potentials correlated strongly with perceived tastes of solid metals described as metallic, bitter, and strong, with an inverse correlation. The zinc and copper spoons rated highest for bitter, metallic, and strong descriptors, while the gold and chrome rated as the most pleasant tasting spoons. When putting these spoons in the mouths, the participants often commented on how they liked them, or at least noted the absence of taste. Gold was determined to be the least strong tasting, followed closely by chrome, but chrome rated as being the least metallic, closely followed by gold. Finally, gold spoon emerged with the highest sweet rating of all the spoons.

It is commonly presumed that metallic tastes are unpleasant. In our taste study the descriptor metallic was statistically correlated with both the adjectives "unpleasant" and "strong", which indeed suggests that, when considering metal spoons, metallic taste is considered both strong and unpleasant. This raises the possibility that our measurements of metallic tastes, where gold and chrome were the least metallic, may correlate with preference for different metals, although this needs to be studied further.

The conclusion of the study was that the taste of solid metals is dependent on their standard electrode potentials. This is a concrete example of how a perceived quality (metallic taste) can be directly linked to a physical property (standard electrode potential).

CONCLUSIONS

The pertinent question to ask at this juncture is how can such information be used in a practical way? Our experiments demonstrated strong links between aesthetic qualities of material—objects and underlying engineering material properties. We have shown that the acoustic quality of tuning forks are correlated with their form and materiality, and we have shown that the intensity of metallic taste of spoons is dependent upon the standard electrode potential of the metals from which they are composed. To answer the question above, we come back again to materials selection. There are many tools to help designers and engineers choose materials with specific physical properties, which allows them to make informed choices before stepping away from the drawing board. When dealing with the sensoaesthetic properties of materials, choices tend to come down to experience, prior knowledge, and intuition, and there is no systematic way to approach such selections. A sensoaesthetic theory of materials may create such an opportunity, allowing designers, engineers, and artists to make informed decisions on aspects of their designed object's properties, both physical and sensorial. However, to date there has been relatively little research activity in the study of the sensoaesthetic properties of materials within the materials science communities (Miodownik, 2007). It can be argued that materials science, as an academic research discipline, is somewhat estranged from the materials arts communities who are experts in and enthusiasts for the aesthetic, qualitative, and sensorial qualities of materials. Additionally, as the study of sensoaesthetics is not quantitative in the same way as more familiar physical studies are (it involves psychophysical methodologies along with physical analysis), such studies are perceived to be detached from materials science. However, we strongly believe that this space between materials science and materials arts is fertile ground, and that new and exciting approaches can be adopted for producing pieces of work and objects that are as sensorially considered as they are technically advanced.

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References

Ashby, M., Johnson, K., 2002. Materials and Design: The Art and Science of Material Selection in Product Design. Elsevier, Oxford, UK.

Atkins, P., Jones, L., 2005. Chemical Principles, third ed. W.H. Freeman and Company, New York.

Bartoshuk, L.M., 1978. History of taste research. In: Carterette, E.C., Friedman, M.P. (Eds.), Handbook of Perception. Academic Press, New York, pp. 3–18.

Berger, S., Hawthorne, G., 2008. Ready Made: How to Make (Almost) Everything. Thames & Hudson, UK.

Callister, W.D., 2005. Fundamentals of Materials Science and Engineering: An Integrated Approach. Wiley, UK.

Chandrashekar, J., Hoon, M.A., Ryba, N.J.P., Zuker, C.S., 2006. The receptors and cells for mammalian taste. Nature 444, 288–294.

Ede, S., 2005. Art and Science. I.B. Tauris & Co.

Esslinger, M., 2006. Touching the senses: materials and haptics in the design process. In: Construction Materials Manual. Birkäuser, Switzerland, pp. 32–35.

GrantaDesign, 2012. Cambridge Engineering Selector Information. Available at: http://www.grantadesign.com (accessed 01.08.12.).

Hauser, J., 2008. Sk-interfaces: Exploding Borders—Creating Membranes in Art, Technology and Society. Liverpool University Press, UK.

Howes, P., Laughlin, Z., 2011. Sensoaesthetic Properties of Materials. Available at: http://www.instituteofmaking.org.uk/research/sensoaesthetic-properties-of-materials/ (accessed 01.08.12.).

Howes, P., Laughlin, Z., 2012. Material Matters: New Materials in Design. Black Dog Publishing, London, UK.

Ikeda, K., 2002. New seasonings. Chemical Senses 27, 847–849.

Karana, E., Hekkert, P., Kandachar, P., 2009. Meanings of materials through sensorial properties and manufacturing processes. Materials and Design 30, 2778–2784.

Latimer, W.M., 1952. The Oxidation States of the Elements and Their Potentials in Aqueous Solutions, second ed. Prentice-Hall Inc, Englewood Cliffs, N.J.

Laughlin, Z., 2010. Beyond the Swatch: How can the Science of Materials be Represented by the Materials Themselves in a Materials Library? Ph.D. Thesis, King's College London, University of London, UK.

Laughlin, Z., Conreen, M., Witchel, H., Miodownik, M., 2011. The use of standard electrode potentials to predict the taste of solid metals. Food Quality and Preference 22 (7), 628–637.

Lawless, H.T., Stevens, D.A., Chapman, K.W., Kurtz, A., 2006. Metallic taste from electrical and chemical stimulation. Chemical Senses 30, 1–10.

Lindemann, B., 2001. Receptors and transduction in taste. Nature 413, 219–225.

Martin, J., 2002. Materials for Engineering. Maney, UK.

Miodownik, M., 2007. Toward designing new sensoaesthetic materials. Pure and Applied Chemistry 79 (10), 1635–1641.

OED, 1999. The Concise Oxford Dictionary. Oxford University Press, UK.

Petroski, H., 1992. The Evolution of Useful Things. Alfred A. Knopf.

Rognoli, V., 2010. A broad survey on expressive-sensorial characterization of materials for design education. METU Journal of the Faculty of Architecture 27, 287–300.

Vanysek, P., 2009. Handbook of Chemistry and Physics. Chemical Rubber Company.