Beatrice Lerma, Claudia De Giorgi, Cristina Allione

# Design and materials

Sensory perception_sustainability_project

Serie di architettura e design
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## Summary

# Introduction

## Design, sensory perception and sustainability

According to the most recent approach to design culture, the right materials for a product should be chosen as early as the metadesign stage because this will make it more important and meaningful. In fact, materials not only play a crucial and acknowledged role in design, they support its technical functions and shape its personality.

Until recently product materials were chosen at the end of the design process. Lately, however, people have begun to realise that choosing materials early on in the design process means the product will have a greater chance of satisfying the initial requirements.

Requirements which in the meantime have evolved: products are no longer asked to perform as they did in the past (regarding physical, technical, and mechanical features, reliability, safety, etc.), they are now expected to consider contemporary social changes and deliver 'soft' performances, such as greater sensory expressivity, and complex performances, for example designing a life cycle respectful of the environment.

In this increasingly complex scenario a designer must be familiar with all available options if he wishes to choose the right materials for his product early on in the design process; above all he must be able to analyse whether or not the materials suit his product. To help him make the right choice he must be able to access the criteria and methods he needs to interpret and assess their sensory and environmental performance.

The interpretation methodologies and criteria illustrated in this book are intended to give the designer a multi-criteria tool to interpret the sensory and environmental performance of a material. This tool can be used in several cultural contexts based on one premise: it is not important to talk about eco-compatible or sensory materials in absolute terms, instead it is more important to select materials, or a mix of relatively better materials, depending on the use, expected lifetime, and end-of-life of the products.

## Materials and sensory perception

There are many reasons why choosing the right material is not only crucial in the design of a good product, but also satisfies the newly revived senses of the public: increased interest in the expressive and sensory features of objects, the desire of consumers to manipulate, touch, and feel the products on their own skin, and the ensuing search to enhance products with sensory and sensual features.

Our body is the first material we use to build and change the world: it creates perception, memory, and images. We use our bodies to relate to the world. From time immemorial bodies have been stretched and 'lengthened' with artificial prostheses and devices which alter its possibility to interact: since our senses extend it beyond our own skin it's difficult to establish just where the body ends.[1]

The body plays 'a crucial role in the perception of the environment and in the construction of objects and meanings'.[2] It comes into contact with the outside world and with materials characterised by their physical elements, but also by colours, sounds, electric waves, sound waves, images, and words.

Our senses guide our body in the world: 'they structure our knowledge and experiences and activate the mechanisms of recognition and memory. […] When we look at an object the feelings

1 Fiorani E. (2000), *Leggere i materiali: con l'antropologia, con la semiotica*, Editori di comunicazione-Lupetti, Milan, pp. 51–53.

2 Ivi, p. 51.

it gives us differ from the ones we have when we touch or feel it. Hearing, taste, smell, and touch, don't just give us additional bits of information compared to what we see with our eyes; they are another way of acquiring knowledge. Every sense has its own language and provides a different kind of contact with the world. […] Materials talk to all our senses: they provide a multisensory vision of the world and involve a synaesthetic perception of tactile and visual feelings of sounds, tastes and flavours'.[3]

In today's world, man (for whom sight is particularly important) has distorted his sensory experience; he now bases it primarily on sight, and this has reduced the sensitivity of our other senses (touch, smell, and taste) and made them less important.[4]

Sight is a cold sense which rationally analyses things from a distance. Like hearing, sight acts from a distance and exerts remote control over our relationship with the world and materials. Instead touch, smell, and taste are hot senses which introduce us to something that is 'physical, tangible, and touchable'.[5]

Some elements of perception are common to all the senses. Every kind of perception has a dual quality. We can talk of the tactile quality of sight, and the visual properties of touch and hearing: we recognise 'synaesthetic expressions like clear sounds, dark sounds',[6] hot and cold colours, etc. 'The hand sees, the eyes touch. The hand sees, but not like our eyes, our eyes touch, but not like our hand. All the senses help to see'.[7] When choosing a product, contemporary consumers no longer consider just its function, but also how soft, delicate, and sensual it is. The smells, sounds, shapes, and colours of an object, and the feelings they inspire in a consumer, are becoming increasingly important.

Modern industries try to give products a sensory and sensual dimension in order to satisfy the demands of consumers who want to manipulate, touch, and feel them on their own skin. In particular,

[3] Ivi, p. 57

[4] Ivi, p. 58.

[5] Ibid.

[6] Riccò D. (1999), *Sinestesie per il design. Le interazioni sensoriali nell'epoca dei multimedia*, Etas, Milan, p. 76.

[7] Fiorani E. (2000), *Leggere i materiali: con l'antropologia, con la semiotica,* op. cit., p. 59.

sensory analysis and the design of new products with a special sensory feature are considered very important by the cosmetics and perfume industry. Just think of how important these feelings are in this sector: the feelings sparked by the perfume of a loved one, the fragrance of body products, the scent of after-sun creams drifting along city streets on a summer's day, etc.

This is why producers spend days and days designing the presentation of a product, starting with the packaging which, if it involves cosmetics or body products, provides a synaesthetic anticipation of their fragrance.

It is also interesting to see how make-up products can evolve in order to 'awake' the senses. These small products are considered by clients as 'little friends'; they want to be able to see and touch them because this arouses subtle feelings. The expectations associated with the packaging of these small make-up products primarily involve handling, manageability, shapes, and opening mechanisms.

Women insist on easy-to-hold packaging, especially small boxes and power compacts: the raised parts, grooves or surfaces facilitate grip and prevent them from slipping, while concave or curved shapes are easier to hold. Shapes appear more human and biological; they are rounded to feel softer to the eyes and hands. These products require interesting and sensual packaging: rounded and convex shapes, surfaces smooth or rough to the touch, or transparent or translucent to look at; shapes that facilitate easy, satisfying gestures, that reflect the pleasant sweetness and intimacy of the moment when a women does her make-up. Make-up shouldn't be something a woman hides behind, it should be a way for her to express her personality and moods. The closing mechanisms of new lipsticks,[8] for example the ones by Estée Lauder, will produce a unique sound and so will the company's compact powders; the sound of these products will be unique[9] and experiments are underway to install new magnetic rather than snap shut mechanisms.

[8] Delogu F. (2005), "Bellezza: ascoltare un profumo, sentire lo scatto di un pennello o il 'click' di un rossetto", *La Repubblica*, 01-10-2005.

[9] "Il rumore del lusso" (2003), *ItaliaImballaggio*, October.

In another, completely different field, air transport,Lufthansa has invested in its clients' sense of smell. It has scented its planes to reduce passenger stress by pulverising microcapsules with different scents on the carpeting in the cabin (vanilla, honey, milk, etc., in other words fragrances psychologists consider 'soothing'); when passengers walk on the carpeting they crush the microcapsules which release their fragrance.

The car industry has also focused its attention on sensory perception. 'After discovering that clients no longer appreciated the classic 'smell of a new car', Fiat hired air engineers to neutralise it and replace it with a pleasant but unrecognisable fragrance (timber) produced by a small piece of wood hidden under the driver's seat. The scent lasts six months (the break-in period) after which it is replaced by the smell of the owner, for which Fiat is not responsible. Instead in all BMW luxury models a scented interior is an optional: the client can choose from several fragrances introduced through the air conditioning system.[10]

Industry can no longer afford to ignore the sensory features of a product, whether it be a car or a lipstick; choosing the right material is a key factor in the revival of a good product. In today's increasingly virtual world, designers consider new materials for design and a sensory experience as a 'necessity' of life.

'Apart from visually perceived formal qualities, in the past sensory qualities didn't have to be designed: the choice of material implicitly included its own tactile, thermal, acoustic, and olfactory values. This is no longer true in a world of 'new materials'[11]: innovative materials acquire new characteristics which in some cases are disturbing. Thanks to countless studies in this field, and the search for made-to-measure materials, we now have soft flexible wood, transparent concrete, bendable tiles, etc. Sensory qualities can now be designed and their features have become an important field of research.

[10] Bonetti A. (2004), "Ci vuole naso", *Carnet*, May.

[11] Manzini E. (1990), *Artefatti: verso una nuova ecologia dell'ambiente artificiale*, Domus Academy, Milan, pp. 96–97.

## Materials and environmental sustainability

Faced with the increasingly difficult conditions of our planet and the environmental disasters caused all too often by man's 'carelessness', there is a growing need for products to add respect for the environment to the newly adopted sensory dimension; in practice this means minimising the use of resources and environmental emissions.

The approval of several environmental laws to reduce energy use and the increased environmental awareness of final users prompted designers to adopt an approach called Life Cycle Thinking; in other words, if a product is to be truly eco-compatible during its life cycle it must minimise, if not eliminate, resource consumption (energy and materials) and emissions (air, water, and solid waste)

Based on this principle – adopted in design practice and culture, and now acknowledged and widespread in the world of production, economics and politics – approaches and tools have been developed to achieve product eco-compatibility during design. Methods and certification systems have been created to measure the real eco-compatibility of a product during its entire life cycle.

These design approaches and evaluation tools are based on the life cycle principle; in a more or less quantitative and scientific manner they take into account the fact that a product's life cycle is made up of several variables quantitatively characterised by a series of inputs and outputs which can be qualitatively described and dealt with.

These variables involve: thorough understanding of the pre-production processes and production systems used to obtain materials and components; correct selection of materials based on the transformation process of a product, its specific context of use, and envisaged useful life cycle; correctly planned assembly systems to achieve greater production efficiency; and, finally, simpler end-of-life disassembly. The latter is crucial vis-à-vis recycling or extension of the useful life of components and materials above and beyond the useful life of the product in which they are used. All together these variables influence the eco-compatibility of a product and when used pro-actively can direct the design process in different and sometimes even opposite directions.

The problems associated with these variables cannot be solved by simply deciding which is the ‘best’ material’. Instead the designer has to adopt a design approach that contemplates all the possible effects his choice may have; he has to make sure that incremental improvements achieved during one stage do not negatively affect another stage and thus compromise the overall energy-environment balance.

With this in mind, it is reductive to think that a product is eco-compatible just because a certain number of eco-compatible materials are used to make it; and it is meaningless to talk about eco-compatibility in absolute terms.

Although several environmental certification systems of materials and products are now widespread, very few of them reward excellence or provide a list of the best ‘green’ materials. Instead most systems offer a multi-criteria interpretation based on several objective indicators regarding the life cycle performance of the material or product.

In other words, these certification systems acknowledge a designer’s critical expertise and yet leave him alone to decide how to use the environmental data available and apply it during the design process. The methodological approach illustrated in this book will give the designer the tools to correctly evaluate the environmental variables influencing the life cycle performance of the product based on the different design contexts, a choice he has to make when choosing the material.

This multi-criteria interpretation system is based on representative qualitative and quantitative parameters of the performance of materials in relation to specific critical issues identified during their life cycle. The system will allow materials to be selected according to their ecological footprint in relative rather than absolute terms, in other words depending on the various design contexts.

The proposed parameters and criteria are not intended to be a definitive list of the best materials, but rather to help designers interpret the environmental performance of everyday materials as well as innovative materials, because we know very little about how the latter are produced or their end-of-life, and even less about their effects on the environment.

This analytical methodology, based on several parameters, will help gather accurate data about the life cycle performance of materials or semi-finished products; it will ultimately be useful in choosing and selecting the most eco-compatible materials based on the expected performance of the product during its life cycle in a specific context and, finally, when it is discarded and disposed of.

## The role of designers in today's world

Selecting materials is a design choice and the designer is a key figure in this process; with his expertise and ability to merge different professional skills he is the lead player and link between the business world and the complex task of governing environmental and sensory issues. His role is crucial vis-à-vis the environment because 'eighty percent of the environmental impact of products, services, and infrastructures is decided during the design stage. These decisions shape the processes which determine not only product quality, but also the materials and energy required to produce them, their everyday use, and their final destination when we no longer need them'.[12]

A designer's role is crucial because it shapes and satisfies the new demands by consumers for sensory perception, appeal, and profound experiences.

As a result, sustainability and sensory perception involve not only ecodesign, but also design in general.

Only changes made in the preliminary stages to the cultural approach and initial strategies leading to the development of a product will make it possible to change business logic and rationalise the object and its entire life cycle; this will make products not only truly eco-compatible, but also representative of their expressive and sensory features.

[12] Thackara, J. (2005), *In the bubble: designing in a complex world*, The MIT Press, Cambridge.

## Worldwide materials libraries and databases

There are millions of different kinds of materials in the world today and new ones are being invented all the time: ‘a whole host of new materials is being produced everyday; their enormous technical and expressive options oblige designers to continually update their properties and possible applications’.[13] Designers and producers are faced with a vast (and growing) selection of options; materials and transformation processes can be combined in so many ways that it’s been labelled ‘hyper choice’.[14] In fact, one kind of material is no longer considered an almost obligatory choice for a product type, because several materials compete against one another: the best solution can only be chosen after a careful and thorough analysis of the entire life cycle of the product. ‘Materials libraries’ have been created to list, classify, and organise technical information about materials and products for the world of architecture, design, and industrial production. These archives showcase real and virtual samples of indexed materials and can be used by designers as a research tool to increase their knowledge of available materials.

The term materials libraries is a recent neologism invented to indicate physical or virtual places in which technical information about a wide range of materials is stored and made available, in particular, materials used in the world of architecture, design, fashion, and industrial production in general.

Material Connexion, founded by George M. Beylerian in 1997 in New York was the first materials library to be created; its subsidiary in Milan was inaugurated in 2002.

Materials libraries were set up not only to make it easier for designers to access data about new materials, but also to help businesses established themselves on the market, become part of a community (and therefore access companies, public authorities and institutions more rapidly), create solid backing and advertising, and meet potential new clients or partners. Materials libraries were the answer to the demand by businesses and institutions for an infrastructure which could interact with users in a physical or virtual

[13] Langella C. (2003), *Nuovi paesaggi materici*, Alinea, Florence, pp. 75–77.
[14] Manzini E. (1986), *La materia dell’invenzione*, Arcadia Editori, Milan, p. 37.

environment, one which could be a sort of follow-on from portals (considered as containers of technical data) as well as a creative laboratory. Generally speaking, materials libraries function in the service sector by researching and classifying innovative materials: they use several means of communication, organise fairs and exhibitions, create newsletters, have user-friendly info sections, and publish books about materials commonly called 'showcase books'.

Materials libraries are constantly updated: those responsible for this service always have to be on their toes and research innovative and interesting materials or manufacturing processes in order to not only enhance and expand the data in the library, but also to compete with the new materials libraries that come on the market. In most cases materials libraries provide services and consultancy 'of a mostly commercial nature, and act as a network between interested parties: producers, designers, researchers, etc'.[15] Materials libraries are increasing in number day by day; their function now ranges from consultancy about innovative materials, to assisting designers during the design process, concept ideation, and prototyping.

'Some designers consider materials libraries chiefly as a place where they can find inspiration for new designs, places to be visited like a modern sculpture exhibition or a 'documentary source' of what's new; places where simple 'strange-looking' extraterrestrial materials become big stars or collection pieces […]. Others regard them as places in which to work, to fully explore a specific component, with the added option of being able to talk to a consultant […]'.[16] This is the best way to consider a materials library: a place of research and documentation where it's possible to touch the materials and get first hand information about their characteristics: a place providing information and consultancy to those who need to find innovative materials and technologies to enhance their designs and industrial processes.

Every library has its own classification method: all libraries usually classify materials according to their family of origin, to their physical, technical, and mechanical features, and current uses.

[15] Lucibello S. (2005), *Materiali@design: verso una nuova modalità di selezione su base percettiva dei materiali per il design*, Editrice Librerie Dedalo, Rome, p. 28.

[16] Campogrande S. (2009), "Diffondere i materiali", in Ferrara M., Lucibello S., edited by, *Design follows materials*, Alinea, Florence, pp. 66–67.

However, while some materials libraries provide a broad spectrum of all material families, others specialise in certain sectors or in a specific material category: for example Matrec®, the first free public Italian database focusing on the main ecodesign features of materials and recycled products, or Materioteca®, also Italian, focusing exclusively on plastic materials and already improved with an online site for education and research, and finally Materiautech, a French structure, also dedicated to research in the world of plastics.

Finally, the last step in the evolution of these materials libraries is to include the perceptive characteristics and eco-compatibility of materials in the classification criteria.

Having acknowledged the importance of tactile, visual, and other features of these materials, multisensory perception has become important in the classification of materials in materials libraries. Classification is based either on a technical approach (reflectivity, heat conductivity, acoustic characteristics, etc.), or on an empirical perceptive approach. Although it's true that the latter is based on how materials are perceived by human organs, practice is often preferred to scientific criteria.

Although some libraries use sensory words to analyse materials, their assessment is often manipulated by the classification team; as a result, the assessment is based only on the experience and knowledge of team members, and not on a good-size, scientific sample of trained 'materials tasters'.

Every institute develops its own classification and assessment system. Unfortunately there is neither a common language/vocabulary, nor a sensory assessment method based on clear and easy scientific criteria so that everyone – industrialists, producers, designers, students, etc. – can use the results of the tests.

The first thing to do is to develop a sensory assessment method which uses words, images, or other forms of communication to collect, translate, and comprehensively simplify sensory assessment methods and existing assessment scales.

A key issue for materials libraries is the (often inconsistent) assessment of the eco-compatibility of innovative materials. Materials libraries have already reacted positively to the demand to respect the environment, for example through the collection and assembly of new materials designed to be eco-compatible during production or use (e.g., biomimetic materials). However, respect for the environment has also emphasised the need to provide data regarding the environmentally-friendly nature of materials already present in libraries.

Likewise, data and information regarding the environmental performance of materials should also be provided and more clearly linked to design opportunities.

There is a need for quantitative data (such as data regarding the input and output values calculated using the Life Cycle Assessment methodology,[17] for example incorporated energy and CO2 emissions), as well as qualitative data, i.e., data which can provide information about the behaviour of materials during their life cycle. This data should be based on scientific methodologies and tools which designers can easily interpret when choosing a design material. Finally, recent changes in several materials libraries all over the world have recently led to the development of several environmental databases (either as software or consultable online).

Databases have often been created to provide Life Cycle Inventory (LCI) data, in other words sets of values linked to quantitative inputs and outputs during the different stages of the life cycle of materials and processes: for example Ecoinvent (developed by the Swiss Centre for Life Cycle Inventories - a Joint Initiative of the ETH Domain and Swiss federal Offices), IdeMat (developed by Design for Sustainability, Faculty of Design, Engineering and Production, TU Delft), the European ELCD core database

[17] The LCA methodology, as defined for the first time in 1993 by SETAC, the Society of Environmental Toxicology and Chemistry, is an objective procedure to assess the energy and environmental consumption of a process or activity; it is conducted by indicating the energy and materials used and the waste released into the environment. This assessment technique of the potential environmental impact associated with a product (or service) covers the entire life cycle of said product or service. In practice, a LCA study performs an important energy–environment assessment which takes into account the ecobalances of various materials and processes involved in the life cycle stages, and compares them by objectively calculating all input values (materials and energy) and output values (solid air, water, and waste emissions); they are then re–organised and turned into indicators which represent how they affect the main environmental effects (greenhouse effect, resource depletion, acidification, etc.). The methodology was classified officially by UNI EN ISO 14040, 14041, 14042 and 14043. For more information, see: Baldo G.L., Marino M., Rossi S. (2008), *Analisi del ciclo di vita LCA. Gli strumenti per la progettazione sostenibile di materiali, prodotti e processi*, Edizioni Ambiente, Milan.

(developed by the European Commission – DG Joint Research Centre - Institute for Environment and Sustainability), PlasticsPortal (developed by Plastics Europe), or existing databases, such as the Cambridge EcoSelector – CES (Cambridge University & Granta Design Ltd),[18] which have also integrated sustainability topics including indicators associated with the environmental performance of a material.

In the first case, the LCI databases are specific databases developed to provide sets of values which can easily be linked to each other and re-elaborated (using specific LCA software) as concise environmental indicators showing the main effects these products have on the environment.[19]

In practice these electronic databases provide sets of data containing all the inputs and outputs regarding a specific material or process considered on the basis of a precise unit of measure (1 kg of material, the manufacturing of 1 kg of semi-finished products, etc.)

These databases are based on the LCA method and related standards of the UNI EN ISO 14040 series and are developed by research centres or trade associations recognised by the scientific community. They provide specific sets of data classified according to specific formats; as a result, they are easy to integrate and justify using LCA calculation software. However, since they provide data which still has to be processed and turned into comprehensible indicators, they are not very useful during design. The reliability of these databases has always been based on a series of credible scientific methods and data collection systems. This has provided

[18] Cfr. Appendix 2.

[19] In the academic world and the world of production, using the Life Cycle Assessment (LCA) methodology as a scientifically recognised assessment procedure of energy–environment loads linked to the life cycle of a product, material or production system, is a recognised method adopted in many countries. The right software, called LCA, is required to perform this analysis, which in practice involves an energy–environment balance; this software is capable of managing and linking a huge amount of data and values such as the data involved in the inventory process, but above all data which can be re–elaborated and re–organised according to indexes representing its impact on the most important environmental effects (greenhouse effect, acidification, etc.). Created in the nineties, these software programmes, for example SimaPro (Prè Consultant Ltd.) or GaBi (IKP Stuttgart University & PE Europe GmbH), have databases which provide the inventory data required to start the analysis, but they often have functions to import data from other LCI databases related to several commodity sectors.

greater reliability and scientific value, but has also involved higher costs regarding the purchase of licences: as a result, this has curbed their enormous potential. To counter this trend a recently created database (the ELDC core database developed by the European Commission, DG Joint Research Centre, Institute for Environment and Sustainability) is freely available on the European LCA platform (http://lct. jrc.ec. europa. - eu/eplca). The database provides sets of LCI contextualised data from European countries which can easily be consulted online; data can be freely downloaded and inserted into any LCA study conducted with contemporary software tools. Finally, apart from the LCI databases, there are other kinds of environmental databases, for example the CES. Although it wasn't created to solve problems associated with complete LCA analysis, it has been around for years and is a useful technical tool with which to select materials.

This database, developed using methods invented by M. Ashby, is based on sophisticated search and selection criteria for materials. It has recently broadened its scope and now includes technical sheets for materials as well as detailed data about their physical, chemical, mechanical and sensory characteristics (obtained using tools rather than direct studies on sample users); this data is indicative of their main ecological footprints expressed in terms of embodied energy (EE) and CO2 equivalent emissions attributable to the specific material or production process.

In this brief excursus we have illustrated the state-of-the-art of materials libraries and environmental databases developed as useful support tools for designers who have to choose a material. It is an excellent example of why we need to propose a common scientific method to interpret the sensory dimension and sustainability of a material.

The appendix contains the technical sheets of the most important materials libraries in the world and the most popular environmental databases.

# 1. Sensory evaluation

**by Beatrice Lerma**

Sensory evaluation has been defined as a scientific method used to evoke, measure, analyse, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste and hearing.[1]

To understand the world we need to look, touch, smell, listen, and even taste it. But it's our brain that interprets what we perceive with our senses.

Our senses are always at work, whatever we do. Without them knowledge is impossible.

What seems like a very obvious insight is often the result of interaction between several or all our senses. We want to taste and touch even with our eyes; a musical melody can be associated with the taste of a beverage; we can be touched by a fragrance that takes our breath away.

Sensory interaction merges and revolutionises different contexts and concepts usually considered separate and sometimes conflicting; figure/background, text/context, nature/artifice, internal/external, subject/object, reality/simulation, everyday event/artistic expression.

Perception or insight is 'the activity with which man or superior animals choose, elaborate and learn about the information received by sensory organs'.[2] The sensory-perceptive experience is therefore an action, a private and subjective event prompted by the contact our

[1] Definition accepted and endorsed by the American Society for Testing and Materials and Institute of Food Technologists.

[2] Gussoni M., Parlangeli O., Tosi F. (2008), *Ergonomia e progetto della qualità sensoriale*, FrancoAngeli, Milan, p. 21.

body and senses establish with the world around us; it involves all the levels into which we can break down our ability to adapt and respond to external stimuli from a physiological, sensory, psycho-perceptive, and emotional point of view. A sensation is the elementary and unanalysable unit of what we perceive when certain receptor organs are stimulated. It is the first psychological response to stimulation of the body produced by interaction between the mind and matter.[3] A feeling involves the initial stages of sensory-perceptive activity, in other words the process used by our body and sensory receptors to record the stimuli produced by the presence of elements in the environment and how they vary.

Can sensations, perceptions, and subjective moments be measured and evaluated? Can we become a measuring tool? Sensory evaluation is the scientific discipline that measures, analyses and interprets the feelings perceived by the senses. We use this discipline to determine the quality and safety of food and beverages, a discipline which is now systematically used in the food industry not only as a quality control tool, but also to develop new products.[4] The goal of sensory evaluation is to turn an intrinsically subjective evaluation -tasting a food sample- into something objective.

However, as a measuring tool humans have a problem, so to speak, of extremely irregular 'calibration': in fact, we all perceive the sensory characteristics of a product differently. Our senses measure perceived quality; the latter is a dynamic concept that varies in time, just like consumer tastes vary in a world which continuously offers new products. As a result, sensory evaluations are a strategic tool to innovate a product. Several properties determine quality, and sensory properties require special attention because, although they determine acceptability, they are also the most difficult to evaluate objectively.

It is important to define quality standards and reliable evaluation methods in order to protect the consumer and ensure acceptable competition between businesses. Sensory evaluation uses structured texts based on strict and precise protocols to quantify perception and assign it the characteristics of all scientific measurements (reproducibility, repeatability, possible comparison with historical

[3] Lo *Zingarelli. Vocabolario della lingua italiana* (1997), Zanichelli, Bologna, p. 1679.
[4] Pagliarini E. (2002), *Valutazione sensoriale*, Hoepli, Milan.

data, statistical importance, and reliability). The result is a sensory-analytical-quantitative profile.

When today's consumers choose a product they consider its function as well as other features such as softness, refinement, sensuality, etc. The smell, sound, shape, and colours of an object, as well as the emotions it arouses in consumers, are also becoming increasingly important.

Industry has to take into account the sensory features of a product, whether it is a car or lipstick; choosing the right material determines the success of a good product.

'Yogurts, beauty creams, fabrics, shampoo; many materials are tested by experts trained to objectively describe their impressions. They make it possible to define several characteristics of the products which consumers perceive as pleasant almost unconscious sensations. Knowing the sensory properties of the products makes it possible to predict consumer preferences and create a sort of common vocabulary shared by marketing, design, production and research'.[5]

Nowadays industries try to enrich a product by giving it a sensory and sensual dimension in order to satisfy the consumer's need to manipulate, touch, or feel it on his own skin. The agrifood sector was the first to use the results of sensory analysis. In fact, choosing a material is extremely important because packaging has to preserve taste, eliminate unpleasant smells, and ensure the product does not absorb odours from outside the packaging.

The sensory evaluations of experts at Nestlé emphasised how important it was to focus on the sound made by someone munching on a bar of chocolate, especially what the consumer hears (inner ear) and the sound perceived by anyone close to the consumer (external ear). More and more experiments are being conducted on the packaging of sweet-baked snacks and crisps, which have to make a 'crock' sound; in this case, materials play an important role in producing sounds which stimulate the consumer. The cosmetics and perfume industry also considers sensory analysis very important, as it does the design of new products with special sensory features.

[5] Campogrande S., *Materioteca per designer* [degree tesi]. Rapporteur: De Ferrari G., Politecnico di Torino, I Faculty of Architecture, Academic Year 1998/1999.

So, can sensory perception become a criteria to define, classify, exhibit, and research materials, and not just foodstuffs? Can the classification of materials and dedicated research be performed using common terms or values defining the sensory characteristics of materials?

## 1.1 Different approaches to sensory perception evaluation

The practical application of sensory science is to improve the sensory quality of different products: fabrics, fashion, cosmetics, advertising, transport modes, the environment, etc.

The key word of sensory science is to connect: sensory science connects the product to a person. By activating several senses at the same time, it makes him aware of a huge amount of chemical and physical data about the product. This means we have to improve our understanding of the interactions between materials/products and the human mind since these interactions change over time and according to the context. Understanding the ‘person/product’ relationship raises questions about the sensation-perception-cognition process which, from an epistemological point of view, involves using our senses to discover the existence of the outside world and its features.

Our own personal perceptive mode depends on our life experiences and the memory of certain things such as smells and moods: what is important is to understand how they transfer from the physical object to personal experience, sociocultural context, the environment, etc.

Categorisation, the link between what we perceive and what is stored in our memory, is crucial. Based on the premise that a recipient interprets or attributes meaning to what is perceived, we have to remember that the first process of attribution of meaning occurs when we categorise something, in other words when, through the perception of certain elements, the subject to whom we refer identifies an object. After categorisation, which ‘reflects the process of identification of a magnitude, understanding is the process we use to extract the more important meanings of the acknowledged object'.[6]

Sensory sciences are unique insofar as they merge several senses, for example the link[7] between the perception of a colour and that of a fragrance. When technical tools were developed they were often designed as an extension of a sensory organ, for example microscopes, amplifiers, or more recently artificial noses or tongues. Sensory science will be essential in order to calibrate the instrumental responses of these tools.

In the world of science and technology sensory science is considered a less challenging discipline, while these same issues are considered problematic in psychology and humanist sciences: technologists do not trust human measurements, and humanists protest against the concept of human beings as measuring tools. Sensory evaluation proposes to use structured tests based on precise protocols in order to quantify perception and assign the latter all the characteristics of scientific measurements (reproducibility, repeatability, possible comparison with historical data, statistical importance and reliability): the result is a sensory, analytical, and quantitative profile. The book will illustrate and discuss several sensory evaluation methods, evaluation tools, and several case studies of methods and studies conducted with different goals: they will be compared with other methods and studies and will be used as the basis on which to develop a new methodology.

### *1.1.1 Sensory evaluation methods*

The primary objective of sensory evaluation is to satisfy the consumer, in other words, to design a product with the characteristics indicated by the consumer. It is difficult to define the characteristics and sensations a product inspires in a consumer because the language

[6] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva*, UTET, Turin, pp. 102-112.

[7] Rigano L., D'Agostino R. (2002), "Il codice dei sensi nella percezione del prodotto tessile", in *Proceedings of the 2nd Meeting Tessile e Salute*, Biella; Rigano L., D'Agostino R. (2001), "Valutazioni di innocuità e misure della percezione sensoriale nel campo tessile", in *Proceedings of the1st Meeting Tessile e Salute*, Biella.

we all use contains a whole range of adjectives which consumers use subjectively and in many different ways.

So we need a tool which can provide an comprehensive description of the product and define its improvements without focusing only on the spontaneous perception of a consumer, or on imperfect evaluation measures which do not reflect perception.

Current sensory evaluation methods include established and verbalised measurement techniques used both by industry and research centres. To provide a fairly reliable sensory description of a product we need to first understand the kind of assessment required and then identify the responses we are looking for. Perceptive characteristics cannot be measured using standard equipment, nor can they be easily expressed in numbers. Sensory parameters often determine whether a user accepts or rejects a product, whether he likes it or whether it upsets him. We use sensory evaluation throughout our lives: we sniff, touch, look, listen, and taste. Our senses are crucial to control the environment, preserve life, and improve social behaviour.

The process of quantifying perceptions differs depending on the field of application (food, textile, cars, etc.). Nevertheless, sensory evaluation methods must be reliable (reproducible in statistical terms when properly conducted), pertinent (since sensory quality refers to the perception of a product by human beings, sensory evaluations are more valid and relevant to the final goal compared to measurements with technical instruments), and consistent (considering that the human brain has an incredible ability to correct evaluations compared to interferences: what is complex for chemistry and physics is much simpler for the human eye and nose).

The perceptions which reach the brain are decoded based on two main evaluation principles: analytical and hedonic. Analytical sensory tests include discriminative and descriptive methods, in other words they define the differences between products, and their magnitude (the intensity of the colour yellow, the softness of a fabric, the dark colour of a suit, or how much and in what way does fabric reflect light). Instead the hedonic method establishes which products are preferred by the consumers/individuals evaluating the product. [8]

[8] Pagliarini, E. (2002), *Valutazione sensoriale,* op. cit., p. 39.

### 1.1.2 Discriminative methods

One of the analytical methods is called a discriminative evaluation method because it can quantitatively differentiate samples without defining the magnitude and type of their differences.

In practice, discriminative tests answer the question 'is A different to B?' without going into the details of why A and B are different. The evaluation response is objective and qualitative insofar as it never describes the magnitude of the differences and often ignores the number of factors which influence this difference.

This kind of evaluation is based on the assessment of the sensory perceptions of a group of individuals, the assessors, who have undergone simple training in order to perform these tests.

The results obtained from the analysis of each assessor are then statistically processed to make them all comparable. Three different evaluation systems exist depending on the assessors involved in sensory product evaluation:

- **Evaluation by experts:** performed by a group of people with a certain expertise in the type of product to be analysed, in other words 'experts'. This measurement method is based on the evaluation of the first impression of the object in question; this makes it possible to highlight small differences which are very useful when screening different processing methods or versions of the same product. One disadvantage is that this kind of survey is heavily influenced by the experiences of each assessor and the fact that first impression evaluation cannot be repeated, in other words, it is difficult to compare this analysis with other evaluations (either carried out by the same person at different moments in time, or by other experts).
- **Evaluation by consumers:** performed by a certain number of consumers (minimum 150 interviewees) and used to analyse the concepts, colours, or shapes of a product. In this case, the consumers/assessors are guided during their test by a series of questions about the features of the product in question. The main problem associated with this approach is the fact it is an expensive evaluation system because it involves lots of people, and the

questions guiding the assessors when they formulate their response may not be correctly balanced.

- **Evaluation by in-house experts:** performed by a group of employees working for the manufacturing company and therefore more familiar with the product in question. This kind of evaluation could replace the ‘consumer test’; furthermore, since it involves company employees it could also be less expensive. Unfortunately, however, the evaluations provided by these employees are influenced by the fact they not only depend on the company, but are also influenced by their own affectivity towards the product. As a result, the responses submitted by these assessors are not representative of the target consumer. Moreover, like the expert evaluation, this evaluation system is based on immediate perception assessment, so it is never possible to repeat these evaluations in controlled situations. Statistically speaking the results may not be entirely reliable.

Finally, another interpretation and classification system of these seemingly simple tests[9] is to separate them according to the study object and the aim/objective of whether or not to concentrate on a reference product. This makes it possible to divide discriminative tests into ‘directional paired comparison’ tests (which fabric is softer?) or ‘difference paired comparison’ tests (which fabric is equivalent to the standard reference?): in turn they can be broken down into more types. The most common are:

- the test known as ‘paired’ used to examine several samples at the same time; this test is based on a series of comparisons between pairs of objects/materials;
- the test known as ‘duo-trio’ in which the assessor is asked to compare two samples against a reference product, which in actual fact is identical to one of the two tested products; the aim is to evaluate whether the different product can be identified;
- the ‘triangle’ test conducted by comparing three products as in the previous test, but without a standard reference sample.

[9] Rigano L., D’Agostino R. (2002), “Il codice dei sensi nella percezione del prodotto tessile”, op. cit.

### 1.1.3 Descriptive methods

Our brain can analytically decipher sensory perceptions using both discriminative and descriptive methods. Descriptive methods[10] are used to describe the perceived sensory characteristics of a product in order to quantify the differences between products.[11]

Descriptive analysis involves all visual, olfactory, gustative, and tactile sensations experienced during product evaluation. The sensory profile analysis is a technique/analytical system which in 1974 the Tragon Corporation[12] developed further; the result was the creation of the Quantitative Descriptive Analysis of a sensory profile. This descriptive analysis method uses linear scales, responses, descriptors, and analyses of variance to describe the sensory profile of a product.

Evaluation is performed by trained sensory groups or panels which, thanks to the use of this 'tare' (in other words linear scales or descriptors), can spot even very small differences between the analysed products. In other words, the panellists elaborate the intensity of the perceived stimulus with a certain degree of specificity and in a quantitative manner.

These measurements are suitably converted/transformed into numbers thanks to the use and guidance of these descriptors; they are then statistically processed to obtain an objective, quantitatively expressed, and graphically represented, sensory profile.

Descriptive analysis can thus achieve a degree of specificity/sensitivity roughly a thousand times greater than sensory evaluations and analyses based on the perceptions of a standard consumer. This improved specificity is also based on the following concept: attributes not perceived by trained assessors will never be perceived by consumers.

Another advantage of this sensory profile analysis technique is the fact it can be used by any market because it is independent and does not depend on consumer preferences and habits. However, this could

[10] Reference UNI U590A1950, 1998.

[11] Pagliarini E. (2002), *Valutazione sensoriale*, op. cit., p. 61.

[12] Quantitative Descriptive Analysis is a descriptive analysis method developed by the Stanford Research Institute in 1972. In 1974, the Tragon Corporation modified the sensory profile method and created the quantitative descriptive analysis, defining it as a 'Conventional Profile QDA'. Pagliarini E. (2002), *Valutazione sensoriale,* op. cit., p. 112.

also be considered a shortcoming; a pH-meter does not say whether a low or high acid value is suited to the skin; likewise, sensory descriptive analysis does not clarify whether a consumer will like a sensory variable. This is the task of consumer surveys.

### *1.1.4 The trained sensory group*

The trained sensory group or sensory panel is a group of people trained to identify and quantify their sensory perceptions during standard product testing conditions. The individuals used as panellists in analytical or hedonic sensory analysis are, generally speaking, qualified individuals, often people who use the product and who either have naturally good sensory skills, or have actually developed them.

To become a member of a sensory panel, assessors usually have to pass a series of tests which determine or evaluate their sensitivity (tactile, olfactory, visual etc.) and their ability to correctly express a verbal evaluation.

Once the individuals are part of a trained sensory group they undergo group training for several months during which they learn to: scale the sensory magnitudes in question, use standard references, correctly repeat the sensory test several times, develop a common expressive language for the same magnitudes, and avoid using terms related to the pleasure of the sensations (hedonic aspects linked to consumer perception).[13]

Training takes place twice a week for many months in order to achieve the statistical repeatability of collective results. Training levels vary according to the type of sensory test; they range from the most complete (descriptive tests) to ones with medium difficulty (discriminative tests). The panellists become real measurement tools, providing accurate, reproducible data which can then be statistically processed.

[13] 'Hedonic evaluations closely linked to consumers or final users are used when trying to evaluate consumer acceptability and establish whether one or more products are preferred to others'. Pagliarini E. (2002), *Valutazione sensoriale,* op. cit., p. 66.

No special training is required by sensory panellists who perform hedonic tests, in other words tests intended to identify the products preferred by final users/consumers, and therefore based on hedonic aspects linked to consumer preferences.

Nevertheless, whether tests involve analytical or hedonic sensory testing, the sensory panel- and therefore the individuals involved -are the main protagonists; they are the tool to measure perceptions linked to the specific sensory characteristics (gustative, tactile, visual, etc.) of the tested materials and products.

Several tools have been developed to facilitate panel members in the evaluation of sensory perceptions and help them evaluate and define sensory measurements. These tools are usually based on a comparison between the materials to be described and reference materials: human beings are the measuring tool. These empirical tools, such as Sensotact® developed by Renault®,[14] make individuals and their perceptions the hub of the measurement system; they are used in conjunction with traditional technical and scientific tools to not only analyse the tactile or optical/visual properties of scientifically recognised and classified materials, but also measure the physical and mechanical properties of materials.

The tools used to measure the sensory characteristics of a material will be presented in detail in the next subsections; after a short description of the sense involved, a comprehensive description will be provided of all the tools used to perform empirical or technical measurements.

## 1.2 The five senses and the empirical and technical tools used to measure perception

### *1.2.1 Sight*

Sight is the sense which we trust almost blindly when we explore the world around us: this is why it is considered the most important of all our senses. To see involves turning light rays into nerve impulses understood by our brain.

[14] Cfr. Chap. 1, Sensotact®.

When the eye, the organ of sight, is stimulated by light rays from external objects it sends messages to the brain which interprets them and turns them into images.

The eye is an almost perfect sphere, the eyeball, divided into several layers or coats and several components; located inside the socket it is protected by lids and lashes. The window through which light enters is called the pupil. The iris expands and contracts the pupil according to the amount of ambient light, just like the diaphragm of a camera lens. Light then crosses the lens and the eyeball and creates an upside-down image on the retina; this stimulates the nerve cells of the retina, the cones and rods, which send the information through the optic nerve to the brain which interprets and classifies it.

All this takes place when we look at a painting or landscape, read a book, or work on the computer. Furthermore, three-dimensional vision and the possibility to understand how far away an object is depends on the fact we have two eyes: the information received by the eyes is processed by the brain, even if this can sometimes create a contrast between the two eyes.

In fact, our vision is dominated by one of the two eyes: one eye will be on a straight line with the object; while the other eye will be slightly off centre. The information we receive through our eyes gives us a stereoscopic image of the world around us; however, sight can be deceiving, because the images we see create confusion in our brain. For example, just think of optical illusions. In fact, to understand the messages it receives from our eyes the brain uses innate and acquired mental models[15] based on our experiences, and then compares the data seen by our eyes with the images we remember: if the image does not correspond to our mental models, the difference between the visual image and the one in the brain creates an optical illusion. Several artists have played with these

[15] 'We can consider a mental model as the basis, or rather, the nature of what shapes the information we receive. […] A model will never include everything that exists, because it is, in itself, a selection, a choice of elements, of relationships which can explore various aspects of reality in-depth, and on different levels; no empirical phenomena will, however, ever have complete models. […] In fact, a mental model is not a copy, but rather a synthesis of characteristics and relationships based on what we perceive'. Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., p. 23.

images and created masterpieces. Many images can be hidden in a drawing: what we perceive depends on the detail we focus on. So it's true that sometimes reality is not really what we see: and sight can play tricks on us.

## Brightness scale, Lightness Meter, and colour systems

The most widespread and well-known tools to empirically evaluate the visual characteristics of materials include: the brightness scale, the lightness meter, and several colour systems (Pantone, RAL and CIE).

The NCS Gloss scale, developed in 1996 by the Natural Color System (NCS),[16] is a tool that measures[17] the qualitative brightness/opaqueness of surfaces (direct comparison between the material to be tested and the various samples provided) and their quantitative brightness/opaqueness (thanks to the measurement on the back of each sample provided with the tool). The gloss level can vary from 0 to 100: level 0 corresponds to a totally opaque surface, and 100 to a shiny glossy black sheet of glass.

Determining the degree of brightness requires samples that can define surfaces with different brightness levels. This is why the brightness scale includes white, black, and grey. Each of the three colours is represented by six nuances of gloss.

Furthermore, the NCS manufactures a Lightness Meter (NCS[18]); this tool visually records colour luminosity. It is has 18 samples of neutral grey taken from the 1950 standard NCS colours. The NCS notation, the NCS lightness, and the value of the luminous reflectance factor is provided for each of the samples.

[16] Natural Color System, www.ncscolour.com

[17] Rognoli V., Levi M. (2004), *Materiali per il design: espressività e sensorialità*, Polipress, Milan, pp. 106-107.

[18] The standard NCS product range is a efficient tool in any field and for any material. There is no longer any need to use different colour codes, because NCS makes it possible to cross-reference many different kinds of materials. NCS Color Center Italia Srl.

Pantone[19] proposes an excellent method to describe a colour based on sample comparison; it provides special colour selection tools including comparative tables and descriptions of the identified colour. In fact, the Pantone system works by comparing the material to be tested with samples provided by the company itself: once the chromatic reference is established, it is described using the code for each colour sample. The Zanichelli chromatic Atlas[20] is another colour system which uses halftone prints to make comparisons.

The Munsell Books of Color are like the Pantone system; they are reference guides used to select and communicate colours: available in countless nuances, they are used in many fields such as art, design, packaging/products, colour specification, and quality control. The RAL system, [21] which provides a scale of normalised colours, defines a normalised colour system.

All these guides are based on the Munsell colour system, a three-dimensional chromatic system classifying the nuances of perceived colour. The sensation we feel when the eye-brain system sees a colour is characterised by three psycho-sensorial values: the colour or hue (hue=H) which defines the colour, green, red, etc. The colour physically depends on the dominant wavelength. The wavelengths of the visible spectrum range from 400 to 750 nanometres. Luminosity or brightness (value-L) is the reflection factor of a colour and physically corresponds to the quantity of light energy reflected by a colour which can be defined as light or dark. With less black, a colour will be lighter; light red will have more light than a darker red. Saturation or purity (chroma-C) is the intensity of a colour and physically depends on how light is distributed across the spectrum. A saturated colour will have no white.

The 1976 l*a*b* CIE model[22] has three coordinates which make up the three-dimensional colour space in which each point represents a different colour. The coordinates L*, a* and b* are, therefore, the

[19] Pantone Inc. is the US company which invented the colour identification system; this system has become an international standard in the field of graphics and has lately been used to manage colours in industry and chemistry; www.pantone.com

[20] Scotti D. (1989), *Atlante cromatico. Prontuario dei colori*, Zanichelli, Bologna.

[21] Originally the acronym for Reichsausschuss fur Lieferbedingungen, the RAL system defines a normalised scale of colours.

[22] The standards to define colour have been established by the International Commission on Illumination (CIE).

three coordinated axes of space: the coordinate L* (brightness[23]) measures the greater or lesser transparency of the sample; the coordinate a* measures the greater or lesser tendency of the colour towards red or green; and the coordinate b* measures the greater or lesser tendency of the colour towards yellow or blue.

## Refractometer, glossmeter and spectrophotometer

The main technical tools used to evaluate the visual perceptions caused by materials are: refractometer, gloss meter, and spectrophotometer. The refractometer is an optic tool used to determine the index of refraction of a substance, normally its transparency. Transparency is described by the quantity of light transmitted by the material through which it passes. If the index of refraction increases, the amount of transmitted light decreases, and as a result so does transparency. In practice, thanks to the different kinds of refractometers now available it is possible to quantitatively evaluate the degree of transparency not only of a material, but also of a gas, a liquid, and transparent or translucent solids such as minerals and gems.

The glossmeter[24] is used to measure the brightness/opaqueness of a surface. The instrument emits a ray of light which hits the surface of the material; some of the light is absorbed and some reflected. The gloss is the ratio between reflected and incident light expressed as a percentage. Before taking the measurement the instrument must be calibrated on a surface with a known gloss. Instead a spectrophotometer is a tool to measure the interaction of light/matter with a material. A spectrophotometer can be used to determine the absorption spectrum of a substance which can be portrayed in a diagram showing the intensity of radiation absorbed according to the

[23] Brightness is an attribute of a visual sensation caused by superficial bodies in relation to white, the reference colour; it represents the fraction of diffuse reflected light: for more information, see Oleari C., edited by (2008), *Misurare il colore*, Hoepli, Milan, p. 209.

[24] *Dizionario Enciclopedico Scientifico-Tecnico*, Inglese-italiano, Italiano-inglese (1994), Zanichelli, Bologna, p. 639.

wavelength and where it is easy to recognise maximum absorption of the substance along certain wavelengths.[25]

### 1.2.2 Touch

For most people touch means to touch, finger, or handle an object: but touch also means to feel (hot, cold, smooth, heavy, etc.), and for some people even to see; the visually impaired, for example, use their fingers to read using Braille and to recognise objects or the faces of people they meet. The skin is the real organ of touch: it is a defence against, but also a window onto the world around us; the skin feels external stimuli and protects the body from being harmed, etc. The outermost layer of the skin is called the epidermis. The derma underneath contains Meissner's corpuscles, the receptors of touch; when the skin comes into contact with an object, these receptors send messages to the brain; the derma also contains free nerve endings (cutaneous receptors) which when stimulated beyond a certain threshold send impulses to the nerve centres (through contact, pressure, heat, etc.). It also contains Pacinian corpuscles, receptors of pressure, which send messages to the brain when the skin is subject to a certain amount of pressure.

The whole body is covered with nerve endings: on our fingertips, the tip of our tongue, lips, etc.: different kinds of receptors present in different quantities; pressure receptors, heat receptors, and pain receptors.

Touch is a complex and unique sense: receptors are present all over our bodies and in some areas are more sensitive. On the one hand, touch in humans is considered the sense with the shortest action radius; on the other, it is considered the sense with the greatest range because it is not located in just one organ like the eye or ear:

[25] Spectrophotometry measures the characteristics of solutions that absorb the radiation of the electromagnetic spectroscopy between infrared and ultraviolet. The spectrophotometer is a tool made up of: a source of electromagnetic radiation (infrared, visible light or ultraviolet); a monochromator to select the wavelengths; a sample holder; a photoelectric transducer; an electronic amplifier with a linear-to-logarithm converter and a display or a recorder. For more information, see the *Enciclopedia Scientifica Tecnica Garzanti* (1969), vol. 2, Garzanti, Milan, p. 1639.

this is why it has special qualitative and quantitative characteristics. Quantitatively speaking it is a sensory system that provides the greatest amount of information about the world around us. Touch has a cognitive value.[26] Instead, from a qualitative point of view, touch uses manipulation to access areas difficult to reach with other senses. In fact, touch is based on the movements of our hands and body. Touch allows us to explore the world: in fact, small children grab, paw, fiddle with, and even put in their mouths everything they can get their hands on.[27]

During haptic exploration the object and hand move constantly over the object and reveal its three-dimensional shape and other features-weight, texture, profile, and heat. However, unlike sight and hearing, touch cannot perceive stimuli that come from a great distance; compared to visual movements, tactile movements are slower and require more time.

Furthermore, touch is a dual sense: it coincides with the perception of one's body at rest and while moving (somesthesia), as well as with the perception of external stimuli in sensitive areas, such as our hands.

## Sensotact®

Sensotact® is a useful empirical tool to measure the sensations perceived through touch. It is a tactile reference system created in the sensory analysis laboratory at the Renault Technocentre and is marketed by the French agency Quinte&sens. The tool was designed to facilitate exchanges between agencies, avoid misunderstandings and confusion, and create a tactile reference frame to promote a common language.

Everyone can access Sensotact®. Although no special training is needed to use it, product familiarisation courses are organised by the manufacturing company. In practice, Sensotact® is a small suitcase

[26] Mazzeo M. (2000), "L'origine tattile della geometria Merleau-Ponty e il triangolo" in *Le tattiche dei sensi*, Libri Montag, Rome, pp. 73-76.

[27] Hall E.T. (1966), *The Hidden Dimension,* Anchor Books, New York.

with 10 descriptors and 50 references which interact to provide the sensory description of a product.

The Sensotact® method divides touch into ten descriptors associated with three main movement patterns: static contact (heat perception), orthogonal movement (stickiness, hardness, shape memory, nervosity) and tangential movement (slipperiness, fibre content, roughness, smoothness, three-dimensionality/relief, adhesion and coarseness).

*Fig. 1 - The three Sensotact® movements*

By developing a common language, Sensotact® can be used in many fields: cosmetics, the automobile industry, aviation, and even sports and the textile industry.

Short tactile evaluation videos on the Sensotact® website[28] illustrate how easy it is to immediately perform tactile evaluation: the short videos show the three movements (static contact, orthogonal movement, and tangential movement) and each descriptor (damping factor, relief, roughness, etc.).

## Roughness meter, 'dito termico', indent-o-meter, hardness meter

Apart from an empirical tool such as Sensotact®, several technical tools are also widely available to evaluate the tactile characteristics of a material, for example the roughness meter, the 'dito termico' [heat finger], the indent-o-meter and the hardness meter.

[28] www.sensotact.com

The roughness meter[29] is a tool to measure and evaluate the roughness or unevenness of the micro-irregularities on a surface. It can accurately measure up to a thousandth of a micron. Furthermore, tools such as the Banco Stick&Slip[30] can also be used to evaluate the roughness or coefficient of friction of a surface. This tool has two parts: a small sliding track on which the samples are placed, and a piston that exerts a variable pressure, from 5N to 30N, on the sliding track. This allows the Banco to establish the coefficient of friction of a surface. The Banco also monitors air temperature and humidity because variations can significantly affect the test; for the result to be as accurate as possible tests have to be conducted in conditions where the temperature and humidity are constant.

Instead the 'dito termico' is a tool developed by the Centro Ricerche Fiat; it can record the speed which with heat is exchanged between the surface of a body (with a 34°C temperature) and any surface at ambient temperature. In fact, the speed with which the two surfaces reach the same temperature is linked to the intensity of the perceived sensation of hot and cold (hotter or colder).

In turn, the indentometer is a tool to measure the millimetric indentation of a surface. A protruding steel ball is placed at one end of the tool. Calibration takes place through measurement on a rigid surface corresponding to a 0 mm subsidence; in this case the ball retracts completely (equivalent to - 6 mm). The hardness of the surface in question depends on how far the ball sinks into the material.

Finally, the hardness meter[31] is a tool to measure the hardness of materials. There are many different kinds of hardness meters, each used for a specific purpose and each with their own measurement scale. To measure the hardness of a material, the hardness meter makes an indent on the material, leaving a mark in the tested point. It is important to note that the test cannot be repeated in the same

[29] *Enciclopedia Scientifica Tecnica Garzanti,* op. cit., vol. 2, p. 1512.

[30] Duò F., Tomalino F., *Valutazione multisensoriale applicata ad un componente Automotive* [degree tesi]. Rapporteur: De Giorgi C.; Co-rapporteur: Peyron B., Politecnico di Torino, I Faculty of architecture, Academic Year 2005/2006.

[31] *Grande Dizionario Enciclopedico* (1956), UTET, Turin, p. 873

position (or even near other marks) because the surface near an indent-mark is geometrically and structurally modified.[32]

Instead the Kawabata Evaluation System differs from all the technical tools illustrated so far. This system uses sensors which perceive even minimum values to objectively evaluate fabrics, to measure traction, compression, shaving, flexion, bending, friction, and roughness. Analysis is based on two approaches: the first involves the transfer of heat which can be absorbed by the surface in order to determine whether the fabric feels hot or cold when it is touched. It is then possible to identify which surface is softer and cooler to touch by analysing the ratio between the two parameters and afterwards deciding how to optimise them.

### *1.2.3 Hearing*

Traffic, rain on glass, a Mozart quartet, or a telephone ringing can all be considered either as pleasant or unpleasant sounds or noises: but they are all heard by the same organ - the ear. Three variables dictate whether or not a person hears a sound or noise: the level of the sound (determined by the frequency of the oscillations of the sound wave), its intensity (determined by the width of the oscillations) and timbre (determined by the total number of harmonics accompanying the sound).

The ear is a very complex structure made up of bone, cartilage, hair cells, and liquid; it is a structure that allows us to listen and keep our balance. The three main components of the ear are: the outer ear, the middle ear, and the inner ear. The pinna, in other words the outer ear, is the cartilaginous component that captures the sound waves and directs them into the auditory canal where the waves cause the eardrum to vibrate. Should the eardrum break, then sound waves will pass through the tear and the membrane will no longer be able to transmit the vibrations: rupture of the eardrum causes deafness which

[32] In general this tool is used to determine the specific weight of a rock. In applied petrography, the specific weight of a rock is determined by the ratio between the weight of the rock sample and the volume occupied by the solid part of the sample itself.

can be due either to a specific disease or to a dysfunction of the hearing organ.

Before reaching the brain sound passes through the inner ear where the vibrations are turned into electrical signals which first reach the medulla oblongata and then the cortex, the most developed part of the brain where sound is classified and understood. The labyrinth, the organ of balance located in the inner ear, reacts to the rotation and movement of the head and to accelerations.

The cochlea, the most important part of the ear, is the organ of auditory transduction: it is a bony, spiral-shaped structure covered in hair cells of the Organ of Corti which transmit the sound received by the ear to the acoustic nerve.

However, we cannot hear all kinds of sounds: we perceive only the sound waves between 16 and 12,000 hertz; sounds with a frequency lower than 16 hertz are called infrasounds, whole sounds with a frequency higher than 12,000 hertz are called ultrasounds (heard by bats, dogs, cats, and cetaceans). We perceive sounds and noises between 16 and 12,000 hertz: the difference between sounds and noises, between pleasure and unpleasantness, is rather subjective.

Studies have shown that sound influences speech. In fact it's not surprising that language genes evolved at the same rate as the genes which perfected our ears and areas of the brain that receive the stimuli of the acoustic nerve. Furthermore, what we hear also influences what we say. Our speech quickens when we talk to someone who talks quickly, while it slows down if we talk to a slow speaker.

This depends on our desire to 'get on the same wavelength' with the other person, and is a completely involuntary.

Individuals who grow up in totally different cultural environments learn from infancy to reject certain information and focus on others.[33] For example, although the Japanese use very advanced technologies, they are quite happy to use paper walls as acoustic screens: for westerners, sleeping in a hotel room next to another room where there's a party is a truly novel experience! Europeans, especially the Germans and Dutch, protect themselves from noise by building thick

[33] Hall E.T. (1966), *The Hidden Dimension,* op. cit.

walls and double doors; they find it very difficult to trust in their powers of concentration to avoid acoustic interference.

Acoustic interference can be noise, but also music: it all depends on the context. 'Several studies have shown that slow music in a shop can help increase sales by 38% because people tend to spend more time in the shop and are therefore more subject to its persuasive communication. In other places, such as fast foods, the rhythm of the music is very fast and this can increase turnover at table because people tend to eat quickly'.[34] All this takes place unconsciously; people are unaware that this is how they tend to behave. In other situations, music can become a threshold and help to create an atmosphere: for example, music is piped into the parking area of big shopping malls or Walt Disney amusement parks to prep the potential consumer by influencing his mood before he actually gets there.

## The xylophone and hands-on manipulation of materials

The empirical tools used to record the sound intensity of the test samples generally provide a sensory evaluation which does not attribute a universal and objective value to the tested sample; instead the test is intended to help choose which material can be used to manufacture an object.

Several different and more or less sophisticated empirical tools can be used for this purpose.

The xylophone can be useful to analyse the sound quality of a material sample; it was used, for example, by Materioteca®[35] to classify plastic materials according to their sound. In fact, a xylophone is a percussion instrument with a graded series of wooden, steel, or glass bars; when struck with wooden drumsticks, each bar corresponds to a musical note.

Another empirical way to evaluate the sounds produced by materials can be achieved by rapping one's knuckles on the

[34] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., p. 95.

[35] www.materioteca.it

materials, or trying to bend the samples, in other words by manipulating the sample materials This method will provide an approximate but immediate and practical evaluation of how robust, fragile, or ductile a material is.

#### The sound level meter

The sound level meter is one of the most well-known technical instruments used to measure sound. ‘An instrument which measures sound pressure level, usually calibrated in decibels’.[36] By measuring sound pressure, the sound meter elaborates the signal to obtain the descriptor indexes typical of noise measurements: level of sound pressure (Lp), equivalent level of sound pressure (LAeq), percentile levels (LN), etc. The market offers several sound measurement systems, even if each system can be schematically reduced to three components: a microphone, a data processing unit, and a data interpretation unit.

### *1.2.4 Smell*

‘Smell is one of the most primitive and basic means of communication. It has a chemical structure and is considered the ultimate chemical sense. It performs several functions […]’.[37] As man evolved he maintained this sense to which he now attributes a new and important role as a powerful activator of emotions and memory-more powerful than sight or hearing.

The sweet smell of wet grass, the aroma of coffee in the morning, or the fragrance of a bunch of flowers, etc., are all different smells, but they are all imbued with memories. ‘The warm fragrance of an embrace. The sensual scent of skin. Of the sea, of hay, of cut grass, or the cakes of our childhood. A society long dominated only by what it sees, hears, and touches, washed and perfumed, is ready to rebel: smell is no longer a taboo. It has become part of marketing

[36] *Enciclopedia Scientifica Tecnica Garzanti,* op. cit., vol. 1, p. 733.
[37] Hall E.T. (1966), *The Hidden Dimension,* op. cit.

strategies, psychological studies, trends, and fashion […]. Some people have flown over the Amazon to try and bottle the air of the forest to make ecological perfumes. In shops, scents are diffused to induce purchases, and in offices to increase productivity'.[38]

For most mammals the sense of smell is absolutely crucial; it helps them find food, to locate the herd, and mark territorial boundaries. 'The sense of smell reveals the presence of an enemy, and can even become a defence weapon, for example for skunks'.[39] Since we do not need to escape from predators or hunt for food, we no longer make good use of our sense of smell. But we like to wear perfume and as humans have our own unique smell, different to everyone else's, a smell which we sometimes do not even perceive ourselves.

But Jean-Baptiste Grenouille can perceive them. The protagonist of Suskind's film 'Perfume. The Story of a Murderer' is an intelligent and ambitious character whose features are linked to the fleeting reign of smell. He doesn't need light to see and often keeps his eyes shut for hours during the day, following only his nose. 'He did not steer by magnetic compass, but only by the compass of his nose which sent him skirting every city, every village, every settlement'.[40]

Like taste, the sense of smell is very difficult to analyse compared to other senses. 'It's difficult to accurately reproduce the memory of a flavour and a scent in our minds; generally speaking we tend to remember the feelings we experienced in that particular situation (a pleasant taste, an unpleasant smell, etc.)'.[41] The two senses obviously differ because they have different physiological characteristics, but also because taste is a contact sense, while olfaction is a remote sense. How exactly do we recognise a smell? The nose, the olfactory organ, has two nostrils which open inside the nasal cavity lined with a mucous membrane and olfactory hairs. The latter, called dendrites - nerve fibres which send nervous impulses- are the receptors. The impulses received by the receptors are then interpreted as olfactory

[38] Bonetti A. (2004), "Ci vuole naso", op. cit.

[39] Hall E.T. (1966), *The Hidden Dimension,* op. cit.

[40] Süskind P. (1986), *Perfume: the story of murder*, Knopf, New York.

[41] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., pp. 98-99.

sensations in the area of the brain that controls thought and reactions and can tell us the name of the smell we have just sniffed.

Our nose tells us where we are. Every city has its own smell: travellers say that New York smells of cucumber; New Orleans of salty water; Lisbon of fish, India of cinnamon and incense. 'Enough, God willing we've landed, the engines have been cut off and they've opened the doors: well, when they opened them it seemed that lukewarm water rather than fresh air had come into the cabin, water with a special smell, a smell you smell everywhere in India: a thick smell, a mixture of incense, cinnamon, sweat and decay'.[42]

Not everyone has the same nose: recent studies[43] maintain that a woman can recognise not only her partner's vest among dozens of other vests, but can also remember the smell of the unknown child she held in her arms for one hour. Youngsters, instead, seem to be less sensitive to bad smells: in fact, they're not in the least disturbed by a very smelly sock.

Olfactory consumer products can be divided into two large groups: products which produce a smell and those which eliminate them. The former include perfumes, food, and flowers; these products try to enhance their symbolic and emotional component. Products which instead propose to eliminate certain smells, such as deodorants for the body or the home, toothpastes, or even sweets, are normally associated with the idea of rejection or with an unpleasant situation in public places. 'Due to their cultural conditioning, Americans have an underdeveloped sense of smell. The widespread use of deodorants and the elimination of all smells from public places have made our country a wasteland of olfactory flatness and uniformity'.[44] Obscuring smells impoverishes our life experiences and obscures our memories, given that smells conjure up our deepest memories.

[42] Levi P. (1978), *La chiave a stella*, Einaudi, Turin, p. 106.
[43] Giammatteo C. (2004), "Questioni di naso", Focus Extra, May-June, n.18.
[44] Hall E.T. (1966), *The Hidden Dimension*, op. cit.

## Olfactory memory

'Smells have the incredible ability to let us relive episodes of the past with an unparalleled immediacy and vividness when compared, for example, to the sense of sight and hearing'.[45] The memories that surface after perceiving a certain smell are normally linked to a stirring of the soul, to a feeling, to joy, pain, tension, etc., depending on the association between the smell and the significant event.

We all know how intensely a smell can revive the past: the fragrance of a soap or the smell of tobacco is very compellingly and can make us relive a situation.

Olfactory memory is emotional, whereas visual and eidetic memory are cognitive. Olfactory memory is governed by its own laws which differ from the laws governing other systems. Furthermore, olfactory stimuli remain in our memory for a very long time and can surface years later. However these stimuli are not easy to define, in other words it's not easy for a person who recognises a smell to recall the attributes that complete the memory. A visual stimulus is easier to define and memorise because it has more attributes.

Another characteristic which sets olfactory memory apart from visual memory is the fact that once the association between a smell and an event has been established it will be very difficult to create another association between the same smell and another event.

Another difference involves 'intentional or incidental learning with different rates of stimuli. In fact, if individuals are specifically asked to concentrate on the experimental material, because a memory test will follow immediately afterwards (intentional memory), the performance of those individuals will be no different to other individuals who are not given this information (incidental memory), or whose attention has been shifted to aspects other than memorisation (for example, the appeal of the stimuli)'.[46]

Furthermore, it's very difficult to name a smell. Generally speaking, to describe a smell, for example the smell of a country house, we use important episodes in our lives, but we are unable to

[45] Zucco G. (2000), "Olfatto: unicità di un senso", in *Le tattiche dei sensi,* op. cit., p. 57.
[46] Ivi, p. 60.

communicate to those around us the sensations which are clear in our minds. The sense of smell has unique characteristics: it is a system which seems to elude the laws of elaboration of stimuli associated with other senses such as sight and hearing.

## The Aroma Wheel

One of the most popular empirical tools to analyse wine is the Wine Aroma Wheel developed by the ASEV Association in America in 1987. [47] This tool classifies on three levels the aromas found especially in wines: very general terms are located in the centre, going to the most specific terms in the outer tier (for example: fruity aroma → citrus fruits →lemon; fruity aroma → soft fruits → black currents; woody aroma → resinous wood → oak; vegetal aroma → plants → eucalyptus, etc.).

Tools like the Aroma Wheel have been developed to facilitate the description of aromas by assessor 'judges'. When we refer to the sensory evaluation of wines, we normally speak of sommeliers, professionals who can perform an organoleptic analysis to assess type, quality, characteristics, and the potential conservation of a wine.

Furthermore, we must not confuse sensory analysis with tasting, even if there are only very small differences; 'in many cases tasting and other similar forms of evaluation simply tend to establish whether or not people like a product. This is important, but not enough to decree the success or failure of a business. Sensory analysis tends to scientifically establish how much people like a product, who likes it, and why they like it; it also tests the difference between several products and establishes their organoleptic profile'.[48]

[47] American Society for Enology and Viticulture (the sciences of winemaking and grape growing), USA, www.asev.org

[48] www.assaggiatori.com

## The electronic nose

The electronic nose is a tool which tries to replace the human olfactory system and make measurements objective. The sophisticated software[49] developed for these 'recreated noses' is able to file and preserve the incredible number of perceived smells classified by the electronic nose.

The electronic nose has three important structural components: the matrix of the chemical sensors to record the smell, the system to process the response of the sensors, and the system to recognise and classify the smells.

Many studies are currently being conducted to explore the practical uses of an electronic nose, such as environmental monitoring and the analysis of food aromas. Studies also focus on the field of medicine, chemicals, and cosmetics, as well as risk prevention through the identification of dangerous substances.

Research in Italy is very dynamic: in particular the Department of Electronic Engineering at Tor Vergata University, coordinated by Arnaldo D'Amico and Corrado Di Natale, which since 1995 has designed electronic noses and developed high resolution chemical sensors.

### *1.2.5 Taste*

This is the first of our senses to develop; in fact babies use their mouths to discover the world and objects. Evolution has given us a sense of taste so that we can immediately identify nutrients, which are normally sweet, and toxic food, which is normally bitter.

The tongue, the organ of taste, is a muscle covered with numerous gustatory papillae; together with its support cells, the receptors inside the papillae make up the rounded-shaped taste buds. Saliva is located in trench-like channels around the papillae. The taste buds are hair-like sensors arranged in clusters along the sides of these channels;

[49] 'Using dedicated software it is possible to define a histogram representing the precise 'physiognomy' of a smell, its identity: a sort of digital footprint'. Gambaro F. (1996), "La fine del consumatore standard", *Stileindustria*, December, n. 8, pp. 57-59.

they all contain taste pores, in other words the receptors of taste. Saliva fills the grooves bringing the dissolved molecules into contact with the pores. The chemical components of food stick to the pores: some are specialised in detecting sweet foods, while others can identify bitter, salty, or sour foodstuffs. The pores then convert the chemical stimulus into an electrical signal that travels along the nerves to the brain where it is interpreted as a gustative sensation.

Since the tongue only allows us to differentiate between four basic flavours, the nose is the most sensitive tool we have to perceive many flavours: when we have a cold, the closure of our nasal cavities stops us from perceiving the volatile part of flavours.

Furthermore, taste is a very unique sense, closely linked to other senses: hearing, touch, sight and obviously olfaction.[50]

Apart from the tongue and nose, other elements play a key role in identifying a flavour: the palate can tell whether food is rough, creamy, or coarse. Teeth can tell if a substance is hard; they can also communicate its consistency, depending on how difficult it is to chew. The tongue, palate, saliva, and lips tell us about what we're eating, and chemicals do the rest.

In the western world, perception became problematic when health and diet foods began to appear; in fact, it's rare for diet foods to taste like popular food products. For example the competition between Coca-Cola and Pepsi-Cola.[51] Coca-Cola changed the taste of its beverage to make it more like Pepsi-Cola and attract younger consumers. Even if market surveys had confirmed that everyone liked its taste, when it was branded and marketed, consumers didn't buy it and the company was forced to reintroduce the old formula.

Taste involves subjectivity and feelings is it is perceived in absolute terms, (i.e., not associated with the brand); if instead it is part of a cultural and communicative context, perception is influenced by aspects other than the ones involving just our sense of

[50] H.Stone and R.M.Pangborn have analysed ten types of sensory interactions: taste immediately emerges as the leading sense, the sensory system with the greatest variety of interactions. Stone H., Pangborn R.M., "Interactions between the chemical senses", in A.S.T.M. - American Society for Testing and Materials (1971), *Principi fondamentali della valutazione sensoriale*, Aldo Merletto, Milan. For more information, see: Riccò D. (1999), *Sinestesie per il design. Le interazioni sensoriali nell'epoca dei multimedia,* op. cit.

[51] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., pp. 97-98.

taste. Psychologists call it the ‘Proust effect’ from the name of the French writer of ‘In Search of Lost Time’: the narrator eats a madeleine dunked in a cup of lime tea and this conjures up memories of his childhood and becomes the catalyst of the story.

## Sommeliers and noses

Rather than using empirical tools, in this case we refer to the experiences and skills people use to describe the quality of a gustative event.

The sensory analysis of food, in other words tasting/sampling, is an organoleptic evaluation procedure (of cheese, olive oil, wine, beer, coffee, chocolate, etc.) involving the sensory qualities associated with taste, olfaction, sight, and touch, and other aspects: for example, the sensory analysis of wine, the sound produced by a crisp when it’s eaten, or the sound made by a chocolate bar when it’s broken.

Sommeliers are one example of ‘food tasters’; they are professionals who not only analyse the organoleptic qualities of beverages and evaluate their type, quality, characteristics, potential conservation, etc., but can also use precise adjectives to describe those characteristics (wines are defined as fruity, tannic, lively, straw-coloured, harmonious, etc.).

‘Noses’ are also involved in olfaction: although there are very few in the world, these are the noses which create the fragrances of perfume companies. If properly trained in special schools these noses enhance their own natural olfactory gift to the nth degree; they can use a much broader olfactory vocabulary and apart from perceiving and recognising many more fragrances, they can also create new ones based on specific sensory requirements.

## The electronic tongue[52]

Vice versa, the electronic tongue is a new technical tool, one of the many that can be used to identify organoleptic properties. A sommelier recently tasted fifty-three wine samples: without making even one tiny mistake, he guessed the grape species, the region the bottles came from, and the organoleptic properties of each sample (fresh, fruity aroma, high acidity, intense ruby red colour, and the insidious presence of mould in the cork). However, this sommelier was not a real person, but a robot. In fact this robot was a system of electronic sensors developed by Prof. Saverio Mannino, director of the Department of Food Science, Technology and Microbiology at the University of Milan and author of the study in question which ended up being publicised on the front page of the Washington Post.[53]

The question which immediately springs to mind is: will robot sommeliers soon replace human sommeliers and recommend wine in a restaurant?

A good question. Prof. Andrey Legin at the University of St. Petersburg has patented another electronic tongue which can identify a wide range of soft drinks and coffees, while in other parts of the world techno-tasters are already used in catering. In Japan the ‘Health and Food Advice Robot’ can identify thirty different wines and several kinds of bread and cheese; it can also give good advice about health. Supermarkets in Australia have long since used a computerised system to classify meat based on its cut, colour, tenderness, and fat content. But robots will not be replacing enologists and sensory evaluators any time soon. Apart from the fact that the software can malfunction, the human brain can do the same thing much more passionately and with much less effort. Above all, human sommeliers enhance the description of an evaluation with a much richer, typical, and common vocabulary – the mark of a very special human trait: to communicate through evocation.

[52] “Finisce l’era del vino taroccato. Arriva il sommelier elettronico”, *La Repubblica*, August 12, 2008.

[53] *The Washington Post*, March 10, 2008.

## 1.3 Case studies

This section reports on several studies conducted by research centres in which man ‘is the measuring tool’. These studies can be used as a basis to compare and elaborate a new method to evaluate the sensory properties of materials.

### *1.3.1 Evaluation of the tactile perception of new fabrics in cars: Centro Ricerche Fiat, Turin (2003-2004)*

Collaboration between the Centro Ricerche Fiat (CRF) and an international textile company which chiefly produces underwear led to the study, testing, and tactile sensory perception analysis of new fabrics to be installed in cars.

These materials can be considered novel because their field of application is innovative: car seats were covered in textiles used to make underwear. The fabrics for the interiors supplied by the manufacturing company were similar to traditional fabrics and were installed in a test car.

How can non-expert users identify the characteristics of several fabrics installed in a car?

Five experts and forty volunteer users (with no previous experience in this field) took part in the study.

The study took place in three stages: Stage 1 experts, tasked with identifying the terms required to describe the fabrics; Stage 1 users, which involved training the users to perform tactile evaluation; Stage 2 users, during which the users chose the final descriptive words; Stage 3 users, during which the fabrics were evaluated and classified.

- *Stage 1 experts*. Five experts defined the most appropriate terms to describe the attributes of the innovative materials: functional (cleanability, maintenance, etc.), physical (softness, roughness, etc.), and hedonic (pleasant to touch, first impressions). The terms were chosen based on an analysis of sensory literature, consumer attitude, and ad hoc market research conducted for the Fiat supplier. Words with similar meanings were grouped in one of the three categories of attributes.

- *Stage 1 users* (blindfolded). During this stage the fabrics were installed in the vehicle. The aim was to teach the forty users how to evaluate tactile perception using three actions: orthogonal, parallel and drape touching.
- *Stage 2 users* (blindfolded). Users had to identify a list of meaningful terms to describe the fabrics from a consumer viewpoint. During this stage the fabrics were not inside the vehicle. Users had to touch the fabrics and choose the best terms to define them.
- *Stage 3 users* (blindfolded). During this stage the fabrics were installed in three areas of the vehicle: the roof, floor, and door; each area was evaluated separately.

The users (not blindfolded) had to decide which was the best fabric after having touched it and then after simultaneously touching and looking at it.

Twenty male and twenty female users voluntarily went through the long and tiring analytical stages: sex was the discriminating factor, because women are better at perceiving the tactile nature of a material or object. Furthermore, individuals are exposed to different kinds of communication because they have different motives, skills, and opportunities; they assign a different meaning to physical objects in the world: this proves that other discriminatory factors exist, including culture and experience.

During the third user stage (Stage 3 users) the fabrics were installed in three different parts of the vehicle: unlike the new sensory evaluation method we propose, the CRF did not separate sensory evaluations from formal implications, even if the latter affect the perception of a material.

### 1.3.2 Tactile grammar

'Physiologically, touch should be divided into three separate sensitivity systems, each with their own receptor organ'[54]: heat sensitivity, which records variations in temperature on the surface of the body and is made up of two separate senses, hot and cold; tactile sensitivity, caused by mechanical stimulation, which allows us to become familiar with the superficial layer of bodies which come into contact with the skin; and pain sensitivity, caused by harmful stimuli, triggered when one of the other forms of sensitivity crosses a certain threshold. Heat sensitivity records not only variations in temperature, but also thermicity, the apparent temperature of materials, which depends on the transmission of heat between the hand and the object, in turn regulated by conductivity, by the specific heat and shape of the surface which comes into contact with the skin. 'Thermicity is, therefore, an objectively tactile quality that can be measured using traditional systems and includes all the stimulations which perceptively correspond to the hot-cold scale'.[55]

With regard to the five fields of qualitative opposition - rough/smooth, soft/hard, liquid/solid, hot/cold and braked/slippery - researchers defined a five-dimensional 'tactile space'[56] including each sensation. This tactile grammar is based on two types of measurement: on the one hand, the subjective sensations of individuals, on the other, objectively measurable material qualities.

'Direct comparison was used to measure subjective perceptions, discretising the dimensional axes according to arbitrary parameters which were uniform for the compared sensations. This helped to identify the reference figures associated with each emotion. Every 'tactile figure' was obtained by interpolating a closed curve passing through the points located on the dimensional axes. This figurative clarification makes it possible to represent sensations with signs, because often verbal descriptions are not enough to communicate content. It is not the area within the curve that is important, but the concise image and intersections on the axes.

[54] Mosconi D., Pacciani A. (1990), "Le basi fisio-fenomenologiche del tatto", *Area*, December n. 4, pp. 98-99.
[55] Ibid.
[56] Ibid.

Measuring the object's characteristic instead helps to decipher whether or not tactile effects can be produced by objects when they are touched.

Scientifically measuring the objects makes it possible to objectivise the existence and possible tactile performance of materials, and be able to use this in production and design to study the potential of these new material supports. Drawing two closed broken lines passing through the ends of the dimensional intervals established for each material will provide the maximum and minimum values within which tactile performances can be selected. This 'tactile identity card', describing its possible characteristics, could easily be used in design choices and also as an explicit communication tool in the world of production.

Furthermore, when these tools are used to create a 'tactile space' in which to position the material characteristics, it is possible to study which areas of tactile space are the most popular and the ones with very little material importance. The challenge to create a tactile grammar is not just a last-ditch attempt to turn something which is still an emotional state into something scientific and capable of being parametrised; its scope is to concretise the control of sensory qualities so it can be used in design and production'.[57]

The objectivisation of sensory perceptions, such as tactile perception, is the stated objective of the research discipline known as 'Qualistics'[58]; it's aim is to design a methodology and also theoretical, manufacturing, and disciplinary tools to manage the tactile, olfactory, and visual qualities of objects.

[57] Ibid.

[58] Qualistics is a new discipline that defines the subjective aspect of quality derived from the heterogeneity of the sensorial experiences of individuals in relation to subjects and products. Qualistics is a new dimension of quality that cannot be generalised. It is intersubjective, personal, and not subject to mediation or measurement. But this doesn't mean it can't be designed. From Qualistic Lab Home, www.castellidesign.it

### 1.3.3 Studies on sound in design

While the universe of sound has been extensively explored in architecture, the sound quality of design products is often neglected; perhaps this issue is considered uninteresting, or perhaps there are no tools to help the designer in his task - despite the fact that many dedicated studies have been performed.

Founded in 1999 by the Pairs-based Institute IRCAM (Institut de Recherche et Coordination Acoustique/Musique), in 2005 the Sound Design team, directed by Patrick Susini, became the Sound Perception and Design Team.[59]

The key focus of the team is the analysis of the perception of sounds in order to understand the perceptive mechanisms associated with describing the meaning of sounds, including identification of the sources of sound and the perception of sound sequences. The applications of sound design are linked to the study and design of our everyday sound environment: sound systems and diffusion in public places, the sound of signals, interfaces, interactions, etc.

The researchers have conducted numerous studies, including studies on the characterisation of the sound quality of air conditioning noise,[60] tests on the perception of noises inside cars, multidimensional techniques for sound quality assessment,[61] etc.

Another interesting project involving sound design as a functional element in interaction with the objects presented at the 2008 edition of the Computer Human Interaction conference (CHI)[62] is the Closed project coordinated by Patrick Susini in Paris in collaboration with the Technical University in Berlin and the University of the Arts in Zurich.

In 2010 an exhibition curated by Marco Ferreri and Patrizia Scarzella was dedicated to the sound of objects. The exhibition 'analysed one element of an object – noise – which until recently

[59] www.ircam.fr

[60] Susini P., McAdams S., Winsberg S., Perry I., Vieillard S., Rodet X. (2004), "Characterizing the sound quality of air-conditioning noise", *AppliedAcoustic*, n. 65, pp. 763-790.

[61] Susini P., McAdams S., Winsberg S. (1999), "A multidimensional technique for sound quality assessment", *Acustica*, n. 85, pp. 650-656.

[62] www.chi2008.org

people had tended to eliminate, but which today, after becoming the key trait of a product, has been transformed and initially become sound, and then the key feature of thousands of objects'.[63]

## Classification of sounds: virtual libraries[64]

Within the framework of sensory evaluation methods, it's interesting to mention several case studies regarding sound databases. Like enormous libraries they classify and reproduce sounds recorded by multimedia sound experts. Soundsnap is a platform that shares audio files and sound effects. The strong, key feature of Soundsnap is their careful and well-organized classification of sounds ranging from more traditional categories such as Animals, Nature and Science Fiction, to new and interesting categories: Sound Art, Interiors, and Unreal. When looking for a sound, users can browse the archive using tags created by the users themselves.

It's also interesting to explore the very specific descriptions posted by users. One example is, 'Water drips in a paper cup'. Note how the sound depends exclusively on the materials involved and the gestures needed to make it. This advanced classification of samples by users reveals the power behind a sound community: the tags are created very meticulously and are the real 'added value' when looking for a sound sample. It's also possible to create the sound while browsing; the search engine will then indicate the categories where it is stored and the number of samples present in each category.

All the sounds can be classified in several different ways (alphabetically, longest duration, most recent). For each result, it is also possible to use the player to listen to the sound, visualise the waves, and see the tags associated with the samples; this helps improve the search and/or move to other sounds.

[63] Ferreri M., Scarzella P. (2009), *Oggetti sonori. La dimensione invisibile del design*, Electa, Milan, p. 11.

[64] Arato F., Dal Palù D., *Il suono nel design. Una guida per il progettista di 'oggetti sonori*' [degree tesi]. Rapporteur: De Giorgi C.; co-rapporteurs: Astolfi A., Buiatti E., Lerma B., Politecnico di Torino, I Faculty of Architecture. Academic Year 2009/2010.

AudioMicro is another community-driven sound library. Like Soundsnap, its homepage clearly shows the objects which produce certain sounds, as well as the categories with the most sounds. One category only contains door sounds, in particular the characteristic elements of the sound, such as its material and function (fridge door, elevator door,…) which obviously radically alter the sound itself. Metallic sounds is another interesting category; this category is divided according to the material and not the type of object. Obviously the objects that make the sounds are mentioned, but even before we start listening we know that the sound will be metallic. This is important: perhaps it is the start of an analysis based on sounds and not objects. And we might even discover that a metallic sound doesn't come from a metal object, but from something else: the sound might have similar characteristics, but refer to different scenarios with similar sensations.

Soungle is another website where users can find and download audio files, such as sound effects or samples of musical instruments. Like the two previous websites, Soungle lets users listen to the results of their search by simply clicking on the preview button. However, this is not a classical web search engine since the files are present in the Soungle server; and their database is growing day by day.

Furthermore, the web application provides very useful and just as precious information, such as frequency, duration, and even the frame and bit rate. The approach to the site differs from the other two: the categories in which the sounds are listed are not clearly and explicitly present on the webpage and the desired sound has to be entered in the search engine. In this case sounds are not categorised but left to navigate in the endless sound world of the web.

## Perceiving the sound of food

The sensory characteristics of the attributes of a food product perceived through the senses are one of the parameters that determine its quality.

In fact, perception of the food we eat depends on the merger of multisensory signals: its appearance, aroma, and taste are important, but so are its structure, the noise it makes inside our mouths, and what it feels like. 'Perception of the food we eat depends on the integration of multisensory signals'[65]: we appreciate food thanks to our sense of smell (80%), while taste accounts for only 20%. The papillae on our tongue transmit basic information (sweet-sour, salty-insipid), but sight, touch and hearing are also involved.

Professor Massimiliano Zampini, teacher of psychology and researcher at the Interdepartment Mind and Brain Centre (Cimec) at Trento University, has conducted sophisticated lab tests with volunteer consumers who thought they were eating a product which was more or less fresh, more or less crunchy, or more or less good, according to how they perceived the 'croc' sound in their headphones. The researchers made the sound louder or quieter, but the crisps all came from the same Pringles crisp tube.[66] Pringles were chosen for the test because they are the same the world over; it's impossible to distinguish one from the other because they all have the same consistency and produce the same clear sound. 'While they bit the crisp', the volunteers who underwent the test listened to a more or less amplified sound coming from the microphone in front of their mouths. On a 1 to 100 scale, they had to move the indicator (set at 50) upwards or downwards, according to whether they thought the crisp was more or less fresh, and more or less crunchy. The results of these tests focused on the relationship between the sound and the freshness/crunchiness of the crisps: the louder the sound, the more it was considered fresh and crunchy. However all the crisps were the same and had the same freshness because they all came from the same Pringles tube. Our senses often deceive us.

[65] Ferreri M., Scarzella P. (2009), *Oggetti sonori. La dimensione invisibile del design,* op. cit., p. 40.

[66] Dell'Arti G. (2009), "L'importanza del crocchio", *Altri mondi*, March 9.

# 2. Proposed sensory evaluation method of materials

by Beatrice Lerma

## 2.1 The expressive and sensory properties of materials

'New materials are the stage on which we can watch the imposing performance of communication, computerised imagery, and artificial intelligence. Information does not exist without a substrate, nor informatics without monocrystalline silicon (or, in the future, other materials)'.[1]

Although we perceive materials as lighter, more transparent, and with a tendency to disappear, their role is as important as it was in the past: their performance remains incisive even if we perceive its effects almost without seeing them. In addition, designers and producers can now opt for the 'made-to-measure' materials they need for their designs; they can choose between an 'endless' selection of materials with similar properties. Since the properties of 'made-to-measure' materials are established by intervening on their macrostructure (arrangement of the anisotropies and internal inhomogeneities), or microstructure (spatial arrangement and quality of the atomic and molecular bonds), we can state that the material exists only as a component of the finished product after it is produced, and not before the object in which it is to be used.

Operators are encouraged to redesign products thanks to available materials developed for more specific uses or high performance solutions: increasingly integrated and lighter objects, less matter and

[1] Manzini E. (1986), *La materia dell'invenzione,* op. cit., p. 37.

more data. Materials were traditionally considered as the basic elements of a more complex system which, when combined with other materials and defined by a product, created objects which performed certain functions: now even materials have intrinsic properties which allow them to carry out complex functions.

A material is considered 'new' depending on what it relates to: a material can be considered innovative even if it was designed ten years ago because its fields of application have changed; in today's world innovative materials represent roughly 5-10% of all materials available on the market.

New materials are not just new alloys, new ceramics, or new polymers, but also materials combined with well-known materials; they can provide high performing solutions thanks to a more sophisticated management of matter and energy.

Research and materials science no longer focus on single families of materials; they are abandoning the traditional division between those involved with composites, metals, or plastics, in order to be able to comprehensively study and compare several solutions based on the data now available in several fields. To design new materials we need to collect all available data from several fields of application.

Innovative materials seem very different to traditional materials. 'New materials no longer resemble inert substances resistant to the transformations imposed by the human beings trying to 'tame' them, instead they behave like fluid substances that adapt to the application almost as if our efforts are not important'.[2] It's crucial for designers to be familiar with the technical specifications of materials, but also to consider other properties associated with sensory perception; what we lack is an 'aesthetic-perceptive' terminology,[3] a sensory terminology capable of solving the problems of communication between the persons involved in design processes.

The sensory analysis of the tactile, visual, and olfactory qualities of a traditional or innovative material, product, or space, presents several kinds of difficulties, in particular it involves comparing a

[2] Langella C. (2003), *Nuovi paesaggi materici,* op. cit., p. 24.

[3] Ashby M., Johnson K. (2002), *Materials and Design. The art and science of material selection in product design*, Butterworth-Heinemann Ltd, Elsevier.

subjective and objective, qualitative and quantitative, and 'physical and phenomenal' dimension.[4]

In fact, when we talk of sensations we refer to a connection between the mind and matter, to a vehicle of information that allows us to perceive the world. Sensations are a necessary part of perception, but sensations alone are not enough since perception involves receiving, elaborating, and recognising the stimuli of the outside world mediated by our sensory system (interface between the organism and the outside world).

'Every day all human beings, and most animals, use phenomenal data to successfully complete their actions. Only man uses physical data […] The difference between the physical and phenomenal does not involve truth, it involves reality'.

Many scholars believe that the reality we experience coincides with the phenomenal world. Snap decisions, the intensity and import of our actions, aesthetic evaluations, what we consider good or bad taste, scented or smelly, smooth or rough – all this is the real world in which we live and is therefore phenomenal.[5]

The dichotomy between physical and phenomenal becomes more complex when we want to quantitatively assess perception and the phenomenal world. 'The classification of thermal, chromatic, and olfactory perception, and the search for their representation',[6] are 'strategic tools to understand sensory experiences'.[7]

Perception involves selecting and recombining physical stimuli according to programmes and codes which are not the mirror image of instrumentally recorded differences. The difficulties associated with classifying different perceptions are not influenced only by the problems related to measurement, but by the difference between what is numerable and what is discretional. Individual perception is characterised by experience and the memory of certain things such as smells and moods: it's important to understand the transition from

[4] Two adjectives 'physical and phenomenal' have been used to distinguish between the properties of physical stimulus and those of perceptive performance; first by gestalt analysts and then by scholars of perception. Massironi M. (1998), *Fenomenologia della percezione visiva*, il Mulino, Bologna, pp. 36-37.

[5] Ivi, p. 38.

[6] Petrillo A. (1991), "I linguaggi della sensorialità", *Area*, n. 6, p. 102.

[7] Ibid.

the physical object to the personal experience, social and cultural context, environment, etc.

'We can consider a mental model as the basis, or rather, the nature of what is behind the communicated information. […] A model will never fully represent reality because it is in itself a selection, a choice of elements and relationships which can provide comprehensive information about different levels of reality; but no empirical phenomenon will ever have complete models. […] In fact, rather than a copy, a mental model is a concise selection of characteristics and relationships inspired by what is perceived'.[8]

The link between what is perceived and what is deposited in our memory is absolutely crucial: categorisation is a basic element of comprehension and occurs when we try to establish this link.[9] Based on the premise that the recipient interprets or assigns a meaning to what he perceives, we must consider that the first process of assignment of meaning takes place when we categorise something, in other words when, through the perception of certain elements, the person in question identifies an object. After categorisation which 'reflects the process of identification of an entity, comprehension is the process we use to extract the superior meaning of the recognised entity'.[10]

Intersubjectivity is the dimension involving the space between the objective and subjective world where people reach an agreement that goes beyond their own individual subjectivity.

The quantitative dimension, or more precisely the 'objective-quantitative dimension, coincides with the technical dimension and refer to the properties which tend to be characteristic of a material on the basis of its atomic and molecular structure from which its so-called technical and performance properties are extrapolated',[11] such as density, thermal and electrical conductivity, elastic modulus, etc. What these properties have in common is that measurements, in other words extremely accurate scientific analyses, can provide univocal

[8] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., p. 23.

[9] Ivi, pp. 102-112.

[10] Ibid.

[11] Lucibello S. (2005), *Materiali@design: verso una nuova modalità di selezione su base percettiva dei materiali per il design,* op. cit., p. 46.

and repeatable data; by using specific tools, it is possible to exclude the problem of variability which normally characterises the experiments performed by humans.

Instead the qualitative dimension is an ensemble of characteristics which cannot be expressed in numbers. Furthermore, the emotional factor of the product, the visceral design[12] (in other words what often characterises the objects and binds it to the user) is seldom something that can be scientifically measured with an instrument; more often than not it is a qualifiable sensation that is difficult to quantify. The qualitative dimension is characteristic of human beings and involves the sensations and tools that allow us to know and understand the world: the senses. The sensory evaluation methodology of materials proposed here[13] considers man as the tool with which to evaluate materials. Human beings, the 'primary actor of design',[14] the declared recipient of the design process, also becomes the means we use to evaluate the properties normally delegated to machines and technical instruments.

The panellists or 'tasters'[15] of materials are crucial in the sensory evaluation of materials. These individuals are trained to scientifically evaluate materials; they can repeat the same evaluations after a certain period of time and yet provide the same results. Like sommeliers, panellists are able to select, describe, and sensorially classify materials using four senses: sight, touch, smell, and hearing. For obvious reasons, when evaluating design and architectural materials, taste has not been considered (unless the subject is food design and one wishes to consider food as a material).

[12] Norman D.A (2004), *Emotional design: why we love (or hate) everyday things*, Basic Books, New York.

[13] The proposal to create a scientific sensory evaluation method of materials was submitted, elaborated, and experimentally applied at the MATto, the Materials Library of the Course in Design and Visual Communication at the Politecnico di Torino. For more information: MATto@polito.it, www.polito.it/MATto.it

[14] Germak C. edited by (2008), *Man at the Centre of the Project. Design for a New Humanism*, Umberto Allemandi Editore, Turin, p. 4.

[15] Colombo A. (2006), "Degustatori d'interni", *Driving interiors*, November, n. 0, p. 8.

## 2.2 Touch and Materials

From the point of view of touch materials can be defined in different ways using terms and adjectives describing the properties of the surface and their physical and mechanical behaviour. Softness is linked to the firmness of a material, which depends on the properties of the elastic modulus, while the sensation of heat or cold transmitted by the materials depends on how quickly it absorbs the heat of a person's fingers. When we explore an object we feel its tangible three-dimensional form which includes texture, weight, shape (when the surface to be perceived is not too big) and heat.

### *2.2.1 Study tools and evaluation methods*

To define materials using only our sense of touch we must first refer to the tools and methods used by other infrastructures, such as materials libraries or research centres. Sensotact®[16] was the tool we chose to evaluate materials because it is a universally recognised system which uses a universal language to define 'the tactile sensations conveyed by materials'.[17]

To define the tactile qualities of materials Sensotact® breaks down the sense of touch into ten descriptors (associated with three possible movements, static contact, orthogonal exploration, and tangential exploration) and then compares the tested material with the Sensotact® reference samples. The sensations defined by the tool are: thermal perception, thermal conductivity, hardness, shape memory, nervosity, elastic modulus, fibre content, roughness, smoothness, three-dimensionality/relief, adhesion and coarseness. Three different levels of analysis can be performed using Sensotact®: the first by non-experts, the second by qualified individuals, and the third by experts. The second and third level are reserved for individuals 'trained' to use the tool. To perform an

[16] Cfr. Chapter 1.

[17] Rognoli V. (2004), *I materiali per il design: un atlante espressivo-sensoriale* [PhD tesi]. Rapporteur: Levi M., Politecnico di Milano, PhD in Industrial Design and Multimedia Communication, XVI cycle, 2001/2004, Milan, p. 94.

advanced analysis, the group testing the item should be made up of twenty to forty individuals of different ages, social class, and culture.

After learning about the tool and how to use it, the panellists then test the item in question following the instructions provided by Sensotact®.

Each panellist touches the material in question based on a precise protocol for every descriptor (for example, to test for incisiveness orthogonal pressure must be exerted by the forefinger which then has to remain in contact with the surface without exerting any pressure; at this point evaluate how quickly the material returns to its original shape, etc.). Each panellist then quantifies his perception after comparing it with the ten descriptors, assigning a value that varies from zero to one hundred; when these values are transferred to a calculus sheet they establish the sensory profile of the tested material.

Each panellist can test several materials in a 'monadic' manner, in other words material by material, or descriptor by descriptor; all the values will be recorded on the same calculus sheet. The weighted average of the values recorded by each panellist with provide the 'tactile profile' of the tested materials.

This is the methodology elaborated by Sensotact® for each descriptor:

**Static Movement**
**Thermal perception**
Describes the flow of perceived heat. The scale varies from cold (the hand releases heat to the product) to hot (the hand appears to receive heat from the product).

**Orthogonal movement**
**Hardness**
Describes the effort required to impress the forefinger into the material.
Reference value: the greater the effort required, the harder the material.

**Nervosity**
Describes the force contrasting the effort by the forefinger to impress the material
Reference value: the greater the force exerted by the product (the finger is resisted), the greater the value of nervosity.

**Shape Memory**
Describes the capacity of the product to maintain a shape after deformation.
Reference value: if deformation persists, the greater the shape memory.

**Adhesion**
Describes the adhesion of the hand to the surface of the material
Reference value: the greater the adhesion to the surface, the greater the strength needed to remove the finger from the material, the greater the adhesion value.

**Tangential exploration**
Three-dimensionality/Relief
Describes the difference in perceived height of the surface of the product.
Reference value: the greater the difference in the height of the relief, the greater the intensity of the relief.

**Fibre content**
Describes the inversion of the fibres on the surface of the product.
Reference value: the greater the inversion, the greater the intensity of the fibre.
An important note: evaluate fibre content by following the two directions and rotating the product by 90°.

**Roughness**
Describes the roughness due to the presence of a relief, particles, unevenness, etc.
Reference value: the greater the roughness of the material, the greater the intensity of the roughness.

**Damping factor**
Describes the force required to begin to move the index finger along the surface of the material.
Reference value: the greater the force needed to move the finger, the greater the intensity of the damping factor.

**Slipperiness**
Describes the ease with which the fingers can be moved.
Reference value: if no force is needed to move the finger, then this gives intense slipperiness.

Choosing where to evaluate the items is also very important: the places must be 'suitable, in other words without any exterior disturbances such as noises, smells, and unusual lighting'[18] which may psychologically influence the panellists and therefore lead to unreliable results. The best places in which the judges can concentrate while conducting sensory analysis of food products are individual spaces, insulated booths; this prevents external interference and stops the judges from influencing each other.

[18] Pagliarini E. (2002), *Valutazione sensoriale,* op. cit., p. 20.

### 2.2.2. Tactile adjectives

Sensotact® descriptors provide a universal language to describe the tactile properties of the materials and associated values; this facilitates dialogue between the researchers and designers who use and are familiar with this tool. However, how can we make people who are not familiar with this tool use this language? First and foremost by using ordinary words and terms.

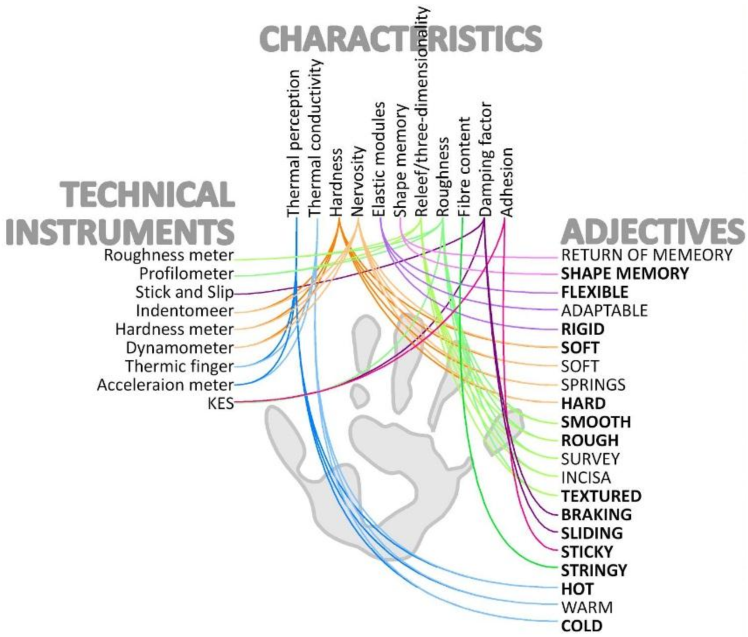



*Fig. 1 - Diagram showing the link between tactile characteristics, technical tools, and adjectives.(Beatrice Lerma)*

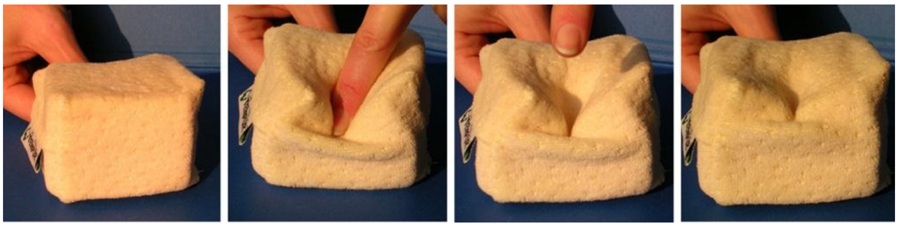


*Fig. 2 - Sequence of images illustrating the shape memory behaviour of the analysed material (photo by Elenia Rotundo)*

We need to turn the properties analysed by Sensotact® into attributes, sensory adjectives which characterise and describe the materials.

We studied the terms used in materials libraries and studies conducted in this field and then compared them to the technical tools measuring their associated properties. This produced a long list of tactile adjectives from which we chose the adjectives which became part of the 'sensory vocabulary'.

To provide a thorough description of the tactile properties of a material, the adjectives were divided into pairs of opposites (flexible/stiff, soft/hard, smooth/rough, braking/slippery, hot/cold); we also identified other adjectives (textured, sticky, fibrous, and shape memory) for which there is no corresponding opposite.

The adjectives were used to describe the materials previously analysed using Sensotact®. The tested materials are described by adjectives and by values/value scales (established after analysis with the tool) which immediately quantify the characteristic described by the adjective.

To further clarify the meaning of the adjectives and values associated with the materials we established a procedure to handle the samples in order to obtain images and videos illustrating their tactile characteristics.

This procedure follows the same analytical procedures proposed by Sensotact®: the movements of the panellists and the 'behaviour' of the materials were filmed and photographed to illustrate and document the evaluations conducted and the opinions expressed.

### *2.2.3 Critical areas and future developments*

The panellists experienced several difficulties when they used the tool to conduct their analyses on different materials, for example polyurethane gels, sheets of recycled plastic, fabrics, and woods.

The surface properties of the reference samples provided by Sensotact were different even within the 'descriptor panel'. They are not all made of the same material and this makes it difficult to compare the reference samples and the tested materials because in some cases the texture of the reference samples varied.

For example, the ‘roughness’ descriptor panel had six samples with values of 0, 3, 7, 15, 25, 40, 75, and 100; the sample for value 75 has an indented surface which to an amateur panellist not familiar with the tool, could seem rougher than sample 100.

The fact the reference samples differed for each descriptor was another problem. For example, the ‘fibre content’ descriptor had five reference samples with five values (0, 30, 60, 80, and 100), while the ‘roughness’ descriptor, as mentioned earlier, had six (0, 3, 7, 15, 25, 40, 75, and 100) and the ‘thermal property’ descriptor had five (0, 20, 50, 70, and 100).

Furthermore, since the reference values were not evenly distributed, it was difficult to evaluate the material, above all when it fell between two figures with a rather ‘big’ interval: greater than 40 but less than 75. In these cases, the repeatability of the values and the evaluations in different sessions become extremely important.

The tool is only partly suited to analysing fabrics. In fact, for fabrics the fibre content descriptors (smoothness, slipperiness, adhesiveness and thermal perception) are meaningful, but the use of descriptors such as hardness, nervosity and shape memory are problematic because evaluation of these properties will be misrepresented by the firmness or flexibility of the substrate; this would also be true for 3D fabrics. The same problem was also encountered during evaluation of very thin materials belonging to other material families.

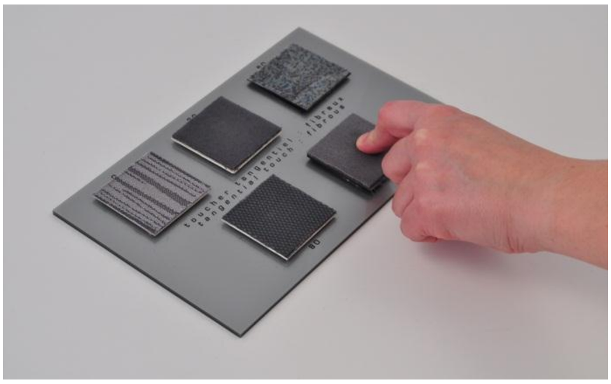
In these cases, the repeatability of the values, and the evaluations produced during several sessions, should be taken as a base line.

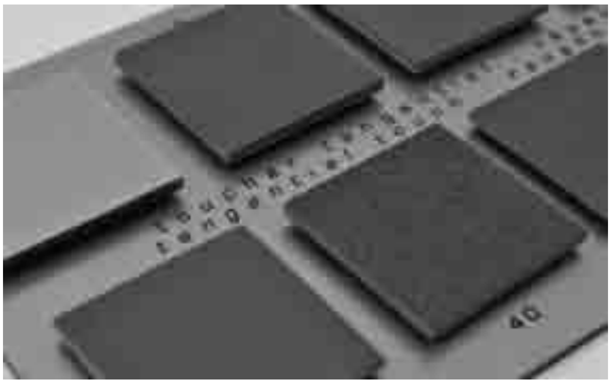
Specific tools can be used to evaluate fabrics, for example the Kawataba Evaluation System (KES) which measures the traction, compression, smoothness and roughness of fabrics. Since 2001, a group of teachers and researchers[19] at the Turin Polytechnic has conducted analyses and studies on the modelling techniques of the physical properties of clothes based on data extrapolated after measurements using the KES. One interesting development could be to establish the properties of innovative fabrics using both the KES

[19] Bottino A., Laurentini A., Scalabrin S. (2001), “Quantitatively comparing virtual and real draping of clothes”, in *Proceedings of 9th Int. Conf. on Computer Graphic, Visualization and Computer Vision WSCG 2001*, Plzen (CZ).

and Sensotact®; the results could then be applied to virtual reality to also evaluate perception once the fabrics are used in products.

In the future we will be able to validate the values established by the panellists and compare them to the values measured on the same samples tested by the specific technical tools mentioned earlier,[20] such as the roughness meter, profile meter, etc.





*Figs. 3 and 4 - Sensotact® descriptors in the MATto materials library (photo by Paulo Miranda)*

The technical measurements will produce technical values which can be compared with the values produced by the Sensotact® tests: correspondence between these two values will confirm the validity of the evaluations of the panellists. Furthermore, in the automobile sector the Centro Ricerche Fiat in Orbassano is already developing a

[20] Cfr. Chapter 1.

‘modified Sensotact’, called a Smart Box,[21] to be used only for plastics: it has developed a tool with equidistant value scales, from -3 to +3, and from -2 to +2, using the same material type (with the same surface texture) for every tactile quality. Likewise, High Tech Design in Paris has developed a ‘tactile sample book with four columns, each with six samples, from the smoothest and most brilliant to the roughest and most opaque; six samples from the most adhesive and brilliant to the most slippery and opaque; six soft samples, from the most rubbery and driest, to the most rubbery and oily; six samples ranging from the finest grain to the coarsest grain’.[22]

## 2.3 Hearing and materials

The analysis of the auditory properties of materials is even more complex than the previous analyses. First of all, to acoustically describe the behaviour of a material you have to consider how the sound is made, as well as the differences in size, shape, and thickness of a material sample.

We will not focus on the evaluations of their phono-absorbent and phono-insulating properties because the latter are provided by the manufacturing company.

We should point out that in the current world of design sounds are, generally speaking, difficult to recognise and almost never give added value to the product; on the contrary, they are often considered irrelevant or even a nuisance. However designers do sometimes look for a material with special acoustic properties, for example a material which, when used for a certain product, does not produce unpleasant sounds, or rather, produces a sound that attracts positive attention. For instance, in a school canteen it’s important to use trays which do not make a loud or unpleasant noise when placed or thrown on a table.

On the contrary. It would be nice if they made pleasant sounds.

[21] Peyron B.[et al.] (2006), “Multisensory Analysis applied in the Automotive Field” in *Proceedings of ESDA 2006 – 8th Biennial ASME Conference on Engineering Systems Design and Analysis*, Turin.

[22] Lucibello S. (2005), *Materiali@design: verso una nuova modalità di selezione su base percettiva dei materiali per il design,* op. cit., p. 65.

How can we solve this problem? How can we acoustically define materials?

A possible quantitative solution is to use a phonometer to numerically express what we normally experience as a sensation (auditory perception); a phonometer is a tool used to measure the pitch and intensity of sounds and provide objective and reproducible data. But we need to go further.

### *2.3.1. The acoustic evaluation of materials*

Unfortunately machine-produced values do not provide a qualitative evaluation of the sounds produced by a material; furthermore, if these sounds are not 'translated', they are meaningless for anyone unfamiliar with the secrets of these tools and relative field of science.

For this reason, an evaluation methodology has been developed to translate the sounds produced by materials. The method considers three elements: the material/materials, the presentation format, and the gestures involved.

It is easy to memorise this 'triangle' of the three crucial elements which make up any mechanical sound system. The triangle concept 'material-shape-gesture' reminds the designer that when he designs any object that makes a sound he has to understand and evaluate the quality of that sound and analyse the influence exerted by each component.

A tool for this purpose has been invented and patented as SounBe® .[23] It produces the same results even if used by different people in different contexts and this makes it possible to create a database with the sound descriptors of material samples (or even of products).

Furthermore, the SounBe® tool can be continuously updated with ad hoc accessories depending on a designer's needs and requirements.

[23] SounBe®, patented by the Politecnico di Torino, and invented by Claudia De Giorgi, Arianna Astolfi, Eleonora Buiatti, Beatrice Lerma, Francesca Arato, and Doriana Dal Palù.

Its role is to help a designer who wishes to incorporate the sound made by the product into his design; the designer uses the adjectives, the semantic descriptors, which define the sound of each material based on scientific literature, unlike the descriptors used for touch and sight (which instead come from the analysis and comparison of adjectives already used in literature and materials libraries), the properties of materials, and the tools to measure them.

The SounBe® tool cannot yet provide quantitative data; one possible development could be to compare sounds (defined with the same adjective) and use the phonometer to measure the amplitude of the sounds and provide numerical data.

## 2.4 Sight and materials

Everything we see is light; colour or the properties of surfaces do not exist without light: the interaction between light, matter, and the viewer defines the visual properties of a material. 'An object is determined not only by its colour, but also by its material properties: gloss/matt, transparent/covering, smooth/rough'.[24] 'Metals can be matt, while ceramics can be both matt and translucent. […] Polymers include a wide variety of transparencies […]'.[25] How can we define these qualities? What ordinary and familiar words can we use to describe them?

Certain tools, similar to Sensotact®, compare the material samples to be tested with the reference samples provided by the tool itself. Two such tools are the Brightness scale,[26] which evaluates the gloss/matt nature of the surfaces of materials, and the Pantone system[27] which evaluates colour.

Since these tools help to describe only one of the numerous visual properties of materials, we decided to study light/matter interaction to define the sensory adjectives used for sight. 'Light always comes from matter: it is born in matter and disappears when modified by

[24] Tornquist J. (1999), *Colore e luce. Teoria e pratica*, Istituto del colore, Milan, p. 255.

[25] Ashby M., Johnson K. (2002), *Materials and Design. The art and science of material selection in product design,* op. cit.

[26] Cfr. Chapter 1.

[27] www.pantone.com

matter. Interactions always occurs when light and matter meet. On the one hand, substances reflect, refract, alter, and also pulverise light. […] On the other, when light strikes a substance, it affects it in different ways'.[28] Furthermore, the chromatic properties of objects depend on how the electrons react to electromagnetic radiation.

We see the objects around us because they re-emit a fraction of the light coming from a light source, for example the sun or a lamp.

We perceive the transparency, colour, and brightness of materials thanks to our sense of sight; these qualities are the result of interaction between light and matter. Light is 'a physical agent we can use to see objects'.[29] A transparent or opaque object exists without the light, but the light reveals what it looks like. Several reactions occur when light strikes the surface of a material. The most usual reactions we can see are absorption, transmission, and reflection.

### *2.4.1 Light-matter interaction*

The method to evaluate the visual traits of materials and the luminous phenomena of light-surface interaction will also include the angular and spectral behaviour of light and the definition of its associated quantitative and qualitative aspects.[30]

'An object that receives light can absorb it, in other words transform it into invisible energy, reflect it, re-emit it as visible light, and transmit it. […] Regular (direct) transmission occurs, for example, through transparent glass; diffuse transmission through opaque glass; mixed transmission through translucent glass'.[31] Light rays striking a transparent material are transmitted through the material itself; different behaviour depends on the type of material through which the light passes: if the material is homogeneous (for example air) a light ray can pass through it undisturbed. This is

[28] Tornquist, J. (1999), *Colore e luce. Teoria e pratica,* op. cit., pp. 40-44.

[29] *Enciclopedia Scientifica Tecnica Garzanti* (1969), op. cit., vol. 2, p. 1245.

[30] Uccelli A. (2006), *Interazione luce e materiali: proposta di un sistema di schedatura di supporto al progettista* [degree tesi]. Rapporteur, De Giorgi C., co-rapporteur, Pellegrino A., Politecnico di Torino, Academic Year 2005/2006.

[31] Tornquist J. (1999), *Colore e luce. Teoria e pratica,* op. cit., p. 41.

called transmission of light. Transmission varies according to the angle of transmission and the transmission factor; quantitatively speaking, it defines the degree of transparency of the material.

'The term reflection defines the way in which any kind of wave strikes a solid object and generates other waves departing from the object. Reflection occurs on the surface between two different mediums, such as the surface between air and glass'.[32] Reflection on a smooth surface is called specular reflection.

The latter differs from diffuse reflection which is a property of a rough surface: in this case, the reflected rays reach the eye of the viewer from many different points and there is no reflected image. The reflection of this page, for example, is diffuse reflection.

Reflection varies according to the angle of reflection and the reflection factor: it quantitatively defines the material/medium/obstacle that light encounters as specular, diffuse, semi-specular, and semi-diffuse.

Absorption, considered as absorbed energy, is defined in quantitative terms by the absorption factor and qualitatively using the terms dark and light.

The spectral definition of transmission, reflection, and absorption indicates the spectral distribution of the radiation absorbed, reflected, and transmitted by the material; it also qualitatively indicates the perceived colour. Qualitative-perceptive properties can be summarised as: global (% transparency; light-dark), angular (specular; gloss; diffuse; semi-specular; semi-diffuse), and spectral (perceived colour).

### 2.4.2 Visual adjectives

The descriptor adjectives of sight were defined by comparing light-matter interaction with the measurements taken with technical tools (for example the gloss meter or spectrophotometer) and the terms used by materials libraries and research centres.

[32] Tipler P. (1991), *Invito alla fisica 2*, Zanichelli, Bologna, p. 429.

To clarify the meaning of the adjectives and values associated with the materials we defined a procedure to manipulate the samples and obtain images and videos illustrating the visual properties.

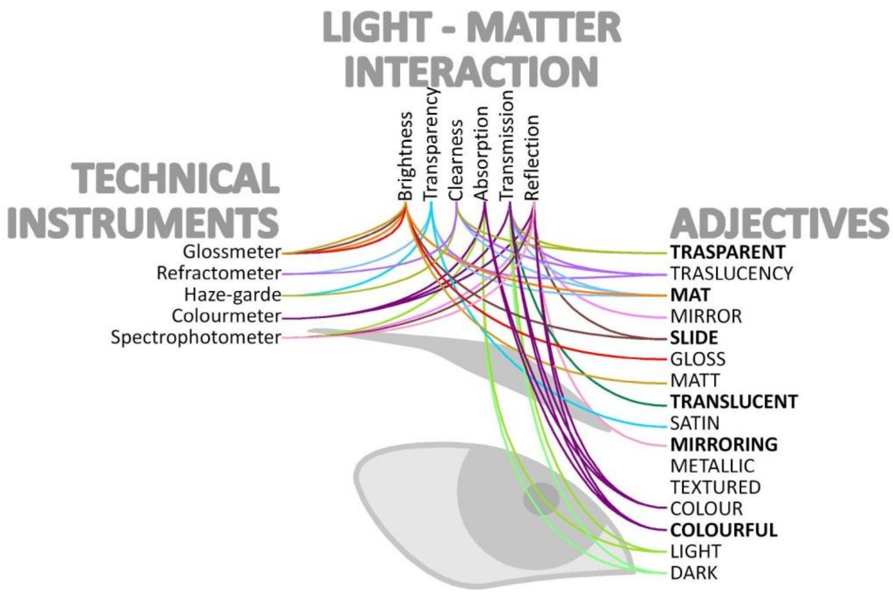



*Fig. 5 - Diagram showing interaction between visual properties, technical tools, and adjectives (Beatrice Lerma)*

This procedure includes several tests on materials which are handled, bent, and 'waved' in front of various kinds of light and at different angles. These tests reveal how materials behave when exposed to light; they are based on the Sensotact® and SounBe® ® evaluation methods illustrated earlier. We filmed and photographed the way in which materials behaved when exposed to light.

A sample group of individuals (60, aged between 20 and 70) were interviewed to identify the adjectives that are currently used more frequently to visually define materials and products, and also to choose the terms to be included in the sensory terminology we were developing.

The adjectives transparent/matt, translucent, gloss/matt, mirroring, and colourful, were considered by the panellists as effective and suitable to describe the visual properties of materials.

The images and videos of the handling of the materials were evaluated by the panellists who defined the materials using the above adjectives.

### *2.4.3 Future developments*

To obtain quantitative values for the adjectives chosen as part of the sensory terminology, the analyses by the panellists had to be backed up by measurements of the tested material samples; these measurements had to be taken using the specific tools (previously indicated), such as the refractometer or colour meter.

A rather complex evaluation and measurement process has to be used to define the colour of several kinds of multicoloured materials, for example the waste from the manufacturing process of recycled materials. There are no adjectives and terms to univocally express the colours of these materials: some could be defined as dotted, streaked, striped, etc., but the colours vary and differ from sample to sample.

In fact, materials recycled from containers, bottles, CDs, mobile phone covers, etc., have non-standard, unique, and personalised colour combinations: their surfaces betray the memory of the recycled materials.

The colouring of these materials can generically be defined as ‘various patterns’, either using the colour palette provided by the manufacturing companies, or through the colour coordinates in the LACIE system, using a spectrophotometer.

#### Eye-tracking: another visual evaluation tool

Today it is possible to use sight together with the eye-tracking method as yet another tool to evaluate the choices (or other issues) made, or to be made, regarding metadesign concepts.

*Fig. 6 - Samples of Origins material made by Yemm & Hart from recycled bottles and detergent containers (materials classified in MATto; photo by Paulo Miranda)*

*Fig. 7 - Samples of Smile Plastics made from recycled bottles and detergent containers (materials classified in MATto; photo by Paulo Miranda)*

Another tool is now available to evaluate and verify the perceived quality of design solutions and materials chosen according to their technical, environmental, sensory characteristics, and cost.

Rather than replacing human beings as assessors, eye-tracking emphasises how crucial and indispensable we are: man is the 'core element of design'[33]: in fact, eye-tracking can analyse what happens when individuals are stimulated and behave without thinking, without controlling their eyes, and without concentrating.

Eye-tracking studies a person's eye movements when he looks at an image or a product; as a result, eye-tracking analyses can be considered as a moment of synaesthetic evaluation.[34] In fact, perceptive evaluation intervenes during when a person looks at a product, the perception of certain stimuli is accompanied by specific mental images which belong to another sensory pathway: in fact, perceptive elaboration intervenes during synaesthetic mechanisms associated with personal experiences and the imaginative ability of the mind.

The theory behind this method comes from the psychology of cognitive processes and recent studies on visual perception. Cognitive processes regarding perception and attention allow us to successfully interact with the world around us – a world which day after day reveals its complexity and multiplicity.

Sight is not a continuous process, it is characterised by two main actions: saccade, when the eye moves rapidly between two stimuli but without perception, and fixation, when the eye remains focused on one stimulus and information is actively perceived. Visual stimuli are seen consciously and in detail only when they fall on the fovea, a small depression on the inner retinal surface.

Attention guides eye movements towards the stimuli we're interested in; by doing so it aligns the fovea (using the saccades) on

[33] Germak C. edited by (2008), *Man at the Centre of the Project. Design for a New Humanism,* op. cit.

[34] Synesthesia, based on its Greek etymology – *syn*, together, and *aisthenesthai*, to perceive means 'simultaneous perception'. More precisely, it can be defined as an association of different sensations simultaneously felt by an individual, or as a phenomenon in which the perception of certain stimuli is accompanied by specific images belonging to another sensory pathway. Pignotti L. (1993), *I sensi delle arti. Sinestesie e interazioni estetiche*, Dedalo, Bari.

these stimuli in an almost stable manner (fixations) so that they can be consciously perceived: eye-tracking records these eye movements (saccades and fixations).

Eye-tracking, a non-verbal research method, is a technique used to study the eye movements of a user while he explores, for example, a website, or looks at an object. In fact it was invented to study the behaviour of the human eye while looking at an image or a product.

Eye-tracking involves using sensors to record the reflection of a ray of infrared light projected onto the pupil. This signal changes according to the position of the pupil (and therefore the direction in which a person looks); by recording and analysing eye movements it is possible to establish at what exact point, and for how long, a user looks at an object. Analysing what a user sees or ignores when he considers a product provides important information about the capacity of the product/interface/object to attract and maintain, or diminish, the attention of that individual.

In actual fact, this method makes it possible to decipher the level of attention a user devotes to what he is looking at, the way he treats the information on a piece of paper or in an advert, and the strategies and possible problems he may encounter during these activities.

Eye-tracking is used in several fields, from image analysis including publicity ads, website design and easy-to-use books, to usability tests, TV research, product tests, shop studies, etc.

Eye-tracking has also shown that we focus on three elements when we recognise a face: the eyes, nose and mouth, and 'we can also evaluate how these elements are the ones to which we assign greater expressive importance, not only due to their position, but also because we consider that variations in these elements provide us with the characteristics we call facial expressions'.[35]

To draw a stylised face we don't need ears, hair, or the contours of the face; all we need are four features which are meaningless if we change their position on the face.

We decided to adopt this kind of tool first and foremost because it can be used not only to evaluate the unconscious processes of individuals undergoing these tests/analyses, but also because sight is

[35] Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva,* op. cit., pp. 90-91.

considered one of the main communication methods used by human beings. In fact sight always ‘dominates’ the other senses when we explore the world around us. We can use this method to identify and interpret the involuntary physical eye movements and see where the user focuses his perceptive attention. Analysing the eye movements made while exploring an image provides important information about the viewer’s cognitive processes, how he elaborates visual inputs and integrates them with his knowledge of the world and the information stored in his memory.[36]

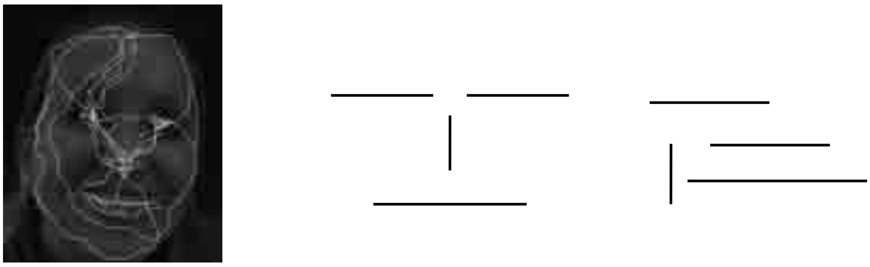


*Fig. 8 - Representation of the four elements we concentrate on when we look at a face (source: Lurija, 1976 and Vannoni, 2001)*

The eye-tracking device (remote eye-tracker[37]) used during the tests is relatively non-invasive because the individual is not obliged to sit in any particular position, or wear special accessories such as helmets, etc. There are several different eye-tracking devices: the remote eye-tracker, where the infrared device is hidden inside a monitor so as not to distract the person looking at the image; reality tracking – used in a natural environment – which uses a small video camera fixed to a purpose-built hat or pair of glasses to record the analyses of the context or use of the product; finally, like the previous devices, the head-mounted eye-tracker. The latter is a kind of helmet with a small camera to record the eye movements and a sensor which transmits the position of the person’s head to a computer.

[36] Delvino L. (2007), *Psicologia dell’emotional design. Uno studio sperimentale sul packaging dei profumi* [degree tesi]. Rapporteur: Riva G., Milan, Università del Sacro Cuore, Academic Year 2006/2007.

[37] Ibid.

## Eye-tracking applications: a general introduction to its most common uses

Eye-tracking is currently used in the design of interfaces and web environments to accurately establish a user's experience, record the areas, words, graphics, spaces, time, and sequence of movements of what a user sees when he interacts with a web page.

In actual fact it is a revolutionary method because it not only records the physical point observed (thanks to the identification and interpretation of the involuntary physical movements of the eye), but also the point where the user focuses his perceptive attention. In other words, eye-tracking can establish what captures the user's attention and how it changes from one moment to the next.

Eye-tracking is also extensively used in the field of packaging, advertisements, the press and television. It is used to: compare different creative proposals and understand which is the most successful; analyse in detail which parts of the message (brand, product, creativity, headline, etc.) capture the attention of users; evaluate the communicative efficiency and emotional impact of each message.

This tool/method is also used to design sales outlets, to weigh up choices, to study purchasing habits (long term), and study visual pathways in exhibition spaces.

Eye-tracking makes it possible to conduct visual impact tests at any stage of a website design process, advertising campaign, or supermarket shelf layout. However, the earlier the tests, the more resources are saved, especially economic resources. Eye-tracking is also used in tools and software designed to solve the communication problems of individuals with moderate movement disorders, or individuals suffering from extremely serious neuromotory diseases.

## Visualisation of the results after the eye-tracking analysis

Data analysis software is the perfect tool to rapidly and automatically visualise the results of the eye-tracking analyses; the information is easy to understand, extensive, and comprehensive.

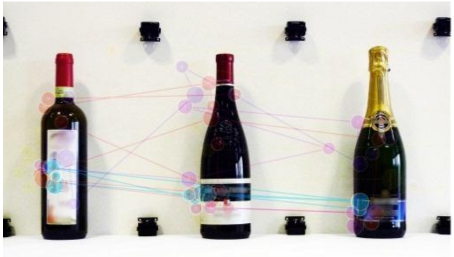
The static, dynamic or interactive gaze plot/scan path reproduces the individual's visual strategy; this makes it possible to retrace the sequence used to access the information in the stimulus and interpret how important it is during decoding by the individuals. The gaze plot can refer to an individual or a group (the points are plotted as circles: the bigger the points, the longer they were looked at, and the greater the interest in these areas shown by the individuals in the test). It is also possible to visualise the gaze replay, a video of the eye movements of each individual.

Thermal maps are images of the stimulus object used in the study; they are characterised by areas highlighted in more or less intense colours. The more intense or 'hotter' areas represent the areas of the stimulus which the individuals looked at most, in terms of frequency and length of fixations, and pauses on meaningful elements; these areas determine the point of active perception of the information (colouring with colour paths ranging from red to yellow to green records the intensity of the gaze on the medium used in the test: red indicates the sectors which caught the most visual attention during the test).

The information and graphic or creative elements in a visual scene can be identified separately as areas of interest (AOI).

By comparing the areas of interest − heterogeneous in a single stimulus (e.g., brand vs. text, text vs. image), or homogeneous in several stimuli (brand vs. brand, etc.) – we can measure the quality of the information of the communication (using several pre-established parameters).

Using a points system, eye-tracking makes it possible to measure the indexes which can identify the quality of fruition/interaction with different kinds of stimuli, such as the threshold of perception, the visual/attention performance of each individual while carrying out each task, etc.




*Figs. 9 and 10 - Examples of the results (gaze-plot, left, and heat maps) of eye-tracking tests on real products and photographs of products. The tests were performed on different products (wines and chocolate) as part of the Poliedro Research*[38]*; eye-tracking glasses were used to analyse the 'real' products. In fact, tests were carried out on several different brands of chocolate bars and wine bottles.*
*To assess the data produced by the eye-tracking tests, the panellists were required to compile a semantic differential.*[39]

Eye-tracking can therefore be used as a possible device to control not only the product, but above all the concept, possible materials, and finishings.

The analysis can be used just as successfully with real and virtual prototypes: an interesting indication towards virtuality in order to optimise the costs of the tool.

[38] The Poliedro Research – Pollenzo Index Environmental and Economics Design was financed by the Regione Piemonte – Social and Human Sciences Contract Notice in 2009. The following university partners were involved from 2009 to 2012: Università degli Studi di Scienze Gastronomiche – Pollenzo, Bra (Cuneo); Università degli Studi di Torino - Department of Management – Commodity Sciences Section; Università degli Studi di Torino - Department of Management – Accounting and Business Economics Section; Università degli Studi di Torino – Department of Social, Economic, Mathematical, and Statistical Studies Section; Politecnico di Torino – DAD Department of Architecture and Design. The research examined the qualitative and quantitative aspects of the environmental, functional, communicative and 'design' performance of food packaging.

[39] The semantic differential is a rating scale with a series of bipolar adjectives (with opposing meanings); it is assessed by an individual using a 5 to 7 point Lickert scale, arranged as opposites on a table. The semantic differential was proposed and developed by Osgood, Suci and Tannenabum to assess people's attitude towards a given product, object, concept, etc.

## 2.5 Olfaction and materials

As regards olfaction, we could either establish four primary attributes using the list drawn up by Aristotle,[40] pungent, bitter, acid, and oily, or repeat the classification of gustative attributes, sweet and sour.[41] Since it is difficult to apply these adjectives or attributes describing olfactory properties to different kinds of materials, how can we define the smell of plastic or metal as bitter or sour?

'Giving a name to a smell is a difficult cognitive task. Smells […] are seldom easy to verbalise. In fact, we all know how difficult it is for individuals to name a smell. Normally they use meaningful episodes of their lives, […] amusing verbal or non-verbal interjections, or else people classify the smell according to its hedonic implications'.[42]

### *2.5.1 The evaluation method and olfactory adjectives*

Rather than defining olfactory attributes, these considerations led us to simply decide whether or not a material had a characteristic smell (smell of the material), whether it had no smell (odourless) or could be scented. Wood, for example has a characteristic smell, and each species has its own fragrance; plastics, which are also unique and specific to a whole family of materials, are defined by 'noses' as smelling of chemicals, petrol,[43] or plastic.

On the contrary, manufacturing companies say that a microencapsulated material can be scented with a whole range of aromas, scents, fragrances, or bad smells. In this case, the materials are classified using the adjective 'scented' and the list will include all the possible fragrances provided by the company. One example is the Scent-a-Vision material, a scented plastic manufactured by the

[40]Aristotele (1994), "Sense and Sensibilia", in *Piccoli trattati di storia naturale*, Laterza, Rome-Bari, pp. 218-220.

[41]Ashby M., Johnson K. (2002), *Materials and Design. The art and science of material selection in product design*, op. cit.

[42]Zucco G. (2000), "Olfatto: unicità di un senso", in *Le tattiche dei sensi*, op. cit., pp. 65-66.

[43]Porretta S. (2000), *Analisi sensoriali e consumer science*, Chiriotti, Turin.

American company California Fragrance Co., made with polyolefin capsules in which the client can put his favourite fragrance. There is a long list of fragrances: apricot, pineapple, wild flowers, brioche, talcum powder; as well as unpleasant smells: tar, smoke, …

Olfactory characteristics have therefore been reduced to three descriptors, in other words 'odourless, smell of the material, and scented'.[44] One consideration influenced this choice: whoever chooses a material for a certain project wants to know if that material has or doesn't have an odour and, if it does, whether the odour will be long-lasting.

The three descriptive terms are therefore accompanied by information regarding how long these smells or odours will last, whether they are permanent, or whether they will disappear. As regards microencapsulated materials, the manufacturing company specifies how long the fragrance will last.

### *2.5.2 Critical areas and future developments*

What will happen in the future should be discussed with the experts, with the sommeliers and noses – masters in the art of defining an odour: it will be possible to describe the characteristic smell of a certain kind of wood using the terms used during the sensory analysis of food products[45] or wines, for example 'spicy', 'fresh green wood'. It will be interesting to see whether in the future the terms currently used to describe the olfactory properties of food products can be successfully used to describe the materials used in design and architecture.

## 2.6 Sensory terminology

Sensory terminology is therefore made up of the above-mentioned descriptor adjectives referred to sight, touch, hearing, and olfaction. These adjectives 'characterising the quality of a material, but also of

[44] Cfr. Appendix 1.
[45] Porretta S. (2000), *Analisi sensoriali e consumer science,* op. cit.

an object',[46] will be used to describe, classify, and then catalogue materials belonging to different material families and presented in different ways; this 'cataloguing' will be performed after repeated sessions by the panellists so that the results can be considered repeatable and shareable.

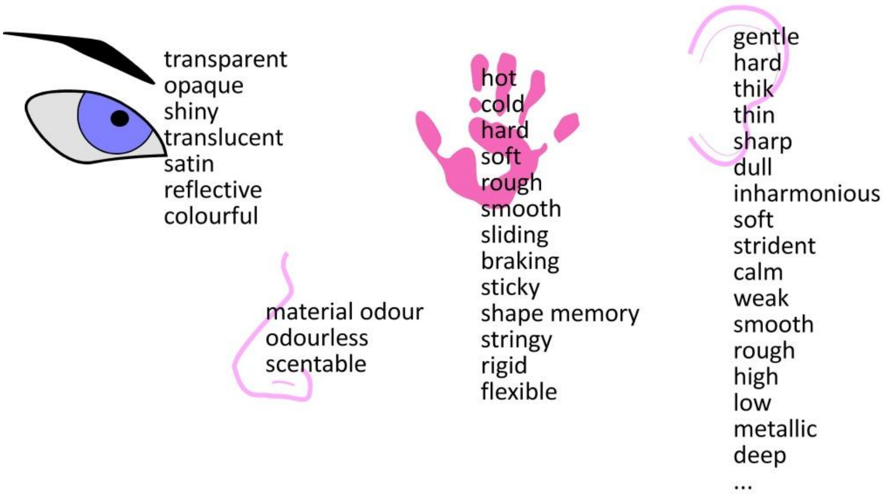



*Fig.11 - The sensory terminology elaborated and used by MATto, the materials library of the Study Course in Design at Politecnico di Torino.*

In the proposed list of sensory terms no adjectives refer to the whether or not the materials are pleasant or unpleasant: we decided not to use the word 'beautiful', 'pleasing to touch or look at', or 'ugly' because these terms are too personal and subject to variations influenced by culture and experience. In the future, when a decision is taken to make the 'sensory terminology' tool legible and useable in other languages, care must be taken to accurately translate the descriptors.

'Language expresses and describes our experience and makes it communicable; but to do this it inevitably sparks a transformation process of the experience itself, adapting it to its own laws, styles, and pre-established categories bound by a set of rules which are not

[46] Lucibello S., *Materiali@design: verso una nuova modalità di selezione su base percettiva dei materiali per il design,* op. cit., p. 75.

necessarily the ones that structure the experience. […] Language is a diacritical system of signs, in other words of linguistic units characterised by a relationship between a signifier (the word) and a meaning (what the word refers to). The relationship is the basis […] behind the semantic function of language, through which a relationship is created between the world of words and the world of things. However this relationship, in other words the meaning of a word, is problematic because it does not primarily depend on an objective reference to the world of experience, but rather to all the structural relations linking each sign to all the others'.[47] Furthermore language also represents the culture and knowledge of a population; 'it contains the memory of its experiences and events; as such it guides and shapes the processes of knowledge and understanding'.[48]

[47] Galati D. (2002), *Prospettive sulle emozioni e teorie del soggetto*, Bollati Boringhieri, Turin, pp. 120-121.

[48] Ivi, p. 122.

# 3. Beyond sensory perception: measuring the eco-compatibility of innovative materials

by Beatrice Lerma and Cristina Allione

Innovative materials are chiefly appreciated for their expressive potential; their eco-compatibility, however, is much more difficult to classify. We have little data about their environmental impact and possible end-of-life scenarios; all we have are assumptions. When we choose a material we also have to consider its 'sustainability'. 'In fact, the growing need to imagine a sustainable future starts when we choose a material, and since it's impossible to stop consumption, the least we can do is to apply and use materials in a more intelligent manner by exploring the various ways in which we can use materials and allow products to be easily disassembled into their component parts and then recycled'.[1]

When we talk of environmental sustainability, which in short means minimising resource consumption and the emission of substances into the environment, it's difficult to think of eco-compatible materials in absolute terms.[2] Several different kinds of environmental certification systems are now used worldwide to classify materials or semi-finished products with the best environmental performance. These certification systems generally provide a complete quantitative assessment of the environmental

[1] Lucibello S. (2009), "Gestire l'iperprogettualità", in Ferrara M., Lucibello S., edited by, *Design Follows Materials*, op. cit., p. 81.

[2] The first-ever definition was in the 1987 Brundtland report (named after Norwegian Gro Harlem Brundtland, President of the Commission); it was later adopted by the World Commission on Environment and Development (WCED): 'Sustainable development is development that meets the needs of the present without compromising the possibility of future generations to meet their own needs'.

performance of products from cradle-to-gate, in other words until they are ready to be used to produce new products. However, we know very little about their environmental performance once they become part of the production process, or during disposal of the product. In fact, when we talk of the eco-compatibility of products, many variables influence the real environmental performance of materials during the life cycle of the product in which they are used. Instead these variables have to be taken into consideration.

An eco-compatible product, i.e., with a reduced input-output environmental load during its life cycle, is not achieved only by using materials considered as more eco-compatible compared to others; it is also heavily influenced by its life time, context of use, and the disposal options available in that area.

This is why the materials chosen during the design process must ensure a reduced environmental load and have a cradle-to-gate life time (based on the specifications provided by the supplier using one of the many environmental certification systems). It is equally important for the materials to be properly used and coupled during production (with minimum waste and surplus, and the use of low energy consumption assembly processes). Materials should also require minimum transportation and have a low environmental impact during the useful life of the product (maintenance, replacement of parts, etc.); they should also be easy to dispose of at the end of their useful life thanks to the reversible assembly systems used during production.

In light of the above, we propose to consider the energy – environmental performance of innovative materials, emphasising not only their environmental performance from cradle-to-gate, but also their performance from cradle-to-grave, and underscoring the main quantitative and qualitative parameters characterising their entire life cycle performance. Our aim is to help designers create truly eco-compatible products. Choosing a material is a design issue. 'The sustainability of a material undoubtedly depends on several of its intrinsic characteristics based on availability or the manufacturing process, but above all on the context and method of use'.[3]

[3] Tamborrini P. (2009), *Design sostenibile. Oggetti, sistemi e comportamenti*, Electa, Milan, p. 68.

In other words, ensuring the environmental sustainability of a product during its entire life cycle is a task assigned mainly to the designer, to his ability to interpret its real context of use and end-of-life and, as a result, choose the right materials and semi-finished products.

In fact, a designer's discernment allows him to play an active role by interacting with the other players and professionals involved in the entire life cycle of the product; a designer can identify the most important environmental prerequisites and include them in the required performance system of the new product.

By acting as a go-between the designer can mediate between the environmental requirements of the users involved; from the very early design stages he can also actively implicate the actors who will be involved in the life cycle of the product. As soon as he starts to design and plan a new product, a designer can constructively influence the future environmental performance of a product.

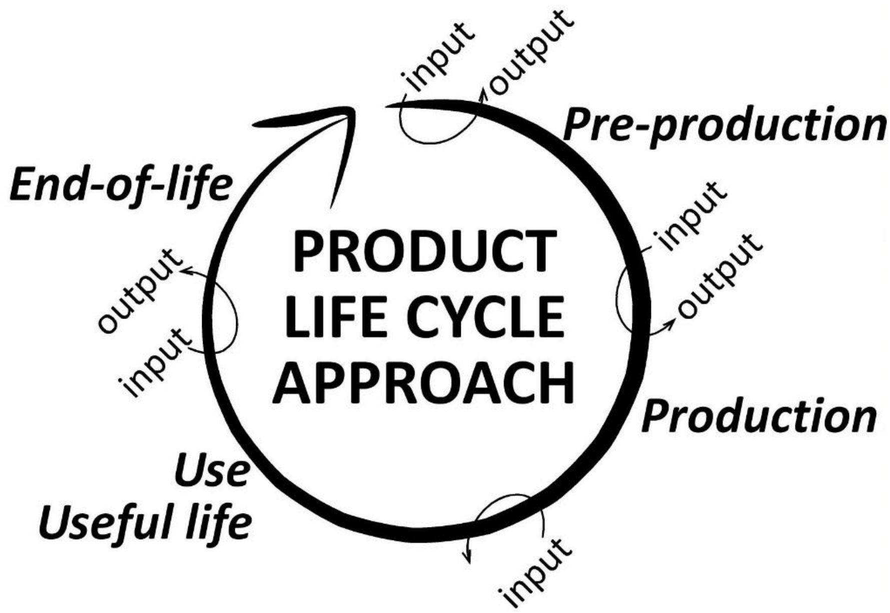



*Fig. 1 - Approach to the life cycle of the product.*

For a designer, considering the environmental impact of a product during its entire life cycle means adopting a systemic approach to design. 'Although we now use a consolidated approach to design shapes based on the coordination and integration of all functional, symbolic, cultural, technical and production factors, the context currently dictates (and will increasingly dictate in the future) that a design process has to be systemic. In other words, several different manufacturing processes have to be integrated so that, in a nutshell, the output of one production can become the input of another. This is the new concept behind systemic design'.[4]

Consideration has to be given to the entire life cycle of the product and not just its design, production, distribution, use, end-of-life, recycle, or reuse. The designer has to consider the effect of these life cycle phases when the product is produced, used, and discarded; he has to understand and be familiar with the production, maintenance, use, and end-of-life of a product. To reduce its overall environmental load he has to elaborate real hypotheses regarding the energy and material flows involved.

Today a designer is asked to design a product that satisfies environmental requirements as well as traditional requirements (physical, technical, mechanical, regulatory, etc.); he will have to tackle the multiple variables associated with very different disciplines and production systems.

Although the choice of materials is important, it's not the only factor that makes a product eco-compatible.

When we talk about environmental sustainability we need to distinguish between two levels of environmental sustainability of the product and the material, a concept already expressed in this book. The environmental sustainability of a product doesn't depend only on choosing the right materials, but above all on the sum total of the environmental performance of a product (and its materials) during its entire life cycle depending on the context in which it is used. Instead the environmental sustainability of a material depends on several intrinsic characteristics influenced by its availability, production, context of use, and possible end-of-life scenarios.

[4] Bistagnino L. (2008), "Innovate, But How?", op. cit., p. 34.

Given the above, when a designer has to create a new, truly eco-compatible product it will help if he has extensive knowledge of the materials he can use from the initial stages of a metadesign project, and in a way pre-empt identification of the most ‘environmentally’ suitable materials.

Unfortunately a designer often knows very little about the world of materials, especially the environmental characteristics of innovative materials: data about the various stages of a life cycle, especially end-of-life scenarios, is often very limited. As data is often unreliable one can only make assumptions.

## 3.1 Tools and methods to assess the eco-compatibility of a product

Widespread use is now made of several different types of Ecotools and quantitative and qualitative approaches and methods to analyse and evaluate the eco-compatibility of a product, material, semi-finished product, or even a production process. These tools help the designer to not only create and produce eco-compatible products, but also select the materials which will ensure its eco-compatibility thanks to their performance.

These tools and methods can be stored in a sort of designer’s ‘toolbox’. The approach adopted by Concurrent Ecodesign (CED)[5] considers Ecotools as instruments to tackle and manage the

[5] Concurrent Ecodesign (CED) is a methodological approach developed by the Research Unit of Industrial Design at DIPRADI (Department of Architectural and Industrial Design, Turin Polytechnic). In practice it gives the designer a ‘toolbox’ he can use to make the product sustainable. It was elaborated based on the consolidated Concurrent Engineering (CE) approach used by industry to manage complex production. The CED is a continually evolving container/hyper-methodological approach available to the designer. It makes no bones about using the now consolidated organisational procedure of CE and maintaining a strong industrial imprinting, but it broadens its field of action and adds to what is already made available by other CE operational methods and tools more or less linked to the issue of the environment. This approach can be used to prefigure the entire life cycle of the product and assess the energy-environmental load during its entire life cycle; it can also accurately evaluate the relationship between the product and Sustainable Development, in other words not only the way in which a product should be made, but also why it should be made, and for whom. For more in-depth information, see Lanzavecchia C. (2000), *Il fare ecologico, il prodotto industriale e i suoi requisiti ambientali*, Paravia Bruno Mondadori, Turin.

complexity of design, and as a multifaceted method capable of mediating between human and artificial intelligence and between the natural/technological/human resources, complexities, and transversal issues of an ecosystem. Ecotools allow the designer to prefigure the entire life cycle of the product and assess its energy-environmental load. In other words, they can act as a link between the individuals inside and outside a company who are involved in creating a product with the minimum possible environmental impact. Often the product is inspired by the Integrated Product Policy (IPP)[6] to promote a 'greener' market of products ultimately aimed at encouraging the development of a sustainable economic model.

In the field of industrial production, pollution prevention was initially tackled using the Clean Technology or Clean Product approach.[7] Later on, a preventive approach based on the life cycle of the product (Life Cycle Thinking Approach) was adopted; this approach considers the entire life cycle of the industrial product from conception. Clean technologies focused mostly on pre-production and production processes, in other words on improving the environmental performance of processes thanks to the use of innovative technologies; however this did not eliminate the risk of simply shifting the environmental damage onto another stage in the life cycle of the product. Instead the Life Cycle Thinking Approach applies an anticipatory design strategy to the entire life cycle of the product.

Based on this approach, the product is considered as a product system, in other words as the sum total of the events which create it and accompany it during its life cycle; these events include the main production, pre-production, distribution, use, and end-of-life stages which in turn include all the processes and activities involving continuous exchange between the environment, materials and energy.

[6] Integrated Product Policy (IPP) is the most recent approach regarding the environment. It was elaborated by the European Commission in its Green Paper on integrated product policy. After a long public consultation process the IPP was published in Communication 302/03 'Integrated product policy – developing the product life cycle concept'. One of Europe's strategic choices is to focus on a new growth paradigm to guarantee a higher quality of life, create wealth, and ensure market competitiveness based on more ecological products and services which use less resources, have less impact, and produce less waste.

[7] Allione C., Lanzavecchia C. (2008), *Dall'Ecodesign all'Architettura*, Time & Mind Press, Turin.

Only a design approach focusing on the optimisation of environmental performance during the entire life cycle of the product will permit advance detection of the environmental effects of a product; this will then allow identification of the right corrective factors and lead to a truly eco-compatible product rather than a restyling.

This anticipatory and operational approach is substantiated by the creation of eco-compatible products, and also by the fact that it is considered the 'trump card' used by enterprises to protect their competitive environmental edge. Why? Because economically and financially environment-oriented initiatives cost less if they are developed during design and consider all the objectives/existing restraints, and all possible solutions. On the contrary, if enterprises are forced to radically redesign a product, this requires extensive investments and leads to the non-use and therefore non-amortisation of material assets.[8]

Broadly speaking, Ecotools (often turned into software and databases) consider the product and ensuing selection of materials from the point of view of their life cycle, the type of support they provide the designer, and the evaluation criteria they exploit. These tools can be divided into two main macro-groups: quantitative tools and qualitative tools.

### *3.1.1 Quantitative tools*

Quantitative tools quantify and provide detailed measurements about the performance of an existing product; generally speaking they use the Life Cycle Assessment (LCA) methodology, but in some cases they employ a simplified version.

Let's assume that design is characterised by four main design stages (metadesign, concept design, product design, and engineering), this tool can be useful during the metadesign stage to measure the eco-compatibility of existing products (either during a possible redesign or during engineering and prototyping) in order to

[8] Lanzavecchia C. (2000), *Il fare ecologico, il prodotto industriale e i suoi requisiti ambientali*, op. cit.

verify the real environmental load of a product before it is launched on the market.

However during the real design stages (concept and product design), when the designer is directly involved, it's difficult to apply these quantitative evaluation tools because most of the data about the future product is either unknown or still being defined. Furthermore, these tools are based on a practice/technique which, according to the procedures established by ISO standards to ensure their reliability,[9] are rather complex, uneconomical (often requiring the work of environmental experts to perform the evaluations), and time-consuming (a complete LCA based on ISO standards takes rather a long time). Finally, although these tools often provide evaluations of the main environmental effects, designers often find them difficult to understand and interpret.

In light of the above, we can conclude by saying that this macro group of tools is indirectly useful during the real design stage when the designer is personally involved.

### *3.1.2 Qualitative tools*

Qualitative tools are guidelines or simplified checklists providing designers with the design indications they should follow to pre-establish the environmental behaviour of a product during its entire life cycle or during certain critical phases, particularly its end-of-life.[10]

Over the years, eco-design guidelines and strategies have been studied by several research centres and national and international organisations.[11]

[9] UNI EN ISO 14040. The norm describes the principles and framework for conducting and reporting Life Cycle Assessment (LCA), Environmental Management – Life Cycle Assessment – Principles and guidelines (1997). Source: webstore.uni.com/unistore/public/, www.ecosmes.net

[10] Allione C., Lanzavecchia C. (2008), *Dall'Ecodesign all'Architettura*, op. cit.

[11] Over the years the delineation of eco-design guidelines and strategies was studied by several research centres and national and international organisations which re-elaborated and re-interpreted them, but always based on a common approach to the life cycle. Examples include the following main studies: Brezet H., Van Hemel C. (1997), *Ecodesign: A promising approach to sustainable production and consumption*, Delft University of

In practice, these guidelines have been re-developed and divided into two main types:

- as a consultation tool (mainly on paper) to help designers identify the environmental requirements which have to be satisfied during design; these tools adopt a requirement-performance methodology[12] such as the one normally used in the cultural design of an industrial product;
- as a checklist and matrix, to be used as an evaluation tool based on simplified criteria to verify the effectiveness of the design intended to improve environmental performance, or to rapidly assess the environmental load of entire production systems in order to establish whether or not they can be improved.[13]

In light of the above, we can conclude that, unlike the quantitative tools in the previous paragraph, this group is directly useful during the concept and product design stages since these tools are intended

Technology & UNEP- United Nation Environment programme, Paris; Keoleian G., Menerey D. (1994), Life Cycle Design Guidance Manual Environmental Requirements and Product System, EPA-600R92226, EPA Environmental Protection Agency, Washington, USA; Manzini E., Vezzoli C. (1998), *Lo sviluppo del prodotto sostenibile, I requisiti ambientali dei prodotti industriali*, Maggioli, Santarcangelo di Romagna (Rn); Lanzavecchia C. (2000), *Il fare ecologico, il prodotto industriale e i suoi requisiti ambientali*, op. cit.

[12] The requirement-performance methodology was developed in the world of construction and since the seventies has also been used in the field of industrial design. In particular, design is based on the survey of the requirements (turned into special prerequisite requirements) which will later be checked against the performance of the designed element. The word prerequisite as a 'required characteristic' is therefore the basis of the requirement vocabulary which in turn is chiefly based on the concept of performance: to demand or determine performance replaces the definition and description of the physiognomic and material features of an object. For more details, see Ciribini G., edited by (1992), *Tecnologie della costruzione*, La Nuova Italia Scientifica, Rome.

[13] On this issue, see eVerdee (www.ecosmes.net), a free online tool to self-evaluate the environmental performance of small and medium enterprises. The guidelines in the tool have been re-elaborated based on four objectives-safeguard indicators (water, air, ground, waste, etc.) and re-organised as a checklist for the different life cycles of the object in question. Evaluation of performance is based on a qualitative points system from zero to five, where zero corresponds to the worst situation and five to the best. For each object surveyed, the score is assigned based on a guide which provides the user with the criteria with which to assign the right evaluation.

to interact directly with the designer during the design stage when there is no time to perform a complete and detailed LCA.

## 3.2 Delineation of a multicriteria system to interpret the environmental performance of materials

Considering the previous division of the Ecotool-software into two macro groups (quantitative and qualitative tools), the guidelines (i.e., the qualitative tools) are obviously the tools best suited to the designer's task.

Based on the main guidelines already established and classified by other studies regarding the design of an ecodesign product, in this chapter we will re-elaborate and identify a series of specific guidelines and indications to be used when selecting materials; these guidelines and indications take into account the life cycle of the product.

The guidelines are linked to the specific performance of materials which will synergistically influence the performance of the product during its entire life cycle; the guidelines can be used by designers as a sort of guide/tool during the design of the product.


*Fig. 2 - From product guidelines to material selection guidelines.*

These guidelines focus on three main ecodesign strategies all intended to minimise consumption and emissions.

1. **use of materials with a reduced environmental load:** strategy aimed at improving the performance of the future product during its entire life cycle; attention must be focused during design on the variables which can synergistically influence the performance of the future product such as eco-efficiency, localisation, toxicity, renewability and low material intensity;
2. **extension of the useful life of materials:** strategy focused on the product and its materials/semi-finished products once they have come to the end of their useful life. Although focused on end-of-life, this strategy indirectly influences the performance of the product during its entire life cycle because the extension of the useful life of materials not only delays the end of its useful life, but also indirectly reduces the use of virgin resources to produce a new product. In practice, using this strategy during design means adopting guidelines regarding aspects such as the durability of the materials in the product and the end-of-life treatment to which they can potentially be destined if correctly assembled and used in the product;
3. **ethics:** a strategy focused on the producers/suppliers of products, materials, and semi-finished products, rather than on the product itself. More specifically, attention has to be paid when selecting the materials and semi-finished products provided by producers and suppliers; the latter have to show they are environmentally responsible by adopting management strategies, development policies, and environmental improvement objectives which in some cases can be officially declared and certified.

Having identified these guidelines focused on material selection it is then possible to identify the environmental, qualitative, and quantitative parameters which provide the best description of the environmental behaviour of the material during the entire life cycle of the product in which it is used.

In other words, these parameters make it possible to 'measure' the behaviour of the material compared to every 'good rule' or guideline that the designer has decided to follow using design.

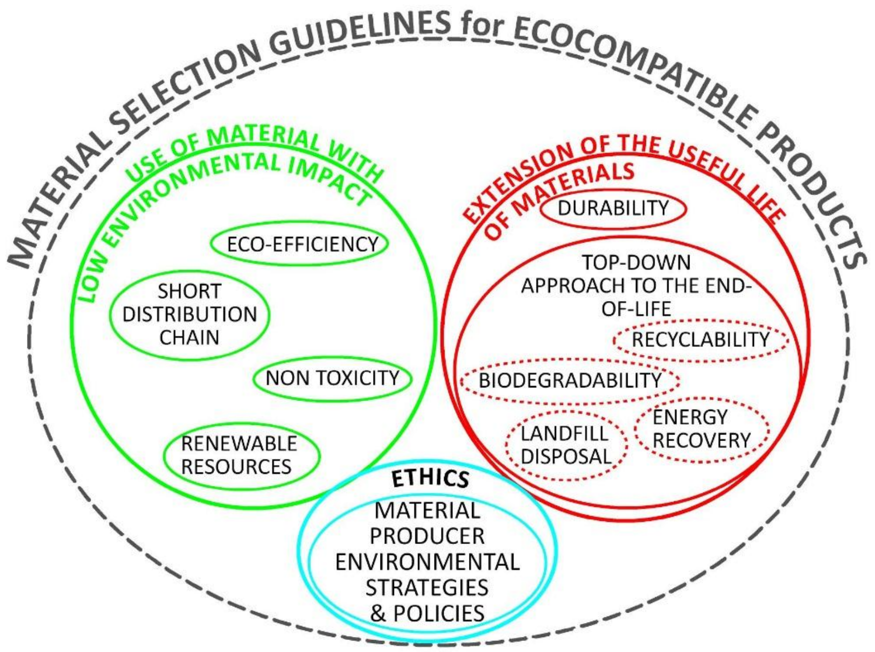



*Fig. 3 - Simplified diagram of the guidelines regarding the selection of materials and semi-finished products.*

This transfer of know-how from the product to the specific moment when materials and semi-finished products are selected provides a sort of 'identity card', a multi-criteria system to interpret the environmental performance of a material; this system is scientifically in line with the life cycle approach, but can easily be used and interpreted by the protagonists of a design process.

The multi-criteria interpretation of materials elaborated according to their life cycle will assist and facilitate the designer when he has to choose the best materials for each type of product, its context of use, and disposal.

The following paragraphs are structured according to these three main environmental strategies; they illustrate the guidelines regarding the selection of materials and the relative qualitative and quantitative parameters which make it possible to assess the behaviour of the material vis-à-vis each guideline.

## 3.3 Using materials with a reduced environmental load

There are many guidelines which can synergistically help to implement this strategy.

### *3.3.1 Eco-efficiency*

Trying to minimise resource consumption and the emissions of substances into the environment during design and material selection involves identifying eco-efficient materials,[14] in other words materials with the same performance but lower environmental loads.

The eco-efficiency of a material can be accurately evaluated using Life Cycle Assessment (LCA); the latter makes it possible to perform a detailed assessment of the overall environmental impact of a material until it is ready to be used (from cradle-to-gate).

A Life Cycle Assessment based on the input and output of the processing/transformation of a material can define the impact of these activities and their main environmental effects.

We decided to evaluate the eco-efficiency of a material using two quantitative parameters: embodied energy and CO2 emissions, the two main and most famous indicators of the input and output flows associated with pre-production and production of materials/semi-finished products.

Apart from these two parameters, there is a third qualitative evaluation criteria which provides an assessment of how many transformations a material or semi-finished product has to undergo to make it useable. This third qualitative criteria can be accompanied by

[14] According to the definition provided by the World Business Council of Sustainable Development (1995), the concept of eco-efficiency corresponds to the principle of 'creating more value with less impact'. In other words, pursuing the principle of eco-efficiency means providing consumer goods (products and materials) and services that satisfy human needs and bring quality of life, while progressively reducing resource intensity throughout the life cycle to a level at least in line with the Earth's estimated carrying capacity.

a flow diagram showing the relationships between these processes. The intention is to understand the systems used to produce materials and roughly estimate their energy-environmental load based on the principle according to which the more numerous the transformation processes and processing, the greater the impact on resource consumption and emission of substances into the environment during pre-production and production.

**Parameters/measurement criteria**

- *Embodied Energy:* indicative estimate of the overall energy consumed (in MJ/kg) to produce a kilogram of ready-to-use material. Based on the energy analysis method, the energy load of a material is usually calculated by adding the different kinds of energy required to produce the ready-to-use material, in other words, direct energy (i.e., the energy directly used during production, for example, electric energy), indirect energy (the energy required to produce direct energy, i.e., the energy used during the previous transformation processes), feedstock energy (the energy embodied in the input materials used as such and not as fuel, but which at the useful end-of-life permits energy recovery through combustion before being discarded in a landfill), and the energy used during transportation required to produce the material/semi-finished product in question.[15]
- *Emissions of equivalent CO2:* simplified assessment of the emissions recognised as being the main contributors to the greenhouse effect (such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons) and produced by the transformation processes required to produce the ready-to-use material. This quantitative indicator is expressed as kilograms of emissions of equivalent CO2, also known as the Carbon Footprint; it is calculated by summing the elements which contribute to the emission of greenhouse gases after being suitably converted using specific coefficients of transformation (the characterisation factor used in a LCA analysis).

**Tools and software**: defining the parameters to measure the performance of an innovative material can be achieved using LCA software tools such as SimaPro or GaBi.[16] Simplified tools can also be used to evaluate the life cycle; these tools are based on the use of

[15] The energy footprint of a material can also be defined by the term Gross Energy Requirement (GER). For more details, see Baldo G.L., Marino M., Rossi S. (2008), *Analisi del ciclo di vita LCA. Gli strumenti per la progettazione sostenibile di materiali, prodotti e processi*, op. cit., pp. 80-90.

[16] www.pre.nl/simapro, www.gabi-software.com

a few representative environmental indicators, for example Eco-it (which uses Eco-indicators[17]), or Ecoaudit (in the Cambridge EcoSelector database), which allow simplified LCA analyses to be performed based on two indicators of the environmental load of a product during its life cycle: energy consumption and CO2 emissions. Alternatively, when traditional materials are assessed, these parameters can be found in databases such as Idemat (available online[18]) with the assessment in Eco-indicators of the most widespread materials, or the Cambridge EcoSelector[19] which, apart from the value in Eco-indicator, also provides the following environmental parameters: embodied energy, CO2 emissions, nitrogen oxide emissions (NOx), sulphur oxide emissions (Cox), and water consumption. It also evaluates of the energy consumption associated with major transformation processes.

### 3.3.2 Localisation

The transportation of raw materials and the processing needed to obtain a ready-to-use material or semi-finished product can have an enormous influence on the life cycle of the final product in terms of energy consumption and environmental emissions.

[17] The Eco-indicator assessment system is a method developed by TUDelft (funded by the Dutch Ministry of the Environment) to assess the environmental performance of a product during the design process. After the first version (Eco-indicator '95), a second version was developed (Eco-indicator '99) to rectify the problems of the first version; the problems were discovered by the scientific community thanks to a joint team of Dutch and Swiss LCA experts who worked on a research project funded by the two Ministries of the Environment in their respective countries. The reports published by Pré Consultant are available online (website: http://www.pre.nl). In practice, the Eco-indicators are artificial numerical indexes representing the environmental load of a material or process; they are based on the principle less is better and calculated using thorough, in-depth LCA analyses. In the LCA study carried out to calculate an Eco-indicator, the impact analysis stage is performed up until normalisation and weighting using a weighting system based on the criteria of a damage function approach. In other words, the disaggregated data of the different environmental effects obtained by a LCA analysis are weighted based on how they affect human health, the health of the environment, and resource depletion. After being normalised on the basis of their effect over a period of time (normally one year) they are then added together to define a single one-dimensional numerical index.

[18] Cfr. Appendix 2.

[19] Ibid.

Choosing materials which can be found along the short supply chain is a strategy which not only minimises resource consumption and the environmental emissions caused by transportation and the number of kilometres covered, but also makes it possible to preserve and enhance material culture, artisanal/industrial traditions, and the local economy.

Furthermore, the principle of the short supply chain should be applied not only during purchase of the material, but also with regard to its end-of-life. Preference should go to materials whose surplus and processing waste can be recovered by other short range production systems or, at its end-of-life, be recycled in local plants. This will eliminate long journeys to places where it can be properly disposed of and recovered since this kind of transportation is not only uneconomical, but can also compromise the environmental benefits of the material-energy recovery.

**Parameters/measurement critieria**

- *Short, medium or long range:* indication of the site where the material is produced to establish the distance from where it is to be used. The distance is divided into three groups: short range (up to 200 km), medium range (from 200 to 1200 km), and long range (1200 km +).

### *3.3.3 Renewability*

Materials and semi-finished products are made up of raw materials and substances which use energy and material resources; in turn the latter can be classified as depletable (coming from fossil resources such as hydrocarbons, methane gas, fossil fuels, or mineral resources) or renewable (coming from resources obtained directly or indirectly from the sun, such as biomasses[20]).

Two factors influence whether or not a resource is renewable or non-renewable: its regeneration speed (i.e., the time nature takes to

[20] Vezzoli C., Manzini E. (2008), *Design for Environmental Sustainability,* op. cit., p. 61.

regenerate the resource), and how often the resource is extracted and used by man.

These two factors influence whether or not we can define a material as renewable, i.e., one made with resources where regeneration is quicker than consumption.

Furthermore, thanks to current material recycling techniques, the increasing number of new materials which are appearing on the market are made with secondary raw materials, i.e., materials made from other materials. This avoids using virgin raw materials during production.

**Parameters/measurement criteria**

- *Renewable or non renewable resource:* this parameter explains whether the raw material comes from renewable or non-renewable resources
- *Virgin or recycled materials:* this parameter is used to emphasise whether or not some of the material contents are recycled.

### *3.3.4 Nontoxic materials*

This guideline suggests that materials which do not give off toxic substances during their life cycle should be used to produce a product.

The toxicity of a product is directly influenced by the materials it is made of. Depending on the substances, agents, and preparations[21] used to make a material, the latter can affect our health during all or some of its life cycle (pre-production, production or use); it can also become toxic when it becomes waste or during its end-of-life treatments. In fact, during its life cycle a material can become toxic

[21] A material is made up of substances, preparations, and chemical agents. Substances are the chemical elements whose compounds, when mixed with additives, create the preparations. Preparations are mixtures of substances made up of two or more chemical substances, and chemical agents are the elements present in the preparations. Legislative Decree n. 52/97 and Legislative Decree n. 285/98 classify substances, preparations, and chemical agents according to how dangerous they are: not dangerous, not dangerous but used in ways which may be harmful, dangerous as classified by regulations and marked with special labels on the packaging of products, and finally, dangerous but not classified by regulations.

or harmful for humans if it produces substances which cause numerous adverse effects on our health.

It is important to emphasise the important role of REACH[22] (Registration, Evaluation and Authorisation of Chemicals), the European legislation on dangerous chemical substances which entered into force in 2007. The REACH system requires the manufacturers and importers of chemical substances to evaluate the risks associated with their use, and take the steps required to properly deal with any potential danger. The regulation also established the European Chemicals Agency, the agency responsible for managing the technical, scientific, and administrative aspects of the REACH system.

The Agency publishes and regularly updates a list of substances ('candidate list of substances') identified as having properties which cause very high concern; the latter include:

- CMR substances (carcinogenic, mutagenic or toxic for reproduction);
- PBT substances (persistent, bio-accumulative and toxic);
- vPvB substances (very persistent, very bio-accumulative);
- several problematic substances with irreversible effects on human beings and the environment, such as endocrine disrupting chemicals.

HERA (Human and Environmental Risk Assessment) is one example of the possible uses of the information about dangerous chemical substances. The project is sponsored by AISE (Association Internationale de la Savonnerie, de la Détergence et des Produits d'Entretein) and CEFIC (European Chemical Industry Council[23]). This project has produced a significant number of documents (available online) about how substances in detergents can affect human health and the environment. This information may help to explain the specific substances in materials and how they are used during their life cycle.

[22] REACH Regulation (Registration, Evaluation and Authorization of Chemicals)(EC) n. 1907/2006 of the European Parliament. This regulatory text replaces much of the community legislation regarding chemical substances currently in force and introduces an integrated system for their registration, evaluation, authorisation and restriction.

[23] www.heraproject.com, www.cefic.be, www.aise.eu

The potential toxicity of a material when it reaches its end-of-life and becomes waste is linked to its end-of-life treatments; the latter may cause the release of toxic or dangerous substances (classifiable according to how dangerous they are) which, either through contact or inhalation, can directly influence human health or environmental balance by polluting water tables or ground soil.

One treatment process applied to materials at the end of their life cycle is material enhancement through 'virtuous' recycling or reuse to extend their useful life (delaying resource consumption and substance emissions used to produce virgin materials). Another option is to collect homogeneous fractions (plastic, paper waste, wood waste, etc.) or refuse from separate waste collection which can be subject to hot or cold treatments (incineration and combustion, waste-to-energy processing) and provide energy enhancement such as fuels or biogas. The last option is to send the material to a landfill where it may create gases which, in very high concentrations, can be toxic for human health and the environment.[24]

The gas which forms in landfills is usually not concentrated enough to be harmful to human health, however should the concentration be high enough due to an accident or bad management of the landfill itself (e.g., letting the landfill function longer than the period envisaged when it was created), then this can damage the environment (soil pollution, water tables, etc.) and harm human health.

Different kinds of landfills have been defined according to the type of waste[25] generated by a material, in other words its ability to emit substances which are toxic and dangerous when sent to a

[24] In fact, landfills receive the residuals of waste treated with a hot or cold procedure and the waste from unsorted urban waste collection which due to bacterial decomposition, volatisation and chemical reactions can generate gaseous emissions of methane, carbon dioxide, ammonia, hydrogen sulphide and non metanic hydrocarbons which, apart from being toxic and polluting, may potentially be an explosion hazard.

[25] The European Waste Catalogue (EWC) assigns a six figure code (called a EWC code) to every kind of waste in order to facilitate identification. According to the EWC, waste is classified according to where it comes from (urban or special), or depending on how dangerous it is. Non-domestic and special urban waste (marked with a special EWC asterisk) is classified according to how dangerous it is; these classes are: explosive, combustion agent, easily inflammable, inflammable, harmful irritant, toxic, cancerogenous, corrosive, infectious, teratogenic, mutagenic, capable of releasing toxic and very toxic gas, source of hazardous and eco-toxic substance).

landfill: landfills for inert, non-hazardous, or hazardous waste for which regulations and safety procedures have been drawn up and must be respected to ensure that the landfill is properly managed.

Knowing which landfill a material will be sent to when it becomes waste makes it possible to establish its potential end-of-life toxicity.

**Parameters/measurement criteria**

- *bio-compatibility: this parameter indicates that the material does not release substances toxic or harmful for human health during the production, distribution and usage phases;*
- *landfill typology: prior knowledge of the landfill where the material will be disposed of makes it possible to predict its potential toxicity level at its end-of-life. As a result, this qualitative parameter can indicate the three possible landfill types: inert waste, hazardous or non-hazardous waste.*

## 3.4 Extension of the useful life of materials

Two main guidelines or directions can be adopted during design; these guidelines are important when it comes to choosing the material to be used in the design.

### *3.4.1 Durability*

Durability involves choosing between two products; the preferred product is the one which has the same function but a longer life, because this delays not only the production of waste which occurs at the end of its useful life, but also the consumption of resources to make a new one.

This design strategy is more or less advantageous in terms of the overall environmental and energy performance of a product during its entire life cycle depending on the kind of product one intends to design (short, medium or long term).

If we're talking about a disposable or single-use product, then it's useless to design it to last; nevertheless reusable or recyclable materials/components should always be preferred. If instead the product has a medium/long life cycle then it should be designed to last depending on its working life; this is achieved by optimising its durability and making sure it can be upgraded and maintained.

In fact, the environmental load of long-lasting products which consume energy and materials during their useful life should be carefully assessed against their overall life cycle performance, and also against new products with lower consumption during use: i.e., optimisation of their useful life.

Designing the right durability and adaptability of a product using components[26] which can be reintegrated and/or components with the same life time, means choosing long-lasting materials. These materials should not break or deteriorate (i.e., they should maintain their properties over a period of time), and should ensure that the product remains functional. Finally, when they are still intact but come to the end of their useful life (due to indifference or real breakages), it should be possible to reuse them after simple cleaning.

In light of the above, three qualitative criteria to assess materials are provided in order to help designers choose the ones which can ensure that their properties remain unaltered over a period of time.

[26] Design by components is a methodological-design approach integrating ecological considerations into the modular products currently manufactured by the contemporary world of industrial production. The product-system is considered as a combination of parts and components from different territories; its design starts with the disassembly of existing products to understand the real function of the various components. Only after understanding their real function, and above all having understood the interrelations between the functional parts, is it possible to eliminate the surplus components and parts and delineate new product 'concepts' which will lead to truly innovative products whose form is the sum total of truly indispensable components and parts. The final shape of the product will include the components believed to be essential and for which it will be necessary to plan and envisage not only the assembly method, but also disassembly, so as to minimise consumption of resources and emission of substances into the environment. Modular design makes it possible to not only eliminate surplus parts and components, but also guarantee greater integration and/or replacement of the parts. On the one hand, this integration satisfies any possible changes in the demands of the final user and determines a differentiated series of the product according to the specific demands of each consumer; on the other, it guarantees the maintenance of the product, the substitutability of the components and their technological upgrading during the life time of the product. This extends the overall useful life of the product, delaying the moment when it is discarded, produces waste and rejects, and consumes resources and energy to produce new products. For more in-depth information about the methodology of Design by Components, see Bistagnino L. (2008), *The outside shell seen from the inside*, Casa Editrice Ambrosiana, Milan.

**Parameters/measurement criteria**

- *expected life span: this quantitative index indicates the number of years the material is expected to maintain the mechanical and physical properties declared by the manufacturer.*
- *maintenance: correct material maintenance is the right way to preserve regular functionality during its expected lifespan. Material maintenance may either be easy or complex depending on the procedure required.*
- *wear resistance: a material can deteriorate if it is used in certain conditions. This qualitative parameter indicates which factors might compromise its reliability, e.g., exposure to acid or salty environments, elements such as UV rays, rain, freezing cold, and extreme temperatures.*

### *3.4.2 A top-down approach to the end-of-life*

Once the product has come to the end of its life and the long-lasting materials and components have been recovered, a top-down[27] or hierarchical approach must be adopted for all the other components and materials; this approach must focus primarily on recyclability and the recovery of a certain fraction of secondary raw materials. Further end-of-life treatments should envisage the energy enhancement of the materials such as incineration or a waste-to-energy process. Only afterwards should the remaining parts be considered for disposal in a landfill.

These procedures make it possible to extend the useful life of materials and reduce the emissions and resource consumption associated with their disposal and the production of new materials. Design should hopefully adopt a Design for Disassembly (DFD) approach and use components which are easy to disassemble at their end-of-life thanks to reversible assembly systems. These systems separate different materials into homogeneous fractions which can be treated by technological systems and thereby extend their useful life.

If these guidelines are followed by the designer when he chooses the materials which make up the components of the product then

[27] Vezzoli C., Manzini E. (2008), *Design for Environmental Sustainability,* op. cit.

these materials have the potential[28] to ensure that their useful life will extend beyond the life of the product in which they have been inserted thanks to an assessment of the possible end-of-life treatments envisaged by the hierarchical top-down approach.

In his effort to select the right materials the designer is assisted by a qualitative assessment criteria, defined by a numerical index, which identifies the end-of-life treatments envisaged for that material.

**Parameters/measurement criteria**

A qualitative evaluation was adopted to facilitate the choice of materials which might have an extended life time; the evaluation was divided into four levels in line with the end-of-life top-down approach and the European Directive on Waste Management. The four levels are:

1. *Potentially recyclable*: the material can be recycled to recover secondary recycled material with a high or low performance;
2. *Biodegradable or compostable*: material waste can be either re-absorbed by the natural environment or transformed into compost thanks to the anaerobic digestion of microbes and organic matter;
3. *Gas or energy recovery*: material waste can be subject either to an energy recovery treatment (through combustion in fossil fuel power plants), or to gas recovery (by pyrolysis and plasma arc gasification);
4. *Landfill disposal*: the landfill is the only possible end-of-life scenario for the material, with the all the afore-mentioned consequences.

## 3.5 Ethics

Responsibility for the different kinds of consumption and environmental impacts of a product during its entire life cycle does not lie exclusively with the designer whose task is to choose the best design strategies depending on the product type and contexts of use; manufacturers or suppliers of the material are equally responsible. According to the extended producer responsibility principle in European Union policies, producers are considered responsible not

[28] We talk of potential because the material used to make the components of a product could have been assembled using irreversible systems which prevent recovery, or else the properties of the material could have changed during the useful life cycle of the product making it impossible to dispose of it according to the specific treatment envisaged for its end-of-life.

only for the manufacturing of their products, but also for the environmental effects of these products during their entire life cycle and especially at their end-of-life.

### *3.5.1 Manufacturers' declarations*

The principle of extended responsibility has lead, both internationally and nationally, to the delineation of several support and management tools regarding the productive activities of a manufacturer; these tools have been coded by standard ISO procedures or European directives and national laws.

These support and management tools make it possible to standardise the management procedures of more than one business and boost the commercial exchanges between the businesses which follow either a certified quality management (UNI EN ISO 9000/2000) and environmental management system (ISO 1400 or EMAS), or an environmental certification system based on the rules regarding labelling and declarations of a product, as per regulation ISO 14020.

When a designer makes his choice he will opt for the materials produced by companies which have undertaken an ethical commitment regarding the environment.

The ethical commitment of a business is confirmed when it indicates which system and tools have been adopted to environmentally manage and certify its productive activities and materials.

**Parameters/measurement criteria**

- *Quality management system:* indicates whether or not the business has adopted a quality management system, such as UNI EN ISO 9000/2000.[29]

[29] The standard provides the fundamental principles and concepts of quality management systems on which the ISO 9000 standards are based. They include the terms and definitions of these management systems. The standard is applied in all organisations, quite apart from their type, size, or products supplied, and in all the activities internal and external to the organisations in order to draft documents, standards and specifications regarding quality.

- The system certifies the overall organisation of the business (processes, human and material resources, activities of the supplies, etc.), but not the product. This certification shows that the business has adopted a holistic approach to quality management, that it can control, guarantee and improve its quality, and ultimately enhance commercial exchanges. A business with ISO 9000 certification does not respect the environment, its organisation simply has the potential to include environmental policies.
- *Environmental management system:* environmental management system (EMS) adopted by the producer company, certified ISO 14000-14001 or EMAS II (Environmental Management and Audit Scheme). A manufacturing company with an environmental management system focuses on the continuous improvement of its environmental performance and is able to tackle the immediate and long term environmental effects of its production system.
- *Material/product certification:* provides information about any product certification system that the business has adopted to market and distribute its products. The ISO 14020 series[30] covers three types of certification schemes:
  - *first level certifications* (e.g., Ecolabel) which acknowledge the environmental excellence of a product during its entire life cycle, establishing which products in the same category have the best environmental behaviour based on a series of criteria;
  - *second level certifications*, which in practice are self-assessments by the producer regarding the environmental performance of the product in relation to a specific aspect (e.g., paper without CFC) or a stage of its life cycle (e.g., the paper packaging of a product is collected by a recycling consortium);
  - *third level certifications,* for example the EDP (based on the energy-environmental performance of the product during its entire life cycle) provides a report or identity card of the performance of the product in relation to its environmental effects.

[30] ISO 14020: the main objective of environmental declarations and labelling is to encourage the demand for, and supply of, products which cause the least possible damage to the environment, and communicate accurate, verifiable and truthful data. The labels must provide relevant data regarding the various stages in the life cycle of a product: from the extraction of natural resources, to manufacturing, use, distribution, and end-of-life. To respect the afore-mentioned requirements the environmental labels and declarations must be based on a scientific method and must use widely accepted and recognised tools which lead to accurate and reproducible results. Furthermore, indications must be provided showing that the label or environmental declaration has either been validated by an independent body or else self-certified. Environmental labels and declarations are a set of voluntary tools to promote the demand for products and services with a low environmental impact by providing data about the life cycle so as to influence the demands of consumers.

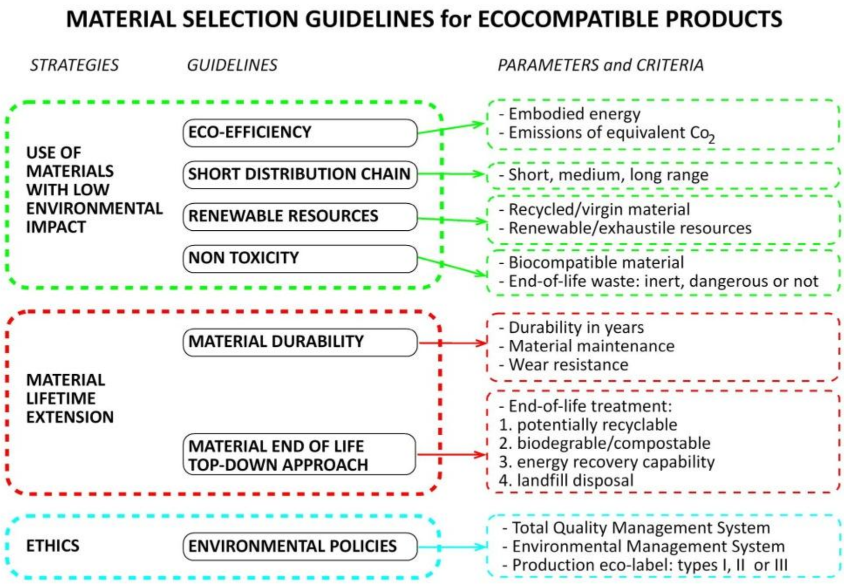



*Fig. 4 - Diagram of the identified qualitative and quantitative parameters to provide a multi-criteria evaluation of materials and semi-finished products.*

## 3.6 Short, medium and long-term products

The strategies and parameters chosen to help in the selection of materials will be effective only if applied/used once the useful life of the product to be designed has actually been defined, in other words whether it is a short, medium or long-term product.[31] In fact, the product will function properly during its useful lifetime only if the performance of the materials is guaranteed. So it is crucial 'before starting to design, to identify one's strategies, in other words the best strategy in relation to the product and its function'.[32]

For example, if it is a short term product, a 'throwaway object or one with a short lifetime', then durability might not need to be

[31] Bistagnino L. (1999), *Ecodesign & Componenti*, Time & Mind Press, Turin, pp. 33-34.

[32] Vezzoli C., Manzini E. (2008), *Design for Environmental Sustainability*, op. cit.

considered, or else it could be considered as a marginal issue by the designer when he chooses the materials.

Instead if it is a medium term product with an average life cycle, in other words roughly five years, then several aspects such as compostability, biodegradability or localisation, could actually be ignored.

Likewise, when a designer designs a product with a long life cycle (fifteen to twenty years) he might consider as non-binding issues the guidelines regarding localisation, reuse, compostability, biodegradability, or making the product lighter.

Instead durability needs to be considered for complex products 'which rapidly become technologically or culturally obsolete'[33]: in fact, some parts can be successfully replaced either by upgrading their efficiency, or by restricting new production activities and disposing only of the components which need to be replaced.

## 3.7 Considerations and future developments

A multi-criteria assessment of the performance of state-of-the-art materials based on the above method and, in particular, the delineation of a system to interpret their environmental performance, will broaden the range of tools available to designers and allow them to compare the eco-compatible characteristics of innovative materials with the characteristics of traditional materials which have been analysed and assessed and are currently illustrated in online databases such as Matrec, ILCA, CES, and Idemat.[34]

This will make it possible to compare the materials libraries, which now catalogue innovative materials, and the databases with information about traditional materials. This comparison should focus on the technical and mechanical properties and eco-compatibility of these materials.

[33] Ivi, p. 73.
[34] Cfr. Appendix 2.

# 4. Strengthening metadesign

**by Claudia De Giorgi and Beatrice Lerma**

In this book we have presented the method used to assess the sensory properties and eco-compatibility of materials. We have also illustrated the sensory vocabulary and eco-compatible parameters designers use to manage the expressive-sensory aspects and environmental sustainability of materials.

These innovative means available to design and designers include the physical, technical and mechanical analysis of materials, and the exploration of their perceptive aspect and environmental sustainability. This method is currently used by MATto, the Materials Library of the Industrial Design Course at the Turin Polytechnic. The latter is a materials library, or better still, an interdisciplinary centre in which to scientifically discuss design, sensory perception and sustainability with experts who work with in-house designers and freelancers to find ways to improve existing products and invent new ones.

MATto provides an interpretation of the parameters of existing materials, as well as theoretical references to a hypothetical sensory perception often involving mere suggestion or experience. To provide a useful and efficient service, the university has opened its doors to companies and designers.

Hopefully other universities and locations will also establish the facility known as MATto_Materials for Design which after the agreement with the Chamber of Commerce of Turin can now be resourced by manufacturing companies in Piedmont. MATto is intended to assist in the most ‘tricky’ and complex aspects of design (innovation based on sustainability and sensory perception) at a time when designers have to make crucial and increasingly pressing decisions involving expression.

## 4.1 Application of sensory terminology

The vocabulary uses 'descriptor adjectives' and values scales to define and describe the sensory properties previously identified by a group of panellists; the vocabulary also exploits reference images, videos and sounds. The role of the values scales associated with the descriptor adjectives is to immediately quantify the value of each adjective. The images of the materials, and the videos of the handling of the samples provided with the vocabulary, are rapid tools to clearly and explicitly represent the meaning and value assigned to the descriptor adjectives.

### *4.1.1 First search level*

The descriptor adjectives that make up the sensory vocabulary represent the first search level of the materials based on expressive sensory aspects.

Materials can be found in MATto by choosing selected adjectives: the search may include adjectives which refer to just one sense, or the four senses which were analysed, for example: 'soft, smooth' for touch, 'opaque' for sight, 'odourless' for smell, and 'gentle' for hearing.

This first search level will identify materials with different and multiple physical, technical and mechanical properties and their eco-compatibility; designers can choose the ones best suited to their designs.

### *4.1.2 Second search level*

The adjectives in the vocabulary are detailed according to scales of values (from 0 to 100 for touch) based on the results of several assessment sessions by a group of panellists (groups of 20/30 individuals trained to test the materials and use specific tools to describe them). The adjectives are also based on sounds and images illustrating and documenting the tests and handling process.

The values scales (now available for the sense of touch) immediately quantify the property described by the adjective. Material handling was performed using methods[1] designed to emphasise their tactile, visual and auditory properties.

The images, videos and sounds of the handling process immediately facilitate comprehension of an adjective or a value describing the material: for example, being able to examine videos of the deformation and shape memory of materials are very useful.

The values scales, images, videos and sounds of the handling process provide a further, more comprehensive search level; this level can help anyone who already has a clear idea about the values of a material (soft 60/100) or someone wants to know more about the meaning of the descriptor adjectives.

### *4.1.3 Eco-compatible properties as a search tool*

This method also explores the environmental sustainability of materials and provides basic data about energy consumption, toxicity, and possible end-of-life waste, quantitative data which can be used together with extremely design-oriented qualitative data. Why? Because more or less sustainable materials do not exist, only sustainable methods exist.

Data regarding the eco-compatibility of materials is grouped in relevant macro areas: use of materials with a low environmental impact, extension of the life of a material, and the ethics of the producer/supplier.

The parameters in these macro areas (embodied energy, toxicity, etc.) were used to elaborate design guidelines to help assess the materials best suited to a sustainable product. Parameters and measurement/assessment criteria of materials were developed based on these guidelines; the parameters indicate how every tested material corresponds to the design guidelines for eco-compatibility.

[1] Cfr. Chap. 2.

## 4.2 Theoretical simulation

Sensory vocabulary, its variations and eco-compatible properties are listed in the data/technical sheets of the materials catalogued in MATto. The data was either provided by the companies themselves or deduced and validated by the research group which helped create the materials library; the properties of the perceptive aspect and environmental impact of the materials has been added to this data.

Technical properties and cost can be used to search for materials in the material libraries. This is the procedure we have always used in the past, but now it's possible to add sensory perception and eco-compatibility to the list. Cross-referencing these four research topics reduces the range of materials corresponding to the question posed by the designer: 'choosing a design material is a chance to transfer innovation and technology. A good designer (or his company) instantly knows the materials he wants to use, and so, depending on his work project, he will streamline his research and adapt it perfectly to his design objectives'.[2]

Materials can be searched according to the four above-mentioned areas; the first classical search based on technical data and cost can provide a rather long list of materials. Nevertheless, the list will be restricted by its sensory properties, eco-compatibility (for example 'soft and smooth' for touch, 'opaque' for sight, 'odourless', 'low' or 'deep' for sound), and embodied energy, which will have to be less than a certain value. One example: cross-referencing these material properties may be based on the need for sustainability, in particular biodegradability; it will then be possible to exclude the materials with sensory properties which are less interesting from a design point of view than the materials corresponding to these requirements.

[2] Lucibello S. (2005), *Materiali@design: verso una nuova modalità di selezione su base percettiva dei materiali per il design,* op. cit., p. 80

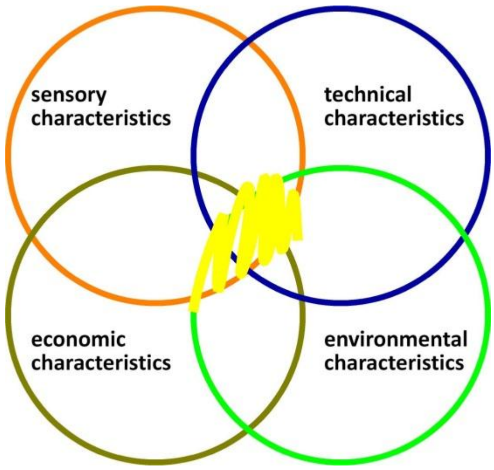



*Fig. 1 – The main properties behind the multi-criteria search for materials.*

Two topics – sensory perception and sustainability – come up again and again in the ongoing search for innovative materials: '[…] a merger which combines, in a systemic and holistic vision, the criteria of ethical and differential production with those of cognisant and plentiful consumption: a union of local and global values. The aim of sustainable sensory perception is to combine the concept of territory with that of consumption, fully aware that to understand a product we need to understand how it is made, and we can only do this if we are able to trace its evolution from matter to final product'.[3] We can achieve this new and complex approach to design, and especially to metadesign, by critically exploring materials; the process comes full circle with the support of virtual reality and prototyping.

The client is provided with real and virtual models of design proposals showing the maps of materials to be assessed; he can then choose to use either traditional methods or the new methods illustrated here. When a designer bases his choice on technical criteria, costs, sensory and environmental properties, his choice can be assessed, even unconsciously, using non-verbal methods and tools

[3] Ceppi G. (2009), "Sensorialità sostenibile", in Ferrara M., Lucibello S., edited by, *Design Follows Materials*, op. cit., p. 117.

such as eye-tracking,[4] a hypothetical final assessment tool providing information regarding the ability of the product/interface to attract, maintain or discourage the attention of the observer.

The analysis is equally successful for real or virtual prototypes. This is interesting as regards costs, especially when the test generates design feedback leading to an evolution of the concept.

## 4.3 Positive effects of the method

This method can be used in several different ways depending on the design stage; it can become a tool to validate the designer's choices, to identify the demands of future users, or to help the designer pinpoint and improve keys areas such as the communication functions of a product or how to use it.

A designer identifies design solutions by assessing the technical, sensory and environmental properties of a product; these solutions can either be rejected or accepted using the above methods and tools, in other words a designer can use them to obtain design feedback about materials, finishings, concepts, and real and virtual prototypes. Virtual prototypes are also an excellent cost-cutting and time-saving solution.

All the sensory assessment and eye-tracking tests, as well as all the other tools, for example semantic differentials or questionnaires, help to identify the demands/desires of users and understand which product areas are linked to specific features of a product such as elegance, convenience, sustainability, etc. One example is the packaging used for wines, especially glass bottles: 'if certain markers are placed in specific areas, a buyer who hasn't even read the information on the labels will already form an opinion about its quality, value and how to use the product'.[5]

[4] Cfr. Chap. 2.

[5] Lerma B. (2013), "La sostenibilità alla seconda. La percezione della sostenibilità e il ruolo del designer", in De Giorgi C., edited by, *Sustainable Packaging? – Packaging Sostenibile?*, Umberto Allemandi Editore, Turin, pp. 136-143; Buiatti E., Lerma B. (2013), "Leggere il packaging: modelli di valutazione ergonomica per l'analisi delle bottiglie di vino", in A.A.V.V., *Pollenzo Index Environmental and economics Design. Indice Poliedro*, Università degli Studi di Scienze Gastronomiche, Pollenzo, Bra (Cn), pp. 120-127.

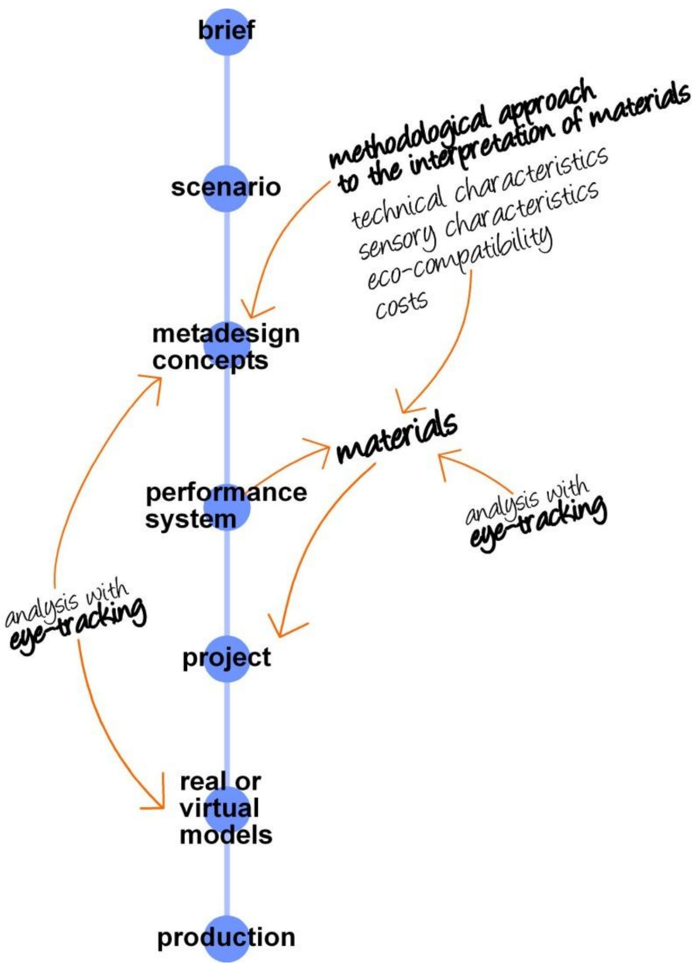



*Fig. 2 – Diagram showing where the proposed analytical method illustrated in this book fits into the design process.*

A more in-depth assessment of these areas will pinpoint the strategic points where the use and communication functions of a product need to be improved; it will also give the designer useful information about design choices regarding shapes, colours, materials, superficial finishings, etc.

## 4.4 Perception of sustainability

The research team has recently forged ahead regarding the use of this method in the field of 'sensory sustainability', in other words as a way for the product to correctly communicate its sustainability so that it can be perceived and appreciated by the consumer.

During the research entitled Poliedro–Pollenzo Index Environmental and Economics Design,[6] the research method was used to test the perception of sustainability of a food product; the approximately fifty male and female panellists ranged from 20 to 50.

The analysis reported in the next paragraph shows how a designer can use the techniques, tools and methods of cognitive ergonomics to test perception of the attributes of a product; it also illustrates the results of this analysis and provides new ideas about the role of designers.

### *4.4.1 Analysis of chocolate packaging: using eye-tracking to assess perceived sustainability*[7]

This case study analyses the packaging of chocolate bars in order to assess and understand how the various end-users perceive its eco-sustainable performance.

An eye-tracking device was used to analyse eye movements and understand a user's perception of different kinds of chocolate bar packaging, in particular its sustainability. It is important to emphasize that data from the eye-tracking device alone is not sufficient to understand the phenomenon of perception in its entirety. In this case study, evaluation of the data from the eye-tracking

[6] Cfr. Chap. 2.4.3, figs 9 and 10.

[7] Allione C., Buiatti E., De Giorgi C., Lerma B. (2012), "Sensory and sustainable strategies in the methodological approach to design", *8th International Design and Emotion Conference,* 11-14 September 2012, London.

analyses involves compiling a semantic differential and using other qualitative techniques, such as questionnaires.

The case study is taken from an existing parallel multi-disciplinary research entitled Poliedro–Pollenzo Index Environmental and Economics Design[8]; its objective is to outline an evaluation index of the social, environmental and economic sustainability of a food product.

The first part of the case study was dedicated to the introductory questionnaire we used to understand and verify the panellists' overall evaluation of the chocolate bar packaging.

The second part was dedicated to the eye-tracking analyses: during the eye-tracking sessions, the panellists were invited to focus on a series of 'stimuli' provided by the researcher during observation of different kinds of packaging, such as elegance, practicality, cost, sustainability, and the excellence of the product. By reading the scanpaths provided by the eye-tracking session we were able to identify the areas of the packaging linked to the stimuli in question: the choices made by the panellists enabled us to separate the different kinds of chocolate bar packaging and make an initial selection of the elements which captured the user's attention depending on the stimulus.

As a result, we compared the heat maps and gaze plots from the eye-tracking session with the data from the semantic differentials; this enabled us to identify similar or opposing trends in the semantic areas presented to the panellists. It also helped us understand which stimuli are combined and which appear to be dichotomous: it was possible to identify the contrasting areas (for example, good values of eco-sustainability appear to coexist poorly with elegance) and the combined areas (for example, good coherence between the perception of the elegance of the product which, if positive, is also linked to its goodness).[9]

[8] Cfr. Chap. 2.4.3., figs 9 and 10.

[9] Buiatti E., Lerma B. (2013), *"Leggere il packaging: modelli di valutazione ergonomica per l'analisi delle bottiglie di vino"*, op. cit., pp. 120-127.

We performed a more detailed analysis of the Venchi chocolate bar packaging: this product was found to be the one which best satisfies environmental performance requirements. However, although it presented the best environmental performance (low material content, low value of embodied energy or CO2 emissions), this aspect does not emerge from the data obtained during the sustainability perception analysis.[10]

After the eye-tracking sessions the Venchi chocolate bar packaging was considered the most efficient as regards elegance and goodness; sustainability was not perceived as good. The question therefore spontaneously arose as to whether the concept of sustainability communicated in the packaging actually affected the perception of the goodness and elegance of the product.

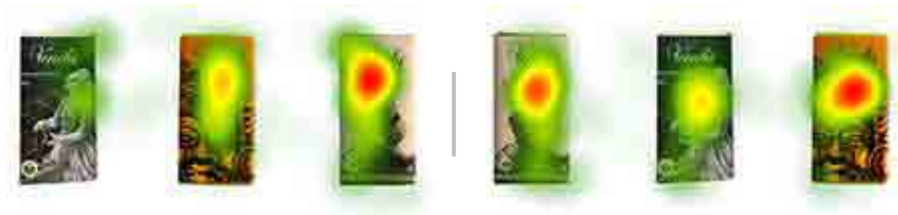


*Figure 3 - Analysis of chocolate packaging: examples of the main results obtained using the eye tracking device during exploration of the 'sustainability' (on the right) and the 'elegance' stimuli.*

## 4.5 Elegant sustainability

Since sustainability was not communicated properly in the tested products it was not considered an added value. The panellists appeared to equate sustainability with a low quality product, an inexpensive product, or one which is not elegantly packaged. These heuristics prevent a truly sustainable product from communicating positive values associated with different semantic areas.

So, should sustainability be communicated or should it remain a hidden, or better still, implicit value? We believe that sustainability

[10] De Giorgi C., Germak C. (2013), "Il sistema di valutazione multicriteria", op. cit., pp. 112-125.

should be communicated to encourage and promote virtuous behaviour, foster conscious choices by consumers, and ‘enrich’ the product. Sustainability should not be synonymous with cheap, unattractive and low quality products.

The designer has to choose whether or not to communicate the sustainability of the design, emphasising its value, turning sustainability into a ‘new elegance’, accentuating the refinement and personality of the product; or he can decide to hide this feature and avoid running the risk of coming up against the heuristics, sustainability – unattractiveness – low quality.

New challenges await designers. They will have to know how to opt for the best compromise between the real and perceived sustainability of a product; they will also have to bear in mind new requirements and take the consumer’s viewpoint into account by trying to understand and anticipate their demands/desires using the tools and methods described in this book.

It’s a world ready to be explored, an increasingly complex reality of increasingly interrelated requirements designed for experience-seeking consumers who are increasingly demanding sustainable and enjoyable products.

This book is our small contribution to the enormous challenges ahead.

# Appendix 1
# Technical sheets of the main materials libraries in the world

**by Beatrice Lerma**

## Material ConneXion®

www.materialconnexion.com

127 West 25th Street, 2nd Floor, 10001, New York, USA.
Thailand Creative & Design Center, 6th Floor, The Emporium Shopping Complex, 622 Sukhumvit 24, Bangkok 10110, Thailand.
Lichtstraße 43g, 50825 Köln, Germany.
Via Davanzati n. 33, 20158 Milan Italy – c/o Milan Triennale (free entrance exhibition), Viale Alemagna 6, 20121 Milan, Italy.
Material ConneXion is also present in Daegu, South Korea.

Material ConneXion is a resource centre for innovative materials used in design and architecture. Materials are collected, classified, and inserted in a library where they can be accessed by users-designers through a cross-reference search.

**Founder:** George M. Beylerian

**Year:** 1997 (New York), 2005 (Bangkok), 2011 (Beijing), 2005 (Cologne), 2008 (Daegu), 2011 (Istanbul, Seoul), 2002 (Milan), 2012 (Shanghai).

**Number of materials:** over 7000 catalogued materials and processes.

**Physical materials library:** open exhibition; the exhibited materials are glued onto rigid substrates vertically fixed to mobile structures; fee-paying subscription is needed to access the virtual materials library and the physical materials library.

**Classification of the materials:** materials are classified in eight chemical categories and not by family (polymers, glass, ceramics, carbon-based, cement-based, metals, natural, and naturally derived); search[1] can be by product name, material category, keyword, attribute, or even by specific field: products, processes and finished raw materials.

**Material data sheets:** provides information about the manufacturer, attributes, technical properties, performance, and also about the type of process, any possible superficial finishes, reasons for insertion, applications.

**Sensory properties:** each data sheet has a section dedicated to the physical characteristics of the materials; some of them refer to sensory properties such as, for example, colour and texture.

**Eco-compatibility:** due to current requests for socially and environmentally friendly materials[2] and products, and the importance for companies to establish the global impact of their production systems, in 2007 Material ConneXion®, MBDC and EPEA[3] joined forces and created a platform to develop eco-compatible materials and products based on the 'cradle-to-cradle' principle; they also intend to improve production systems, develop intelligent green materials and the principles of use and re-use, by implementing the following:

[1] Search modes of materials library databases: simple search of a material is based on its most important data, i.e., the name of the material, manufacturer, material family, applications, etc.; instead an advanced search involves selecting the material based on more specific data and properties such as, for example, its physical and mechanical properties, possible processing, etc.

[2] Marino G.P. (2008*), Innovazione materica e design*, Time & Mind Press, Turin, pp. 40.

[3] MBDC and EPEA: MBDC (McDonough Braungart Design Chemistry, LLC) is a product and process design firm dedicated to revolutionizing the design of products and services worldwide. William McDonough and Dr. Michael Braungart founded MBDC in 1995 to promote and shape what they call the 'Next Industrial Revolution' through the introduction of a new design paradigm called Cradle-to-Cradle SM Design, and the implementation of eco-effective design principles. EPEA (Environmental Protection Encouragement Agency) works with clients worldwide to apply the Cradle-to-Cradle methodology to the design of new processes, products and services.

- made-to-measure workshops for design groups, and large and small companies, to explain intelligent materials and the principles of sustainability and eco-compatible design;
- assessment and certification of interested companies and comparison of their ecological footprints with national and international standards so as to provide them with the tools needed to be competitive on the global market;
- development of new materials and products based on the principles of eco-compatibility

**Miscellaneous:** the MC staff organises exhibitions, thematic displays and publishes books with the latest novelties juried into the materials library.

## matériO

www.materio.com

matériO Paris: 74, rue du faubourg Saint-Antoine, 75012 Paris, France.
matériO Bruxelles: Allée Hof-ter-Vleest 5, 1070 Brussels, Belgium.
matériO Praha: Říčanova 19, 169 00 Prague 6, Czech Republic.
matériO Bratislava: Továrenská 10, 811 09 Bratislava, Slovakia.

'MatériO is an independent network of innovation surveillance dedicated to new materials and technologies. It provides a physical materials library with thousands of samples of innovative materials, an online database, and a worldwide team of experts. MatériO also focuses on different aspects of materials including the inspiration and innovation they arouse'.[4]

**Founders:** Quentin Hirsinger and Elodie Ternaux.

**Year**: 2001

**Number of materials**: approximately 6000 materials/semi-finished products/technologies indexed in the database

**Physical materials library:** matériO has open shelves with informally displayed samples not glued to specially designed substrates: here it's possible to 'feel' the material, touch it and handle it. After paying a fee and making an appointment it is possible to visit the material library; paying membership is required to consult the online database.

**Classification of materials[5]:** the matériO database is called 'matériOthéque universelle'; a multi-criteria materials search is available: family (glass, wood, metal, plastics, paper and derivatives, composites, fabrics, stones), presentation (panel, tube, film, gel, wires, blocks, treated surfaces), level of transparency (completely transparent, partially transparent, translucent, opaque), level of hardness (hard,

[4] www.materio.fr
[5] Data sheet updated in 2011.

flexible, fragile, variable), appearance (light, dark, metallic, iridescent, holographic, phosphorescent, satinated, mirror effect), and technical properties (density, water resistant, fire resistant, UV resistant, ecological properties). The latter can be chosen based on three levels (low, medium and high), and sensation (soft/hard, hot/cold, springy/rough, smooth/texturised).

**Material data sheets:** the material is described in great detail and accompanied by several photographs and a short video of the material being handled to give the viewer the feeling he is touching it; all its technical properties, certifications, and data provided by the manufacturer are also included.

**Sensory properties:** the material data sheets focus primarily on the sensory and evocative properties of the material, especially the following: soft/hard, hot/cold, springy/rough, smooth/texturised;

**Eco-compatibility:** referred to the possibility of a material to be the most suited to a sustainable product. Many materials can have interesting properties: recycled, recyclable, biodegradable, produced with very renewable resources, etc.

**Miscellaneous:** matériO provides several services to its virtual and real visitors, a range of consulting services, training sessions, exhibitions, lectures, trade fairs; the materials library also publishes a free monthly newsletter and holds thematic ‘mornings’.

## Materia

www.materia.nl

Pedro de Medinalaan 1b, 1086 XK Amsterdam, The Netherlands.

'materia is an independent consulting firm with a solid architectural culture; it specialises 'in the selection of materials and technologies to be used in architecture and design'.[6]

**Founders:** Arnold van Bezooyen, Michael Ashby

**Year**: 2001

**Number of materials:** over 4000 manufacturers of materials indexed in the database

**Physical Materials Library:** free access and open and free consultation; free online consultation is available thanks to the Material Explorer database.

**Classification of materials:** selection is based on the name of the material, designer, manufacturer, family (ceramics, coatings, concrete, glass, metals, natural stones, other naturals, plastics, wood), native country, and technical and sensory properties.

**Material data sheets:** technical and sensory properties are provided for each material as well as information about the manufacturer, applications of the material, reasons for use in a certain product, and product process.

**Sensory properties:** one of the selection criteria for the materials proposed by Material Explorer involve its sensory properties, such as colour, texture, softness, sound, etc. In particular the user can choose the 'value' referred to: glossiness (brilliant, satinated, opaque), translucency (0%, 0-50%, 50-100%), texture (rough, medium, smooth), structure (high/low density), hardness (hard, soft, deformable), temperature (hot, cool, medium), and sound (good, moderate, poor).

[6] Lucibello S. (2005), *Materiali@design,* op. cit., p. 38.

**Eco-compatibility:** the only parameter regarding eco-compatibility of the material is whether or not it can be recycled (renewable: yes/no).

**Miscellaneous:** material samples are often on display in universities or other infrastructures, and catalogues and publications are often published afterwards. Every year Materia organises Material Xperience, a large-scale exhibition of all the innovative materials invented worldwide. Furthermore, Materia provides consultancy services to help define successful marketing strategies.

## Innovathèque

www.innovathequectba.com

10, avenue de Saint-Mandé, 75012 Paris, France.

Innovathèque is part of the C.T.B.A., Centre Technique du Bois et de l'Ameublement (Wood and Furnishings Technical Centre) a subsidiary of V.I.A. (Enhancement of Innovation in Furnishings) a non-profit organisation established in France in 1979 by CODIFA (French Furniture Industries Development Committee), and funded by the Ministry of Industry. Innovathèque specialises in the field of furnishings and the environment.

**Founder:** Jean-Marc Barbier

**Year**: 2000

**Number of materials:** about 2000

**Physical Materials Library:** the materials are collected in labelled boxes on closed shelves; consultation by appointment and payment of a fee. Consultation of the online database requires payment of a fee.

**Classification of materials:** materials can be searched using a 'multi-criteria' selection tool; like the real materials library, materials are classified mainly according to their family (wood and derivatives, other natural products, plastics, composites, glass, metals, ceramics, paper and cardboard, stones, leather and skins), presentation (textiles, panels, semi-finished products, grilles, tubes, etc.), field of application (medical, sports, construction, transport, apparel, packaging, etc.), tactile aspects (hard, soft, rough, etc.), visual aspects (transparent, opaque, shiny, satinated, etc.), ecological aspects (recycled, renewable, 100% natural, etc.) and technological properties (elastic, rigid, thermal conductor, etc.).

**Material data sheets:** the data sheet of each material provides information about the manufacturer, technical properties, performance, composition, applications, and several images of the material.

**Sensory properties:** Innovathèque assesses the materials through handling by the materials cataloguing team. Innovathèque began focusing on the sensory properties of the materials as a way to provide data to clients, furniture makers, or interior designers who are looking for something more, so that materials are not considered only according to their mechanical and technical properties, but also according to their more sensory properties. The sensory adjectives to search for materials refer to sight and touch and include: transparent/opaque/ translucent/ pierced, shiny/satinated/mat, metallised reflective/illuminating/ fluorescent/phosphorescent/trompe l'oeil, light/dark; hard/soft, smooth/texturised/rough.

**Eco-compatibility:** although the materials library is not specialised in the eco-compatibility of materials and processes it does focus on the following:

• the material data sheets include the keywords Ecologie, Recyclé, Renouvelable, 100% naturel;

• the glossary contains the keywords Biodéchets, Biodégradabilité, Ecomatériau, Monomatière, Recyclage, Recyclé, Renouveabilité and Renouvelable;

• materials conferences have been organised regarding the end-of-life eco-design of furnishings (proceedings are already on sale) as well as a thematic exhibition ('Eco-materiaux').

**Miscellaneous:** Innovathèque also uses other methods to encourage the use of innovative materials including:

• thematic events;

• 'la lettre de l'innovation', the quarterly online magazine with all the latest novelties;

• 'les fiches matériaux', data sheets about the most innovative materials.

Finally, every four months Innovathèque organises a committee of 'veille' to discuss the materials and a specific topic (eco-materials, lightness, light, etc.); this is an opportunity to exchange information and select the materials to be juried into the materials library. The topics of the 'veille' are also used to organise in-house displays to present and discuss the latest selected materials.

## Materiautech®[7]

www.materiautech.org

Maison des entreprises, Technopôle de la plasturgie.
80, rue Pierre et Marie Curie, BP95, Bellignat, 01116 Oyonnax cedex, France.

Operating window specialising in polymer materials. Allizé Plasturgie is the local General Confederation of ‘Plastic Valley’; the main offices of Materiautech® are located in Oyionnax (Lyon province).

**Year**: 2005

**Number of materials:** 65 different materials (mostly thermoplastic materials) presented on the website; more than 350 catalogued materials.

**Physical Materials Library:** free display. Free physical and virtual consultation.

**Classification of materials:** there are three ways in which to search materials: sensory, technical and creative; however, these three modes cannot be used together. The technical search involves selecting a plastic material according to its family (thermoplastic, thermoset, elastomers), industry, production process, surface treatment, physical, technical, mechanical, optical, thermal, electrical, chemical properties, data flame, eco-compatibility, and price.

**Material data sheets:** the data sheet has a short description of the material and information about the sector, production processes, sensory properties, technical aspects (accompanied by another data sheet with data about the technical properties of the material and corresponding numerical values), chemical compatibility, ecodesign (recyclable, non recyclable material), costs.

[7] Data sheet updated in 2011.

**Sensory properties:** plastic materials can be searched on the Materiautech® website using either a Sensory or Creative Search which provides a sensory journey through the world of plastics. The sensory search method obviously uses the five senses: sight, touch, hearing, smell and taste. The different sensory adjectives used to describe a material are used by Materiautech® for each sense; the latter can be used as search criteria.[8]

**Eco-compatibility:** Materiautech® appears to be very focused on about the problems associated with eco-compatibility. In fact the website has a section dedicated exclusively to ecodesign; the section proposes well-known or innovative biodegradable polymers, and also offers its visitors the possibility to become familiar with the principles, history and different ecodesign strategies

**Miscellaneous:** in the 'News-tech', and 'Innovations' sections Materiautech® provides data about the materials, products, applications, production processes, meetings and fairs in the sector of plastic materials and technologies. It is interesting to note that the exhibition system adopted by Materiautech® does not include a sectoral display of the materials. In fact, the material samples are haphazardly displayed on the exhibit walls. Several samples are displayed for each material so that visitors can take a sample of the material they're interested in. The material samples presented by Materiautech® have a rather special shape: Gem® is a small standard material sample[9] designed chiefly to highlight the behaviour of the materials and transformation processes considering the design restraints which usually apply during injection moulding and rotational moulding. The Gem® has been designed so that for every sample the following can be assessed: transparency, opaqueness, luminosity, photochromic effect, photoluminescence or fluorescence, tactile features (hard, soft, flexible, shape-memory, smooth, rough, adhesive, hot, tepid, cold), olfactory features, or even the sound made by the material. Gem® is a super-technological concentrate which makes it possible to: highlight the material or its superficial effects with its convex shape; visualise the material flows, weld lines and point

[8] Cemas, Centre d'évaluation des microtechniques pour l'analyse sensorielle (www.groupecemas.com), is a group of different assessment centres which work to define and often discover sensory concepts and parameters produced during technical experiments, and particularly suited to qualify sensory and multisensory assessments. In other words, Cemas makes it possible to compare data discovered by sensory analysis (where man is the measurement tool) with instrumental parameters, associated with a measurement protocol reproducing the sensory 'gestures' of the senses involved (touch, sight, smell, learning and taste). To do this Cemas proposes, on the one hand, tools dedicated to this correlation and, on the other, a series of sensory assessment references, real 'samples' of the descriptors; calibration, commercialisation and continuity are ensured by the research team. Finally, Cemas guarantees the sensory design of products, materials and their market presentation, and certifies their function.

[9] www.materiautech.org

of injection in various parts of the surface; have a bi-injection to test bi-material or bi-colour solutions; have an area with a different thickness to test differences in transparency, colour and rigidity; have an exclusive assembly system which facilitates tactile assessment. Gem®, however, due perhaps to its rather well-designed shape, is more a product than a material; it may distract or divert attention from the sensory assessment of a ‘more simple’ material sample.

## materioteca®

www.materioteca.com

LOFT D7, Via Savona, 97, 20144 Milan, Italy.

Materioteca was an idea participated by Domus Academy, plastic Consult and ProPlast; it provides services to designers ranging from consultancy regarding the choice of the most suitable plastic materials for a design, to prototyping; Materioteca makes it possible to see and touch the polymer materials and receive precise design indications.

**Founders:** Diana Castiglione and Antonio Petrillo

**Year**: 2005

**Number of materials:** continuously updated

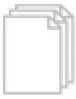
**Physical Materials Library:** exhibits on open and closed shelves; free consultancy on request; small standard 10 x 12 cm polymer samples are on display; these standard material samples differ in material, shape, colour and surface. The size and type of the samples have been studied to highlight the properties of the materials. The samples are displayed in three different kinds of showcases: wall display case, interaction exhibition case, and interaction table.

**Classification of materials:** presents samples and objects made from the following families of plastic materials: Polypropylene, Polycarbonate, expanded Polyurethane, Blends, Polyamide, Polymethylmethacrylate. Search by polymer family, sector of application, transformation technology, and name of the producer.

**Material data sheets:** the data sheet provides information about the manufacturer, attributes, technical properties, performance, type of process, any possible surface finishes, reason for insertion, and applications

**Sensory properties:** the materials library has focused on sensory properties; during 2006, the Consorzio Proplast, together with the Cultural Centre for the engineering of plastic materials, began the second phase of the materioteca® project which involves enlarging the exhibition areas to include a section dedicated to multisensoriality. The materials library already has an area dedicated to sensory interactions. A sensory interaction showcase has been organised in order to be able to personally touch the materials, making it possible to perceive the differences between materials. This single showcase has samples of several materials so that some of their properties can be tested: transparency, touch, sound, elasticity, etc. Interaction 'from sense to material' and 'from material to sense' is available so that visitors can perceive the differences between samples from the same family and assess samples of different thicknesses, transparency, etc.

**Eco-compatibility:** the Materioteca database has a section dedicated to recycling and related processes.



**Miscellaneous:** a newsletter can be freely downloaded from the website; it provides an update about events in the world of materials as well as the articles about materioteca® published in several specialist magazines. The exhibited samples, made exclusively of thermoplastic polymer materials, are particularly important for the materioteca® set up. They are standard in size (10x12 cm) and apart from the brand, every standard sample has two numbers and the name of its material family; these date stamps makes it possible to always recognise a sample, even when it is not in its original exhibition context. The date stamp in the middle records the type of material the sample is made of, while the ones on the side provide an identification code.

## MATREC® Material Recycling

www.matrec.it

HEAD OFFICE AND RESEARCH CENTRE
Via Luigi Arnaldo Vassallo, 43
00159 Rome
service@matrec.it

Centro MATREC Milano
c/o SPD – Scuola Politecnica di Design
Via Privata Giovanni Ventura, 15
20134 Milan

Centro MATREC Firenze
c/o Design Campus di Calenzano - Faculty of Architecture - University of Florence
Via Sandro Pertini, 93
50040 Calenzano (Florence)

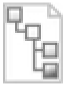
This Italian database of recycled materials/products and ecodesign topics is freely available to the public; it was designed by the CAPELLINI design & consulting studio to offer professionals, companies, universities and other institutions the opportunity to freely exchange technical data required in the design and development of products and services with a low environmental impact.

**Founders:** CAPELLINI design & consulting studio in collaboration with the national recycling consortia Cial, Comieco e Corepla.

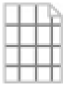
**Year**: 2002

**Number of materials:** 1200 materials of which approximately 400 are available to the public at the Milan and Udine centres as well as online.

**Physical Materials Library:** open display; the material samples are glued to rigid substrates fixed vertically to mobile bases.



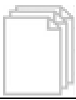
**Classification of materials:** the materials cataloged are classified in recycled materials, natural materials and by field of application. An advanced, multi-criteria search is also available, such as: Size (granules, panels, boards, chips ...), Technologies (milling, laminating, extrusion, etc..), Material (compostable, biodegradable, etc.), Product certified by the company; Company; Continent and Country of origin. Matrec also presents a section called Projects, with a continuously updated catalogue of products made with natural, recycled and low environmental impact materials. The Eco-design section presents books and news 'especially about the eco-design of recycling'.[10]



**Material data sheets:** materials are classified in macro families (paper; plastic; aluminium; inerts; wood; rubber; glass; fabric; leather, cork, hemp, cotton, etc.).

**Sensory properties:** provides data about gloss, transparency, hardness and colour of the sample materials.

**Eco-compatibility:** environmental data is behind the Matrec philosophy and refers to eco-compatible properties based on a mostly qualitative and easy-to-understand description. Information about the footprint of the analysed material is present in the data sheet of the materials.



**Miscellaneous:** a newsletter providing updated information about the world of eco-design can be freely downloaded from the relevant section of the website.

[10] Marino G.P. (2008), *Innovazione materica e design*, op. cit., pp. 46-47.

## MaTech

www.matech.it

Parco Scientifico e Tecnologico GALILEO, Corso Stati Uniti, 14/bis, 35127 Padua, Italy

MaTech collects, presents, and disseminates information about innovative materials and provides technical assistance and acts as a research laboratory to verify whether or not it is feasible to use a material when developing a project. The material search proposed for the development of a project tends to prefer locally available materials.

MaTech offers a series of different formulas to access the technical data sheet of each catalogued material and the manufacturer's specifications.

**Founders:** Parco Tecnologico Galileo with the Department of Engineering of Materials, University of Padua

**Year**: 1998

**Physical Materials Library:** closed, consultation by appointment.

**Classification of materials:** is based on material family (polymers, metals, alloys, fibres, fabrics, composites, ceramics, glass, pigments, surface treatments, foams, adhesives, technical, natural and technological fluids, eco-materials and nanomaterials) and technical properties (divided into 10 groups: mechanical, optical, thermal, chemical, electric, acoustic, etc).

**Material data sheets:** the data sheet has a detailed and very technical description focusing primarily on how the material is produced, its material family and some of its main properties; it also provides a classification based on a qualitative description of its perceptive properties.

**Sensory properties:** assessment refers to the optical properties of the materials (luminescent, photochromic, thermochromic, mechanochromic, transparent, refractive, reflective, iridescent, etc.) and how pleasant they are to look at, touch, and smell.

**Eco-compatibility:** the material catalogue refers specifically to the topic, in a section called Eco-materials.

**Miscellaneous:** several MaTech Points, centres for the promotion and consulting of MaTech, are located in Italy: these points provide access to Ma tech services and a showroom with a selection of innovative MaTech material samples. MaTech Corners are also open in Italy to disseminate material culture through the exhibition of innovative materials; these centres are chiefly intended to be used by primary and secondary school students.
MaTech Points and MaTech Corners are present in Vicenza, Bolzano, Trieste, Pordenone, Rome and Bari.
MaTech also operates internationally working with centres specialised in the transfer of technology in Boston, London, Tokyo and Beijing.

## MaterialieDesign at the POLIteca, Politecnico di Milano

www.politeca.polimi.it

Politecnico di Milano - Campus Bovisa, via Durando 10, 20158 Milan, Italy.

POLIteca is a documentation centre for design. Students, teachers, and technicians at the Polytechnic, as well as professionals in this field (designers, architects, journalists, companies, etc.), use POLIteca to find documents, data, and cognitive tools to help them in their design work, from the initial creation of the concept, to the final engineering stages: POLIteca archives are dedicated to several sectors, for example MaterieDesign, a didactic materials archive and documentation centre created to provide information about materials to anyone involved in the field of design.

The POLIteca online catalogue is available as part of the OPAC library service.

**Founders:** 'Giulio Natta' Department of Chemistry, Materials and Chemical Engineering at the Politecnico di Milano with the support of INDACO (Industrial Design, Arts, Communication and Fashion).

**Year**: 1999

**Number of materials:** 5,000 catalogued material samples; POLIteca presents 10,000 company catalogues about products and interior design; 17,000 titles about textiles, clothing and fashion; 600 publications specialising in design oriented production sectors (fashion and textile technology, product, interiors, communication, materials) and the ancillary construction industry.[11]

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**Physical Materials Library:** free access to the materials library. Closed shelf display.

**Classification of materials:** material families, technological properties, mechanical properties, sensory properties, and environmental requirements.

[11] www.politeca.polimi.it/index.php. Data sheet updated in 13-09-2013.

**Sensory properties:** the expressive and sensory atlas designed by Valentina Rognoli[12] is intended for students and designers to inform them of the technical, technological, expressive and sensory properties of materials. The expressive and sensory characterisation of materials is a method facilitating the description and design of materials; it also determines their communicative and phenomenological features based on physical and technological properties.
Phenomenological features can be analysed by breaking them down into their individual components: in this case Valentina Rognoli[13] analysed tactile and photometric features chosen due to the importance of touch and sight in the sensory perception of the final user.

**Miscellaneous:** the documentation centre works in close contact with design and fashion companies which collaborate by providing information, documents and materials; this allows them to activate a privileged channel of communication with students, teachers and professionals.

[12] Rognoli V., Levi M. (2011), *Il senso dei materiali per il design*, FrancoAngeli, Milan
[13] Levi M., Rognoli V. (2005), *Materiali per il design: espressività e sensorialità,* op. cit.

Apart from the materials library illustrated above, there are other smaller and less well-known libraries active in the world of materials. The following are a few examples.

## TU/EINDHOVEN – MATERIALS LABORATORY – MATERIALS ARCHIVE OF THE UNIVERSITY OF EINDHOVEN (NL) c/o UNIVERSITY OF EINDHOVEN

A university materials library with a small display of illustrative and technical material where the samples are used primarily as teaching tools. The catalogue includes chiefly construction materials used in most traditional building systems, although it also focuses on innovative products.

Access to the space is free. The archive is linked to the models workshop and is a good solid reference tool as regards current production techniques: in fact, the products and moulds present in the archive make the materials library particularly useful for educational purposes.

## ARTEC – Venice, IUAV University

Dorsoduro 2196, 30123 Venice

The materials library ArTec is a support tool for the university's teaching and research programmes; it include materials and techniques from the field of industrial design and architecture. The library has a display of real, life-size models of technical elements and components, a multimedia archive, as well as a secretariat which works with the building industry to organise apprenticeships, seminars, and ad hoc meetings. It also has a research area focusing on architectural design, especially building details and innovation.

Basic and advanced search modes can be used to consult the online database regarding technical and functional properties and perceptive and environmental characteristics.

## md MATERIAL DESIGN

www.materialdesign.it

The research laboratory of the Department of Architecture at the Faculty of Architecture in Ferrara was established in late 2008.

The laboratory focuses in particular on the creation of a strategic bridging asset to synergistically merge production in the Emilia Romagna area (ceramics, car manufacturing, fashion, furnishings, etc.). The material design laboratory also comprehensively explores usability and user-centred design and develops products according to the requirements of companies which aim to provide high quality customer satisfaction.[14]

## IMATTER

www.israelidesign-imatter.org.il

The university materials library, iMatter, was established in 2008 as part of the Holon Design Museum in Israel. It is an information centre for designers, producers, researchers, students and businesses. In particular, the materials library is an info centre with hundreds of materials samples, books, periodicals, and catalogues. The materials are organised according to their material family: plastic, wood, ceramics, paper, metal, composites, fabrics, biodegradable materials. Physical and virtual access to the materials library requires payment of a fee. The online database uses the following search criteria (material family, technical characteristics, sensory properties).

iMatter was set up to mediate between designers, professionals and industries and get them to cooperate and organise initiatives, for example, conferences, territorial promo tours, and consultancy services.

[14] http://www.materialdesign.it/it/md/material-design_14.htm. Date last access: 13-09-2013.

## The materials library of the Centro Stile of FIAT Group Automobiles

c/o Officina 83, via Plava 80, Turin, Italy.

The automobile sector has always been more focused on the sensory properties of products because using and enjoying a car should be an emotional experience.[15]

The Color&Material department of the Centro Stile of FIAT Group Automobiles uses the materials library to submit proposals regarding the exterior, interior, and finishings in a car (bodywork, dashboard, seats, etc.). The materials library collects and researches materials, technologies and colours; it also analyses and interprets social trends in order to anticipate and influence them according to the target type.

Choices and studies are made specifically for each brand the company works for; the objective is to enhance the specific traits of the materials; for example, the colours proposed by Lancia reflect its elegant style, while Fiat focuses on functionality and Alfa Romeo on the sporting nature of its cars. The materials library can only be accessed by in-house researches due to the need for industrial confidentiality.

## Stylepark

www.stylepark.com

Stylepark AG, Brönnerstrasse 22, D-60313 Frankfurt am Main, Germany.
Materialbiblioteket, Tellusgången 4, SE-126 37 Hägersten, Sweden.

Stylepark is an international platform, a reference point for architects, designers, builders, and town-planners who want up-to-date information about the latest innovations in the field of design and architecture. One Stylepark section is dedicated exclusively to innovative materials such as 3D fabrics, flexible wood, etc. The

[15] Taken from "Officina 83. Laboratorio di design". *An episode of Questione di stile*, channel Nuvolari TV, Sky218, 21/5/2009.

database can be accessed using a keyword or multi-criteria search in seven macro categories: material groups, manufacturer, form, colour, structure, surface, and applications. The product groups in Stylepark are: plastic, rubber, wood, paper, cardboard, natural fibres, metals, glass, ceramics, sand, stones, and composite materials.

The material data sheets provide a description of the material and principal properties, including how it is presented, its measurements, optical and tactile properties, and surface treatment. Several photographs of the material is provided along with data about the manufacturer and its current applications.

## Matweb

www.matweb.com

2020 Kraft Drive, Suite 3000, Blacksburg, VA 24060 USA.

Matweb users can access information by searching either the material family, or composition and basic properties. The Matweb database includes materials such as thermoplastic and thermoset polymers, metals, ceramics, wood, natural materials, fluids, and other engineering families.

Materials can be searched by name, manufacturer or specific characteristics. There is no physical material library but users can freely download the material data sheets from the basic version of the database.

## Design inSite

www.designinsite.dk

An online guide to the world of design and industrial production developed for designers. The guide has a section dedicated exclusively to materials which are organised according to their material family: ceramics, composites, plastics, fibred, glass, metals, ‘smart’ materials, textiles and wood.

Design inSite also has a section dedicated to the methods and tools used to research materials and production processes such as Bio-Inspired Design (BID).

## materiali innovativi per l'architettura e il design

www.materialinnovativi.com

For years this company has searched for innovative surfaces to be used in furnishings, design, and architecture; it researches and sells (online) materials, surface substrates, and surfaces made from concrete, wood, stone, metal, plastic and glass.

The site search for materials uses specific criteria such as type, manufacturer, applications, and sector (ship, plane and car furnishings, fashion, doors, stage sets, etc.).

# Appendix 2
# Data sheets of the most popular environmental databases

**by Cristina Allione**

## Cambridge EcoSelector – CES

www.grantadesign.com

Granta Design Limited, Rustat House, 62 Clifton Road, Cambridge, CB1 7EG, United Kingdom.

A database with the physical, technical, economic and environmental properties of technological materials and processes belonging to the most important material families.

Simple consultation or sophisticated search filters can be used to select and identify materials using the methods developed by Prof. Mike Ashby. Technical specifications and properties are used to identify the materials which best fulfil the search parameters.

The database was designed to be used to select materials during the engineering stage, but over the years it has been improved with data regarding the environmental features of materials as well as estimates of energy usage during transformation processes.

The database software has an Eco-Audit tool which quantifies the key life-phases of a product based on two indicators: Embodied Energy and CO2 Footprint.

**Founder:** Granta Design Limited. Prof. Mike Ashby

**Number of materials:** depending on the version and database which is included, the database provides information about a huge number of materials. The number of consultable materials and processes and the level of information in the standard version of the database may be increased by purchasing specific databases which include information about specific categories of materials used in certain sectors (aeronautics, biomedical, construction, etc.).
It is also possible to import data about other materials not included in the database. The Hybrid Synthesizer function enables the user to create datasheets of semi-finished products made up of one or more materials such as composite materials, sandwich and multilayer panels.
The software function known as the Eco Audit Tool is included in the database; the tool makes it possible to estimate the environmental performance of a product delivered as Embodied Energy and CO2 Footprint.

**Computerised Database:** materials can be selected either by simple consultation or using the methodology developed by Prof. Ashby, based on their physical, technical, environmental or sensory properties.
The search system uses filters which exploit the performance of the materials or processes; the database then selects the best materials and visualises them in visual maps. It is possible to choose materials and processes in a quantitative, rational and systematic manner according to the design requirements rather than subjective and personal criteria associated with routine use or knowledge of a material.

**Classification of the materials:** the database is divided into several sections: materials, processes, manufacturers, bibliographical references and shapes. These sections also act as selection filters when searching for materials. In particular, the materials are organised and classified according to major material classes: ceramics and glass, metals and alloys, polymers and hybrid materials (composites, foams and natural materials); the materials in these classes are then organised and classified in subcategories. Processes are instead divided into forming, fabrication and finishing processes, each of which is further subdivided.

**Material data sheets:** the materials and processes in the database are structured according to three levels of details; they are presented as interrelated, i.e., the materials are linked to the main manufacturing processes in which they can be used; instead as regards processes, data is provided as to which materials can be subjected to these processes.
Data about the materials includes: composition, physical and technical

properties (mechanical, thermal, optical, electric, water and air permeability, durability/fire-resistance, fluids, light, annual production data), toxicity, economic aspects, and a general description of their key applications.
Data about processes relate to: general description, main materials which can be subject to this kind of manufacturing, fabrication/joining, processing/transformation, (dished, etc.), characteristics of the manufacturing process (level of precision, sections of formable materials, etc.), economic data (set-up time, waiting time after manufacturing, equipment costs), main applications, technical and environmental data.

**Sensory properties:** apart from traditional and environmental properties, consultation also provides access to data about the sensory properties of the material associated with sight, touch, hearing, smell, and taste. These properties can be quantified to produce visual maps; the same can be done for other properties.

**Eco-compatibility:** Environmental data regarding production is provided for each material. This data includes: Embodied Energy, CO2 Footprint, NOx creation, SOx creation and water usage. Information about energy usage and CO2 emissions (Carbon Footprint) is provided for the main processes to which the material can be subjected.

**Miscellaneous:** extensive bibliographical reference material is provided for all materials and processes. GrantaDesign regularly organises online seminars to update its users about the latest novelties in its database.

## Idemat

www.idemat.nl

Delft University of Technology, Faculty of Design, Engineering and Production. Design for Sustainability Program, Landbergstraat 15, 2628 CE Delft, The Netherlands.

A database with the physical and technical characteristics of most materials commonly used in industrial design. Apart from the physical and technical properties, an Eco-indicator ‘99 assessment is also provided for each material.

Online consultation of materials is free, while detailed data about manufacturing processes, more complex components, or the materials themselves, require the purchase of a licence; the latter provides access to a more extended version of the database.

**Founder:** Delft University of Technology, Faculty of Design, Engineering and Production, Design for Sustainability Program

**Number of materials:** the database contains information about more than 400 materials and process. The free online version provides access to limited information about the materials, while the fee-paying version provides more detailed data about the materials, manufacturing processes and components.

**Computerised database:** based on the criteria outlined below, several selection filters can be used to search and select the most suitable materials or technological processes:
• Properties: it is possible to establish the maximum and minimum limits required of the material;
• Applications: materials can be searched according to the performance to be provided when used in a specific application or subjected to certain loads;
• Technologies: materials can be selected according to the technologies with which they may be processed;
• Categories: materials can be searched according to their material family.

**Classification of the materials:** the information and data in the Idemat database is organised based on a hierarchical tree structure using the following category names:
• materials: information relating to ceramics, fibres, glass, laminates,

ferrous or non-ferrous materials, polymers, wood, and miscellaneous. In turn, every category is further divided into categories containing all the material types.

• processes: the database includes all the most common transformation processes used to obtain semi-finished products ready to be used in the assembly of a product; the processes required to obtain useful energy during production or use (low or high voltage electricity, etc.); different transportation modes by sea, land or air (assessment of fuel consumption or the kilometres covered); the different end-of-life treatments such as recycling, incineration, disposal, and relative material collection modes;

• components: information is provided about metal shapes in aluminium, steel or brass, with a round or square section. Data relating to size, costs and economic value is provided for each component.

**Material data sheets:** a general description of the material or the process is provided for each selected material, plus two more kinds of data:

• performance profile: with values relating to the physical, mechanical, thermal and electric properties of the selected materials or processes, as well as an estimate of their cost;

• environmental profile: all the environmental data about the selected material (or process) is provided as well as an assessment of its energy-environmental load delivered as a single score, including the upstream processes required to produce it.

• The energy-environmental assessment of the material or processes is provided using three assessment systems, Eco-indicator ‘99, EPS or Exergia, based on the scientific LCA method.

**Eco-compatibility:** apart from the physical and technical data for each material, environmental data is also provided; the latter is divided into sections:

• environmental data: an assessment of the energy and environmental loads is provided and expressed in Eco-indicator, EPS or Exergia; it is graphically accompanied by a flow chart illustrating the processes which have led to the production of the material in question;

• input-output flows: a list is provided with the values of the materials or input and output energy values used so that the material is ready to be used in the manufacturing and production of a component. This data is used to elaborate the inventory data and impact assessment, which is then delivered as Eco-indicator, EPS or Exergia.

**Miscellaneous:** the information in the database can be extrapolated and inserted in assessment software using the Ecoindicator assessment method.

## The Plastics Portal

www.plasticseurope.org

PlasticsEurope. Association of Plastics Manufaturers.

This free online portal focusing on the world of plastics was set up by PlasticsEurope, a trade association representing the main European plastics manufacturers.

The portal provides extensive information about different types of polymeric materials and their uses. The section dedicated to environmental sustainability provides eco-profiles about the most common and widely used plastics.

**Founder:** PlasticsEurope, a trade association of the most important European plastics manufacturers.

**Number of materials:** the portal provides the eco-profiles of the most common and widely used plastics.

**Computerised database:** the eco-profiles of available plastics are easy to consult and can be freely downloaded. There are three ways in which the eco-profile of plastic materials can be identified and selected: flow chart, product family, or product list.

**Classification of the materials:** under the heading ‘eco-profiles’ in the plastics and sustainability section, the eco-profiles of the most common plastics are divided into monomers, polymers and semi-finished products: a total of more than 80 reports. Every heading has a hyperlink to a very detailed flowchart about how the item in question is related to the manufacturing context, types of plastics, and basic substances contained in the chart. It is also possible to download an extremely detailed eco-profile based on comprehensive LCA studies.

**Material data sheets:** the environmental eco-profiles of several different kinds of plastics not only provide detailed eco-profiles with disaggregated inputs and outputs, but also the following data: objectives of the study, approach and methods, study objectives and scope, functional reference unit (unit of measure), boundaries of the analysed manufacturing system, quality indicators of the data provided, a description of the process/material, and the impact categories considered in the study.

**Eco-compatibility:** the detailed environmental eco-profile of every semi-finished product or finished plastic material usually provides disaggregated values for the main inputs (such as Gross Energy, with details about primary fuels, fuels and feedstock values, raw materials used, and water usage) and outputs (such as air emissions, values of equivalent CO2, solid waste, and water emissions).

**Miscellaneous:** the information in the database can be extrapolated and inserted in assessment software using the Ecoindicator assessment method.

## European ELCD database

http://elcd.jrc.ec.europa.eu/ELCD3/index.xhtml
European Commission - DG Joint Research Centre - Institute for Environment and Sustainability (IES).

Free online database comprising specific Life Cycle Inventory (LCI) data relating to emissions and resource consumption of key materials, energy and technological carriers, transport and waste management. Compared to other materials databases, the values available in this database have been specifically formatted to be included in an LCA assessment, making them difficult to interpret and use by non-experts The data is provided by front-running EU businesses and trade associations.

**Founder:** European Commission - DG Joint Research Centre - Institute for Environment and Sustainability

**Number of materials:** the database contains Life Cycle Inventory (LCI) datasets about 329 processes and materials.

**Computerised database:** apart from simple consultation, several search filters are available to search and select technological materials or processes; the kind of filter depends on the section of the database. Searching can also be based on specific parameters such as the reference period of the data or the geographical context to which they refer

**Classification of the materials:** the database has five main sections, each with several LCI datasets. The datasets in the various sections are further divided as follows:
• waste management: data is divided into energy recycling, waste water treatments, landfilling;
• production of materials: in turn divided into plastics, glass and ceramics, metals, wood, other mineralic materials, organic and inorganic substances, and water;
• energy carriers and technological transformation processes: divided into electricity, mechanical energy, crude oil based fuels, hard coal based fuels, natural gas based fuels, and lignite based fuels;
• transportation: in turn divided into air, road, water, rail and other transport;
• systems: packaging and construction.

**Material data sheets:** for every LCI dataset the values are organised in four key groups: information about the process, information regarding data processing and validation models, administrative data and detailed input and output data.

**Eco-compatibility:** : the datasets are organised and outlined using the pre-established ILCD format divided into four sections; each section has further information and is structured as follows:
• process information: general data, quantitative references, geographical, temporal and technological representativity;
• modelling and validation: LCI and load allocation methods, data sources, data completeness, validity and conformity;
• administrative information: client and study objectives, data modelling, person responsible for data compilation, owner of the data;
• input and output: elementary input flows (energy usage and materials) and output flows (solid waste, air, water and soil emissions).

**Miscellaneous:** the data in the database can be extrapolated and integrated into major LCA software.

## Ecoinvent

www.ecoinvent.ch

(ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa) and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART).

Ecoinvent is a computerised database for which a licence can be purchased separately or as part of other LCA software programmes. The database is continually updated with inventory datasets useful in a LCA analysis. Its goal is to provide a single LCA database in which relevant, reliable, transparent, complete, and high-quality data can be continuously updated, a task which goes well beyond the possibilities of a single institute. Ecoinvent makes reliable datasets of the main technological processes used to produce materials, as well as energy systems, transport, and end-of-life. These datasets can be easily integrated into a LCA analysis, making it credible and reliable. This is why it is a very specific environmental database intended to be employed by users very knowledgeable in LCA analyses and studies

**Founder:** c oinvent Centre, research centre participated by the w iss ederal Institute of Technology ric h ( T urich) and Lausanne ( Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa) and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART).

**Number of materials:** the database provides values relating to the inventory flows of more than 9000 activities classified as transforming, production mixes and market activities. Values inherent in activities which can be used for different types of environmental assessments (LCA, carbon footprint, etc.) The database has several libraries with values relating to the following assessment methods: IPCC Global Warming Potential, Ecological Scarcity 2006, Impact2002+, CML2001, ReCiPe, Eco-Indicator 99.

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**Computerised database:** the inventory data in the database can be freely consulted. The Query tool can also be used to ‘question’ the database and download only data relating to a specific field, a specific economic sector, or the data elaborated only by certain institutes.

**Classification of the materials:** EcoInvent contains updated Life Cycle Inventory data relating to the following sectors: agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics, and waste treatment.
References are always provided for all data referring to the products and services analysed and reported. These references attest to their reliability, such as the time horizon during which they were collected and recorded, the geographical context in which they were processed, and the typical energy mix used by the countries involved in the production of electricity.

**Material data sheets:** the inventory data, in other words the disaggregated data relating to the various input and output flows or processes, are provided in relation to the technosphere and environment. Every dataset has a name and unit of reference; the following six properties are also provided for each dataset:
1) Wet mass (this equals the total mass including any water)
2) Water in wet mass (this is the total mass of water in the product)
3) Dry mass (this equals the wet mass minus the water in wet mass)
4) Water content (this equals the water in wet mass / dry mass)
5) carbon content, fossil
6) carbon content, non-fossil

**Eco-compatibility:** the data regarding the environmental profile of the various materials and processes is delivered as:
• unit process (U R ): all the inputs and outputs of a process are described in detail and their link with other processes is then specified;
• system model (LCI): in this case, the various unit processes can be linked in a system model using two different methods;
• partitioning (attributional linking) activities are allocated according to the criteria; all activities supply the markets, and by-products are allocated at the point of substitution;
• system model with substitution (consequential linking); only unconstrained (marginal) activities supply the markets, and by-products are treated by substitution (system expansion)

**Miscellaneous:** free consultation is provided for a limited period after which a licence has to be purchased. The database can easily be imported into several different LCA software programmes because it is developed in an EcoSpold Data Exchange Format 2. Using the SPOLD import/export interface function it is possible to import and export the data to and from other calculation programmes.

# Bibliography


Alberti M., Berrini M., Bettini V., Falqui E., Melone A., Zambrini M. (1988), *La valutazione di impatto ambientale: istruzioni per l'uso,* FrancoAngeli, Milan.

Allione C., Lanzavecchia C. (2008), *Dall'ecodesign all'architettura*, Time & Mind Press, Turin.

Antiseri D. (2001), *Teoria unificata del metodo*, UTET Libreria, Turin.

Arato F., Dal Palù D., *Il suono nel design. Una guida per il progettista di 'oggetti sonori'* [degree tesi], rapporteur De Giorgi C., co-rapp. Astolfi A., Buiatti E., Lerma B., Politecnico di Torino, I Facoltà di Architettura, Academic Year 2009/2010.

Arielli E. (2003), *Pensiero e progettazione*, Paravia, Milan.

Aristotele (1994), "Del senso dei sensibili", *Piccoli trattati di storia naturale*, Laterza, Rome-Bari.

Ashby M. (2009), *Materials and the environment: eco-informed material choice*, Butterworth-Heinemann Ltd, Elsevier.

Ashby M., Johnson K. (2002), *Materials and Design. The art and science of material selection in product design*, Butterworth-Heinemann Ltd, Elsevier.

Azzolini T. (2003), "Segnali cromatici", *Modo*, February/March, n. 225.

Baldo G.L., Marino M., Rossi S. (2008), *Analisi del ciclo di vita LCA. Gli strumenti per la progettazione sostenibile di materiali, prodotti e processi,* Edizioni Ambiente, Milan.

Bandini Buti L. (1998), *Ergonomia e progetto dell'utile e del dilettevole*, Maggioli, Santarcangelo di Romagna (RN).

Barbara A. (2000), *Storie di architettura attraverso i sensi. Nebbia, aurorale, amniotico*, Bruno Mondadori, Milan.

Belpoliti M. (2003), *Doppio zero. Una mappa portatile della contemporaneità*, Einaudi, Turin.

Bergando S., Gallerani C., *Materiali, ricerca, emozioni. Sperimentazione verso una nuova metodologia di valutazione sensoriale* [degree tesi], rapporteur. De Giorgi C., co-rapp. Vannoni D., Politecnico di Torino, I Facoltà di Architettura, Academic Year 2004/2005.

Bertola P., Maffei S., edited by (2009), *Design research maps. Prospettive della ricerca universitaria in Design in Italia*, Maggioli, Santarcangelo di Romagna (RN).

Bistagnino L. (1999), *Ecodesign & Componenti*, Time & Mind Press, Turin.

Bistagnino L. (2003), *Design con un futuro*, Time & Mind Press, Turin.

Bistagnino L. (2008), *The outside shell seen from the inside*, Casa Editrice Ambrosiana, Milan.

Bistagnino L. (2008), 'Innovate, But How?', in Germak C., edited by, *Man at the Centre of the Project Design for a New Humanism*, Umberto Allemandi Editore, Turin.

Bistagnino L. (2011), *Systemic Design sistemico. Designing the productive and environmental sustainability*, Slow Food Editore, Bra (CN).

Bonapace L., Bandini Buti L., Tarzia A. (1997), "Sensorial Quality Assessment: a method to incorporate perceived user sensation in product design. Application in the field of automobiles", *Proceedings of the 13h Triennal Congress IEA '97*, International Ergonomics Association, Helsinki.

Bonetti A. (2004), "Ci vuole naso", *Carnet*, May.

Bonfantini M., Zingale S. (1999), *Segni sui corpi e sugli oggetti*, Moretti & Vitali, Bergamo.

Bottino A., Laurentini A.,. Scalabrin S. (2001), "Quantitatively comparing virtual and real draping of clothes", *Proceedings of 9th Int. Conf. on Computer Graphic*, Visualization and Computer Vision WSCG'2001, Plzen (CZ)

Branzi A. (1984), *La casa calda: esperienze del nuovo design italiano*, Idea Books Edizioni, Milan.

Branzi A. (1999), *Introduzione al design italiano: una modernità incompleta*, Baldini & Castoldi, Milan.

Brezet H., Van Hemel C. (1997), *Ecodesign: A promising approach to sustainable production and consumption*, Delft University of Technology & UNEP – United Nation Environment programme, Paris.

Brownell B. (2006), *Transmaterial*, Princeton Architectural Press, New York.

Bucchetti V. (1999), *La messa in scena del prodotto. Packaging: identità e consumo*, FrancoAngeli, Milan.

Bucchetti V., edited by (2007), *Packaging tra vista e tatto*, Edizioni POLI.design, Milan.

Buiatti E., Lerma B. (2013), "Leggere il packaging: modelli di valutazione ergonomica per l'analisi delle bottiglie di vino", in A.A.V.V., *Pollenzo Index Environmental and economics Design. Indice Poliedro*, Università degli Studi di Scienze Gastronomiche, Pollenzo, Bra (Cn), pp. 120-127.

Cairoli A. (2004), "Aprite la finestra dei sensi", *Focus Extra*, May-June, n. 18.

Campogrande S., *Materioteca per designer* [degree tesi], rapporteur De Ferrari G., Politecnico di Torino, I Facoltà di Architettura, Academic Year 1998/1999.

Capra F. (1996), *The Web of Life: A New Scientific Understanding of Living Systems*, Anchor Book, New York.

Capra, F. (2002), *The Hidden Connections: A Science for Sustainable Living,* Anchor Book, New York.

Cardillo M., Ferrara M. (2008), *Materiali intelligenti, sensibili, Interattivi*, Editori di comunicazione-Lupetti, Milan.
Cascinai S. (2001), "Prada reinventa la moda", *Domus*, April, n.836.
Castelli Clino T. (1999), *Transitive design*, Electa, Milan.
Cecchini C. (2005), *Plastiche: i materiali del possibile*, Alinea, Florence.
Celaschi F., Deserti A. (2007), *Design e innovazione. Strumenti e pratiche per la ricerca applicata*, Carocci Editore, Rome.
Ciribini G., edited by (1992), *Tecnologie della costruzione*, La Nuova Italia Scientifica, Rome.
Colia E., Faccin C., *Ecocompatibilità_materiali_progetto. Manuale per la scelta di materiali per il progetto ecocompatibile* [degree tesi], rapporteur De Giorgi C., co-rapp. Allione C., Lerma B., Montanaro L., Politecnico di Torino, I Facoltà di Architettura, Academic Year 2009/2010.
Colombo A. (2006), "Degustatori d'interni", *Driving interiors*, November 2006, Milan, *Edinterni*, n. 0.
Cornish E.H. (1987), *Materials and the designer*, Cambridge University Press, Cambridge.
Croci V. (2004), "Corpo e superficie: l'abito interfaccia", *Ottagono*, Bologna, 2002, July-August, n. 152.
Croci V. (2004), "Evoluzione per il gusto", *Ottagono*, June, n. 171.
De Angelis A. (2003), "Milioni di colori", *Modo*, February/March, n. 225.
De Giorgi C. (2003), "Imballaggi: svolta epocale. Package al pomodoro per il Ketchup", *Il Giornale dell'Architettura*, October, n. 11.
De Giorgi C. (2003), "L'auto 'fuzzy' nasce nel centro di Londra", *Il Giornale dell'Architettura*, March, n. 5.
De Giorgi C., Allione C., Lerma B. (2010), "Environmental & perception properties of materials for pursuing the eco-compatibility of the industrial product", in *Environmental Protection in the New Era: Proceedings of the 4th International Conference on Sustainable Energy & Environmental Protection,* SEEP 2010, Politecnico di Bari, BB Press, Bari.
De Giorgi C., Allione C., Lerma B. (2010), "Environmental and perception properties of materials for industrial product. How to select the materials for pursuing the product life cycle eco-compatibility?", in *Atti del convegno internazionale Sustainability in Design: Now! Challenges and Opportunities for Design Research, Education and Practice in the XXI Century, Creative Commons in association with Greenleaf Publishing Limited*, Vol. I, pp. 631-643.
De Giorgi C., edited by, *Sustainable Packaging?-Packaging Sostenibile?*, Umberto Allemandi Editore, Turin, pp. 136-143.
De Giorgi C., Germak C. (2008), *Piemonte Torino Design*, Electa, Milan.
De Giorgi C., Germak C. (2013), "Il sistema di valutazione multicriteria", in De Giorgi C., edited by, *Sustainable Packaging?-Packaging Sostenibile?,* Umberto Allemandi Editore, Turin, pp. 112-125.
De Haes U., Van Rooijen, M. (2005),"Life Cycle Approaches. The road from analysis to practice", *UNEP/SETAC Life Cycle Initiative*, United nations

Environment programme, Division of Technology, Industry and Economics (DTIE), Paris.
De Liso G. (2002), *Creatività e pubblicità*, FrancoAngeli, Milan.
Dell'Arti G. (2009), "L'importanza del crocchio", *Altri mondi*, March 9.
Delogu F. (2005), "Bellezza: ascoltare un profumo, sentire lo scatto di un pennello o il 'click' di un rossetto", *La Repubblica*, 01-10-2005.
Delvino L., *Psicologia dell'emotional design. Uno studio sperimentale sul packaging dei profumi* [tesi di laurea], rel. Riva G., Milan, Università del Sacro Cuore, Academic Year 2006/2007.
Deni M. (2002), *Oggetti in azione. Semiotica degli oggetti: dalla teoria all'analisi*, FrancoAngeli, Milan.
Di Nocera F. (2004), *Che cos'è l'ergonomia cognitiva*, Carocci Editore, Rome.
*Dizionario Enciclopedico Scientifico-Tecnico*, Inglese-Italiano, Italiano-Inglese, (1994), Zanichelli, Bologna.
Duò, F., Tomalino F., *Valutazione multisensoriale applicata ad un componente Automotive* [degree tesi], rapporteur. De Giorgi C., co-rapp. Peyron B., Politecnico di Torino, I Facoltà di Architettura, Academic Year 2005-2006.
*Enciclopedia scientifica tecnica Garzanti* (1969), 2 vv., Garzanti, Milan.
Fabio G. (1996), "La fine del consumatore standard", *Stileindustria*, December, n. 8.
Ferlazzo F. (2005), *Metodi in ergonomia cognitiva*, Carocci Editore, Rome.
Ferrara M., Lucibello S. edited by (2009), *Design follows materials*, Alinea, Florence.
Ferraresi M. (1999), *Il packaging: oggetto e comunicazione*, FrancoAngeli, Milan.
Ferreri M., Scarzella P. (2009), *Oggetti sonori. La dimensione invisibile del design*, Electa, La triennale di Milano, Milan.
Ferrone S., *La sensorialità e i rivestimenti degli interni auto* [degree tesi], rapporteur De Giorgi L., co-rapp. Lerma B., Politecnico di Torino, I Facoltà di Architettura, Academic Year 2009/2010.
"Finisce l'era del vino taroccato. Arriva il sommelier", *la Repubblica*, August 12, 2008.
Fino F., Peyron B. (2010), "Perceived quality : design and evaluate a new vehicle interior', Déc'autex – Textiles et Plastiques: comment innover dans le décor automobile", *7th International Conference on Automotive and Transport Interior*, Parc des expositions, Mulhouse (France).
Fiorani E. (2000), *Leggere i materiali: con l'antropologia, con la semiotica*, Editori di comunicazione-Lupetti, Milan.
Fiorani E. (2001), *Il mondo degli oggetti*, Editori di comunicazione-Lupetti, Milan.
Francesco R., a cura di (2004), *Acusmetria. Il suono visibile*, FrancoAngeli, Milan.
Frova A. (2000), *Luce, colore, visione. Perché si vede ciò che si vede*, BUR – RCS Libri, Milan.
Fuad-Luke A. (2008), *The Eco-Design Handbook*, Thames Hudson; 2nd Revised edition, London
Gafforio L. (2003), "La materia dei sogni", *Abitare*, February, n. 425.
Galati D. (1993), *Teorie, oggetti e metodi in psicologia*, Giappichelli, Turin.

Galati D. (2002), *Prospettive sulle emozioni e teorie del soggetto*, Bollati Boringhieri, Turin.

Gallucci F. (2006), *Marketing emozionale*, Egea, Milan.

Gambaro F. (1996), "La fine del consumatore standard", *Stileindustria*, december, n. 8.

Germak C. (2008), *Design e Industria in Piemonte*, Umberto Allemandi Editore, Turin.

Germak C., edited by (2008), *Man at the Centre of the Project. Design for a New Humanism*, Umberto Allemandi Editore, Turin.

Giammatteo C. (2004), "Questioni di naso", *Focus Extra*, May-June, n. 18.

Gibson J.J. (1979), *The Ecological Approach to Visual Perception*, Houghton Mifflin, Boston.

Gilotta S., Calligher R. (2008), "Eye tracking: analisi dell'interazione con il sito www.youtube.com", *Usermatter*, April/May, June/July, n. 9 e 10.

Giordano R. (2010), *I prodotti per l'edilizia sostenibile La compatibilità ambientale dei materiali nel processo edilizio*, Simone editore, Gruppo Editoriale Esselibri, Naples.

Goedkoop M. (2007), "Why ecodesign tools and methods do not really work", in *Proceedings of Conference LMC2007*, in *LMC2007 – From Analysis to implementation*, 3rd international Conference on Life Cycle management, August 27-29, Zurich.

Goedkoop M., Demmers M., Collignon M. (2000), *The Eco-indicator 99, Manual for Designers*, NOH report, Prè consultants, Amersfoort.

Goedkoop M., Spriensma R. (2001), *The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Methodology report*, Prè consultants BV, Amersfoort.

*Grande Dizionario Enciclopedico* (1956), Unione Tipografico-Editrice Torinese, Turin.

*Guidelines for Life Cycle Assessment, a code of practice* (1993), SETAC Press, Brussels.

Gussoni M., Parlangeli O., Tosi F. (2008), *Ergonomia e progetto della qualità sensoriale*, FrancoAngeli, Milan.

Hall E.T. (1966), *The Hidden Dimension*, Anchor Books, New York.

"Il rumore del lusso" (2003), *ItaliaImballaggio*, October.

Imperiale A. (2001), *Nuove bidimensionalità. Tensioni superficiali nell'architettura digitale*, Testo & Immagine, Turin.

Itten J. (1969), *The Art of Color: the subjective experience and objective rationale of color*, Van Nostrand Reinhold, New York.

Johnson-Laird P. (1983), *Mental Models: Toward a Cognitive Science of Language, Inference and Consciousness*, Harvard University Press, Harvard.

Jordan P.W. (1997), "The four pleasures – taking human factors beyond usability", *Proceedings of the 13h Triennal Congress IEA '97*, International Ergonomics Association, Helsinki.

Kanizsa G. (1991), *Vedere e pensare*, il Mulino, Bologna.

Kanizsa G., Caramelli N., edited by (1988), *L'eredità della psicologia della Gestalt*, il Mulino, Bologna.
Katz D. (1948), *Gestaltpsychologie*, Benno Schvabe, Basilea.
Kemp S. E. (2009), *Sensory evaluation: a practical handbook*, Wiley-Blackwell, Chichester (UK).
Keoleian G., Menerey D. (1994), *Life Cycle Design Guidance Manual Environmental Requirements and Product System, EPA-600R92226*, EPA Environmental Protection Agency, Washington, USA
Koivunen K., Kukkonen S. (2004), "Towards Deeper Understanding of How People Perceive Design", *CADE2004 Web Proceedings of Computers in Art and Design Education Conference*, Copenhagen Business School.
Kukkonen S. (2005), "Exploring eye tracking in design evaluation", *Proceedings of JoiningForces, International Conference on Design Research*, UIAH, Helsinki, Finland.
Langella C. (2003), *Nuovi paesaggi materici*, Alinea, Florence.
Langella C. (2007), *Hybrid design*, FrancoAngeli, Milan.
Lanza A. (2002), *Lo sviluppo sostenibile*, il Mulino, Bologna.
Lanzavecchia C. (2000), *Il fare ecologico: il prodotto industriale e i suoi requisiti ambientali*, Paravia Bruno Mondadori, Turin.
*Le tattiche dei sensi* (2000), Libri Montag, Rome.
Lemaitre G., McAdams S., Susini P. (2008), "Psychological measurement for sound description and evaluation", *MINET. Theory and methods of measurements with persons*, Genoa.
Lerma B. (2009), "Innovative materials and multisensoriality", *R'09 Twin World Congress Resource Management and Technology for Material and Energy Efficiency*, Nagoya/Japan and Davos/Switzerland.
Lerma B. (2013), "La sostenibilità alla seconda. La percezione della sostenibilità e il ruolo del designer", in De Giorgi C., edited by, *Sustainable Packaging?-Packaging Sostenibile?*, Umberto Allemandi Editore, Turin, pp. 136-143.
Lerma B., *Materiali e multisensorialità. Una metodologia di valutazione sensoriale dei materiali per il rafforzamento del metaprogetto, con particolare attenzione all'ecocompatibilità* [PhD tesi], rapporteur De Giorgi C., Politecnico di Torino, PhD in Production Systems & Industrial Design, XXII ciclo, Academic Year 2007-2009.
Levi M., Rognoli V. (2005), *Materiali per il design: espressività e sensorialità*, Edizioni Polipress, Milan.
Levi P. (1978), *La chiave a stella*, Einaudi, Turin.
*Green paper on integrated product policy (2001)*, Commission of the European communities COM (2001) 68 final, Brusselles.
*Life Cycle Impact Assessment: striving towards best practice* (2002), SETAC Press, Brusselles.
*Lo Zingarelli Vocabolario della lingua italiana* (1997), Zanichelli, Bologna.
Lucibello S. (2006), *Materiali@design. Verso una nuova modalità di selezione su base percettiva dei materiali per il design*, Editrice Librerie Dedalo, Rome.
Lurija A. (1973), *The Working Brain*, Basic Books, New York.

Lurija A. (1970), *Course of general psychology*, Moscow.
Lusher Max (1990), *Luscher Color Test*, Pocket, New York
Luzzato L., Pompas R. (2001), *Il colore persuasivo: grafica, pubblicità, comunicazione, new media*, Il Castello, Milan.
Manzini E. (1986), *La materia dell'invenzione*, Arcadia Editori, Milan.
Manzini E. (1990), *Artefatti: verso una nuova ecologia dell'ambiente artificiale*, Domus Academy, Milan.
Manzini E., Vezzoli C. (1998), *Lo sviluppo del prodotto sostenibile. I requisiti ambientali dei prodotti industriali*, Maggioli, Santarcangelo di Romagna (RN).
Marino G.P. (2008), *Innovazione materica e design*, Time & Mind Press, Turin.
Marotta A. (1999), *Policroma*, Celid, Turin.
Massironi M. (1998), *Fenomenologia della percezione visiva*, il Mulino, Bologna.
Mazzeo M. (2000), "L'origine tattile della geometria. Merleau-Ponty e il triangolo", in *Le tattiche dei sensi*, Libri Montag, Rome.
Mazzocut-Mis M. (2002), *Voyerismo tattile: un'estetica dei valori tattili e visivi*, Il Melangolo, Genoa.
Melgaard M.C., Civille G.V., Carr B.T (2007), *Sensory Evaluation Techniques*, CRC press, Boca Raton.
Moore R. (2002), "Reinventare lo shopping", *Domus*, February, n.845.
Mosconi D., Pacciani A. (1990), "Le basi fisio-fenomenologiche del tatto", *Area*, December, n. 4.
Munari B. (1981), *Da cosa nasce cosa*, Laterza, Rome-Bari.
Munari B. (2004), *I laboratori tattili*, Edizioni Corraini, Mantua.
Munari, B. (2006), *Fantasia. Invenzione, creatività e immaginazione nelle comunicazioni visive*, Laterza, Rome-Bari.
Neisser U. (1976), *Cognition and Reality*, W.H. Freeman and Company.
*Neolite: metamorfosi delle plastiche* (1991), Domus Academy, Milan.
Nicolao U., Noselli G. (1998), *AudioDizionario: una guida alla comprensione e al corretto uso dei termini tecnici in lingua inglese ed americana*, il Rostro Milan.
Niewiadomska J.D. (2007), *Il codice percettivo del suono*, Rubbettino, Soveria Mannelli (CZ).
Norman D.A (2002), *The Design of Everyday Things*, Basic Books, New York.
Norman D.A (2004), *Emotional design: why we love (or hate) everyday things*, Basic Books, New York.
Norman D.A. (2009), *The Design of Future Things*, Basic Books, New York.
Novara R., *Comunicazione olfattiva. Progetti nella città di Torino* [degree tesi], rapporteur Console L., Università di Torino, Academic Year 2000/2001.
Oleari C., edited by (2008), *Misurare il colore*, Hoepli, Milan.
Osgood C.E., Suci G., Tannenbaum P. (1957), *The measurement of meaning*, University of Illinois Press, Urbana.
Pagano V. (2004), "Scoperte da gustare", *Ottagono*, June, n. 171.
Pagliarini E. (2002), *Valutazione sensoriale*, Hoepli, Milan.
Pasca V., Trapani V., edited by (2001), *Scenari del giovane design: idee e progetti dall'Europa e dal mondo*, Editori di comunicazione-Lupetti, Milan.

Petrillo A. (1991), “I linguaggi della sensorialità”, *Area*, editore Azzurra, then Il Sole24Ore, n. 6.
Peyron B. (2006), “Multisensorial Analysis applied in the Automotive Field”, in *Proceedings of ESDA2006 8th Biennial ASME Conference on Engineering Systems Design and Analysis*, Turin.
Peyron B. (2008), “Innovative instruments to measure perceived quality of vehicle interiors and benchmark”, *IQPC-Smart Interior Surfaces & Materials. Innovations in plastics and polymers for attractive new design features*, Wiesbaden, Germany
Pignotti L. (1993), *I sensi delle arti. Sinestesie e interazioni estetiche*, Dedalo, Bari.
*Integrated Product Policy. Building on Environmental Life-Cycle Thinking* (2003), Commission of the European communities COM (2003) 302 definitive, Brusselles.
*Pollenzo Index Environmental and economics Design. Indice Poliedro* (2013), Università degli Studi di Scienze Gastronomiche, Pollenzo, Bra (Cn), pp. 120-127.
Pompas R. (1994), *Textile design: ricerca, elaborazione, progetto*, Hoepli, Milan.
Porretta S. (2000), *Analisi sensoriali e consumer science*, Chiriotti, Turin.
Proust M. (2005), *Alla ricerca del tempo perduto,* Mondadori, Milan.
Restelli B. (2002), *Giocare con tatto*, FrancoAngeli, Milan.
Ricci C. (1980), *Il differenziale semantico: una proposta di revisione*, Vita Pensiero, Milan.
Riccò D. (2008), *Sentire il design. Sinestesie nel progetto di comunicazione*, Carocci Editore, Rome.
Riccò D. (1999), *Sinestesie per il design. Le interazioni sensoriali nell'epoca dei multimedia*, Etas, Milan.
Rigano L., D’Agostino R. (2001), “Valutazioni di innocuità e misure della percezione sensoriale nel campo tessile”, *Proceedings of the1st Meeting Tessile e Salute*, Biella.
Rigano L., D’Agostino R. (2002), “Il codice dei sensi nella percezione del prodotto tessile”, *Proceedings of the 2nd Meeting Tessile e Salute*, Biella.
Rizzari F. (2002), “A lume di naso”, *Gambero rosso*, Rome, June, n. 125.
Rizzi G. (2006), *Abitare essere e benessere*, Casa editrice Led, Milan.
Rognoli V., *I materiali per il design: un atlante espressivo-sensoriale* [PhD tesi], rel. Levi M., Politecnico di Milano, PhD in Industrial Design and Multimedia Communication, , XVI ciclo, Academic Year 2001/2004.
Rognoli V., Levi M. (2004*), Materiali per il design: espressività e sensorialità*, Polipress, Milan.
Rognoli V., Levi M. (2011), *Il senso dei materiali per il design*, FrancoAngeli, Milan.
Rubik F., Keil M. (2006), *Cooperative Approaches to Integrated Product Policy (IPP)*, Ministry of the Environment and Transport Baden-Wurttemberg, Stuttgart.

Rutelli P., Bortolanza E. (2006), *Gli oggetti di qualità e i loro significati. Il design tra ergonomia di prodotto, di processo e di consumo*, Raffaello Cortina, Milan.

Salce M. (2003), "Si applica a Roma la cromoterapia", *Il Giornale dell'Architettura*, October, n. 11.

Salce M. (2004), "Materiali a memoria di forma", *Il Giornale dell'Architettura*, January, n. 14.

Salvi S. (1997), *Plastica tecnologia design*, Hoepli, Milan.

Sardella M., *Materialeimmateriale* [PhD tesi], rapp. D'Alessandro M., Università degli studi La Sapienza, Roma, Facoltà di Architettura, PhD in Technologies of Architecture, XV ciclo, Academic Year 2000-2003.

Scotti D. (1989), *Atlante cromatico. Prontuario dei colori*, Zanichelli, Bologna.

Simon M., Evans S., McAloone T., Sweatman P. (1999), *Ecodesign Navigator, A key resource in the drive towards environmentally efficient product design*, Manchester Metropolitan University, Cranfield University, EPSRC.

Sterling B. (2005), *Shaping Things*, The MIT Press, Cambridge.

Sudjic D. (2003), "Lusso Virtuale", *Domus*, November, n. 864.

Susini P., McAdams S., Winsberg S. (1999), "A multidimensional technique for sound quality assessment", *Acustica*, n. 85.

Susini P., McAdams S., Winsberg, S., Perry I., Vieillard S., Rodet X., "Characterizing the sound quality of air-conditioning noise", *AppliedAcoustic*, n. 65.

Süskind P. (1986), *Perfume: the story of murder*, Knopf, New York.

Tamborrini P. (2009), *Design sostenibile. Oggetti, sistemi e comportamenti*, Electa, Milan.

Tamborrini P. (2010), "Come declinare la sostenibilità", *Il Sole 24Ore*, 13-04-2010

Thackara J. (2005), *In the bubble: designing in a complex world*, The MIT Press, Cambridge.

Tipler P. (1991), *Invito alla fisica* 2, Zanichelli, Bologna.

Tornquist J. (1999), *Colore e luce. Teoria e pratica*, Istituto del colore, Milan.

Uccelli A., *Interazione luce e materiali: proposta di un sistema di schedatura di supporto al progettista* [degree tesi], rapporteur De Giorgi C., co-rapp. Pellegrino A., Politecnico di Torino, I Facoltà di Architettura, Academic Year. 2005-2006

Vannoni D. (1997), "Far parlare gli oggetti", *Stileindustria*, March, n. 9.

Vannoni D. (1998), *Della pubblicità. Mente, contesti, mondi immaginari*, Giappichelli Editore, Turin.

Vannoni D. (2001), *Manuale di psicologia della comunicazione persuasiva*, UTET Libreria, Turin.

Vezzoli C., Ceschin F., Cortesi S. (2009), *Metodi e Strumenti per il Life Cycle Design*, Maggioli, Santarcangelo di Romagna (RN).

Vezzoli C., Manzini E. (2008), *Design for Environmental Sustainability*, Springer-Verlag, London.

Vincente K. (2004), *The Human Factor. Revolutionizing the Way People Live With Technology*, Routledge, New York.

Von Bismarck G. (1974), "Timbre of steady sounds: a factorial investigation of its verbal attributes", *Acustica.*
Zucco G. (2000), "Olfatto: unicità di un senso", in *Le tattiche dei sensi*, Libri Montag, Rome.

# Webliography


closed.ircam.fr
micro-la.com
minet.wordpress.com
www.1to1lab.com
www.athenasmi.ca;
www.boustead-consulting.co.uk
www.castellidesign.it/projects/
www.contactlab.com
www.crf.it
www.cromoambiente.it
www.ctba.fr
www.designinsite.dk
www.dialogonelbuio.it
www.ecoinvent.ch
www.ecosmes.net
www.eyetracking.com
www.gabi-software.com
www.grantadesign.com
www.groupecemas.com
www.innovathequectba.com
www.io.tudelft.nl/research/dfs/idemat/index.htm
www.ircam.fr
www.iuav.it
www.matech.it
www.materia.nl

www.materialconnexion.com
www.materialiedesign.polimi.it
www.material-lab.co.uk/
www.materialworks.com
www.materiauech.org
www.materio.com
www.materioteca.com
www.matrec.it
www.matweb.com
www.modulor.de
www.mutr.co.uk
www.ncscolour.it
www.pantone.com
www.politeca.polimi.it
www.pre.nl
www.realeyesit.com/homepage.aspx
www.sbi.dk
www.sensable.com
www.sensotact.com
www.sistemadesignitalia.it
www.soundobject.org
www.srlabs.it
www.sturmundplastic.it
www.terratorium.nl
www.tessileesalute.it
www.tis.bz.it/servizi/tecnologie/materiali
www.tobii.com
www.via.asso.fr
www.visualcomplexity.com

In today's world design has to consider not only the technical and functional performance of products, but also the increasingly important cultural issues which make a product acceptable to man and the environment: sensory perception and sustainability.

This book presents a method to assess the sensory characteristics and eco-compatibility of materials; designers can use this method as a tool and guide to manage the expressive-sensory aspects and environmental sustainability of the product.

It is a multi-criteria tool to interpret the sensory and environmental performance of materials; the tool can be tailored to suit all kinds of cultural contexts based on the premise that it is impossible to talk of eco-compatible or 'sensory' materials in absolute terms. Instead it is more important to select materials, or a mix of materials, according to the various contexts of use, useful life, and end-of-life of a product.

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