PRODUCT DESIGN

Materials and Product Design

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Version 3.0 October 2012
First published February 2004, Version 2.0 2008,

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1. Introduction

Good design works. Excellent design also gives pleasure.

Products achieve success through a combination of sound technical design and imaginative industrial design. The amalgam creates product character – the way material and processes have been used to provide functionality, usability and satisfaction in ownership. This last – satisfaction – is greatly influenced by the aesthetics, associations and perceptions that the product carries; a combination that we shall refer to as product personality.

Materials, you might say, are the foodstuffs of design, processes the ways of preparing the materials for consumption. How are they chosen? The choice must meet the technical requirements of the design, establishing its functionality, its safety and its cost. These we will leave to the technical engineer. Here we focus on another set of criteria, equally important in product design: how do designers choose materials and processes to create its personality? This is a question that does not require a degree in engineering for an answer – personality, after all, is a human quality. What it does require is an ability to observe, to compare and to relate.

This paper is about the way materials and processes can be used to create product personality and character.

2. The requirements pyramid

The pen with which I am writing this paper cost £5 (Figure 1, upper image). If you go to the right shop you can find a pen that costs well over £1,000 (lower image). Does it write 200 times better than mine? Unlikely; mine writes perfectly well. Yet there is a market for such pens. Why?

A product has a cost – the outlay in manufacture and marketing it. It has a price – the sum at which it is offered to the consumer. And it has a value – a measure of what the consumer thinks it is worth. The expensive pens command the price they do because the consumer perceives their value to justify it. What determines value?

Functionality, provided by sound technical design, clearly plays a role.

Figure 1. Pens, inexpensive and expensive. The chosen material – acrylic in the upper picture, gold, silver and enamel in the lower one – create the aesthetics and the associations of the pens. They are perceived differently, one pair as utilitarian, the other as something rare and crafted. (Lower figure courtesy of David Nishimura of Vintagepens.com).

The requirements pyramid of Figure 2 has this as its base: the product must work properly, be safe and economical. Functionality alone is not enough: the product must be easy to understand and operate, and these are questions of usability, the second tier of the figure. The third, completing the pyramid, is the requirement that the product gives satisfaction: that it enhances the life of its owner.

The value of a product is a measure of the degree to which it meets (or exceeds) the expectation of the consumer in all three of these – functionality, usability and satisfaction. Think of this as the character of the product. It is very like human character. An admirable character is one who functions well, interacts effectively and is rewarding to be with. An unappealing character is one that does none of these. An odious character is one that does one or more of them in a way so unattractive that you cannot bear to be near him.

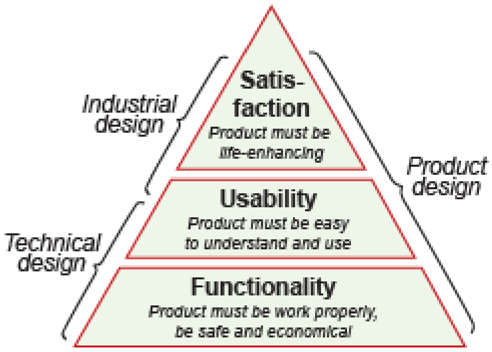

Figure 2. The requirements pyramid. The lower part of the pyramid tends to be labeled "Technical design", the upper part, "Industrial design"; better, perhaps, is to think of think of all three tiers as part of a single process that we shall call "Product design".

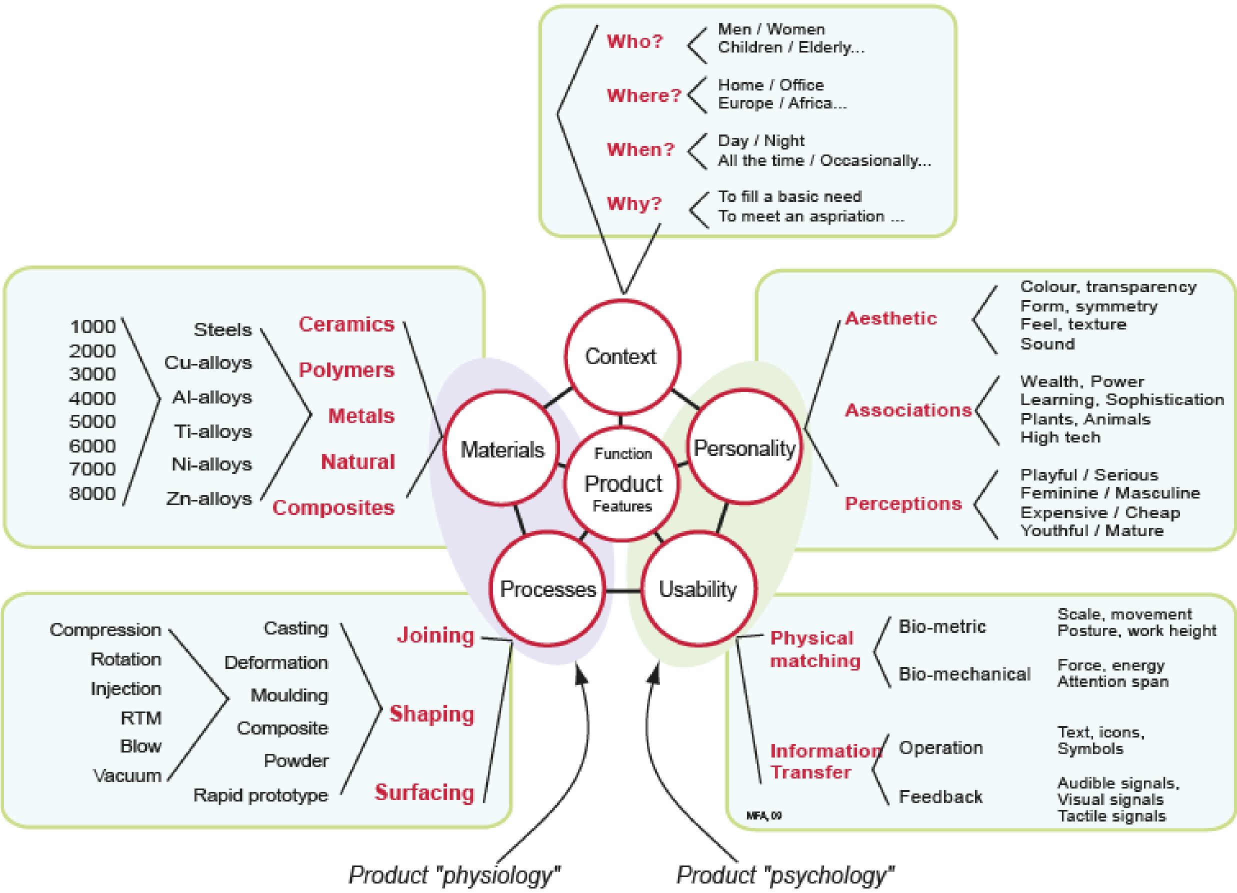

Figure 3. The dissection of product character. Context defines the intentions or "mood"; materials and processes create the flesh and bones; the interface with the user determines usability, and the aesthetics, associations and perceptions of the product create its personality. These terms are explained more fully in the text. (Material short-names are explained in the appendix.)

Products are the same. All the pens in Figure 1 function well and are easy to use. The huge difference in price implies that the lower pair provides a degree of satisfaction not offered by the upper ones. The most obvious difference between them is in the materials of which they are made – the upper pair of molded acrylic, the lower pair of gold, silver and enamel. Acrylic is the material of tooth-brush handles, something you throw away after use. Gold and silver are the materials of precious jewelry; they have associations of craftsmanship, of heirlooms passed from one generation to the next. So – the obvious question – how do you create product character?

3. Product character

Figure 3 shows a way of dissecting product character. It is a map of the ideas we are going to explore; like all maps there is a lot of detail, but we need it to find our way. In the center is information about the *product* itself: the basic design requirements, its function, its features. The way these are thought through and developed is conditioned by the *context*, shown in the circle above it. The context is set by the answers to the questions*: Who? Where? When? Why?* Consider the first of these: *Who?* A designer seeking to create a product attractive to women will make choices that differ from those for a product intended for children, or for elderly people, or for sportsmen. *Where*? A product for use in the home requires a different choice of material and form than one to be used – say – in a school or hospital. *When?* One intended for occasional use is designed in a different way than one that is used all the time; one for formal occasions differs from one for informal occasions. *Why?* A product that is primarily utilitarian involves different design decisions than one that is largely a life-style statement. The context influences and conditions all the decisions that the designer takes in finding a solution. It sets the *mood*[1].

On the left of products lies information about the *materials* and the *processes* used to shape, join and finish the product – the main focus of this article. Each illustrates the library, so to speak, from which the choices can be made. The primary step in selecting both material and process is that they can meet the constraints imposed by the primary design requirements – the essential functions and features of the central circle. Material and process give the product its tangible form, its flesh and bones so to speak; they create the *product physiology*.

On the right of Figure 3 are two further packages of information. The lower one – *usability* – characterizes the ways in which the product communicates with the user: the interaction with their sensory, cognitive and motor functions. Products success requires a mode of operation that, as far as possible, is intuitive, does not require taxing effort, and an interface that communicates the state of the product and its response to user action by visible, acoustic or tactile response. It is remarkable how many products fail in this, and by doing so, exclude many of their potential users.

One circle on Figure 3 remains: the one labeled *personality*. Product personality derives from *aesthetics*, *associations* and *perceptions*.

Anaesthetics dull the senses. Aesthetics do the opposite: they stimulate the five senses of sight, hearing, touch, taste, and smell. The first row of the personality box elaborates: we are concerned here with color, form, texture, feel, smell and sound – think of the smell of a new car and the sound of its door closing.

Products also have associations – the second row of the box – the things they remind you of, the things they suggest. The Land Rover and other SUVs have forms and (often) colors that mimic those of military vehicles. The streamlining of American cars of the 1960s and 1970s carried associations of aerospace. It may be an accident that the VW Beetle has a form that suggests the insect, but the others are no accident; they were deliberately chosen by the designer to appeal to the consumer group (the *Who?*) at which the product was aimed.

Table 1. Some perceived attributes of product with opposites.

Perceptions (with opposite)	
Aggressive	Passive
Cheap	Expensive
Classic	Trendy
Clinical	Friendly
Clever	Silly
Common	Exclusive
Decorated	Plain
Delicate	Rugged
Disposable	Lasting
Dull	Sexy
Elegant	Clumsy
Extravagant	Restrained
Feminine	Masculine
Formal	Informal
Hand-made	Mass produced
Honest	Deceptive
Humorous	Serious
Informal	Formal
Irritating	Loveable
Lasting	Disposable
Mature	Youthful
Nostalgic	Futuristic

Finally, the most abstract quality of all, perceptions. Perceptions are the reactions the product induces in an observer, the way it makes you *feel.* Here there is room for disagreement; the perceptions of a product change with time and depend on the culture and background of the observer. Yet in the final analysis it is the perception that causes the consumer, when choosing between a multitude of similar models, to prefer one above the others; it creates the “must have” feeling. Table 1 lists some perceptions and their opposites, in order to

[1] Many designers, working on a project, assemble a *mood-board* with images of the sort of people for whom the product is intended, the surroundings in which they suppose it will be used, and other products that the intended user group might own, seeking to capture the flavour of their life-style.

sharpen the meaning. They derive from product reviews and magazines specializing in product design; they are a part of a vocabulary, one that is used to communicate views about product characteristics[2].

4. Using materials and processes to create product personality

Do materials have a personality? There is a school of thinking that holds as a central tenant that materials must be used 'honestly'. By this they mean that deception and disguise are unacceptable – each material must be used in ways that expose its intrinsic qualities and natural appearance. It has its roots in the tradition of craftsmanship – the potters use of clays and glazes, the carpenters use of woods, the skills of silversmiths and glass makers in crafting beautiful objects that exploit the unique qualities of the materials with which they work – an integrity to craft and material.

This is a view to be respected. But it is not the only one. Design integrity is a quality that consumers value, but they also value other qualities: humor, sympathy, surprise, provocation, even shock. You don't have to look far to find a product that has any one of these, and often it is achieved by using materials in ways that deceive. Polymers are frequently used in this way – their adaptability invites it. And, of course, it is partly a question of definition – if you say that a characterizing attribute of polymers is their ability to mimic other materials, then using them in this way *is* honest.

5. Materials and the senses: aesthetic attributes

Aesthetic attributes are those that relate to the senses: touch, sight, hearing, taste and smell (Table 2).

Almost everyone would agree that metals feel 'cold'; that cork feels 'warm'; that a wine glass, when struck, 'rings'; that a pewter mug sounds 'dull', even 'dead'. A polystyrene water glass can look indistinguishable from one made of glass, but pick it up and it feels lighter, warmer, less rigid; tap it and it does not sound the same. The impression it leaves is so different from glass that, in an expensive restaurant, it would be completely unacceptable. Materials, then, have certain characterizing aesthetic attributes. Let us see if we can pin these down.

Table 2. Some aesthetic attributes of materials.

Sense	**Attribute**	
Touch	Warm Cold Soft Hard	Flexible Stiff
Sight	Optically clear Transparent Translucent Opaque	Reflective Glossy Matte Textured
Hearing	Muffled Dull Sharp Resonant	Ringing Low pitched High pitched
Taste/Smell	Bitter	Sweet

Touch: soft-hard / warm-cold[3].

Steel is 'hard'; so is glass; diamond is harder than either of them. Hard materials do not scratch easily; indeed they can be used to scratch other materials. They generally accept a high polish, resist wear and are durable. The impression that a material is hard is directly related to the material property *hardness*, measured by materials engineers and tabulated in handbooks. Here is an example of a sensory attribute that relates directly to a technical one.

'Soft' sounds like the opposite of 'hard' but, in engineering terms, it is not – there is no engineering property called 'Softness'. A soft material deflects when handled, it gives a little, it is squashy, but when it is released it returns to its original shape. Elastomers (rubbers) feels soft; so do polymer foams, and this has to do with the engineering property *elastic modulus*: both have moduli that are 100 to 10,000 lower than ordinary 'hard' solids; it is this that makes them feel soft. Soft to hard is used as one axis of Figure 4.

[2] Aesthetics, associations and perceptions are discussed more fully in the book by Ashby and Johnson (2010).

[3] CES Project files for the Charts of Figs 4, 5 and 6 are available from the Granta Design Teaching Resource website

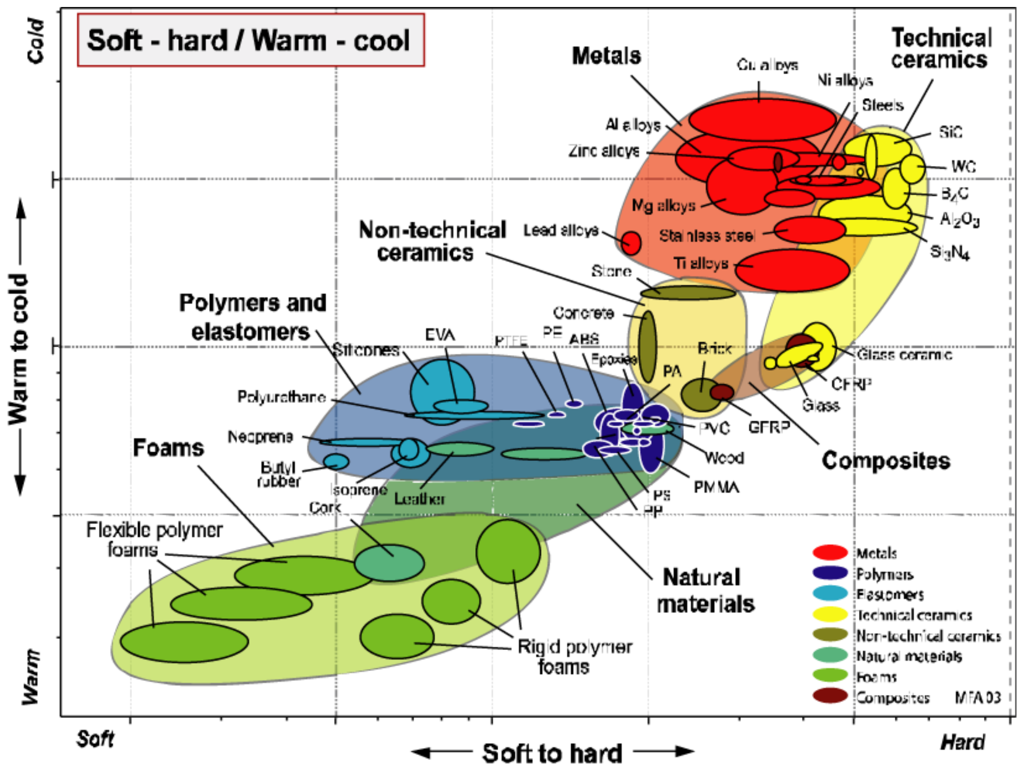

Figure 4. Tactile qualities of materials. Foams and many natural materials are soft and warm; metals, ceramics and glasses are hard and cold. Polymers lie in-between. (Material short-names are explained in Appendix 2.)

A material feels 'cold' to the touch if it conducts heat away from the finger quickly; it is 'warm' if it does not. This has something to do with the technical property *thermal conductivity* but there is more to it than that – it depends also on the property *specific heat*. A measure of the perceived coldness or warmth of a material is shown as the other axis of Figure 4, which nicely displays the tactile properties of materials. Polymer foams and low-density woods are warm and soft; so are balsa and cork. Ceramics and metals are cold and hard; so is glass. Polymers and composites lie in between.

Sight: transparency, color, reflectivity.

Metals are opaque. Most ceramics, because they are polycrystalline and the crystals scatter light, are either opaque or translucent. Glasses, and single crystals of some ceramics, are transparent. Polymers have the greatest diversity of optical transparency, ranging from transparency of optical quality to completely opaque. Transparency is commonly described by a 4-level ranking that uses easily-understood everyday words: 'opaque', 'translucent', 'transparent', and 'waterclear'. Figure 5 (overleaf) ranks the transparency of common materials. In order to spread the data in a useful way, it is plotted against cost. The cheapest materials offering optical-quality transparency ('water-clarity') are glass, PS, PET, and PMMA. Epoxies can be transparent but not with water clarity. Nylons are, at best, translucent. All metals, most ceramics and all carbon-filled or reinforced polymers are opaque.

Color can be quantified by analyzing spectra but this – from a design standpoint – doesn't help much. A more effective method is one of color matching, using color charts such as those provided by Pantone[4]; once a match is found it can be described by the code that each color carries. Finally there is reflectivity, an attribute that depends partly on material and partly on the state of its surface. Like transparency, it is commonly described by a ranking: dead matte, eggshell, semi-gloss, gloss, mirror.

[4] Pantone (www.pantone.com.) provide detailed advice on color selection, including color-matching charts and good descriptions of the associations and perceptions of color.

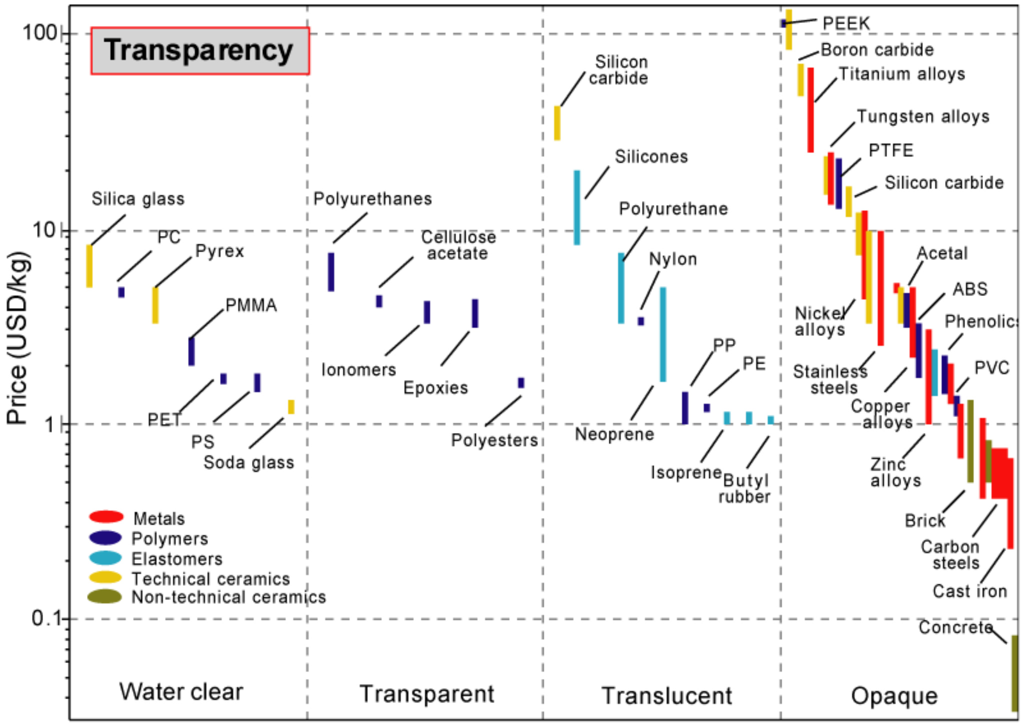

Figure 5. Here transparency is ranked on a four-point scale, from water-clear to opaque. Water-clear materials are used for windows, display cases and lenses. Transparent and translucent materials transmit light but diffuse it in doing so. Opaque materials absorblight. (Material short-names are explained in Appendix 2.)

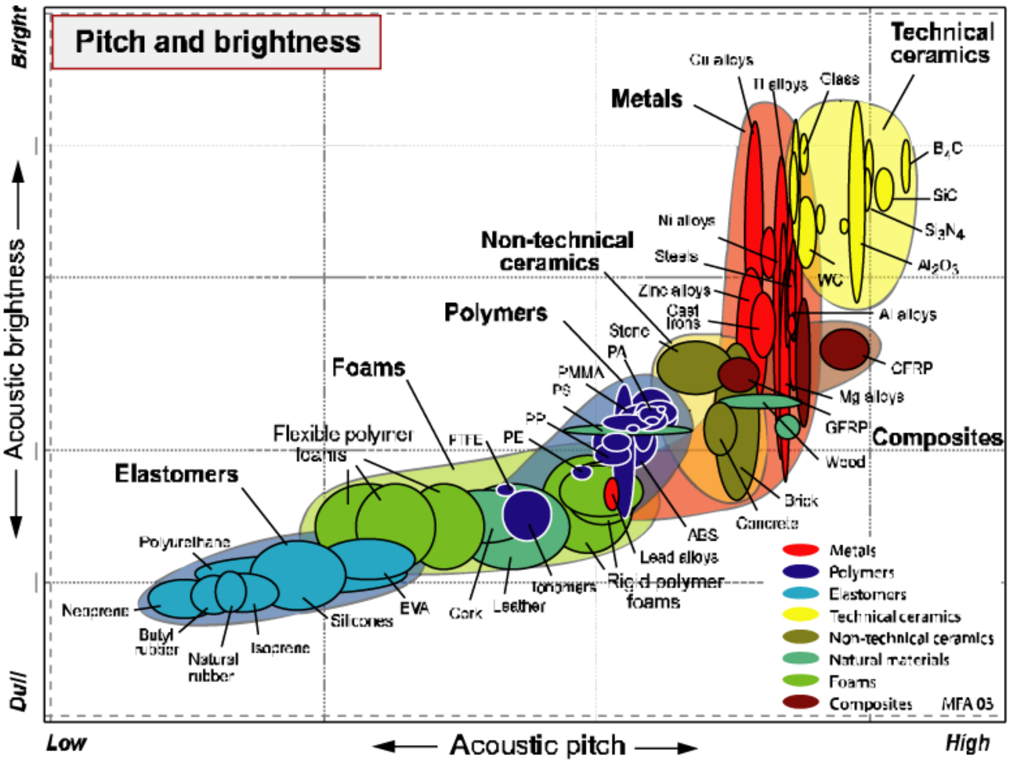

Figure 6. Acoustic properties of materials. The “ring” of a wine glass is because glass in an acoustically bright material with a high natural pitch; the dull “ping” of a plastic glass is because polymers are much less bright and – in the same shape – vibrate at a lower frequency. Materials at the top right make good bells; those at the bottom left are good for damping sound.

Hearing: pitch and brightness.

The frequency of sound (pitch) emitted when an object is struck relates to its material properties. A measure of this pitch is used as one axis of Figure 6. Frequency is not the only aspect of acoustic response – the other has to do with damping. A highly damped material sounds dull and muffled; one with low damping rings. Acoustic brightness – the inverse of damping – is used as the other axis of Figure 6. It groups materials that have similar acoustic behavior.

Bronze, glass and steel ring when struck, and the sound they emit has – on a relative scale – a high pitch; they are used to make bells; alumina, on this ranking, has bell-like qualities. Rubber, foams and many polymers sound dull, and, relative to metals, they vibrate at low frequencies; they are used for sound damping. Lead, too, is dull and low-pitched; it is used to clad buildings for sound insulation.

Figures 4-6 (each made using the CES EduPack software) show that each material class has a certain recognizable aesthetic character. Ceramics are hard, cold, high-pitched and acoustically bright. Metals, too, are relatively hard and cold but although some, like bronze, ring when struck, others – like lead – are dull. Polymers and foams are most nearly like natural materials – warm, soft, low-pitched and muffled, though some have outstanding optical clarity and almost all can be colored.

These qualities of a material contribute to the product personality. The product acquires some of the attributes of the material from which it is made, an effect that designers recognize and use when seeking to create a given personality. A stainless steel facia, whether it be in a car or on a hi-fi system, has a different personality than one of polished wood or leather and that in part is because the product has acquired some of the aesthetic qualities of the material.

6. Materials and the mind: associations and perceptions

So a material certainly has aesthetic qualities – but can it be said to have a personality? At first sight, no – it only acquires one when used in a product. Like an actor, it can assume many different personalities, depending on the role it is asked to play. Wood in fine furniture suggests craftsmanship, but in a packing case, cheap utility. Glass in the lens of a camera has associations of precision engineering, but in a beer bottle, that of disposable packaging. Even gold, so often associated with wealth and power, has different associations when used in microcircuits: that of technical functionality.

But wait. The object in Figure 7 has its own somber association. It appears to be made of polished hardwood – the traditional material for such things. If you had to choose one, you would probably not have any particular feelings about this one – it is a more or less typical example. But suppose I told you it was made of *plastic* – would you feel the same? Suddenly it becomes like a bin, a waste basket, inappropriate for its dignified purpose. Materials, it seems, *do* have personality.

Expression through material

Think of wood. It is a natural material with a grain that has a surface texture, pattern, color and feel that other materials do not have. It is tactile – it is perceived as warmer than many other materials, and seemingly softer. It is associated with characteristic sounds and smells. It has a tradition; it carries associations of craftsmanship. No two pieces are exactly the same; the wood-worker selects the piece on which he will work. Wood enhances value: the interior of cheap cars is plastic, that of expensive ones is burr-walnut and calves leather. And it ages well, acquiring additional character with time; objects made of wood are valued more highly when they are old than when they are new. There is more to this than just aesthetics; there are the makings of a personality, to be brought out by the designer, certainly, but there nonetheless.

Figure 7. A coffin. Wood is perceived to be appropriate for its sombre, ceremonial function, plastic inappropriate.

And metals…Metals are cold, clean, precise. They ring when struck. They reflect light – particularly when polished. They are accepted and trusted: machined metal looks strong; its very nature suggests it has been *engineered*. They are associated with robustness, reliability, and permanence. The strength of metals allows slender structures – the cathedral-like space of railway stations or the span of bridges. They can be worked into flowing forms like intricate lace or cast into solid shapes with elaborate, complex detail. The history of man and of metals is intertwined – the titles "bronze age" and "iron age" tell you how important these metals were – and their qualities are so sharply defined that that they have become ways of describing human qualities – an iron will, a silvery voice, a golden touch, a leaden look. And, like wood, metals can age well, acquiring a patina that makes them more attractive than when newly polished – think of the bronze of sculptures, the pewter of mugs, the lead of roofs.

Ceramics and glass? They have an exceptionally long tradition – think of Greek pottery and Roman glass. They accept almost any color; this and their total resistance to scratching, abrasion, discoloration and corrosion gives them a certain immortality, threatened only by their brittleness. They are – or were – the materials of great craft-based industries: the glass of Venice, the porcelain of Meissen, the pottery of Wedgwood, valued at certain times more highly than silver. But at the same time they can be robust and functional – think of beer bottles. The transparency of glass gives it an ephemeral quality – sometimes you see it, sometimes you don't. It interacts with light, transmitting it, refracting it, reflecting it. And ceramics today have additional associations – those of advanced technology: kitchen stove-tops, high pressure/high temperature valves, space shuttle tiles…materials for extreme conditions.

And finally polymers. "A cheap, plastic imitation", it used to be said – and that is a hard reputation to live down. It derives from the early use of plastics to simulate the color and gloss of Japanese handmade pottery, much valued in Europe. Commodity polymers *are* cheap. They are easily colored and molded (that is why they are called 'plastic'), making imitation easy. Unlike ceramics, their gloss is easily scratched, and their colors fade – they do not age gracefully. You can see where the reputation came from. But is it justified? No other class of material can take on as many characters as polymers: colored, they look like ceramics; printed, they can look like wood or textile; metalized, they look exactly like metal. They can be as transparent as glass or as opaque as lead, as flexible as rubber or as stiff – when reinforced – as aluminum. Plastics emulate precious stones in jewelry, glass in drinking glasses and glazing, wood in counter tops, velvet and fur in clothing, even grass. But despite this chameleon-like behavior they *do* have a certain personality: they feel warm – much warmer than metal or glass. They are adaptable – that is part of their special character; and they lend themselves, particularly, to brightly colored, light-hearted, even humorous, design. But their very cheapness creates problems as well as benefits: our streets, countryside and rivers are littered with discarded plastic bags and packaging that decay only very slowly

The ways in which material, processes, usability and personality combine to create a product character tuned to the context or "mood" are best illustrated by examples. Figure 8 shows the first. The lamp on the left is designed for the office. It is angular, functional, creamy-grey, and it is heavy. Its form and color echo those of computer consoles and keyboards, creating associations of contemporary office technology. Its form and weight transmit the ideas of stability, robustness, efficiency and fitness for task – but for tasks in the workplace, not in the bedroom. Materials and processes have been chosen to reinforce these associations and perceptions. The enamelled frame is pressed and folded sheet steel, the base-weight is cast iron, the reflector is stainless steel set in a high-impact ABS enclosure.

Figure 8. Lamps. Both have the same technical rating, but differ completely in their personalities. Materials, processes, form, weight and color have all contributed to the personality.

Figure 9. Consumer electronics. The products on the left are aimed at a different consumer group than those on the right. The personalities of each (meaning the combination of aesthetics, associations and perceptions) have been constructed to appeal to the target group. Materials play a central role here in creating personality. (Figure courtesy of Bang & Olufsen)

The lamp on the right of Figure 8 has the same technical rating of that on the left; the same functionality and usability. But there the resemblance ends. This product is not designed for the busy executive but for children (and adults that still enjoy being children), to be used the playroom or bedroom. It has a contoured form, contrasting translucent colors, and it is very light. It is made of colored acrylic in translucent and opaque grades, so that the outside of the lamp glows like a neon sign when it is lit. Its form is partly derived from nature, partly from cartoons and comic strips, giving it a light-hearted character. I perceive it as playful, funny, cheerful and clever – but also as eccentric and easily damaged. You may perceive it in other ways – perception is a personal thing; it depends where you are coming from. Skilled designers manipulate perception to appeal to the user-group they wish to attract.

Figure 9 shows a second example. Here are two contrasting ways of presenting electronic home entertainment systems. On the left: a music center aimed at successful professionals with disposable income, comfortable with (or addicted to) advanced technology, for whom only the best is good enough. The linear form, the use of primitives (rectangles, circles, cylinders, cones) and the matt silver and black proclaim that this product has not just been *made*, it has been *Designed* (big *D).* The formal geometry and finish suggest precision instruments, telescopes, electron microscopes and the shapes resemble those of organ pipes (hence associations of music, of culture). The perception is that of quality cutting-edge technology, a symbol of discriminating taste. The form has much to do with these associations and perceptions, but so too do the materials: brushed aluminum, stainless steel and black enamel – these are not materials you choose for a cuddly toy.

On the right: electronics presented in another way. This is a company that has retained market share, even increased it, by *not* changing, at least as far as appearance is concerned (I had one 40 years ago that looked exactly like this). The context? Clearly, the home, perhaps aimed at consumers who are uncomfortable with modern technology (though the electronics in these radios is modern enough), or who simply feel that it clashes with the home environment. Each radio has a simple form, it is pastel colored, it is soft and warm to touch. It is the materials that make the difference: these products are available in suede or leather in at least 6 colors. The combination of form and material create associations of comfortable furniture, leather purses and handbags, (hence, luxury, comfort, style), the past (hence, stability) and perceptions of solid craftsmanship, reliability, retro-appeal, traditional but durable design.

So there is a character hidden in a material even before it has been made into an recognizable form – a sort of embedded personality, a shy one, not always obvious, easily concealed or disguised, but one that, when appropriately manipulated, imparts its qualities to the design. It is for this reason that certain materials are so closely linked to certain design styles (Figure 10). A *style* is shorthand for a manner of design with a shared set of aesthetics, associations and perceptions.

The Early Industrial style (1800 – 1890)[5] embraced the technologies of the industrial revolution, using cast iron, and steel, often elaborately decorated to give it a historical façade. The Arts and Crafts movement (1860 – 1910) rejected this, choosing instead natural materials and fabrics to create products with the character of traditional hand-

[5] The dates are, of course, approximate. Design styles do not switch on an off on specific dates, they emerge as a development of, or reaction to, earlier styles with which they often co-exist, and they merge into the styles that follow.

Figure 10. Design styles and the materials they exploited to create product personality. (Image Bauhaus chair courtesy of Steelform; image of Dyson cleaner courtesy of Dyson.co.uk.)

crafted quality. Art Nouveau (1890 – 1918), by contrast, exploited the fluid shapes and durability made possible by wrought iron and cast bronze, the warmth and textures of hard wood and the transparency of glass to create products of flowing, organic character. The Art Deco movement (1918 – 1935) extended the range of materials to include for the first time plastics (Bakelite and Catalin) allowing production both of luxury products for the rich and also mass-produced products for a wider market. The simplicity and explicit character of Bauhaus designs (1919 – 1933) is most clearly expressed by the use of chromed steel tubing, glass and molded plywood. Plastics first reach maturity in product design in the cheeky iconoclastic character of the Pop-Art style (1940 – 1960). Since then the range of materials has continued to increase, but their role in helping to mould product character remains.

Expression through process

Creating form is one of the earliest forms of human expression: carved stone and molded pottery figures, beaten ornaments and cast jewelry pre-date any documented ability to write or draw, exemplifying shaping as a channel for self-expression. The processes used in product design today are evolutionary descendants of these prehistorical antecedents. Figures 8 & 9 showed ways in which form and materials have been chosen and shaped to create the personalities of products, each designed for a particular user-group.

Joining, too, can be used expressively. It reaches an art form in book binding, in the dovetailing of woods, and in the decorative seaming of garments. In product design, too, joints can be used as a mode of expression. The fuel cap of a contemporary performance car shown in Figure 11, left, machined from stainless steel and attached by eight Allen screws, is an expression of precision technology that implies the same about the rest of

Figure 11. Joining as a means of expression. The precision-machined stainless steel fuel cap, left, attached by eight Allen screws (it carries no significant loads) projects a sense of the precise engineering of the entire vehicle. Right: the Aquanautic super-pro deep-div resists the harshest treatment.

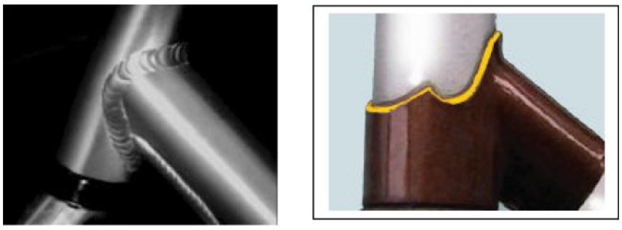

Figure 12. The bold, prominent weld of the mountain bike on the left carries an aura of robustness, implying the same about the bike itself. That of a town bike, on the right, suggests decorated delicacy.

the car. The watch on the right, intended for sports-diving, uses the same motif to suggest the robustness quality. The prominent welds on the frame of the mountain bike of Figure 12, left, suggest a stronger, tougher product than does the brazed sleeve joints of the town bike on the right.

Surface finish, too, carries messages. The late 20th and early 21st Century is addicted to flawless perfection[6]. Makers of earth moving-equipment have long known that – if their products are to sell – they must deliver them with a class A finish, the same as that required for a passenger car. And this, despite the fact that the first thing a purchaser does is to lower the thing into a hole full of mud to start digging. It is because the perfection of the finish expresses the perfection of the equipment as a whole; a poor finish implies, however mistakenly, poor quality throughout. Look again at the brushed aluminum and dyed leather of the products of Figure 9 and the way they create associations, the one of technical perfection the other of luxury handbags and luggage.

So surface processes can also serve to attract. It can suggest, sometimes with the aim of deceiving; metalized plastic is an example. It can surprise, adding novelty – a jug kettle with a thermochromic surface coating that changes color as the water heats up. It can entertain: holographic surface films can suggest something lurking inside the article to which it is applied. It can add function: non-slip coatings add an ergonomic function, contrasting colors identify different function-elements. And it can simply dress up the same product in different clothes, each to fit a different context (Figure 13).

Figure 13. Fuji Nexia Q1s: the same performer presented in four different costumes. Clockwize from top left: blush, beach, cool, tech.

7. Using old materials in new ways

You don't need new materials to create exciting new designs. Innovation often means using old materials in new ways. Here are two examples.

Concrete. Think, for a moment, about concrete. How do you perceive it? The pervasive view is that of a cold, gray material that is sterile, bland, utilitarian; the epitome of bare functionality. Its traditional and widespread use is in construction, from which most of its associations arise. It is the material of sewage pipes, of war-time pill-boxes and bomb-proof bunkers, of the "brutalist" architecture of public buildings and shopping malls of the 1960s. Not a personality you would welcome into your living room.

But think now of this. Concrete is a ceramic. It is hard and brittle, yet, before it sets, it can be cast (like a metal) or molded (like a polymer). Its texture and properties are easily adapted by varying the choice and the relative mix of cement and filler – fine sand, or gravel, or coarse aggregate. It is readily available, can be colored, and it is very cheap. If it can be shaped so easily, could it not be used in more imaginative ways, ways that created new perceptions, acceptable in a domestic setting? The challenge is not just to find new uses, but to do so in ways that escape its present associations, allowing it to be perceived in new ways.

[6] A mistake. Surface perfection is violated by the slightest defect – it has no hope of ageing gracefully. Better, to make visual imperfection a part of the personality of the product – something that gives it individuality. It is this, in part, that makes natural materials – wood, leather and stone – attractive.

Figure 14. The organic spiral shape of the base of this glass-topped table is made of reinforced concrete. (Figure courtesy of Jamie Cobb and Tom Vaughan, and the British Cement Associations, 2003).

Figure 15. The use of wood in a precision instrument such as this is unexpected but arresting, creating the perception that much thought and craftsmanship has gone into the design (Figure courtesy of ALPA of Switzerland).

Figure 14 shows a glass-topped table with a flowing, sensuously curved tubular base made by casting concrete in a PVC tube wrapped round a cylindrical former. The free-standing organic shape escapes the usual perception of concrete as a sterile, bland material. This is one, among many, submissions to the British Cement Association Design Competition of 2003. They include concrete furniture, table lights and jewelry – all examples of what can be done by thinking of a material in a new way.

Wood. Wood – as we have said – is a material of furniture, of musical instruments. But it not something you would expect to find in advanced scientific equipment or precision instrument. Yet the designer of the camera shown in Figure 14 has chosen wood as part of what is a professional-level piece of photographic kit. The result is eye-catching; it sets the camera apart from the large number of high-level cameras now on the market. Because of the variability of wood, no two instruments are completely identical. Its presence diminishes the hostility associated with mechanical and electronic equipment, makes it a little more human and – as in the polished wood dash and paneling of an expensive car – it adds an association of handcraftsmanship.

8. Summary and Conclusions

What do we learn? The element of satisfaction is central to contemporary product design. It is achieved through an integration of good technical design to provide functionality, proper consideration of the needs of the user in the design of the interface, and imaginative industrial design to create a product that will appeal to the consumers at whom it is aimed.

Materials play a central role in this. Functionality is dependant on the choice of proper material and process to meet the technical requirements of the design safely and economically. Usability depends on the visual and tactile properties of materials to convey information and respond to user actions. Above all, the aesthetics, associations and perceptions of the product are strongly influenced by the choice of the material and its processing, imbuing the product with a personality that, to a greater or lesser extent, reflects that of the material itself.

Consumers look for more than functionality in the products they purchase. In the sophisticated market places of developed nations, the "consumer durable" is a thing of the past. The challenge for the designer no longer lies in meeting the functional requirements alone, but in doing so in a way that also satisfies the aesthetic and emotional needs. The product must carry the image and convey the meaning that the consumer seeks: timeless elegance, perhaps; or racy newness. One Japanese manufacturer goes so far as to say: "*Desire* replaces *need* as the engine of design".

Not everyone, perhaps, would wish to accept that. So we end with simpler words – the same ones with which we started. Good design works. Excellent design also gives pleasure. The imaginative use of materials provides it.

9. Further reading

Ashby, M.F. and Johnson K. (2010) "Materials and Design – the Art and Science of Materials Selection in Product Design", 2nd edition, Butterworth Heinemann, Oxford, UK. ISBN 978-1-85617-497-8. (*A book that develops further the ideas outlined in this paper.*)

Autodesk (2011) "Imagine, Design Create – how Designers, Engineers and Architects are changing our world", Editor Wujec, T., Melcher Media, NY. ISBN 978-1-59591-067-7.*(An exploration of the ways that the creative tools of design are changing, and the things they can do.)*

Clark, P. and Freeman, J. (2000) "Design, a Crash Course", The Ivy Press Ltd, Watson-Guptil Publications,

BPI Communications Inc. New York, NY, USA. ISBN 0-8230-0983-1. *(An entertainingly-written scoot through the history of product design from 5000BC to the present day.)*

Dormer, P. (1993) "Design since 1945", Thames and Hudson, London UK. ISBN 0-500-20269-9. *(A well illustrated and inexpensive paperback documenting the influence of industrial design in furniture, appliances and textiles – a history of contemporary design that complements the wider-ranging history of Haufe (1998), q.v.)*

Forty, A. (1986) "Objects of Desire – Design in Society since 1750", Thames and Hudson, London, UK. ISBN 0-500-27412-6. (*A refreshing survey of the design history of printed fabrics, domestic products, office equipment and transport system. The book is mercifully free of eulogies about designers, and focuses on what industrial design does, rather than who did it. The black and white illustrations are disappointing, mostly drawn from the late 19th or early 20th centuries, with few examples of contemporary design.*)

Haufe, T. (1998) "Design, a Concise History", Laurence King Publishing, London, UK (originally in German*).* ISBN 1-85669-134-9. *(An inexpensive soft-cover publication. Probably the best introduction to industrial design for students (and anyone else). Concise, comprehensive, clear and with intelligible layout and good, if small, color illustrations.)*

Jordan, P.S. (2000) "Designing Pleasurable Products", Taylor and Francis, London, UK. ISBN 0-748- 40844-4. *(Jordan, Manager of Aesthetic Research and Philips Design, argues that products today must function properly, must be usable, and must also give pleasure. Much of the book is a description of market-research methods for eliciting reactions to products from users.)*

Julier, G. (1993) "Encyclopedia of 20th Century Design and Designers", Thames & Hudson, London, UK. ISBN 0-500-20261-3. *(A brief summary of design history with good pictures and discussions of the evolution of product designs.)*

Manzini, E. (1989) "The Material of Invention", The Design Council, London UK. ISBN 0-85072-247-0 *(Intriguing descriptions of the role of material in design and in inventions. The translation from Italian to English provides interesting – and often inspiring – commentary and vocabulary that is rarely used in traditional writings about materials.)*

McDermott, C. (1999) 'The Product Book' D & AD in association with Rotovison, UK. *(50 essays by respected designers who describe their definition of design, the role of their respective companies and their approach to product design.)*

Norman, D.A. (1988) "The Design of Everyday Things", Doubleday, New York, USA. ISBN 0-385-26774-6*. (A book that provides insight into the design of products with particular emphasis on ergonomics and ease of use.)*

Appendix 1. Creativity aids – a brief survey

Introduction. Tools for creative thinking work by breaking down barriers and forcing new angles of view. To do so, you have to escape from the view of the "product" as it is now, seeking to see it in new ways. There are several ways of doing this, some unstructured, some more systematic.

Brain-storming, mood boards, mind maps. *Brainstorming* relies on the group dynamics that appear when participants express their ideas, however wild, deferring all value judgment until the process is over. Humor plays a role. A joke that works relies on a creative jump, an unexpected outcome, by-passing normal reasoning. It switches the points, so to speak, deflecting thought off its usual rails onto a new track. It is the creativity of a good joke that gives pleasure, makes you laugh. Introducing it creates an environment for creative thinking. To work, brain-storming sessions must be fun and be kept short – experience suggests that one lasting more than 20 minutes ceases to be productive.

Mind-mapping is a sort of personalized brainstorming in which ideas are placed on a page and linked as appropriate; these links are used to stimulate further thinking: "light-weight materials …. wood… cells... porous solids… foams… metal foams… titanium foam…?"

A *mood board* is a visual scrap-book, arranged on a large board placed where the designer will see it easily. It takes of the form of a personalized, project-focused collection of images, objects or material samples, chosen because they have colors, textures, forms and associations that might contribute to the design. Images of products that have features like those sought by the designer and images of the environment or context in which the product will be used act as prompts for creative thinking. Many designers confronted by the challenge of creating product-character, to first buy examples of other product that have a surface finish, an association, a style that might be exploited in a fresh way. The mood board acts as a trigger for ideas both about choice of materials and about their juxtaposition.

More formal methods: Inductive reasoning and analogy. Inductive reasoning (Kolodner 1993) has its foundations in previous experience. The starting point is a set of design requirements expressed as *problem features*. A match is then sought between these and the problem features of other solved problems, allowing new, potential solutions ("hypotheses") to be synthesized and tested.

A central feature here is the library of previously-solved problems or "cases" – a "case" is a problem, an analysis of its features, a solution and an assessment of the degree of success of this solution. The challenge in assembling the library is that of appropriate indexing – attaching to each case a set of index-words that capture its features. If the index-words are too specific the case is only retrieved if an exact match is found; if too abstract, they become meaningless to anyone but the person who did the indexing. Consider, as an example, the "case" of the redesign of an electrical plug to make it easy to grip, insert and pull-out by an elderly person with weak hands. Indexing by "electrical plug" is specific; the case will be retrieved only if the "plug" is specified. Indexing under "design for the elderly" is more abstract, and more useful. Plugs are not the only thing elderly people find hard to use. Cutlery, taps, walking sticks and many other products are adapted for elderly people. Examining their shapes and materials and processes used to make them may suggest new solutions for the plug.

Software shells exist that provide the functionality to create case-based systems, but, for any given domain of problems, the library has to be populated.

TRIZ and the 9-Windows Method. TRIZ (standing for Theory of Innovative Problem Solving – but in Russian) is the brainchild of the Russian patent expert Genrich Altschuller. He distilled from his study of patents 40 principles and 8 patterns of evolution for creating engineered products. There are disciples of his methods and there are non-believers. Be that as it may, one technique, the 9-windows method claimed as part of the TRIZ tool-set, finds wide use as stimulus for creative thinking. The obstacle to innovation is, often, a preoccupation of the system as it is *now.*

Figure A1 The 9-window method applied to the redesign of an electric kettle

The 9-window method forces a view of the system on different conceptual scales and at times other than the present. It takes the form of a 3 x 3 matrix of initially empty boxes[7]. The system for which creative thinking is sought is put in the central box – it can be described in words or recorded as a schematic or an image. It represents the system as it is now.

The horizontal axis is time past, present and future (it helps to make this quantitative, thus: 1 year ago, now, one year from now; or 50 years ago, now, and 50 years hence). The vertical axis is that of scale: subsystem (the components of the system) in the bottom row, above this the system scale, and above that the super-system of which the system is a part or in which it must operate. There are several ways to use the past, present and future columns. One is to ask: what are the antecedents of the system (subsystems, super-system), and what, ideally, would you like these to become in the future? Another is to ask: if you could have designed the system differently (in the past) what would you have done? What can I do now to enhance the system? What – given time – should I aim for in the future? A third is to ask: where are we now? Where have we come from over the last 5 years? Where do we wish to be 5 years from now? The idea is encourage a view of the problem from in front and behind, and from above and below, allowing a freedom to zoom in and out. The method is sufficiently useful that an example is justified

Figure A1 shows the 9-windows. The product to be re-designed is the electric kettle in the middle box of the "Today" column. The kettle has long history. It evolved from kettles that looked like that in the middle box of "Yesterday". The aim is design a kettle for "Tomorrow".

Think first of the super-system in which the kettle will be used. The top row suggest the size, color, décor and equipment of kitchens from yesterday and today, and a guess at how these might look tomorrow – increasingly hi-tech but increasingly small. The re-design must accommodate this evolution – it is the environment in which the kettle-users will live. The ascetic, rectilinear design of the future kitchen suggests a compact, cuboid kettle with similar minimalist aesthetics.

[7] Some advocates use two 9-window sets, one to analyze the problem, the other to explore solutions.

The bottom row reports aspects of the technology of kettles that have changed radically, notably choice of materials and ways of introducing heat. What opportunities are presented by new materials and heat-transfer methods? Advanced ceramics and glasses are now used in many demanding applications. They have the merit of extreme durably. Heat-transfer technology has change greatly. It is well to remember, too, the emerging global priorities, globally, are those of conserving energy, mineral resources and water, and the prerequisites of environmental and economic responsibility. How can emerging technology be used to adapt the new kettle to meet these expectations?

The 9-window analysis broadens the horizons of thinking. It gives doors out of the box in which we started – that of a single focus on today's kettle.

Analyzing innovation. Products evolve through innovation. It takes more than one form, as suggested by the matrix of 2.2, mysteriously known as a transilience map[8]. The cell-headings don't explain themselves well, but we will use them because they are those used by market analysts. *Regular innovation* is incremental improvement of performance, reliability or economy, built on established technical and production competence, targeting existing markets and customers. *Niche creation* exploits existing technology to capture new markets by adapting or developing it to increase its appeal to a particular user-group. *Revolutionary innovations* displace established technical and production methods, but allow a manufacturer to sell to their existing markets and customers (Digital broadcasting replacing analog transmission, for example). Lastly *architectural innovation* involves new technology that disrupts both existing manufacturing competency and existing market and customer linkages (the much-cited example is that of the automobile replacing the horse-drawn carriage).

The first example below illustrates the four categories of innovation.

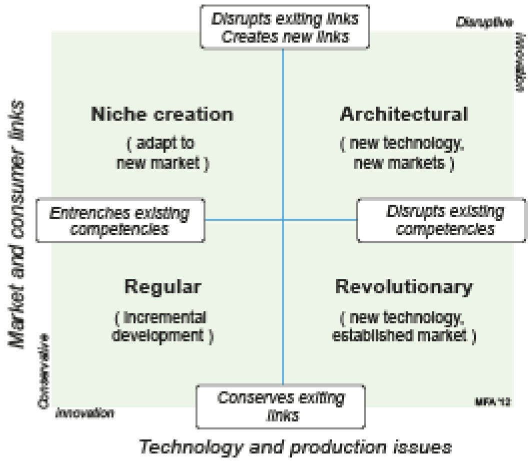

Figure A2 *The transilience map showing the four extreme types of innovation. The upper right is most disruptive but also has the greatest* potential for profit.

In-house techniques and tools

Design enterprises like IDEO, ARUP or Porsche Design develop their own in-house strategies for innovation. Those of which I am aware are not specifically targeted at environmental design, more at innovation in general. The IDEO method (Jacoby and Rodriguez, 2007 shown in Figure A3) is an example. It is based around a "Ways to grow" matrix with three sectors: "extend", "adapt" and "create" that has much in common with Figure A2. "Extend" and "adapt" relate to evolutionary change, "create" relates to revolutionary change.

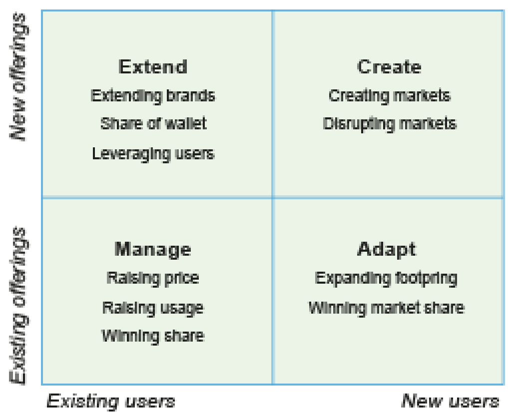

Figure A3. The IDEO innovation matrix.

[8] See Abernathy and Clark, 1985

Further reading: creativity aids

Altshuller, H. (1994) "The Art of Inventing (And Suddenly the Inventor Appeared)" *tr*anslated by Lev Shulyak. Worcester, MA: Technical Innovation Center. ISBN 0-9640740-1-X

Jacoby, R. and Rodriguez, D. (2007) "Innovation, growth and getting to where you want to go" Design Management Review, Winter 2007.

Johnson, S. (2010) "Where do good ideas come from? The natural history of innovation" Penguin Books, London, UK. ISBN978-1-846-14051-8. *(A remarkable survey of innovation across a wide spectrum of industry sectors.)*

Kelly,T. and Littman, J. (2001) "The art of innovation", Doubleday, NY. ISBN 0-385-49984-1. *(An exposition by the founder of IDEO of the philosophy and methods of his design company.)*

Kolodner J.L. (1993), *Case based reasoning*, Morgan Kaufmann Pub. San Mateo, CA. ISBN 1-55860-237-2.

Rantanen, K. and Domb, E. (2002) "Simplified TRIZ: new problem-solving applications for engineers and manufacturing specialists", St. Lucie Press, CRC Press, USA. ISBN 1-57444-323-2. *(The authors, proponents of the TRIZ method for creating thinking, introduce its used in industry.)*

Savransky, S.D. (2000) "Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving", CRC Press, USA

Technology Futures Analysis Methods Working Group (2004) "Technology futures analysis: toward integration of the field and new methods" Technological Forecasting & Social Change 71 pp. 287–303. *(A comprehensive survey analyzing future technology and its consequences , including technology intelligence, forecasting, road-mapping, assessment, and foresight.*

Appendix 2.: 67 widely used engineering materials, with short names

Metals	**Polymers and elastomers**
Aluminium alloys: Al-alloys	Acrylonitrile butadiene styrene: ABS
Cast irons	Butyl Rubber: BR
Copper alloys: Cu-alloys	Cellulose polymers: CA
Lead alloys: Pb-alloys	Epoxies
Magnesium alloys: Mg-alloys	Ethyl vinyl acetate: EVA
Nickel alloys: Ni-alloys	IonomerL I
Steel – carbon: Steel	Isoprene: IR
Steel – low alloy: LA steel	Natural Rubber: NR
Steel – stainless: SS	Phenolics
Titanium alloys: Ti- alloys	Polyamides: Nylons, PA
Tungsten alloys: W-alloys	Polycarbonate: PC
Zinc-alloys: Zn-alloys	Polychloroprene: Neoprene, CR
	Polyester
Ceramics and Glasses	Polyetheretherkeytone: PEEK
Alumina: Al_2O_3	Polyethylene terephalate: PET or PETE
Aluminium Nitride: AlM	Polyethylene: PE
Boron Carbide: BC	Polymethyl methacrylate: Acrylic, PMMA
Borosilicate glass	Polyoxymethylene: Acetal, POM
Brick	Polypropylene: PP
Concrete	Polystyrene: PS
Glass Ceramic	Polytetrafluroethylene: PTFE
Silica glass: SiO_2	Polyurethane: PUR
Silicon	Polyvinylchloride: PVC
Silicon Carbide: SiC	Silicone elastomers: SiL
Silicon Nitride: Si_3N_4	
Sode-Lime glass	**Composite**
Stone	Aluminium/Silicon Carbide Composite: AlSiC
Tungsten Carbides: WC	Carbon fibre reinforced polymers: CFRP
	Glass fibre reinforced polymers: GFRP
Natural Materials	
Babboo	**Foams**
Cork	Felixible Polymer Foam
Leather	Rigid Polymer Foam
Wood	