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The CES EduPack Products, Materials and Processes Database - a White Paper

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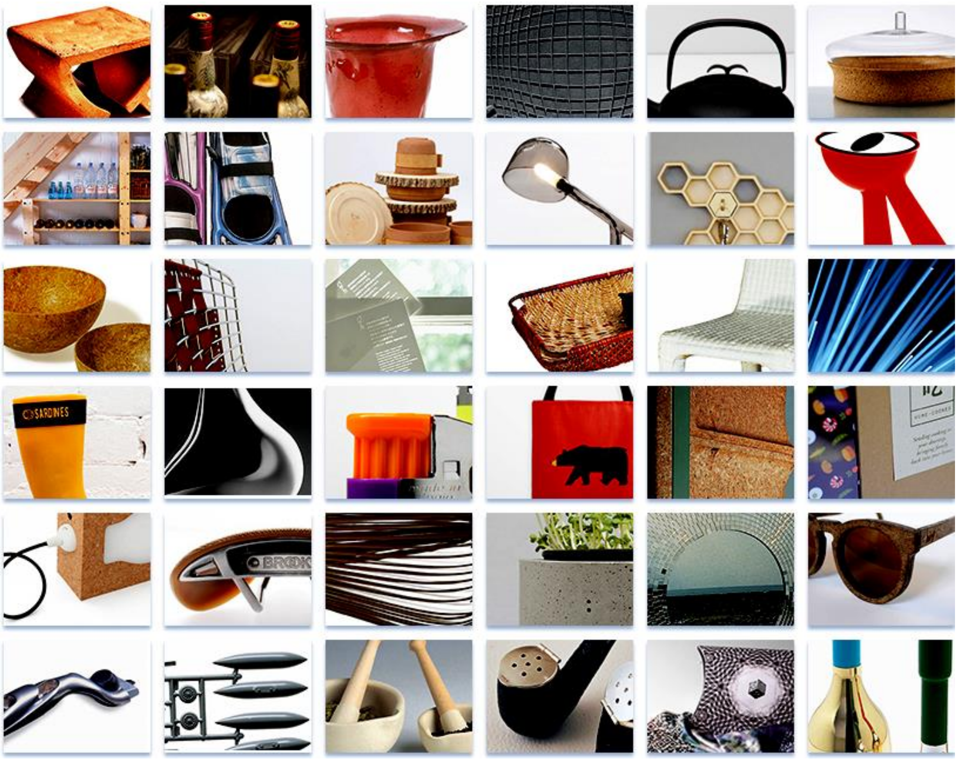

Abstract

Well-designed products provide both function and satisfaction. Materials and processes play a key role in achieving both. This White Paper describes a computer-based platform for design students (be they engineers or industrial designers) to explore products and the materials and processes used to make them. It is product-centered, but unlike most other such databases, it also contains high quality data for materials and processes, and profiles of designers and manufacturers. To build it we contacted over 200 designers for help in populating the database with products that use materials in innovative ways and drew on Granta Design's extensive databanks to populate the materials and process records. The paper describes its use, illustrated by case studies.

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The CES EduPack Products, Materials and Processes Database

- a white paper

1. Introduction

Consumers buy products because they need and like them. To succeed, a product must function properly, but that is not enough: it must be easy and convenient to use, and it must have a personality that satisfies, inspires, and gives delight. This last aspect, "product personality", depends strongly on the industrial design of a product. When many technically equivalent products compete, market share is won (or lost) through visual and tactile appeal, emotional connections and associations, the way the product is perceived, and the experiences it enables. Consumers now expect delight, as well as function, in everything they purchase. Good products work. Excellent products also give pleasure.

The CES EduPack Products, Materials and Processes Database (the PMPDb) and White Paper are resources to support the teaching of Design in a wide range of contexts. A number of Industrial Design websites offer images and descriptions of products, presented in a way that appeals to product designers; some are listed in Section 5 of this White Paper. Other resources present data for materials and their properties in a format intended for engineering design; the standard Edition of CES EduPack is an example. None successfully bridge the gap between these two views.

That is what the CES EduPack PMPDb aims to do. It can be viewed and interacted with using any 2016 edition of CES EduPack[1]. It is product-centered, initially offering a portfolio of product thumbnails from which the user accesses product records with more detailed images, descriptions, and tag words for the chosen product. Each product is linked to information about its designer, its manufacturer, and the materials and processes by which it was made. The bridge between engineering and industrial design is made by offering a double-portrait of each material: the first presenting the "engineering" view of its properties, the other presenting the "designer" view with measures of tactile, visual, acoustic, and other sensuous properties. Both views include the environmental properties, providing a window into eco-design.

It is hoped that this double-portrait view of materials will inspire and engage students, drawing them in through familiar products, and enable a productive dialogue between the two communities so that products can be created that are both functional and aesthetically pleasing.

The copyrights of the images contained in this database (as listed in the Acknowledgements) have been granted for educational purposes and cannot be reused commercially without confirmation from relevant designers, studios, manufacturers, photographers, or any individual or organization that shares rights in the images.

[1] CES EduPack (2016), Granta Design, Cambridge (www.grantadesign.com/education)

2. Database Structure

Figure 1 shows the structure of the database. It contains five linked, so-called, data-tables. At the center is a data-table for Products, chosen because they are innovative or are in some sense design classics. There are four further data-tables for Materials, Processes, Designers, and Manufacturers, allowing records for a product to be linked to records for the materials of which it is made, the processes used to make it, and the Designer and Manufacturer that created it.

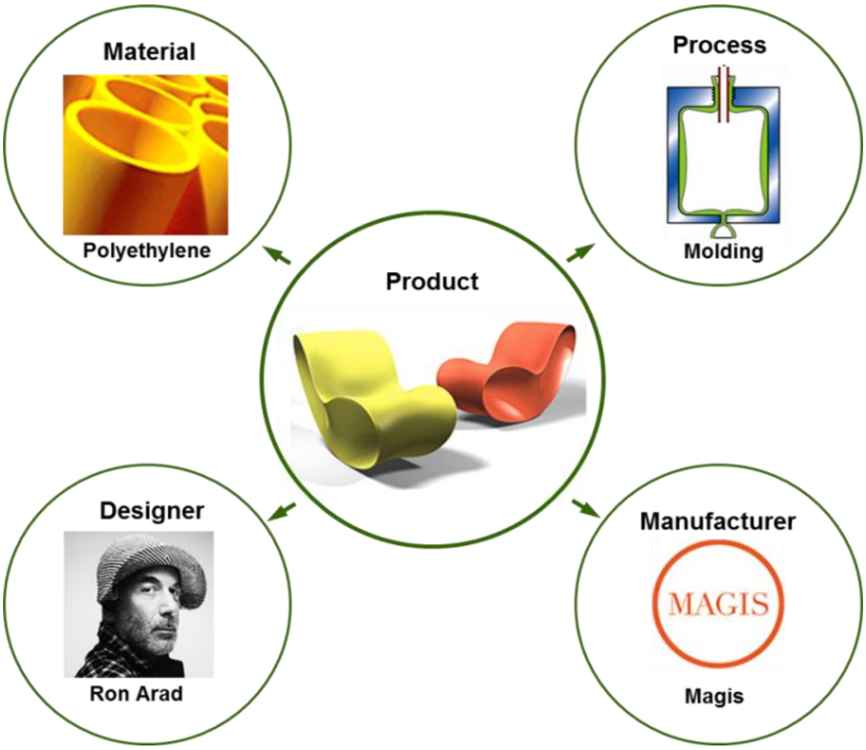


Figure 1. Database schematic showing the links between the new and old data-tables within the database

The content of the data-tables are data records that are organized in a tree structure, described in the next page.

The Homepage. *The image on the cover page of this White Paper is a screen shot of part of the Homepage interface. Thumbnails link to the records in the database. The default presentation is to show all records. Subsets are selected from the categories listed across the top of the home page (detailed in the table below).*

ALL	*Interior*	*Packaging*	*Consumer*	*Technology and Healthcare*	*Leisure*	*Fashion*

Table 1. Product subsets

3. Database content

The Products data-table

The central feature of this database is the Products data-table. It contains records for products, most of which were selected by browsing online design magazines, blogs, online libraries provided by educational institutions, and popular industrial design companies. Products were chosen because of their excellence in design and inventiveness in the use of materials and manufacturing processes. Each record (Figure 2) contains one or more images, a description (provided, where possible, by the designer or manufacturer), background information, and tags or keywords. Copyright permission for the use of images and for product and personal information was collected from the designer or manufacturer.

Beolit 12 by Cecilie Manz for Bang&Olufsen

Overview

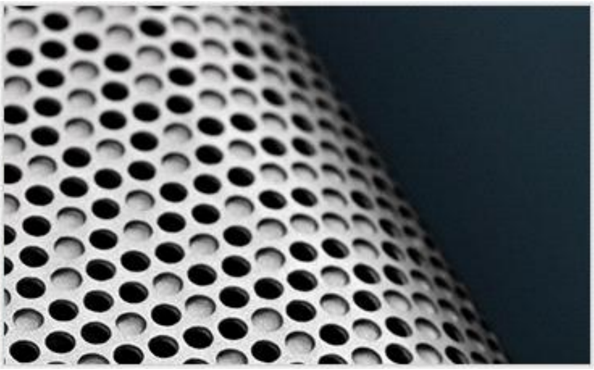



Image Credit Courtesy of B&O Play

Materials Used	Plastic housing, aluminum, rubber, leather, electronics
Designer	Cecilie Manz
Manufacturer	B&O PLAY, Bang&Olufsen Group

Detailed Information

Full Description

A small but mighty stereo speaker, Beolit 12 is designed to be sleek and functional at the same time. Attentions are especially paid to the unique aesthetics and ergonomics of the speaker: the design of the leather strap ensures that the speaker won't wobble when carried around, and the rounded corners enhance the safety of the speaker.

Year of First Production	2013
Dimensions	23 x 18.8 x 13.3cm
Production Scale	Batch

Tags

sound, communication, consumer electronics, technology, electrical, home, household, modern

Figure 2. Part of a record from the Products data-table

The Designers data-table

The Designers data-table contains records of designers whose products are used in the database. Figure 3 shows a typical record. It contains a headshot, basic information and contact details, and an outline of the designer's history, provided wherever possible by the designer themselves. This gives users of the database insight into possible cultural, educational, and historical influences in the products.

Manz, Cecilie

Image Credit	Courtesy of Bang & Olufsen
Studio	Cecilie Manz Studio

Description

Cecilie Manz designs furniture, glass, lamps and related products, mainly for the home. In addition to her work with industrial products, her experimental prototypes and more sculptural one-offs make up an important part of her work and approach.

"I view all my works as fragments of one big, ongoing story where the projects are often linked or related in terms of their idea, materials and aesthetics, across time and function"

-- Cecilie Manz's Website

Education	The Royal Danish Academy of Fine Arts - The School of Design, 1997
Website	http://www.ceciliemanz.com/
Email	info@ceciliemanz.com

Figure 3. Part of a record from the Designer data-table

The Manufacturers data-table

The Manufacturers data-table contains records for manufacturers of products that appear in the database. A typical record (Figure 4) lists the manufacturer's name and logo, founding year, location, specialization, and web site.

Skultana

Basic Information

Manufacturer logo

Manufacturer Name	Skultana
Area of Specialization	Brass and silver sterling objects, everyday objects, special occasion products
Founded in	1607

Contact Details

Company HQ Location Company Website http://skultuna.com/

Figure 4. Part of a record from the Manufacturer data-table

The Materials data-table

The Materials data-table is based on the CES EduPack Level 2 MaterialUniverse. Some technical materials, not relevant for product design, have been removed; others (including hardwoods, natural and man-made fibers, terracotta, and porcelain) have been added.

Material records can be viewed in two alternative formats, shown schematically in Figure 5 and as screen-shots in Figure 6. The first, the “engineering” view, starts with images and a description of the materials, followed by the technical properties (modulus, strength, thermal conductivity etc.) in standard engineering units. The second, the “designer” view, starts in the same way but lists the properties as points on a scale of 1 to 10 measuring the qualities listed in Table 2, below.

Warmth	Touch	Pitch
Tone	Flex	Resilience
Scratch resistance	Light but stiff	Light but strong

Table 2. Sensorial properties of materials

The way these are calculated is detailed in Appendix A and in Notes linked to the field names in each record. Figure 7 shows a full record in designer view. Both views include environmental characteristics such as embodied energy and carbon footprint.

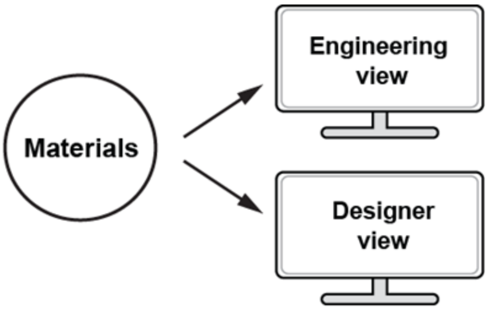


Figure 5. The new layouts available for Materials

The ability to switch between these views is one of the special features of this database. It enables engineers and designers to share the same data but in their preferred viewing format, helping to bridge the gap between the two aspects by enhancing mutual understanding between the disciplines.

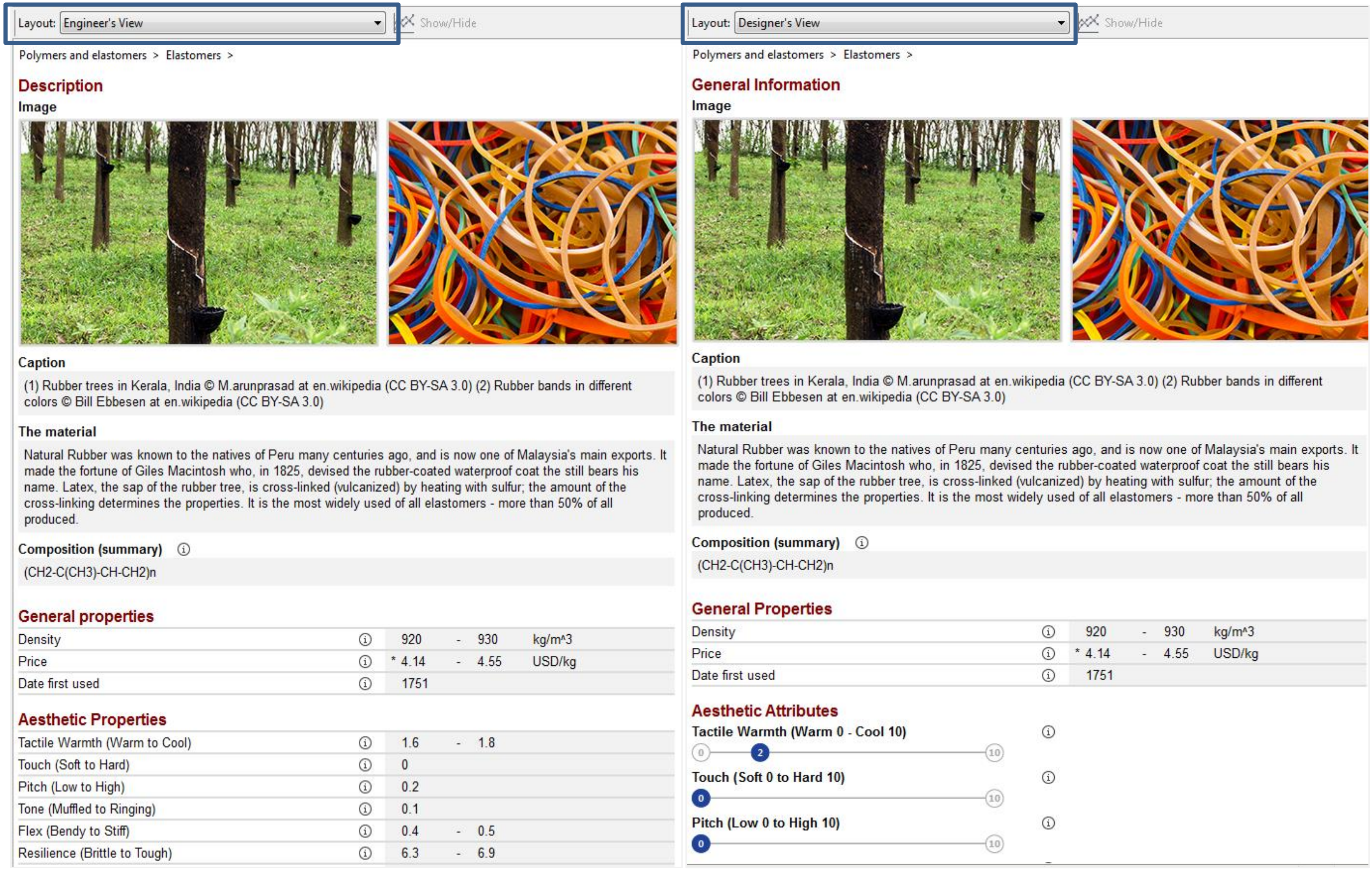


Figure 6. Screenshots to compare the Designer's View (left) to the Engineer's View (right)

Borosilicate glass

The material

Borosilicate glass is soda lime glass with most of the lime replaced by borax, B203. It has a higher melting point than soda lime glass and is harder to work; but it has a lower expansion coefficient and a high resistance to thermal shock, so it is used for glassware and laboratory equipment.

Composition (summary) 74% SiO2/1% Al2O3/15% B2O3/4% Na2O/6% PbO

General Properties

Density	2.2e3	-	2.3e3	kg/m^3
Price	2.82	-	4.69	GBP/kg

Aesthetic Attributes

Warmth - Warm(0) to Cool(10)
0 5 6 10

Touch - Soft(0) to Hard(10)
0 7 10

Pitch - Low(0) to High(10)
0 8 10

Tone - Muffled(0) to Ringing(10)
0 8 9 10

Flex - Bendy(0) to Stiff(10)
0 9 10

Resilience - Brittle(0) to Tough(10)
0 10

Scratch Resistance - Low(0) to High(10)
0 6 10

Light but Stiff - Poor(0) to Good(10)
0 6 10

Light but Strong - Poor(0) to Good(10)
0 5 10

Abundance and Sustainability

Silica, the prime ingredient of glass, is the commonest compound in the earth's crust, though it is harder to find it in a form sufficiently pure to make glass. Nonetheless, the ingredients of glass are ubiquitous, and the material is readily recycled at the end of its life.

CO2 Footprint
0 3 10

Current Recycling Percentage
0 6 7 10

Biodegrade		False			
Embodied energy, primary production	*	27.3	-		
Embodied energy, recycling	*	21.2	-	23.4	MJ/kg
Landfill		True			

Links

Processes

New Products

Figure 7. Example record from the Materials data-table in "designer" view

e) *The Processes data-table*

The Processes data-table is a modified version of the CES EduPack Level 2 ProcessUniverse. Processes not relevant to product design have been removed. Additional handcrafting techniques have been added. Figure 8. A Schematic of a Process Universe record.

Injection molding, thermoplastics

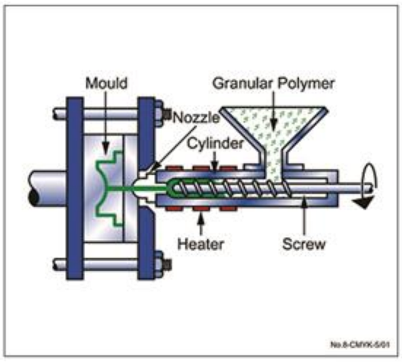


Image Caption

(1) Plastic granules © Granta Design (2) Injester duroplast © Arburg GmbH (3) Lego building blocks © Alexas_Fotos at Pixabay [Public domain]

The process

No other process has changed product design more than INJECTION MOLDING. Injection molded products appear in every sector of product design: consumer products, business, industrial, computers, communication, medical and research products, toys, cosmetic packaging and sports equipment. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected.

Shape

Circular prismatic	✓
Non-circular prismatic	✓
Solid 3-D	✓
Hollow 3-D	✓

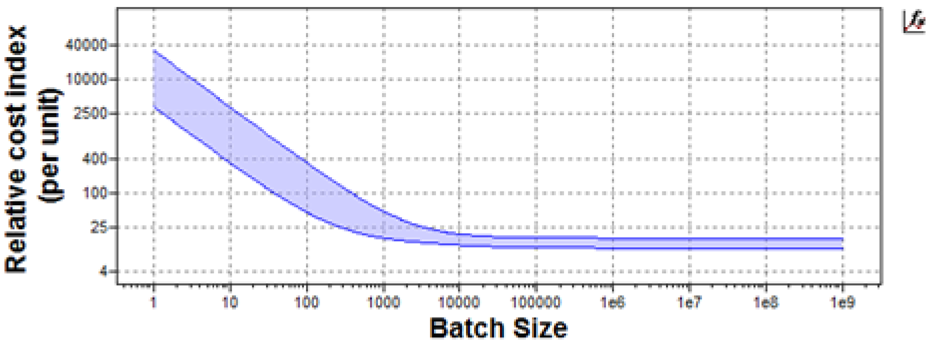
Process characteristics

Primary shaping processes	✓
Discrete	✓

Economic attributes

Relative cost index (per unit)	* 15.8 - 47.2

Parameters: Material Cost = 8USD/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 150USD/hr, Capital Write-off Time = 5yrs, Load Factor = 0.5



Material Cost=8USD/kg, Component Mass=1kg, Overhead Rate=150USD/hr, Capital Write-off Time=5yrs, Load Factor=0.5

The Main Toolbar of the Database

The database allows exploration of products as well as the materials and the manufacturing process used to make them, via three sets of tools.

Browse Mode

The PMPDb opens, by default, in the Products data-table set to the Browse mode. Thumbnail images identifying products, some of which are shown on the cover page of this White Paper, allow browsing of product records. The products are organized in categories as shown in Figure 9.

Material records are organized by material class: Metals, Polymers, Ceramics, and Hybrids. Process records are organized under the headings Shaping, Joining, and Surface Finishing. Designers and Manufacturers are organized alphabetically.

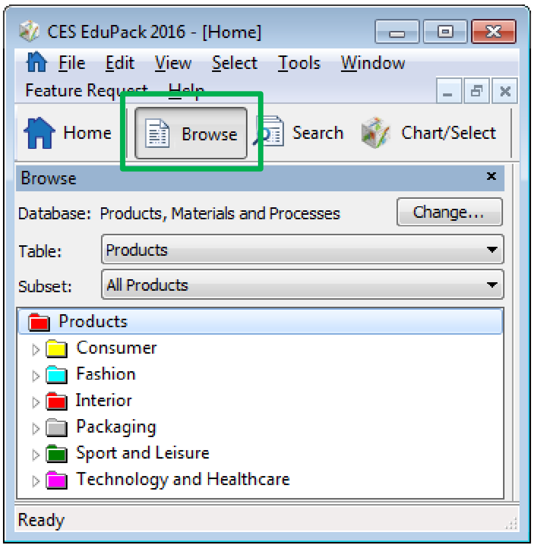
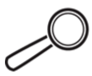


Figure 8. The Browse



Search Mode

The Search mode allows a full-text search of all the records in the database. Entering a search string such as "Chairs" delivers the results shown in Figure 10, from which records relevant to furniture can be opened. The "Tags" in the Products records allow searches on keywords that have been used to identify certain features of a product. Records from the other data-tables also appear because they too contain the string used in the search. Sear operators such as AND can also be used.

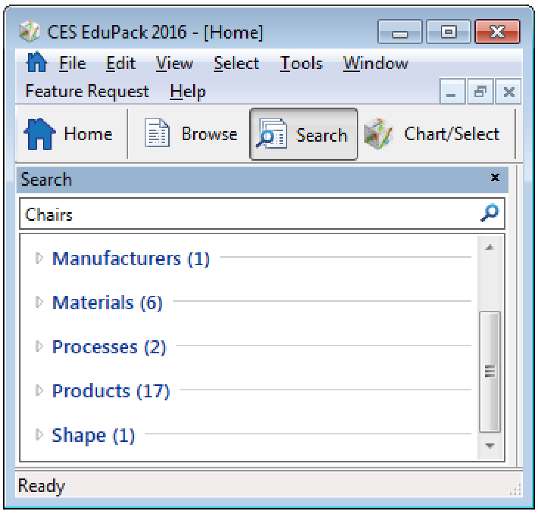


Figure 8. The Search mode

Chart/Select Mode

The CES EduPack system, in which this PMPDb runs, allows selection by several different routes. To deploy them the user must first choose the data-table from which the selection is to be made: e.g., to select Products choose the Products option, as shown in the upper part of Figure 11. This exposes three selection tools: Graph, Limit, and Tree, shown in the lower part of Figure 11. How to use these tools is explained in video tutorials.

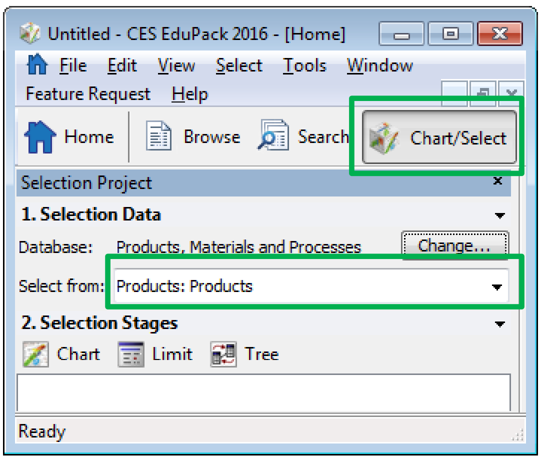


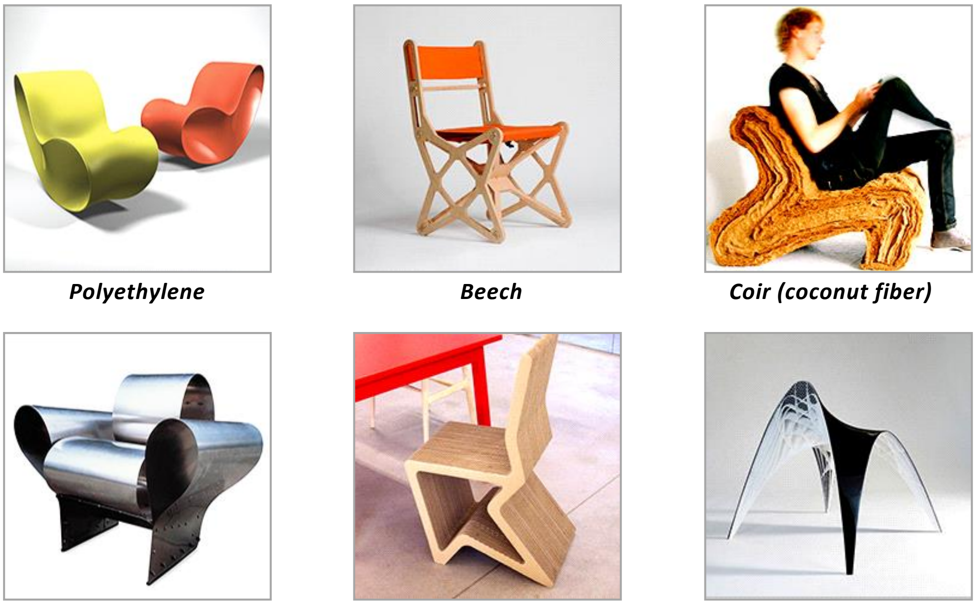
Figure 10. The Chart/Select

4. Case Studies using the database

The database and its tools introduce engineering students to aspects of product design and Design students to aspects of Materials and Processes. Browsing, either with the thumbnails on the home page or through the ***Browse*** facility, allows exploration of products through images; the associated text and links to designer, manufacturer, materials, and processes give background. The ***Search*** facility allows search by product type, by designer name, or by descriptive words contained in the product descriptions in the records. The ***Chart/Select*** facility allows the user to create charts of both the engineering and sensorial properties of materials and to use these to select materials to meet multiple criteria. The following sections illustrate these with examples.

a) How materials are used to create style.

A search on "Chairs" brings up 17 records, each linked to records for the materials of which they are made. The images from six of these are assembled in Figure 12. They nicely illustrate the successful integration of material and style. Plastics allow brightly colored pop-art styles of design. Wood creates a crafted feel. Coir, as used here, creates an eccentric eco-impression; steel a cold, clinical feel, cardboard a warm nursery-friendly impression and carbon fiber a space-age shadow.



Polyethylene ***Beech*** ***Coir (coconut fiber)***

Stainless steel ***Cardboard*** ***Carbon fiber***

Figure 12. Materials and style (1): chairs

A similar search on "Lamps" delivers 10 records, of which Figure 13 shows six. Here the material has been chosen to contribute to the visual and tactile style of the product, using wood and cork for warmth and reassurance, ceramic and glass to convey clinical functionality and steel to suggest modernity and delicacy.


Bamboo


Ceramic


Glass


Cork


Hardwood


Steel

Figure 13. Materials and style (2): lamps

b) *New materials enable design innovation.*

A search on “Bicycle OR Bike” (an example of a more refined search to allow for differing terminology or spelling) produces 10 records. Images from 6 of these, ordered by the year of first production, are shown in Figure 14. In each case an advance in materials technology has enabled an advance in bike design. In 1860 designers had to rely on wrought iron and wood shaping technologies that had been developed for wagons and carts. By 1900 steel tubing was widely available, stimulating the A-frame configuration that persisted over the following 120 years.

Steel is heavy. Seeking to reduce weight designers in 1980 began using age-hardening aluminum alloys that had been developed for aircraft construction. In the same decade two developments process technology attracted designers: injection molding of plastics and die-casting of magnesium alloys. The appeal of both was the ability to produce a complete frame in one shot, by-passing the more tedious route of brazing or welding of tubes and brackets. Neither design was a commercial success. Success came in 1992 with the adoption of another aerospace material – carbon fiber reinforced epoxy resin (CFRP). The extremely low weight and the aerodynamic qualities of the monocoque construction enabled a bike that set performance records for and established standards for high-end bike design that persist today.

The sequence illustrates well the way in which new materials stimulate design experiments, some of which fail, but the best of which advance the field in which they are applied.


1862, Iron and wood


1900, Mild steel


1980 Aluminum

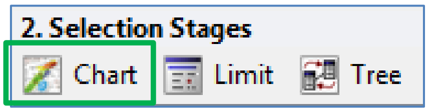

1983, Molded plastic


1986, Cast magnesium

1992, Hand laid-up CFRP

Figure 14. The influence of materials on product design: bicycles.

c) *Charting sensorial (aesthetic) properties.*



Materials differ in their feel, their color and texture, the sound they make when struck, the sense they give of strength and stiffness. These sensorial properties can be modelled in terms of their underlying physical, thermal and mechanical properties – the models are outlined in the Appendix. The software allows these property groups to be plotted as charts using the Chart option that appears when the ***Chart/Select*** mode of the database is selected from the main toolbar, scaling the values so that they range from 1 to 10. The resulting charts are used later to select materials based on their sensorial properties. First, however, a brief description of the charts themselves, all of which can be made and edited by the user by loading the Project files supplied with the database.

Tactile properties (Figure 15) characterize the sense that a material is warm or cold, soft or hard to the touch. This sense derives from the thermal conductivity, specific heat, modulus and hardness of the material in ways modelled in the Appendix. Foams, elastomers and many natural materials feel warm and relatively soft. Metals – particular copper and silver – and ceramics feel cold and hard. Polymer feel warm, but are fairly hard.

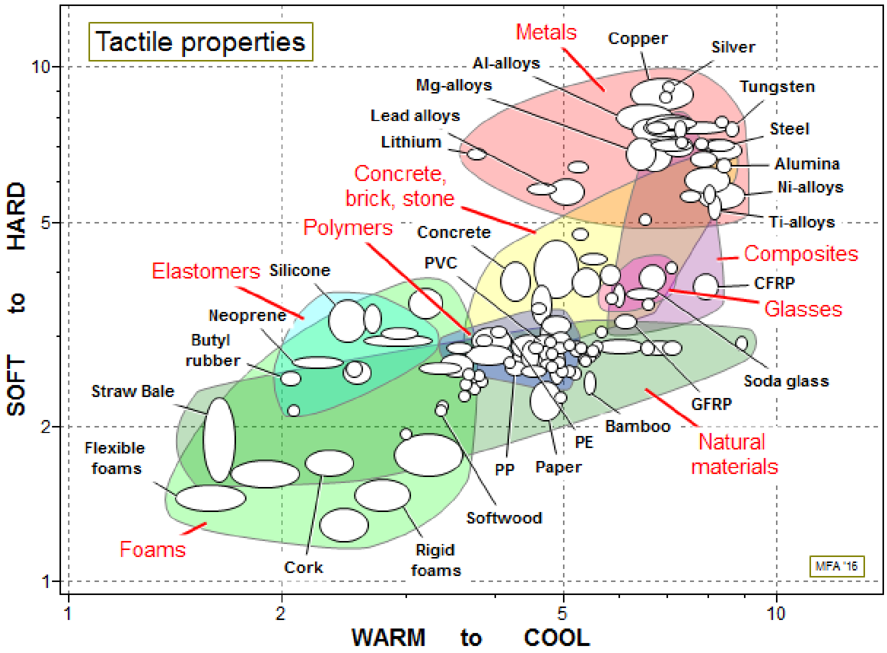


Figure 15. The tactile characteristics of materials

Acoustic properties (Figure 16) characterize the way a material sounds. Does it ring when struck or does it sound dull? Is the pitch of the sound it emits high or low? These characteristics depend on the modulus, the density and the mechanical damping coefficient of the material. This chart explains why a glass wine-glass rings but one made of plastic has a dull sound, why bells are made of bronze and why rubber, cork and leather damp sound effectively.

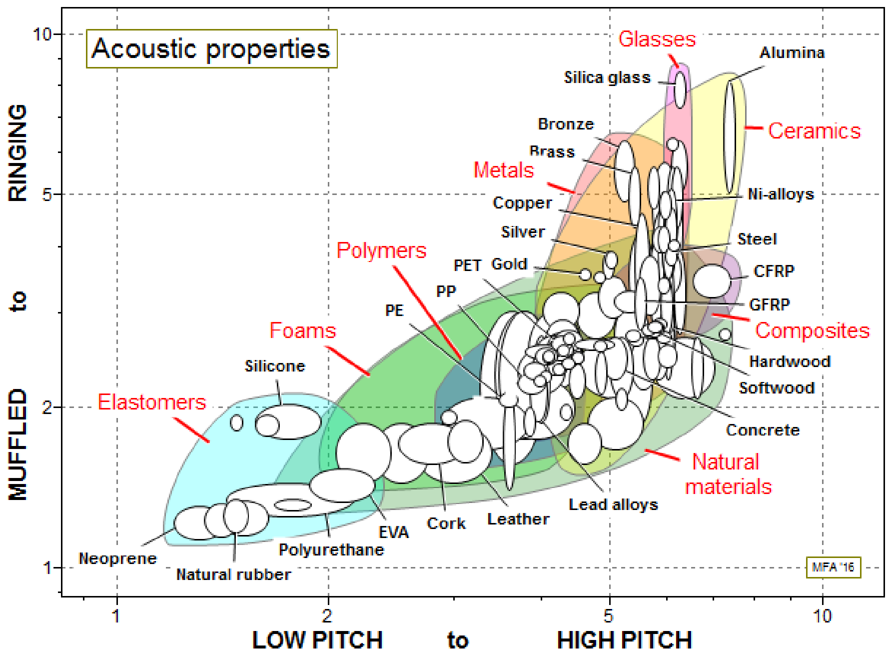


Figure 16. The acoustic characteristics of materials

Robustness properties (Figure 17) characterize the resistance of the material to damage, either surface damage like scratching or more extensive damage by accidental impact. These characteristics depend on the hardness of the material and on its toughness – the impact energy it can absorb without breaking. Metals, particularly steels and titanium alloys, resist abrasion and are very tough. Ceramics and glasses are even more scratch-resistant but tend to shatter if dropped onto a hard surface. Polymers are easily scratched but are almost as tough as metals.

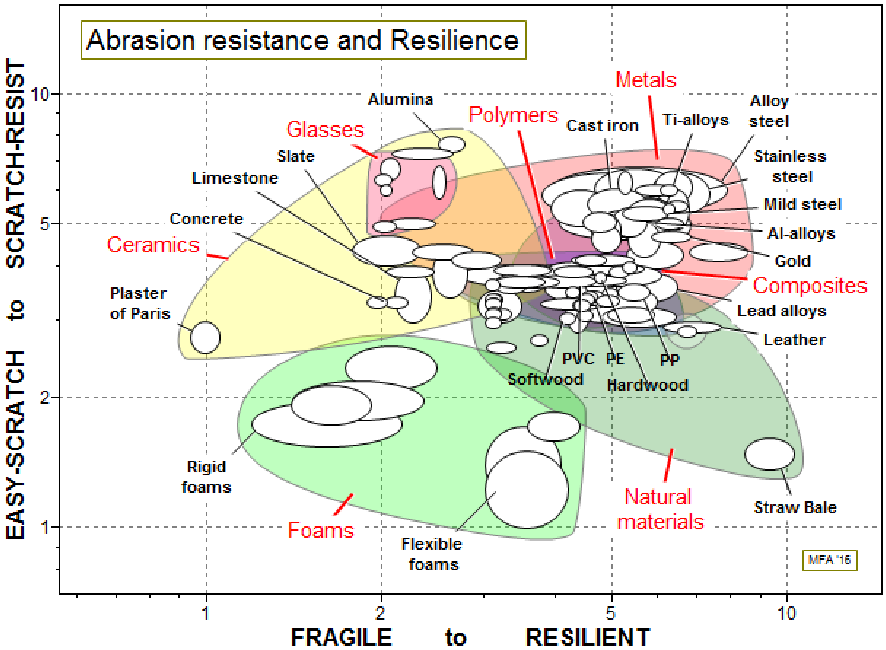


Figure 17. The robustness characteristics – scratch resistance and toughness – of materials

Lightweight mechanical response (Figure 18). Aircraft, ground transport, even bicycles and scooters need materials that light, stiff and strong, particularly when loaded in bending. These characteristics are captured by groups of material properties that include modulus, yield strength and density. The chart shows the carbon-fiber reinforced plastics (CFRP) excels by these criteria. Aluminum and magnesium alloys perform well, as do bamboo and woods.

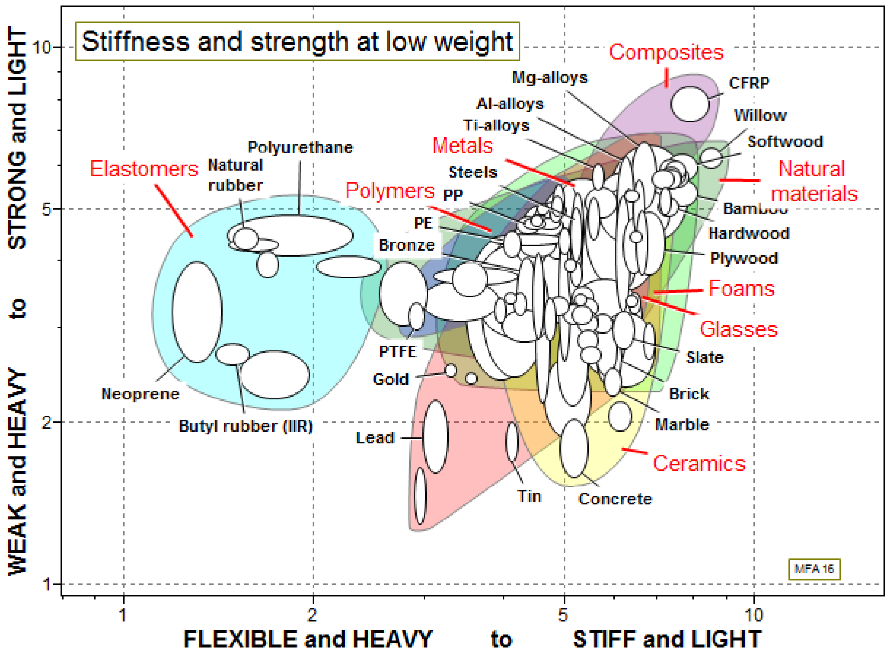


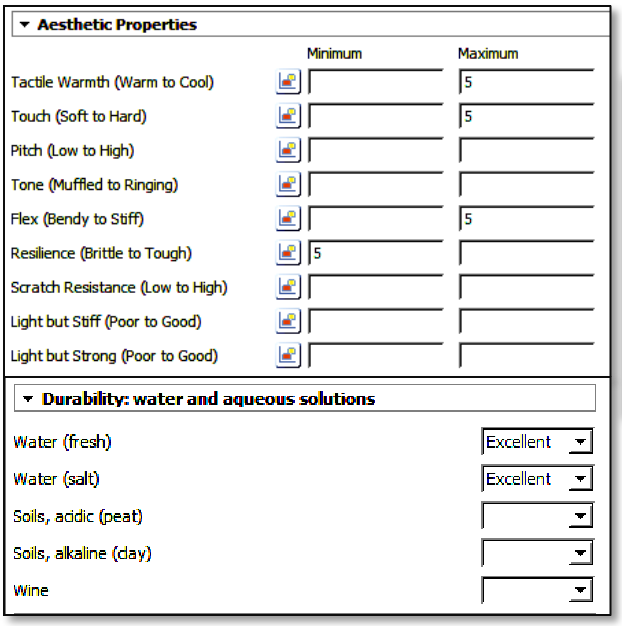
Figure 18. Stiffness, strength and with low weight characteristics of materials

d) Using Aesthetic properties for material selection

Using CES EduPack to select materials based on engineering properties is well documented elsewhere (see section 6). Here we examine how far aesthetic properties achieve the same thing. When many constraints are applied it is a mistake to make them too severe – if the material fails just one of them, it will be lost. A good first step is simply to assess whether the material meets the constraints better than the average. Assigning a value 5 to the "Minimum" constraint box limits the selection to those with values 6 to 10. Assigning the value 5 to the "Maximum" box limits selection to those with values 1 to 4. The constraints can be tightened later, but this is often unnecessary – the short-list is short enough to start exploring the materials in depth. Opening the record for each and clicking on the link to "Products" allows the way the material is used to be explored.

Figure 19. Links.

(1) A camera grip. The hand-grip of a camera is one of the more visible features and the one for which tactile properties are most important. The constraints set in Figure 20 limit the choice to materials that are warmer to the touch, softer and more flexible than average, but require also that it be tough and with excellent resistance to moisture. Only 6 materials of the 126 in the database meet these constraints. All are elastomers.



Selected materials (6 out of 126)

Carbon black reinforced styrene butadiene rubber (SBR)
Natural rubber (NR)
Polychloroprene (Neoprene, CR)
Polyisoprene rubber (IR)
Polyurethane
Silicone elastomers (SI, Q)

Figure 20. The selection for the camera grip

(2) A laptop casing. The design trend for laptops is slenderness and low weight, with a screen extending as close to the edge of the casing as possible. The outer casing performs a critical role – it must be as thin and light and light as possible while still have enough bending stiffness and strength to protect the delicate screen and the electronics from damage. Figure 21 shows the selection that results when the choice is restricted to materials that are stiffer, more resilient and harder than average, are stiff and strong at low weight and resistant to water. 8 materials survive. If the "light but stiff" and "light but strong" constraints are set at 7 (so that only materials with values of 8, 9 or 10 will pass), just one survives: carbon fiber reinforced plastic (CFRP).

Aesthetic Properties

	Minimum	Maximum
Tactile Warmth (Warm to Cool)		
Touch (Soft to Hard)	5	
Pitch (Low to High)		
Tone (Muffled to Ringing)		
Flex (Bendy to Stiff)	5	
Resilience (Brittle to Tough)	5	
Scratch Resistance (Low to High)		
Light but Stiff (Poor to Good)	5	
Light but Strong (Poor to Good)	5	

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	
Soils, acidic (peat)	
Soils, alkaline (clay)	
Wine	Excellent

Selected materials (8 from 126)

Age-hardening wrought Al-alloys
Aluminum/Silicon carbide composite
Cast Al-alloys
Commercially pure titanium
Non age-hardening wrought Al-alloys
Polyetheretherketone (PEEK)
Polyoxymethylene (Acetal) (POM)
Titanium alloys

Figure 21. The selection for the laptop casing

(3) Materials for children's toys. Children's toys require materials that are relatively resilient, warm and soft, with stiffness and strength at low weight and sufficiently water resistant that the toy can be wiped when grubby. The first five of these constraints are applied in Figure 21, requiring above average performance for each (though in the case warm and soft this means imposing a maximum value of 5, thereby selecting materials with values of 1 – 4 (Figure 22). Durability in water is added as a second selection stage. Just nine materials survive the constraints; all are commodity plastics. Adding a further requirement that the material should cost less than \$3/kg reduces the list to five. The use of these five in products can then be explored by opening the record for each and clicking on the link at the bottom of the record to "Products".

Aesthetic Properties

	Minimum	Maximum
Tactile Warmth (Warm to Cool)		5
Touch (Soft to Hard)		5
Pitch (Low to High)		
Tone (Muffled to Ringing)		
Flex (Bendy to Stiff)		
Resilience (Brittle to Tough)	5	
Scratch Resistance (Low to High)		
Light but Stiff (Poor to Good)	5	
Light but Strong (Poor to Good)	5	

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	
Soils, acidic (peat)	
Soils, alkaline (clay)	

Selected materials (9 from 126)

Acrylonitrile butadiene styrene (ABS)
Polycarbonate (PC)
Polyetheretherketone (PEEK)
Polyethylene (PE)
Polyethylene terephthalate (PET)
Polyoxymethylene (Acetal) (POM)
Polypropylene (PP)
Polyurethane (tpPUR)
Polyvinylchloride (tpPVC)

Figure 22. The selection for the child's toy

5. Conclusions and reflections

Inspiration (the ability to stimulate creative thinking) has many sources. One of these is the stimulus inherent in materials. It is one that, since the beginning of time, has driven humans to take materials and make something out of them, using their creativity to choose function and form in ways that best exploit the materials' attributes. The most obvious of these attributes are the engineering properties - density, strength, resilience, thermal conductivity, and such; it is these that enable the safe and economical design of products. The enormous economic importance of technical design in any developed society has made material and process development to meet technical needs a high priority. There are standardized methods to select materials and processes for technical applications, widely taught and extensively documented in texts and software, based on pure engineering properties. But a material has other attributes too: color, texture, feel, a sort of "character" deriving from the shapes to which it can be formed, its ability to integrate with other materials, the way it ages with time, the way people feel about it. These, too, can stimulate creativity—the kind of creativity that can give a product its personality, making it satisfying, even delightful.

We have sought, in assembling this database, to draw together lines of thinking about the selection of materials to serve both technical and industrial design. The suite of databases that make up the CES EduPack and the methods that go with them provide resources for technical design; with the PMPDb the emphasis is more heavily on industrial design.

What are the new perspectives? First, that a material has many dimensions: a technical dimension, the one seen by the engineer; an economic dimension, its role in adding value to products; an eco-dimension, that seen by the environmentalist; and an aesthetic dimension, the one encountered by the senses of sight, touch and hearing.

Attributes of aesthetics and perception are less easy to pin down than those that are technical, yet it is essential to capture them in some way if their role (and it is obviously an important one) is to be communicated and discussed. There are words to describe visual, tactile, and acoustic attributes; they can even, to some extent, be quantified. Perceptions and emotion are more difficult. A few, perhaps, can be identified—gold is, almost universally, associated with wealth, steel with strength, granite with permanence, plastics with modernity... well, even these are uncertain. The way we think about materials or materiality depends on context, culture, demographics, style, trend, and more. This is why we have concentrated on the objective physical aesthetic attributes that are related to engineering materials properties.

It is hoped that the database will enable Engineers and Designers to get a greater understanding and appreciation for each other's role in the design process, via inter-disciplinary team projects or simply by using the same tool for materials selection.

Another side effect of this new database, may be to inspire Engineering students, who have not chosen to study materials, but need to understand fundamental properties in order to design well; by starting with Products and allowing the curious to dig down into the materials and processes used, and by presenting examples of successful products with innovative use of materials.

The CES EduPack Products, Materials and Processes Database described in this White Paper seeks to make complicated links between product, material, and process and how they affect aesthetics more explicit. It provides access to product images, described in the words of the designer. It provides a window onto the designers and the manufacturers of successful products. Uniquely, it links these to portraits of the materials the designer chose, viewable from both a technical design and industrial design perspective.

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Appendix: Derivation and Calculation of Aesthetic Attributes

Softness to hard (to the touch). Hardness is resistance to indentation and scratching. It is directly measured by the material property of hardness (*H*). Softness has to do with stiffness – or, rather, to lack of stiffness. The stiffness of a material in a given shape is proportional to its modulus (*E*), another material property. It is convenient to have a single measure that allows materials to be ranked along a single axis. One that works here is the measure

$$S = EH$$

If *S* is small, the material feels soft; as *S* increases it feels harder.

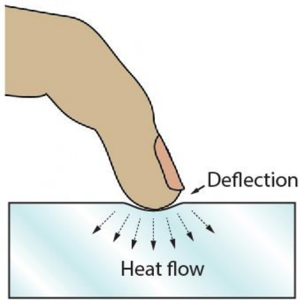

Figure 23. Heat flow and deflection on contact

Warm to cold (to the touch). A material feels 'cold' to touch if it conducts heat away from the finger quickly; it is 'warm' if it does not. Heat flows from the finger into the surface such that, after time '*t*' a depth '*x*' of material has been warmed significantly while its remoter part has not. Solutions to transient heat-flow problems of this class all have solutions with the feature that

$$x \approx \sqrt{at}$$

where, a, is the thermal diffusivity of the material

$$a = \frac{\lambda}{\rho C_\rho}$$

here, λ, lambda is the thermal conductivity, CP is the specific heat and, ρ, is the density. The quantity of heat that has left each unit area of finger in time t is

$$Q = x\rho C_\rho = \sqrt{\rho\lambda C_p}$$

If *Q* is small the material feels warm; if large, it feels cold. Softness and Warmth are used as the axes of Figure 15.

Pitch (of sound). Sound frequency (pitch) when an object is struck relates to the modulus, E, and density, ρ, of the material of which it is made. We use the quantity

$$P = \sqrt{\frac{E}{\rho}}$$

as a relative measure of natural vibration frequency, and thus pitch. If *P* is small the material's pitch is low, as *P* increases the material's pitch is higher.


Figure 24. Identical tuning forks made from 4 different materials (Miodownik 2007)

Brightness (of sound). Sound attenuation (damping or muffling) depends on its loss coefficient, η. We use the quantity

$$L = \left(\frac{1}{\eta}\right)$$

as a measure for ranking materials by acoustic sense. If L is small the material sounds muffled; as L increases the material rings more. Pitch and Brightness are used as axes of Figure 16.

Abrasion Resistance is directly related to the material property 'Hardness', H.

Toughness is the ability to absorb energy when struck – a tough object survives a hammer blow. It is measured by the technical attribute, 'Toughness', defined by

$$G_{1C} = \frac{K_{1C}^2}{E}$$

Abrasion resistance and Toughness are used as the axes of Figure 17.

Stiffness (in bending) at low weight is characterized by the material property group

$$\frac{E^{1/2}}{\rho}$$

where E is Young's modulus and ρ is the density (Ashby, 2011).

Strength (in bending) at low weight is characterized by the material property group

$$\frac{\sigma_y^{2/3}}{\rho}$$

where σ_y is the yield strength and ρ is the density (Ashby 2011). Stiffness and strength at low weight are used as the axes of Figure 18.

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