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Functional materials and material selection

Functional materials, also called “smart materials”, are materials that can “sense environment events, process that sensory information and then act on the environment” [1]. These materials are able to transform a given stimulus into a response. We use the general term “transition phenomenon” to account for the diversity of the underlying physical phenomena (e.g.: mechanoluminescence, which is a light emission produced by the application of a strain [2], or thermoelectricity, the conversion of a temperature difference into an electric potential [3]).

Using the general framework proposed by Ashby [4]: (i) translation by expressing the dominant functionality; (ii) screening based on constraints and (iii) ranking based on objectives, we develop a specific database in the Cambridge Engineering Selector software [5] and propose an associated selection process. The central object is a data table of stimuli-responsive phenomena, since they express the main functionality sought by product designers. Additional tables containing information about materials, processes and products are added to support designers and engineers at implementing functional materials

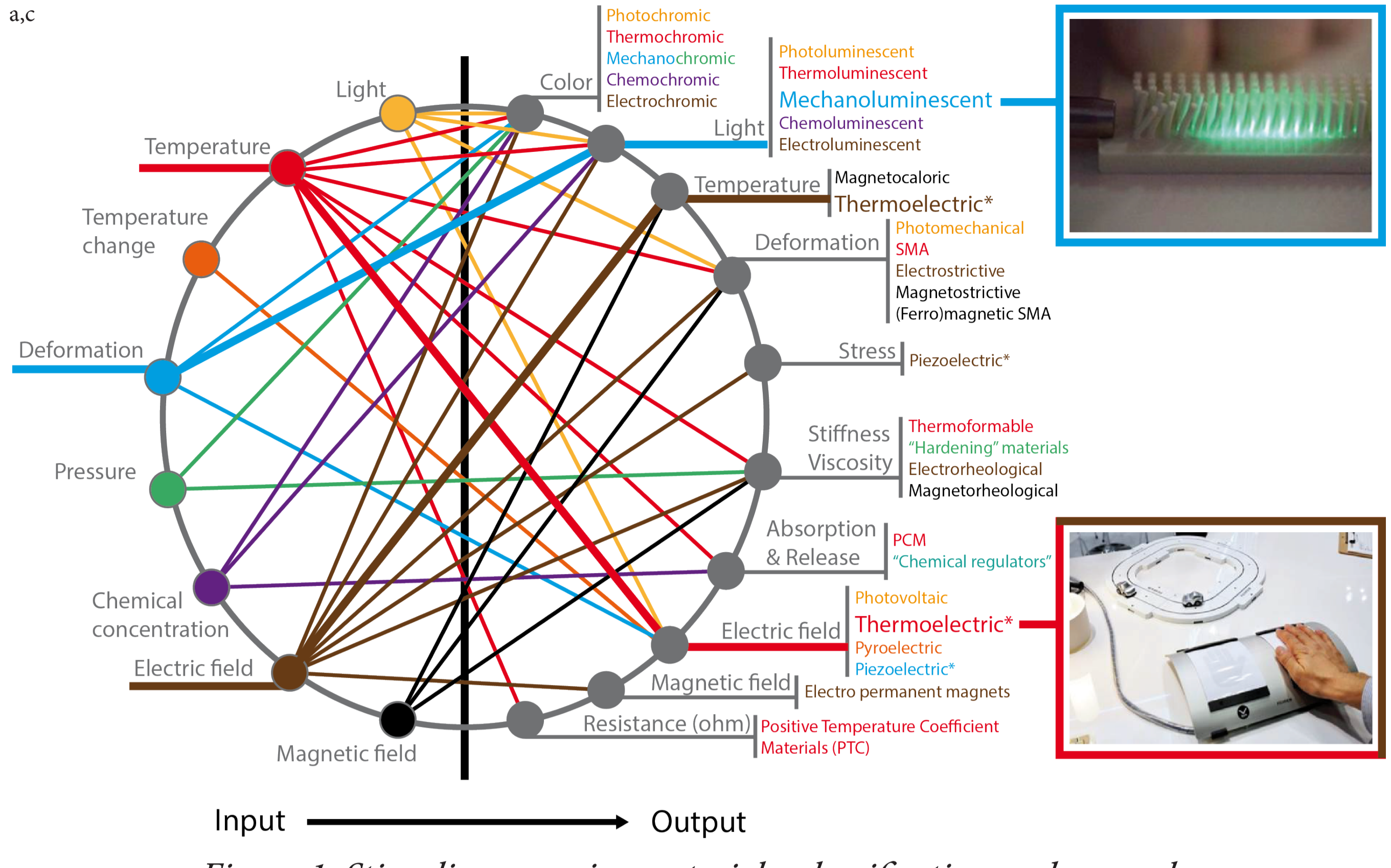


Figure 1: Stimuli-responsive materials: classification and examples

Stimuli-responsive phenomena

The stimuli-responsive phenomena table describes all the possible behaviors the functional materials can exhibit.

The tree structure of this table starts from the first element as families, since it is the first element of the functional material's behavior the end user will perceive. Then the stimuli-responsive phenomena are reported as sub-families, making further partition thanks to the stimulus.

Stimuli-responsive phenomena	Input -> Output	Characteristics	Maturity	Programmability	Chronic properties
Chemical regulation	Input: From the environment	Type of change: Single	Industrialized: ✓	Level of programmability: Good	Clear to dark: ✓
Color changes	Output: Bi-directional	Switch on/off: ✓		By composition: ✓	Dark to clear: ✓
Chemochromism		Continuous input needed: ✓		By assembly: ✓	Opaque to transparent: ✓
Electrochromism		Immediacy: Poor			
Mechanochromism		Activation time: *1 - 60 s			
Photochromism		Relaxation time: *1 - 60 s			
Thermochromism					
Electric resistivity changes					
Electricity production					
Light emission					
Magnetic induction					
Shape changes					
Electrostriction					
Magnetostriction					
Photomechanical effect					
Piezoelectricity					
Piezomagnetism					
Shape memory effect					
Temperature changes					
Viscosity/Stiffness changes					

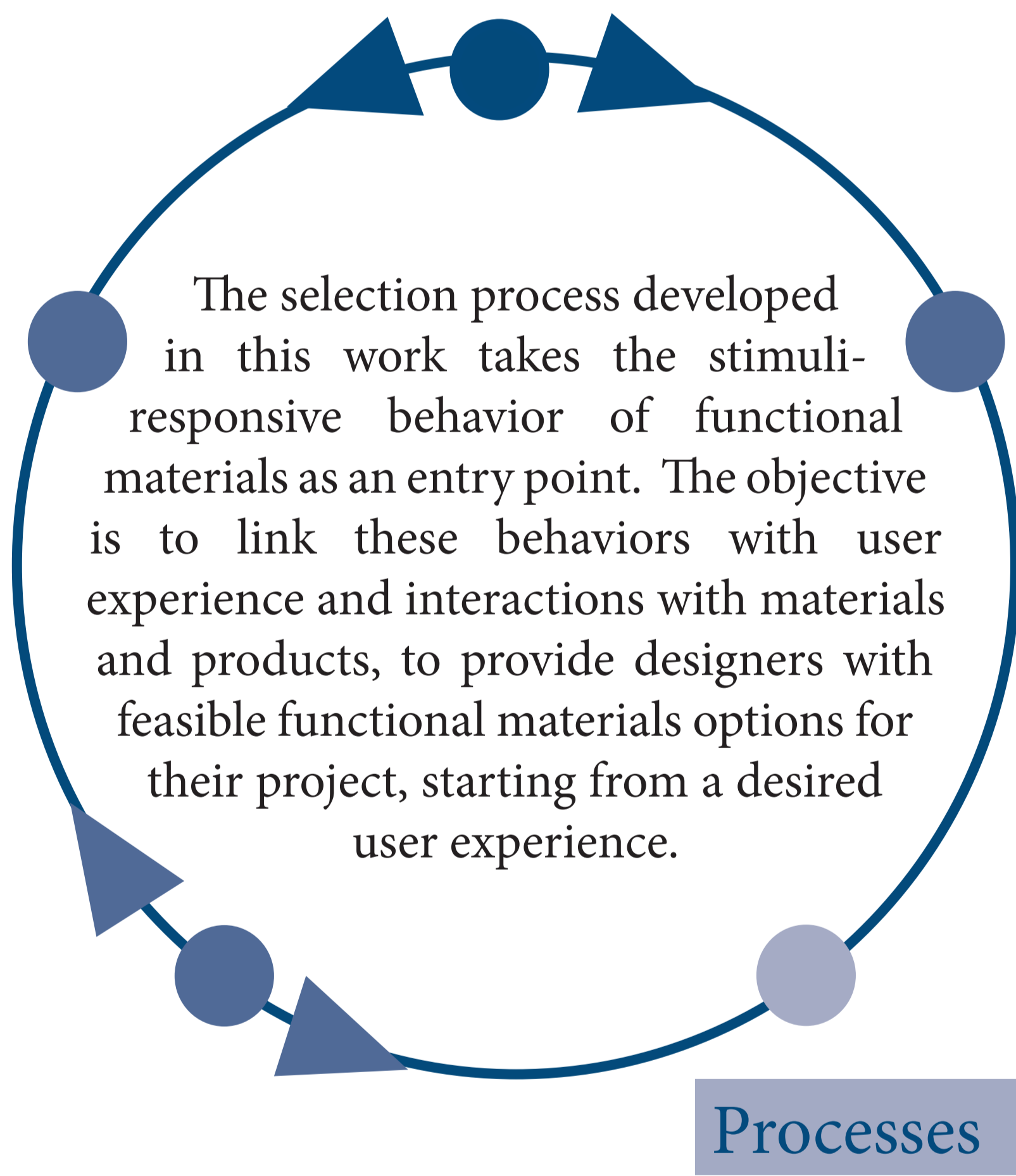
Each type of stimuli-responsive phenomenon is described in a dedicated datasheet. Basic information common to all phenomena is their related stimulus (or input) and response (or output), and main characteristics such as reversibility, immediacy, etc... Information linked to the user perception of the phenomena is also included.

Other data are specific to a phenomenon, or to a response. For example, chromatic properties will be described when the phenomenon's response is a color change.

Base materials or systems

Base materials or systems
Single support material
Ceramics and glasses
Fibers & Particulates
Hybrids: composites, foams, natural materials
Metals
Polymers
Supporting system

Some functional materials can be used as bulk materials, but many others are used as in-mass additives, as surface treatments, or as part of a system. Therefore, to implement functional materials, it is necessary to know in and/or on which base materials they can be used, or if it is necessary to surround the functional material with a particular system. The «Base materials or systems» table is an attempt to describe the materials that can be functionalized. Each member of this table, i.e. each material or system, is linked to the functional materials that can be used with it.



Processes

Functional materials

Functional materials	BKT-KNN
Ceramics and glasses	
Ceramics	
BKT-KNN	
BNKT	
BNKT-BT	
BNT	
KNN	
Metal oxides	
PMN-PT	
PT	
PZT	
Glasses	
Fibers and particulates	
Hybrids	
Inorganic materials	
Metals and alloys	
Polymers: plastics, elastomers	

General	Stimuli-responsive properties	Composition (summary)	Electrical	Links
Designation: BKT-KNN	Piezoelectric distortion coefficient: 129 pC/N	0.97Bi0.5K0.5Ti0.3-0.03K0.5Na0.5Nb0.3	Piezoelectric voltage coefficient: 10 0.001 V/m/N	ProcessUniverse
				Stimuli-responsive phenomena
				Products
				Producers

The functional materials table describes the materials themselves, including their mechano-physical properties. Some sensory properties are also described. The relationship between materials and stimuli-responsive phenomena is made by linking the tables together. Some attributes describe more precisely the stimuli-responsive properties of the materials. Some of them are specific to the type of stimuli-responsive phenomenon the materials exhibit, and some are common for all materials.

Products

The «product» table describes products where functional materials have been implemented. It aims at providing examples of the use of functional materials and illustrating some of the possibilities that they offer. The table is organized by «departments» as usually done in commercial resources. The datasheets present basic information about the product, with images and a description of the effect of the implementation of functional materials. Each product is linked to the functional material(s) it embeds.

Products	Noumenon chair
Consumption	
Arts and crafts	
Consumer electronics	
Food and beverages	
Health and beauty	
Home and garden	
Appliances	
Furniture	
Chair	
Noumenon chair	
Garden	
Kitchen	
Lighting	
Walls, floor and windows	
Locomotion	
Office products	
Piezoelectric lighter	
Sports	
Toys	
Travels	
Wearables	
Others	

Product description
Picture
Description: Shape memory effect used to reduce the storage space
Product's level of industrialization: Prototype
Designer information: Designer: Carl de Smet
Source: www.noumenon.eu
Links: ProcessUniverse, Functional materials, Stimuli-responsive phenomena, Base materials or systems, Producers

Conclusion and future works

Because of their stimuli-responsive phenomena, functional materials are being implemented in a way that differs from structural materials. For this reason, the selection framework of functional materials must also be different. For this reason, we proposed an adaptation of existing selection tools and methods. Using CES constructor, we developed specific tables that describe the different stimuli-responsive phenomena, functional materials, and the possible way of implementation, through the «Base materials or systems» and «Product» table. A «Processes» table will also be implemented to give further information on the way functional materials can be used in industry. In parallel with the database, we are developing the associated selection method as well as other tools that aim to support designers in the implementation of functional materials. These various tools will be tested with designers and adapted in function of their feedback.

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 [3] A. da Rosa, Thermoelectricity, Fundamentals of Renewable Energy Processes, Elsevier, 2013, 149–212
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