

THE SELECTION OF MATERIALS TO MATCH HUMAN SENSORY ADAPTATION AND AESTHETIC EXPECTATION IN INDUSTRIAL DESIGN

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It is significantly important to integrate various sources of knowledge and information for selecting and combining materials in today's industrial design practice and education. Compared to the engineering and technical properties of materials, the information about the aesthetic attributes and sensory or perceptual features of materials is equally important but has been less explored. Based on theoretical and experimental research, this article addresses the fundamental contents of material aesthetics and sensory perception and the methodology in approaching the research in this area. A material aesthetics database resulting from the author's research activities with a focus on texture is also introduced. Examples are given to showcase how the research results are applied as a reference for new product development in industry, and how the research results are combined with other resources in facilitating materials teaching in industrial design education.

INTRODUCTION

The process of material selection in product design can be quite complex as it depends on a range of factors such as functional requirements, manufacturing constraints, economics and life cycle, ecological sustainability, aesthetic and sensory material properties, and their cultural and representative meanings. These factors may influence the decision-making separately, but in most cases, they are interrelated. For example, stainless steel has good corrosion resistance, for which carbon steel is not compatible, but carbon steel has better manufacturing flexibility particularly in welding, and is cheaper than stainless steel; Titanium alloys are even better than stainless steel in corrosion resistance, with a slightly darker tone of grey and more elegant colour, and are also much lighter in weight, however they cost much more. Bamboo is now trendy in interior (e.g. floors) decoration in China, not only for its excellent physical properties, fine textures, and weather durability, but also for its

rich cultural meanings and very well matched sustainable requirements (Huang et al., 2009). In a word, an experienced designer needs to integrate and balance these different factors in material selection to ensure that the designed product will not only fulfil its functions, but produce aesthetic appeal, elicit positive user experience, and with the lowest expense of resources, energy and labour.

With complex interaction of the above-mentioned factors, general guidelines are necessary to enable designers to make an informed selection of materials. Nowadays, information resources for materials selection are tremendous, coming from material textbooks/manuals, lectures, databases, Internet, industry, and lessons from good (and bad) product examples. For instance, the Cambridge Engineering Selector (CES) developed through collaboration between Professor Mike Ashby at Cambridge University (Ashby, 1999; Goodhew, 2002) and Granta (2010), is a widely used database software which helps to identify and select materials and processes based on various engineering properties and parameters of materials. It has also been developed into different versions, one of which is tailored for students and practitioners in industrial product design. Furthermore, some well-known industrial companies have their own on-line databases of materials, such as DuPont (2010) and Distrupol (2010). However, databases from industry usually address only special material types, and due to enterprise confidentiality, may not always be free to access. Compared to the engineering and technical properties of materials, the sensory properties (colour, texture, sound, smell and taste) of materials, and their perceptual and representational meanings, are equally and significantly important but remain unsystematic and superficially explored. Information of this aspect is somewhere available, but traditionally this was addressed from the perspective of an artefact itself, not from the perspective of human-artefact 'interaction'. In today's technology-saturated market, understanding of how people respond to the sensory properties of materials under different conditions will help designers and engineers to select materials with more positive user-experience embedded into the product and ensure the product will match human sensory adaptation, aesthetic and perceptual expectation.

It is noticeable that, in a pragmatic situation, no reputable industrial designers work in isolation for decision-making of materials and processes selection. As Pedgley (2009) indicates, the stakeholders (clients, manufacturers/vendors, users and designers themselves) will and should have significant influences on the selection process, although they have different focus concerns. For example, users tend to focus more on perceptual and experiential aspects such as aesthetic and emotional experience, whilst manufacturers on production feasibility. In this article, the author will not differentiate the stakeholders in the perception of materials. The word 'human' in the term 'human perception' represents a general subject group. However, information discussed herein mainly aims for selecting materials/textures to match users' expectations particularly the sensory and emotional satisfaction.

Starting with a conceptual clarification of material sensory perception, this article addresses the methodological issues raised for conducting research in this area, and introduces a database of material aesthetics and sensory perception with a focus on material textures, resulting from the author's research work in the past years. The article also discusses how to apply the

research results in both industrial design practice and industrial design education.

SENSATION, PERCEPTION AND AESTHETICS

The terms sensation, perception and aesthetics are conceptually overlapped to some extent. Sensation is concerned with the first contact between an organism and its environment (Harvey, 2000). The sensations themselves refer to certain immediate, fundamental, and direct experiences, that is, the conscious awareness of qualities or attributes linked to the physical environment, such as 'hard', 'rough', 'cold', 'red', generally produced by simple, isolated physical stimuli. Potential energy signals from the environment emit light, pressure, heat, chemicals, and so on, and our sensory organs receive this energy and transform it into a bio-electric neural code that is sent to the brain. This first step in sensing the world is performed by receptor cells, which are special units that react to specific kinds of energy. For instance, specialized cells of the eye react to light energy and equally specialized cells of the tongue react to chemical molecules of compounds. In the case of materials, the sensation-related questions might be how we perceive brightness, loudness, or colour; however, the nature of the object having a given brightness, sound, or colour would not make much difference to different perceivers (Stanley et al., 1999).

Perception, on the other hand, generally refers to the result of psychological processes in which meaning, relationships, context, judgment, past experience, and memory play a role (Harvey, 2000). According to this sensation / perception distinction, a sensory question related to a material might be 'how rough does the surface appear to be?' whereas the perceptual questions might be, for example, 'can you identify that surface as metallic or polymeric?', 'is it comfortable to touch?' or 'is it good for grip?'. In a more global sense, the study of perception is mainly concerned with how people form a conscious representation of the outside environment and with the accuracy of that representation. Our eyes may initially register a fleeting series of coloured images on the surface of a television screen (i.e. the work of sensation), but we see or perceive a representation of visual events with people and objects interacting spatially in a meaningful way (the work of perception).

However, in many meaningful environmental encounters it is difficult, perhaps even impossible, to make a clear distinction between sensation and perception. For example, when we hear a tune, it is hard to be initially aware of any isolated tonal qualities of the notes, such as their pitch and loudness, distinct from the melody. When we grasp a door handle or a hammer, we can hardly sense the pressure on our fingers and palm independent of how the object feels. Thus, generally, sensation and perception are unified, inseparable processes. Usually it is only in well-controlled laboratory conditions that one can initiate isolated sensations, which are distinct from meaning, context, and past experience etc.

As to aesthetics, it is usually defined as the branch of philosophy that deals with the nature and expression of beauty (Answers.com, 2010). The word beauty is commonly applied to things that are pleasing to the senses, imagination and/or understanding. It is often what an artist or a designer makes great efforts to achieve in their works, either for personal or mass interest and pleasure. However, although aesthetic experience usually



Figure 1. The connotation of product aesthetics.

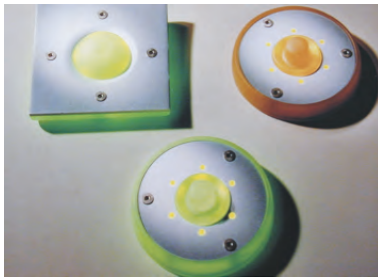


Figure 2. Doorbell button designed by Tom Gordon and Ted Pierson (1995).

initiates from sensory stimuli (Maclagan, 2001), it does not simply equal to sensory pleasure. Aesthetics, widely speaking, can have different meanings from different perspectives of approach and study. For example, a designed and manufactured artefact can be judged as beautiful or pleasing because of its unique functions (functional aesthetics), the application of advanced technology (technological aesthetics), its fascinating form characteristics such as attractive shape, colour, texture etc (formal aesthetics), or its representation of life experience and social identity or a symbol of cultural reflection (psychological and cultural aesthetics). These aspects are twisted together in their contribution to the whole perception of product aesthetics (Figure 1).

In today's marketplace, creating products, which not just fulfil the functional requirements but also evoke sensory pleasure and aesthetic expectation, is an increasingly developing trend, and will be facilitated by the suitable selection and combination of materials and their surface effects.

SENSORY PERCEPTION OF MATERIALS

Since it is not easy to distinguish sensation and perception, the author proposes using a united term 'sensory perception' to describe subjective responses to materials. In this subjective-objective interaction process, the stimuli are materials from which humans can receive sensations, from herein called 'sensory properties' of materials. Sensory properties, in this context, are defined as the properties that can be perceived by humans via sensory organs and can evoke physiological and psychological responses. These properties include colour, texture, sound, smell and taste. Unlike traditionally defined engineering properties or physical properties of materials, which are completely objective (this is due to the fact that these properties are specified by instrument and have widely-accepted standards of formulation and good test accuracy and repeatability), the sensory properties of materials have objective-subjective dual attributes. The objective side is referred to as the content of the sensory properties, such as a green colour or a rough texture, which exists physically. The subjective side is referred to as the interpretation of such an existing property, which results from the sensory perception initiating from the peripheral organs (eyes, skin, ears, etc.) and then processed via corresponding areas within the brain. These dual attributes make a perceived sensory property of a material depend not only on the intrinsic material features, such as the material's physical structure, but also the differences amongst human individuals and particular environmental contexts. Therefore, the investigation into material sensory properties should be carried out holistically with a series of variables taken into consideration such as sensory modalities, user characteristics, product context and environmental conditions. However, sensory properties must at first fall within human sensory thresholds in order for them to be recognised.

Sensory properties of materials play such an important role in the perception of a product's total image that they are actually being utilised by designers whether consciously or subconsciously. An innovative doorbell button designed by Tom Gordon and Ted Pierson is made of coloured translucent elastomeric resin with UV inhibitors, and the faceplate is satin finish anodised aluminium (Figure 2). This gives not only a function of 'to be seen out of doors at night', but also amiable welcoming semantics and a warm soft-touch feeling due to the attractive colour and texture of the elastomeric material. In most cases, industrial designers utilise sensory

properties of materials by experience, without a systematic information resource. By exploring what kind of subjective feelings (physiological or psychological responses) can be evoked in the user-product interface, and by exploring the relationship between the subjective feelings and a particular sensory property (e.g. translucency), along with the underlying parameters that objectively influence that property (e.g., refractive index), it will be possible to know how users' sensory and perceptual expectations can be satisfied through materials selection.

METHODOLOGY FOR APPROACHING MATERIAL SENSORY PERCEPTION

Direct and indirect methodologies can be used to study material sensory perception. A direct methodology employs collecting and analyzing primary data of how people perceive materials via experiment, observation and interview, using real material samples or real product samples. Indirect methodologies originate from two perspectives. One is the theoretical deduction or modelling from related disciplines. For example, the formula by Ashby and Johnson (2002), $S=EH$ (S represents softness, E represents modulus, H represents hardness), can be used to assess perceived softness of materials. The second perspective involves collecting and analysing secondary data regarding material perception, usually through visual media from existing sources such as magazines, books, journals and other publications where materials are represented in the form of photos or images. In this case, the data consists of the assessment of these images and how designers/users will perceive the materials and their experience of using those materials. Both direct and indirect methodologies have their advantages and disadvantages. The author's opinion is to combine elements of both direct and indirect methodology for optimizing the quality and reliability of research data.

Information needed for approaching material sensory perception comes from three aspects. First, information about the materials: the objective data – physical properties, or physical parameters, that underlie the investigated material, for instance roughness or transparency as surface properties. Second, information about people: the subjective data - participants' sensory responses to materials, their affective feelings and any other associations that are evoked when interacting with materials. Third, information about the relationships between subjective responses from people and the objective material information. To obtain the three aspects of information, qualitative and quantitative methods can be used separately or in conjunction, depending on different purposes and in different stages.

Objective data is comparatively easy to collect providing the necessary equipment is available and the corresponding testing conditions can be achieved. Cautions must be taken to ensure consistent measurements. For example, when measuring surface roughness by using Taylor Hobson texture equipment, the parameters such as Roughness Average (Ra) and Peak Spacing (Rsm) will significantly depend on the shape and size of the equipment probe, sampling length, measuring trace direction (if the surface is anisotropic) and other factors (Dagnall, 1997). Another example is the measurement of surface gloss by means of a gloss meter, in which case the light spot size, the reflecting angle, and the surface geometry of material samples all need to be well specified. Differing surface geometry (e.g., one flat, one curved) will result in different readings and difficult comparisons

1. Passive touch refers to a touch under the condition in which the subject is stationary and the stimulus is imposed upon the skin. Active touch refers to a touch under the condition in which the stimulus is stationary and the subject actively explores an object or surface.

(Mizrach et al., 2008). Thus consistency in test conditions is a prerequisite for results to have good comparability.

Subjective data has certain complexities compared to objective data. The main challenge perhaps lies in the difficulty in quantifying the subjective responses. The essence of quantification is a numeric measurement. There exist different types of subjective responses. Taking material texture as an example, the subjective responses within the geometrical dimension and the physical-chemical dimension are the recognition of the objective attributes of the materials such as roughness, warmth, hardness etc. These attributes are essentially quantifiable by means of physical facilities, therefore it is reasonable to assume that the subjective responses to or judgment of these attributes can also be quantified. For example, given a well-defined scale, subjects can possibly feel that one particular surface is about twice as rough as another surface. Another type of subjective response is located within associative and emotional dimensions. These responses are related with past experience and memories, and are completely subjective both in content and description. In a rigorous sense, it is difficult to apply a quantitative method to measure responses such as comfort, happiness, or perception of style. This is firstly due to subjective responses being usually individually-dependent, and unstable over time, thus having poor repeatability. Other reasons include the limitations of the test methods such as the suitability and accuracy of evaluation scales, benchmarks (reference samples) etc. However, in order to explore the relationship between the two different types of responses - between the responses within geometrical, physical-chemical dimensions and those within emotional, associative dimensions - and the relationship between subjective responses and physical parameters, it is necessary to identify them in a compatibly quantitative way. Despite their non-quantifiable nature, emotional responses can still be measured technically using quasi-quantitative methods. One such method is the semantic differentiation scale. However, studies of responses within the associative dimension can only be qualitative.

To ensure the effectiveness of combining qualitative and quantitative methods in collecting subjective data on material properties, the author has developed techniques for controlled experimental research by fixing a series of conditions. These include environmental conditions (temperature, humidity, lighting etc.); well-prepared material samples (consistent grades and properties with changes in just one parameter, e.g., roughness or hardness); and conditions for sensory tests (touch methods etc.). For example, in the touch tests, issues such as 'how to touch, passive or active?'(1), 'touch speed and force', and 'with or without integrity of other senses' need to be considered.

In our own research, taking into account the modes of interaction in a retail sales context, we considered people's hands to be the most widely used means of evaluating the tactual interface between consumers and products. Also, since our research findings were intended to be related to a practical product context -a range of hand-operated products- the texture perception tests we conducted were concerned only with touch sensed by the hand, rather than other body regions. Only active touch was investigated because in most cases, especially at the first contact with the product at the sales point, active touch may be more involved in the decision to purchase. Regarding touch speed between fingers and material surfaces, according to research of early psychologists such as Katz (1989) and William and

Emerson (1982), it seems better to adopt the middle moving speed. However, it is more important to keep the moving speed constant during all tests.

We have conducted material surface tests in two phases: a preliminary study, followed by an in-depth study. The purpose of preliminary study was to find ways in which people describe their perception of a material surface through touch. Focusing on the qualitative description of texture perception rather than the accurate touch activity itself or the perception mechanism, tests were influenced little by the limitation of factors such as using which fingers to touch, or touch speed etc. Participants were asked to touch the surface of material samples in a natural way, so that they would be more concentrated on the surface texture stimuli rather than being distracted by a particular way to touch. However, the natural way in which the participants touched the surfaces of the material samples was studied by video recording the total touch process. In-depth research has the purpose of exploring the correlation between various subjective responses to texture and the correlation between subjective responses and objective physical parameters. In this case, the fingers, the touch direction, the touch speed etc. should be kept the same for each participant and for each trial. When executing the tests, it was necessary both to set up some constraints and simultaneously let the participants feel comfortable. From the video recording, we found that index, middle, and ring fingers were the three fingers mostly and comfortably used by participants; these were adopted during the in-depth research.

In the testing of subjective response to material texture, a material surface is subjectively evaluated relative to other material surfaces. It is therefore important to set up a reference sample, i.e. the benchmark. Even if a benchmark surface is not physically presented to the participants, people actually still use a benchmark in their memory from their experience, though it will vary from individual to individual. Therefore a benchmark sample is necessary to be set up for the scale of measurement. In the present research, a piece of wood with a naturally smooth surface was selected as the reference sample, which represented a zero point of the measurement scale. The subjective scores to evaluation descriptors could therefore go in both directions (positive and negative) from the zero point.

It is worth considering the two different but related cases: materials as isolated samples and materials employed in a particular design (product) context. Using well-prepared isolated material samples can meet the requirements of both qualitative and quantitative research. On the other hand, using product samples may be suitable for qualitative evaluation research, but might be less suitable for quantitative psychophysical research as it is usually difficult to change just one variable of a material such as roughness, softness, gloss etc. The time and cost implications of this would be uneconomical as small changes to material and material surface would need to be made at the manufacturing level. Production of a particular product will be geared towards mass production rather than changes to tooling to produce a series of products varying in surface properties. However, the final goal of material sensory perception research should aim at solving practical design problems regarding materials. Contextual research within particular product contexts thus

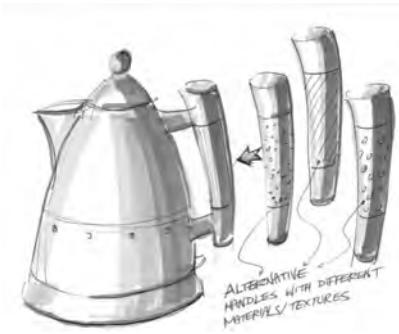


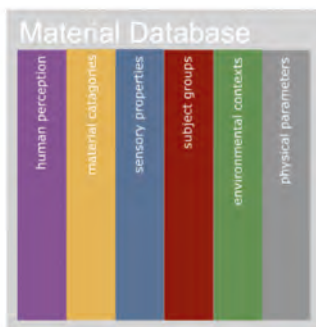
Figure 3. Disassemble-reassemble implemented in handle texture tests.

makes considerable sense. In certain cases, there still exists appropriate ways to conduct contextual research with product samples but with a quantitative approach. The author proposes a method called 'disassemble-reassemble', which makes it possible to evaluate a material in a product context with the material having controlled changes in one parameter, such as roughness or gloss level. This is realised by replacing only the material/texture of certain component(s) of the product with alternative materials or textures off of the manufacturing line. For example, in a research project investigating the texture of materials used for handles of domestic appliances, we disassembled a group of kettles and replaced the handles with alternatives in different materials or finishes (this principle is illustrated in **Figure 3**). The approach enables a quantitative comparison between the different textures with reference to certain aspects of sensory perception such as perceived roughness, warmth, shininess etc. and the emotional feelings and associations that are stimulated by using these kettles with different handles.

MATERIAL DATABASE

The material database hosted at www.material-aesthetics.com is a visual narrative database that derives from the author's research work at Southampton Solent University in the UK. It contains holistic information about the sensory perception of materials. The basic concept in building the database was to identify the factors involved in human perception of materials and to collect and illustrate the information about the interrelationship between these factors in a dynamic and systematic way. The database has a hierarchical structure, echoed in the interface which initiates from six main dimensions: human perception, material categories, sensory properties, subject groups, environmental context, and physical parameters, each coded in different colours (**Figure 4**). Each dimension has certain components. For example, the dimension 'human perception' currently has 'visual' and 'tactual' components, and will have other components 'auditory' and 'olfactory' to be added in the future. Components from different dimensions combine to form a permutation of relationship to be explored. For example, **Figure 5b** lists a few permutations, one of which is 'vis-tac-tex-sebs', representing the relationship between the texture perception of SEBS thermoplastic elastomer via the senses of vision and touch. Most of the information within the database takes the form of datasheet (**Figure 5**).

The information within the database addresses the following questions. What are the basic theories and information of sensory perception (perception by vision, touch, hearing, smell and taste)? How do people verbally describe the sensory properties of materials through a particular sensory route, e.g., a material's surface texture via visual touch or blindfolded touch? What inter-relationships exist between various responses to the sensory properties? For example, how does a texture influence emotion? How will the perception of materials vary in the context of being represented in different forms of different products and environmental conditions? What relationship exists between subjective perception of materials and objective physical parameters of materials? What technological methods are required or available to realise an expected sensory property for a particular material? The following paragraphs will give more detail to some of these topics.



Dimension1- human perception
looks into what sensory modalities such as visual, factual, auditory, olfactory or gustatory sensation will be evolved in the perception process in the material-human interface

Dimension2 - material categories
looks at which particular materials with which particular manufacturing and surface treatment are presented as the stimuli to be perceived by the user groups.

Dimension3 - sensory properties
looks into what properties of materials such as colour, texture, sound, smell or taste, or combination of these, are to be perceived by the user groups.

Dimension4 - subject groups
looks into what factors influence the perception of a particular subject group, such as their age, gender, cultural background, professional background etc.

Dimension5 - environmental context
looks at the effect and control of particular environmental conditions during the materials-human interaction process. This includes the natural environment (such as weather, temperature etc.), artificial environment (such as mechanical force, electrical field, chemical media etc.) and the particular product context.

Dimension6 - physical parameters
looks into what physical parameters of materials are the underlying factor that influence a particular feature of texture, therefore provides the possible technical solution to match the subjective requirement.

Figure 4. Dimensions of the material-aesthetics database.

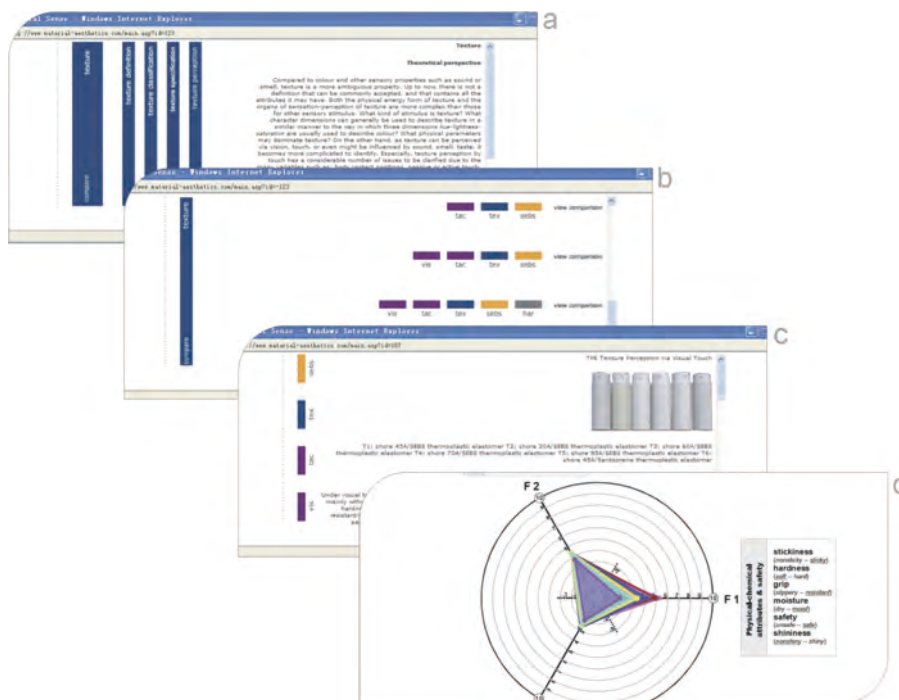


Figure 5 (a-d). Datasheets within the material-aesthetics database.

Subjective Description of the Sensory Properties of A Material

When facing any product that is presented in the marketplace, consumers generally may not know how the product is made. They are mainly interested in the end-quality of the product. The overall perception of quality will be directly related with the perception of the materials used in the product. Consumers make their judgement through sight, touch, hearing, smell etc. Therefore, knowing how consumers describe colour, texture, sound, aroma etc. will ensure a consistent communication language between designers and consumers and enable designers to establish criteria for a product aiming to achieve good sensory appeal. From the author’s previous research, a ‘Dimension-lexicon’ system has been proposed to summarise the description of material textures (Zuo et al., 2001). The subjective description of texture includes the following dimensions: geometrical, physical-chemical, emotional, and associative. Each dimension contains frequently used descriptors, which are termed texture ‘lexicons’. Except for those belonging to the associative dimension, lexicons usually consist of a pair of adjectives, for example, ‘smooth-rough’, ‘dense-loose’ (Figure 6).

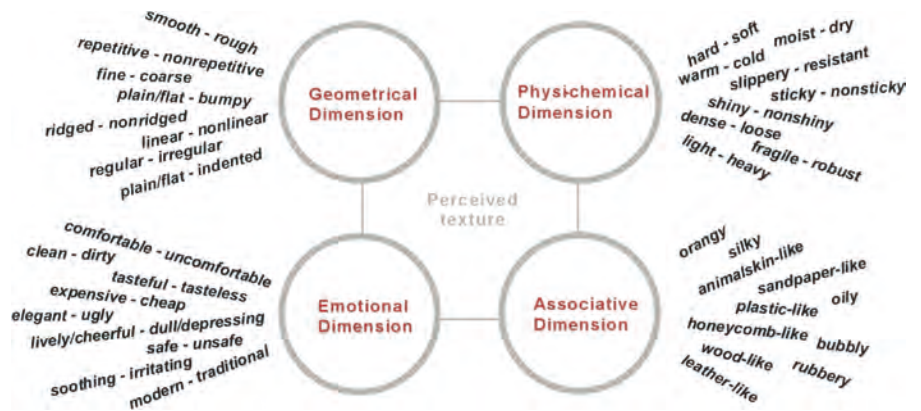


Figure 6. Four dimensions and lexicons for texture description.

The description of material properties can be dependent on different conditions such as age, gender, cultural background and sensory modalities. For example, the description of a material surface texture by touch can be different from a description gained visually solely from the perception of an image. Furthermore, the description under visual touch conditions can be different from that under blindfold touch conditions. Previous research revealed that vision could increase the response to geometrical configuration, and enrich and strengthen the emotional feelings, whilst the removal of vision and reliance purely on touch can increase people's sensitiveness to some physical-chemical characteristics such as warmth, moisture and hardness (Zuo et al., 2001).

Correlation Between Different Subjective Responses

Subjective responses tend not to be isolated but correlated between each other. For example, to some extent, a perceived 'rough' texture, compared to a 'smooth' one, tends to correspond with the feeling of 'non-shiny', 'warm', and 'non-sticky'. These responses within the geometrical dimension and the physical-chemical dimension also have correlations with responses within the emotional dimension (Zuo et al., 2004). The emotional response to a material's texture was defined as people's affective, hedonic and valuable feelings, which are evoked by sensing/touching the material surface. Generally speaking, the sensory responses themselves within the geometrical dimension and the physical-chemical dimension can be regarded as 'neutral'. For instance, it is hard to say whether 'smooth' or 'rough' is either a good or bad attribute. To decide which particular surface attribute is preferred (e.g., 'smooth' or 'rough') will depend upon a number of considerations, one of which is how these geometrical responses or physical-chemical responses affect the functional operation of the product in which the material is used. That is, how the surface attributes influence users' performance or operation with a product (e.g. grip, push, sit, walk etc.).

Another consideration is how geometrical responses or physical-chemical responses correlate with emotional responses: will a certain surface texture stimulate a positive emotional response? Information about these correlations is also available in the database. For example, the experimental results reveal that the surface texture attribute that mostly correlates with a positive feeling is shininess, i.e., a 'lively/cheerful' response mostly corresponds to a 'shiny' surface. This is consistent for different material categories and under both visual touch and blindfold touch conditions (although, when people are blindfolded, a shiny sensation is derived

from an illusion) (Zuo et al., 2005). Practical examples can be found in the design of a computer mouse. A 'lively/cheerful' feeling can be elicited by using a 'shiny' ceramic-like sphere, or a single curved shiny polymer case. Compare this to the traditional non-shiny plastic mouse, which seems to be dull. However, such kind of correlation can be quite complex, due to three factors: 1) different emotional responses may correspond to different perceived surface attributes, whilst one certain perceived surface attribute may correspond to a variety of emotional responses to differing degrees; 2) an amendment needs to be considered due to the difference in either direction or strength between varying statistical analysis methods, e.g., Pearson correlation and partial correlation; and 3) for different materials and under different sensory conditions, results may be different.

Further, such kind of correlation needs always to be re-examined when used in any design context, as various contexts can weaken, strengthen, or totally change the correlation. Usually, environmental contexts play an important role in emotions. For example, if you hear a frightening sound when you are alone and in the dark, your level of fear will increase. If you touch a strange and unpleasant object in a primitive forest rather than in a museum, your level of fear will also increase. This means the correlation between emotional responses and outside stimuli are dynamic and complicated. However, it still makes sense to seek some general phenomena about the correlation between emotional responses and the perceived surface attributes of materials, even if under controlled conditions and with material samples. The results of such research will serve as reference for designers to select materials or textures for any new product development where no existing products can be used as a reference.

Cross-Sensory Interaction in Texture Perception

Texture can usually be perceived via the sense of vision and touch. However, when applied singularly, both vision and touch have their limitation in texture perception. Vision usually provides more information on the global impression of texture, but will depend upon the viewing field and distance, and may not reveal the real situation of the nature of an object or material with regard to its three-dimensional features such as roughness, warmth, moisture, abrasiveness, softness, etc. Touch can more subtly explore the local, tiny features of a surface or the body of a material/object. The tactual feelings of materials may be regarded as more honest and richer than the feeling gained by vision. However, when vision is blocked while touching, the identification of objects/materials on a global basis can be impeded or become slow, as dominant information that contributes to our memory is obtained via our sense of vision. On the other hand, visual judgement of texture can cheat our other senses, which sometimes is called visual illusion. But it is this visual illusion that can be, and has continually been, utilised as a tool to produce fascinating effects when vision is the main channel for users to engage with a product. In the case of tactual perception, most tactual feeling cannot be specified unless you are engaged with the material/object in an interactive mode. It is rarely the case to feel a texture by a static touch on the surface without any movement. Full experience of a texture will require twisting, pressing, squeezing, or knocking the object or material.

With regard to the interaction between vision and touch in texture perception, from the author's experimental research, it was found that, qualitatively, good consistency exists between visual touch and blindfold

touch in texture perception; whilst, quantitatively, differences lie in the sensitivity of subjective responses to material textures and the strength of the correlation between those responses (Zuo, 2003). It is proposed that this result is not casual as it can be explained by existing and other emerging related theories. Evidence from neural science reveals that visual cortical involvement (and presumably, visual imagery) may facilitate tactile judgments about 'macro-geometric' object features such as orientation, shape and size, but not 'micro-geometric' features such as surface texture, which depend on the size of constituent elements and their spacing (Zangaladze et al., 1999). Therefore it is understandable why most of the texture perception results in this research were found to be similar under both visual touch and blindfold touch conditions.

Usually, designers are sophisticated in identifying materials/textures for a product that have visual appeal, but are less competent or sometimes ignorant in satisfying other senses, for example, touch. This is why, in recent years, in-depth research into subjective responses or feelings to various materials via other senses, particularly touch and sound, has become increasingly prominent.

Relationships Between Subjective Responses and Physical Parameters

The previous sections of this article focused on the subjective aspects of material/texture perception. On the other hand, there usually exist certain physical properties of materials that underlie or correspond to those subjective descriptions. Understanding the relationships between objective measures of those properties and subjective responses can help pinpoint particular manufacturing processes to create desirable material properties, which correspond to an optimised or balanced mixture of positive user feelings. Such a goal has potentially great significance in the new product development process.

This type of research can be traced back to the stream of psychophysics, the oldest branch of psychology that particularly explores the relationship between the physical and mental worlds. It should be pointed out that traditional psychophysical research focuses on two variables, of which one is physical, and the other is psychological (Figure 7). In addition to this 'one to one' relationship, a 'one to more' or 'more to one' relationship is also worth exploring, as long as this kind of relationship exists. For example, the psychological feeling of a surface's moisture could be related to a number of physical factors, such as different materials with different surface energy, or the same type of materials with different surface roughness, or the same type of materials but with different softness (Figure 7, Part B). On the other hand, one physical parameter, e.g. physical

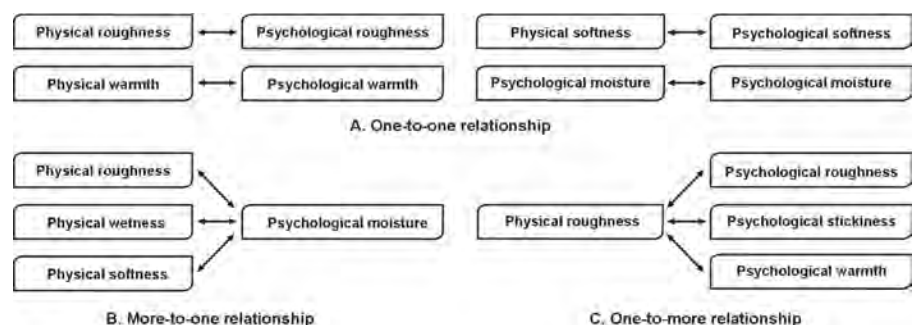


Figure 7. Types of psychophysical relationships for materials.

roughness, can correspond to a number of psychological feelings, e.g. subjective roughness, stickiness, warmth (**Figure 7**, Part C).

Representative Meanings of Materials

In addition to the sensory properties of materials, the representative meanings of materials, cultural connotation, metaphors, and other associations also play important roles in material perception. However, the boundaries between material sensory properties (attributable to sensation) and representative meanings (attributable to perception) may be ambiguous. For example, texture seems just to be a sensory property, but our research has revealed people's description of a texture goes beyond the surface geometrical configuration and physical-chemical attributes, to include the expression of emotional and associative feelings. An analysis of the descriptive words given for a material surface such as moist, sticky, shiny, cold, comfortable, cheerful, oily, orangy, and mirror-like', reveals a combination of what people sense initially by their organs (eyes, skin, etc.) and what they perceive mentally including association via memory recall.

People's experience with either a whole product or a material used in a product is multi-faceted. Desmet and Hekkert (2007) identified three distinct levels of product experience: aesthetic experience, experience of meaning, and emotional experience. It is indicated that even though these three components of an experience can be clearly conceptually separated, they are very much intertwined and often difficult to distinguish in our everyday experience, and one particular experience may activate other experiences. This kind of relationship can also be recognised in the case of material or texture perception, as a sub-domain of product perception. Among the four dimensions of texture description, the descriptions within the geometrical and physical-chemical dimensions tend to be more sensory or aesthetics-based; the descriptions within the emotional and associative dimensions correspond to emotional experience and experience of meanings respectively. And as with products, the kinds of experiences to be gained from material samples are considerably intertwined. For example, as mentioned previously, the author's research based on studies of isolated material samples and within consumer product contexts such as hairdryers indicated that a 'shiny' surface (sensory and aesthetic experience) corresponds to 'cheerful/lively' feelings (emotional experience); or a 'black shiny' plastic surface (sensory or aesthetic experience) evokes the associative feeling of 'high-class' or 'high-quality black cars' (experience of meanings); or a 'metallic' 'grey' or 'smooth' plastic surface (sensory or aesthetic experience) is associated with 'hi-fi' or a 'space gun' (experience of meanings) (Zuo, 2005).

The relationship between a material and a product is similar to the relationship between an actor and the role played by the actor. Even before a material has been processed into a product form, it can still have a character, though sometimes this kind of perception is a little ambiguous: "...a sort of embedded personality, a shy one, not always visible, easily concealed or disguised, but one that, when appropriately manipulated, can contribute to good design" (Ashby and Johnson, 2002, 76). For example, iron and steel represent industrialisation, a hard, heavy, cold or cool impression; wood gives the feelings of warmth, soft, nature, domesticity; leather represents luxury, grace, elegance; marble magnificence, nobleness, etc. This is also apparent in the case of material colour. Colours can have some general connotations even without a specified application context. For example, the colour red can usually be associated with a number of

emotional feelings such as strength, power, energy, passion, enthusiasm, courage, love, vigour, sexuality. However, although some of the emotional feelings and meanings of colours are universal, in many cases, they are culturally dependent. For instance, a large difference exists between Chinese and Western cultures for the associative meanings and use of red, black, and white. Red means good luck in China while Westerners associate red with a sporting spirit. White flowers in the front of a car in China represent a funeral; whilst in Europe it is usually associated with weddings. It is also conceivable that differences may exist between different cultures for the associative meanings attributed to different materials and textures. Cross-cultural material sensory perception is an area of work in need of further exploration.

Perceived meanings and associations tend to vary with different people, different contexts and over different time periods. For example, whether a material or product is perceived as 'modern' in response to a 'shiny' or a 'non-shiny' surface will probably be dependent on the age of the person, their cultural background, product category and the environment in which the product is used. As another example, at the beginning of 20th century, plastics were perceived as symbols of progress, modernity and democracy, which made them so popular that some materials including iron, wood and leather were replaced by plastic in many applications. Later, most of the common thermoplastics such as PVC, PE, PP and PMMA, along with thermosets such as PF/Bakelite, were taken for granted as their widespread use was witnessed throughout domestic appliances. However, people's perception of plastic keeps evolving, from the concept of plastics as cheap, ugly and easily broken, to that of being suited for use in high technology applications. Plastics now present a wide range of new categories with extended functions, strengthened technical properties and improved/diversified sensory properties. Put briefly, understanding the representational and associative meanings of materials and textures can help guide the selection of appropriate materials and textures for a new product design. These activities may be tailored towards one of two perspectives: designing particular 'culture-centred' products, or designing products with a fusion of multi-cultural influences that could be suited to more generic and global markets.

INTEGRATION OF MATERIALS RESOURCES INTO INDUSTRIAL DESIGN EDUCATION

In industrial design education, within a limited period of time, delivering knowledge of materials and processes to students and training their ability to select materials in a comprehensive manner remains a serious challenge. Generally, there are two ways of teaching materials: one is following the route from microstructure to macro-application, which is a science-led methodology; the other is following the route from macro-requirement to a specific material with a particular microstructure, which is design-led (Ashby et al., 2007). It is reasonable to assume that for industrial design, the second way will be more effective and efficient.

Design is a form of highly innovative practice-based activity. This determines that teaching materials in design would be more effective if students were engaged in an experimental or exploratory context, with the chance to participate in hands-on activities with materials. This would stimulate their curiosity, interest, and inspiration in knowledge-learning and solution-finding of problems. **Figure 8** shows product design students

at Southampton Solent University attending the author's research in both sensory tests of material samples and contextual studies of consumer products. The material samples used in the experiments were collected for display in a physical material library located in the Design Studio at the University. Simultaneously, the research results of material sensory perception further expanded the students' knowledge about various materials.

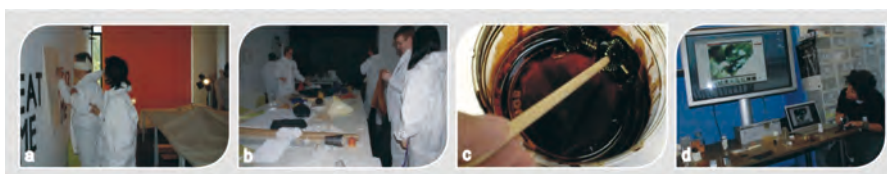
As vision is such a dominant modality of information source in people's daily life, other sensory modalities seem to be non-sufficiently utilized. This remains a potentially large space for designers to expand multi-sensory solutions to design problems. It is necessary to consciously strengthen the integration of multi-sensory appeal of materials in design teaching. The author attended interesting materials-based workshops co-organized by MADE (Materials And Design Exchange), RCA (Royal College of Art), and IOM3 (Institute of Materials, Minerals, and Mining), such as the one shown in **Figure 9**. The experiment sessions in Figure 9a and b involved perception of materials via vision, touch, hearing, smell and taste, and involved interactions with daily objects and associated mental imagery. This was similar in methodology and content as the associative dimension of texture description from the author's research, but extended beyond just the tactual domain. It would be valuable to promote this kind of materials exploration within industrial design education.

In addition to experimental and exploratory interaction with materials, integrating various resources of materials information also significantly facilitates materials teaching. The author has tried to combine the Cambridge Engineering Selector (CES) and the Material-Aesthetics database as effective tools in teaching. Usually, CES is used as an assistant for pinpointing a few material candidates at the early stage of a project, where logical thinking deduction on functional and technical requirements dominates the materials selection process. In contrast, the Material-Aesthetics database is promoted as an assistant for deciding which texture or surface finish (with regard to roughness, shininess, hardness, warmth etc.) would be most appropriate for a particular material, where lateral thinking, synthesis and association are the focus. For example, in a student project to design an electric kettle, an initial selection of handle materials suggested wood, polypropylene, and stainless steel as candidates.



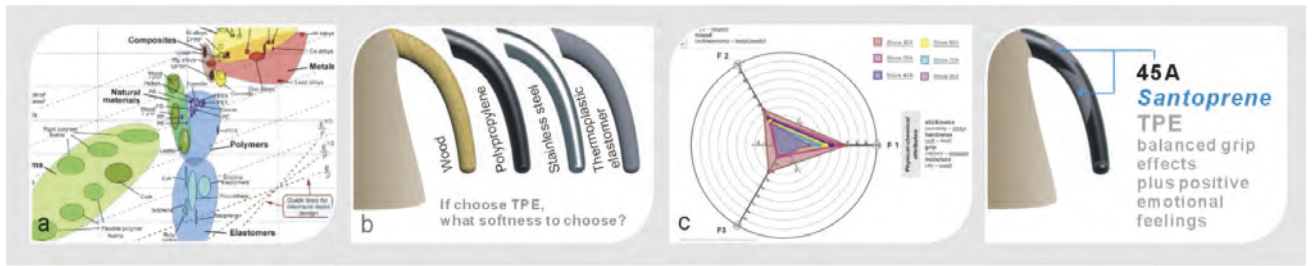
a, b - sensory evaluation tests within product context (kettles and hair dryers)
c, d - sensory tests of isolated material samples (elastomer and metals)

Figure 8. Students' involvement in research on material sensory perception.

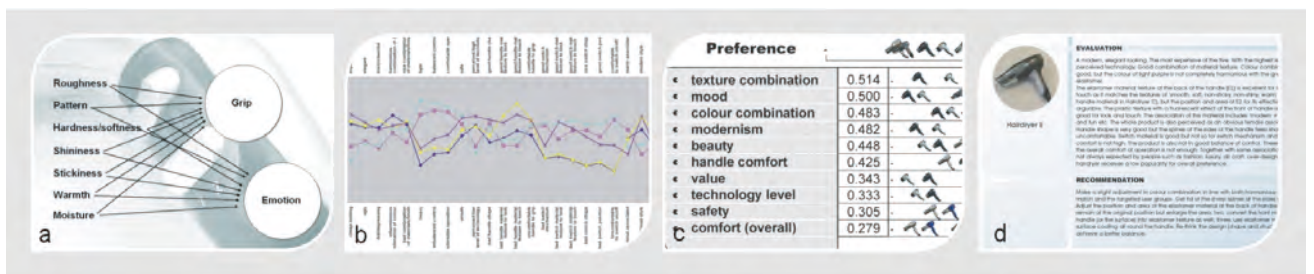


a, b - mapping between materials and sensory experience and imagination
c - learning the characteristics and application of nano-material particles
d - observing the enlarged surface patterns and micro-structures of materials

Figure 9. 'Material experiment' workshops for art and design educators.



a - using Cambridge Material Selector to filter material candidates
 b - wood, polypropylene, stainless steel as candidates plus thermoplastic elastomer for grip comfort to cover a certain area of handle or the overall handle
 c - using texture perception map within the material-aesthetics database to choose a suitable softness of TPE
 d - a 45A shore hardness Santoprene TPE has been chosen to balance grip and positive emotional feelings



a - focus on the relationship between handle texture and grip, emotional feelings
 b - 23 items of evaluation in terms of sensory response to the materials and the whole product
 c - correlations revealed between overall preference of product and the evaluated items
 d - recommendation of materials/textures re-combination and redesign of product form has been given to each hair dryer

Figure 10. Combining the CES and material-aesthetics databases in teaching materials for design.

Figure 11. Example of contextual study of material sensory perception for industry.

Considering comfort of grip, thermoplastic elastomer (TPE) was chosen as an additional material to cover the handle or a part of handle. Under the conditions of low cost, lightweight, and sustainability, a polypropylene with elastomer touch pad was selected for the handle. At the next stage of identifying a specific TPE, guidelines were obtained from the Material-Aesthetics database: was it a case of 'the softer the better' for a TPE? The answer was 'no'. A texture perception map of TPE indicates that the middle-range of shore hardness between 20A to 90A, in this case, around 45A of Santoprene TPE, corresponds to a balanced requirement for both grip (soft, resistant, non-sticky) and emotional feelings (comfort, safe and elegance), as shown in **Figure 10**.

In addition, the aforementioned physical library of material samples provides students with a platform where they can view, touch and smell the material samples directly, and can stimulate their creative thinking and improve their selection decisions. Although the selection of materials within the classroom can still be preliminary, because there will be more practical issues such as moulding cost and compatibility to consider, as a fundamental training of material selection for design students, the methodology has proved to be effective.

It is also highly important to synergize research, learning and enterprise into materials and design education, collectively forming three blades of a metaphorical fan. At Southampton Solent University, tests of materials used in product contexts are conducted in collaboration with industrial



Figure 12. Award winners in 2009 acrylic design competition with Lucite International China.

partners who provide their existing domestic products such as kettles, hairdryers and irons. The results of materials/textures evaluation and analysis for these consumer products are taken as a reference for modifying existing products or for new product development within the companies. **Figure 11** shows one such project for a leading British company supplying hairdryers.

At Tsinghua University, partnerships with material industries have been continually strengthened. In a recent design competition project in collaboration with Lucite International China, student participants were required to use acrylic to achieve a design innovation. The main sensory property of acrylics utilised by the students were transparency, or varying degree of transparency (from opaque, translucent, through to transparent) and texture effects when blended with other mineral substances. **Figure 12** shows the award-winning student designs from the 2009 project event. Through such an event, students have obtained in-depth knowledge about acrylic and its forming processes, whilst the industrial partner effectively promoted its brand and developed a strong basis for further collaboration in material research and design.

CONCLUSION

In parallel to material engineering and technical properties, material sensory properties such as colour, texture, sound, and smell, and the representative or associative meanings of materials, linked to human emotional feelings, play an equally important role in materials selection for products. The ideal methodology for approaching research into material sensory perception should be to combine both direct and indirect methods, with materials presented and examined as both isolated samples and product examples. An on-line material database (www.material-aesthetics.com) developed from the author's research results contains key information about material sensory perception, namely: 1) subjective descriptions of material textures (geometrical dimension, physical-chemical dimension, emotional dimension, and associative dimension); 2) correlations between different subjective responses to material textures; 3) quantitative relationships between subjective responses and material physical parameters; 4) cross-sensory interaction in texture perception, e.g., vision-touch comparisons; 5) a number of material texture perception maps organized by material categories and sensory modalities; and 6) information on material sensory perception within industrial product contexts.

Further research is on-going. Teaching of materials in industrial design, if it is to be effective, should encourage experimental and exploratory

interaction with materials, whilst integrating logic and lateral thinking by utilizing various resources and tools, such as the Cambridge Engineering Selector and Material-Aesthetics database.

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Anahtar Sözcükler: duyu; algı; estetik; malzeme dokusu; veri bankası; ürün tasarımı.

İNSAN DUYUMUNA UYABİLECEK MALZEME SEÇİMİNİ YAPMAK VE ENDÜSTRİYEL TASARIMDA ESTETİK BEKLENTİ

Günümüz endüstriyel tasarım pratiği ve eğitiminde, malzeme seçimi yapmak ve malzeme bileşenleri hazırlamak açısından farklı bilgi ve enformasyon kaynaklarının bütünlüğünü sağlamak oldukça önemlidir. Malzemeye yapılan estetik atıflar ve malzemenin duyumsal ya da algısal özellikleri, malzemenin mühendislik ve teknik özelliklerine göre aynı önemde fakat daha az incelenen bir konu olmuştur. Bu makale kuramsal ve deneysel araştırmaya dayanarak malzeme estetiği ve duyumsal algı konusundaki asal içeriği ortaya koymaya çalışmakta ve bu alanda yapılacak araştırmaların yöntemi üzerinde durmaktadır. Yazıda ayrıca yazarın doküman malzemeler üzerine yaptığı araştırmalara dayanan bir malzeme estetiği veritabanı tanıtılmaktadır. Araştırma sonuçlarının endüstride yeni ürün geliştirmede nasıl referans olarak kullanıldığı ve bu sonuçların başka kaynaklarla birleştirilerek tasarım eğitiminde malzeme özelliklerinin öğretilmesi için nasıl kullanılabilceği anlatılmaktadır.

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