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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

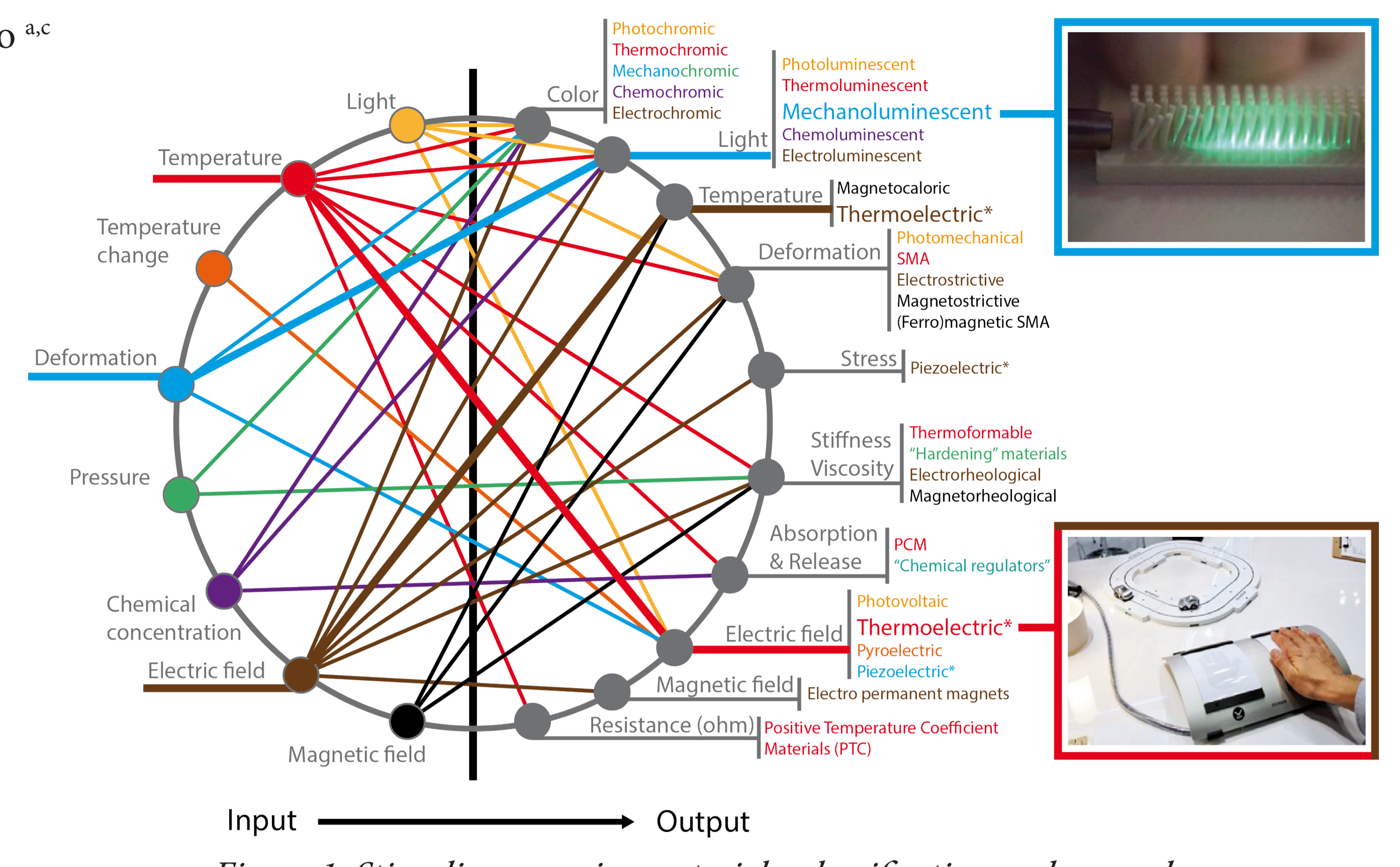


Figure 1: Stimuli-responsive materials: classification and examples

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

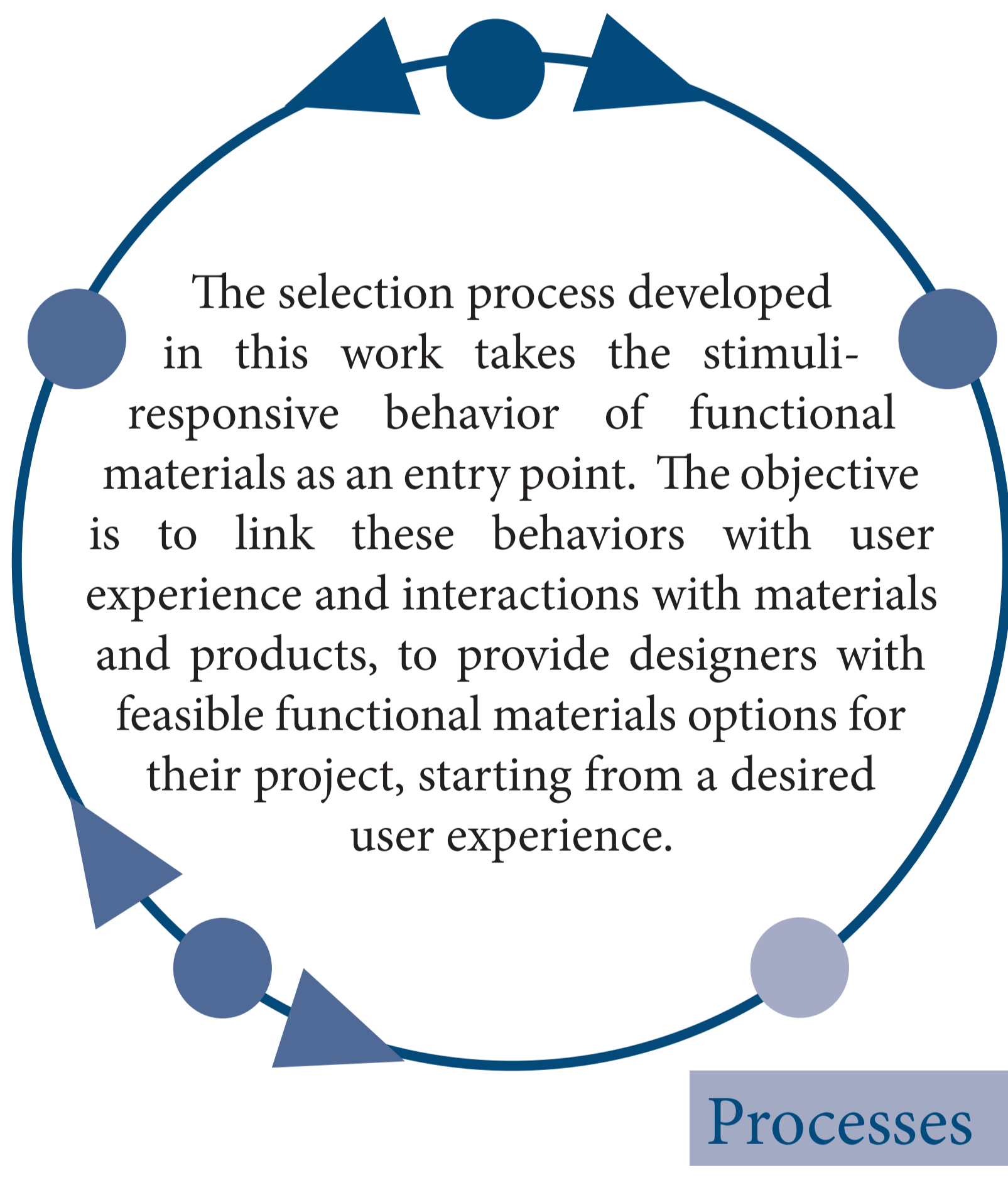
Each type of stimuli-responsive phenomena is described in a dedicated datasheet. Basic information common to all phenomena is their related stimulus (or input) and response (or output), and main characteristics such as reversibility, immediacy, etc... Information linked to the user perception of the 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	Designation		
BKT-KNN	BKT-KNN		
Stimuli-responsive properties	Piezoelectric distortion coefficient	129	pC/N
	Piezoelectric voltage coefficient	10	0.001 Vm/N
Composition (summary)	0.97Bi0.5K0.5Ti0.3-0.03K0.5Na0.5Nb0.3		
Electrical	Dielectric constant (relative permittivity)	1500	
Links	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
Shape memory effect used to reduce the storage space	
Product's level of industrialization	Prototype
Designer information	Carl de Smet
Designer	
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 test 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  
 [4] M. Ashby, Materials Selection in Mechanical Design, Elsevier, 1992-2005(Third edition)  
 [5] http://www.grantadesign.com/products/ces/