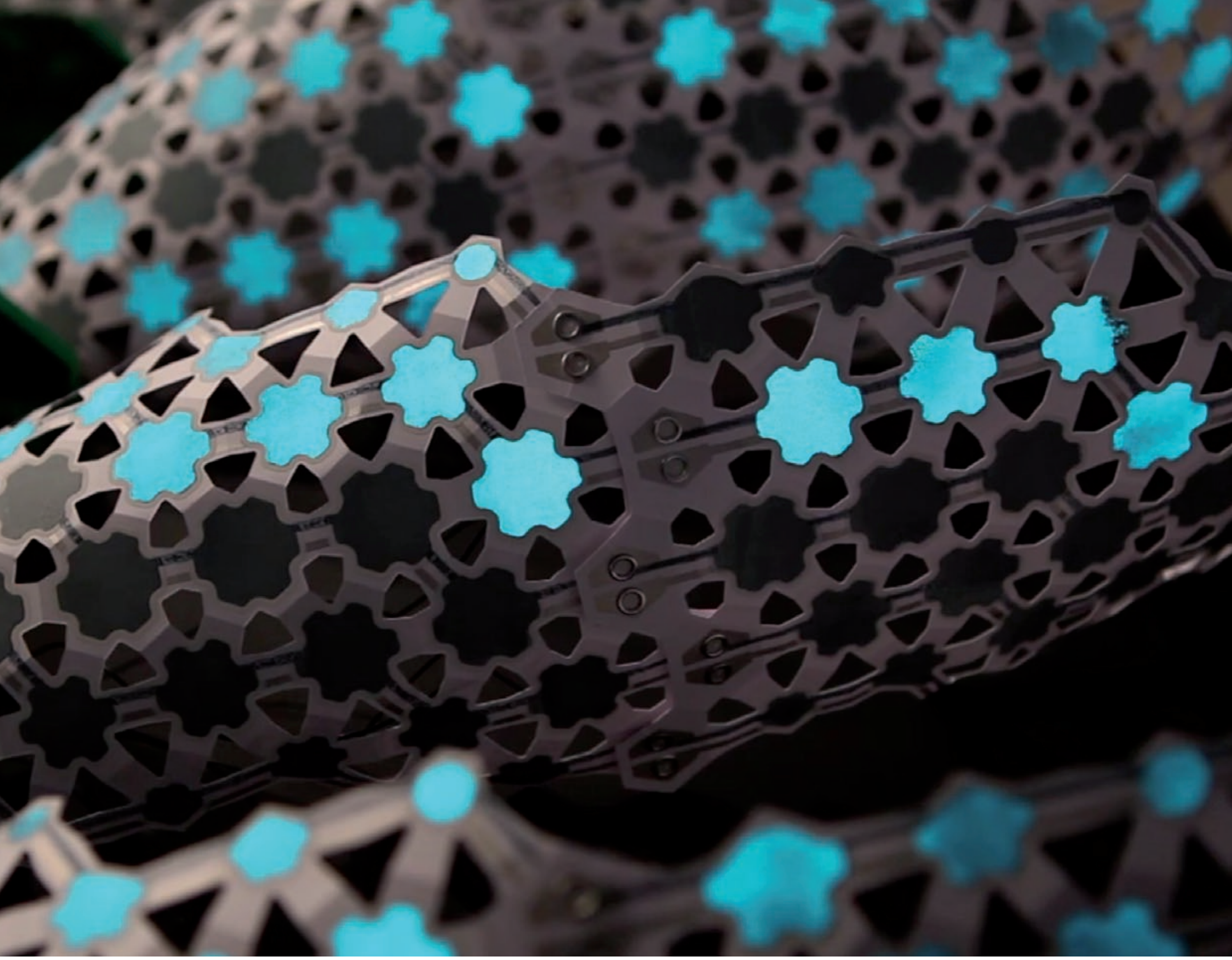

Lin-Lin Chen, Tom Djajadiningrat, Loe Feijs, Jun Hu, Steven Kyffin, Lucia Rampino, Edgar Rodriguez, Dagmar Steffen

Design and semantics of form and movement

DeSForM 2015

Aesthetics of interaction: Dynamic, Multisensory, Wise

Cover image: Electroluminescent surface printed on folded paper (Karmen Franinovic and Luke Franzke, "Luminous Matter. Electroluminescent Paper as an Active Material", page 37-47)

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Interactive Demos

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Kinetic Materials Experience

Abstract
Shape memory alloys and polymers respond to changes in temperature, light or other environmental stimuli by changing their shape. This paper shows new kinetic experiences with objects and surfaces that apply memory shape materials, describing some case histories based on design experimentations that open up new frontiers in design. The present article investigates how the shape memory effect can add useful features to everyday objects, create unusual user experiences, and how this new potential has been tapped by designers so far. The authors present considerations on design methods, describing the convergence of product design, interaction design and experience design in the new scenario of smart materials. They discuss models from literature to understand and describe the emotional aspects of interaction design with shape-changing materials. Such models could be useful reference points for designers of interactive products that offer kinetic experiences.

Keywords
Smart materials, shape memory materials, kinetic experience, tangible interface, interaction design

1 Introduction

At this stage of scientific development, technology and materials proliferate. Traditional materials take on a new life; they perform better than ever. They become less and less natural and more and more artificial, but more compatible with human life and more environmentally sustainable. Their complexity increases, moving to the direction of alloys, composites, copolymers, and functionally graded materials. At the same time new materials appear in our life, absolutely unusual for a common understanding and experience of materials, typically characterized by properties such as weight, volume and resistance, and soft (i.e. sensorial) qualities such as color, opacity, texture; fixed in time and defined by design. Today, smart materials show us that products will become lighter, tinier, more dynamic, and generating their own energy. The behavior is inscribed in the material as a code in its molecules, crystals, or micro-structure. This new essence of material introduces elements of radical changes in the material design cultures.

In smart materials, an input such as a temperature change, an increase in light intensity, or any other change in environmental variables, triggers a reaction in their molecules or crystal structure, which in turn causes a change in shape, volume, color, transparency, or density [1]. This makes them look like living organisms with their specific character and behavior, ready to interact under the influence of other living organisms or environmental changes. The reaction is visible, and through the filter of a code of communication, can be utilized to transmit messages. Shape memory alloys or polymers react to changes

in temperature or magnetic field, by changing their shape. Under the effect of the stimulus, they move back to a memorized form. They move without the need for mechanical or electromechanical components or mechanisms of movement, hence their intrinsic sustainability, i.e. less material and fewer manufacturing processes for the realization of the products.
Materials that change shape and materials that change color [2] have a dynamism that allows them to continually adapt to environmental conditions, so as to be called "chameleonic" for their ability to change color and form almost in a "magical", extraordinary way.
The qualities of smart materials include sustainability, compact size, very often bio-compatibility, the ability to react and interact, the ability to communicate in the interaction, to describe something that is approaching, and to make visible what is normally invisible [2].
Ecology, engagement, materiality-driven communication and interaction are some of the new qualities that smart materials offer to the design community. It is up to the designer to ensure that smart materials are used in a manner actually useful in the future we envision.

2 Shape memory experience

The shape memory effect was discovered in Au-Cd alloys by Arne Ölander in 1932 [3]. This was followed by the development of various shape memory alloys including NiTi (nitinol), Fe-Mn-Si, Cu-Zn-Al, and Cu-Al-Ni [4]. Among these materials, nitinol proved to be the most reliable and feasible material of its kind, making it the material of choice for most shape memory applications.
The market diffusion of nitinol shape memory alloys took about three decades from their first introduction in 1962 [4] to applications in the medical field in the 1990s [5]. Shape memory alloys were mostly used for their superelastic properties in the medical field, rather than the shape memory effect. The superelastic effect was later employed in consumer products, for example in eyeglasses frames, bra wires, and headphones [6, 7]. Nitinol eyeglass frames were comfortable to wear and their spring-like quality was a competitive advantage. Superelastic bra wires were preferred due to their soft feeling, flexible fit, and aesthetically pleasing body line [6]. The superelastic headband of MiniDisc Walkman headphones allowed it to be folded into a compact egg shape, earning it the nickname "eggo" in the 90s. The headphones were comfortable to wear and they provided a constant push on the ears.
Although products making use of shape memory materials (SMMs) have been in use for many years as summarized above, the sensory experience has been addressed by designers only recently. The first sensation of someone who is not familiar with SMMs and watches its motion when exposed to heat is typically surprise. As one of the authors demonstrates the effect of a flame on nitinol wire, causing it to "remember" a previously given shape in the Materials for Industrial Design course, students make sounds of surprise and ask many questions about it. Similarly, any product that clearly demonstrates the shape memory effect has the potential to surprise and please the customer, at least during the first few uses. A design strategy of surprise and a "perceptual slip" have been utilized by designers to influence people's appreciation. In products that people can use without any cognitive effort, a surprise may be welcomed by the user. Conversely, in products with a complex functionality that requires full attention from the user, a surprise will probably not be appreciated [8].
Below, some case studies are briefly presented. These show a variety of different user experiences with SMMs that open the possibility for new aesthetic and technical explorations capable of playing a significant role in the development of design-driven product experiences.

2.1 Hanabi lamp by Nendo

One of the earlier examples which benefited from the surprising effect is the Hanabi lamp, which spreads up its petals like a flower trying to catch some rays from the sun (Fig.1). The lamp blooms as it gets warmer by the heat of the light bulb. The Japanese word hanabi means firework or literally flower + fire, referring to the fragility of flowers that flicker between beauty and disappearance [9].
This design was presented for the first time in 2006 at Salone del Mobile di Milano, in a setting which proposed a field of hanabi in order to create a surprising aesthetic experience to engage the visitors in a satisfying emotional contemplation. The unfolding of the petals of nitinol with the lighting creates a synesthetic stimulation that leads back to the beauty and harmony of nature, like slow movements of plant organisms, using the design strategy of metaphor.

Fig. 1. Hanabi lamp designed by Oki Sato for Nendo. The lamp made of shape memory Nitinol alloy "blooms" when it is warmed up by the heat of the light bulb. Cour-tesy Nendo.

2.2 Fashion design by Hussein Chalayan

Fashion designer Hussein Chalayan's garments that use shape-shifting fabrics push the limits of moving textiles to the extreme. His spring/summer 2007 collection displayed a combination of different materials and technologies including remote control electronics, motor driven levers, and shape memory fabric. The shape memory fabric contained one nitinol fiber weaved into five nylon fibers [10]. This material technology enabled the design of garments which "open like the flowers that remember how to take several forms" as Chalayan puts it. The shape change in the garment causes the skirts to be lifted slowly, creating an erotic experience for the viewer. Unlike an ordinary dress that moves in concert with a moving body, many of Chalayan's garments move independently from the body's movements. A new spatial relationship is built between the garment and the environment [11].

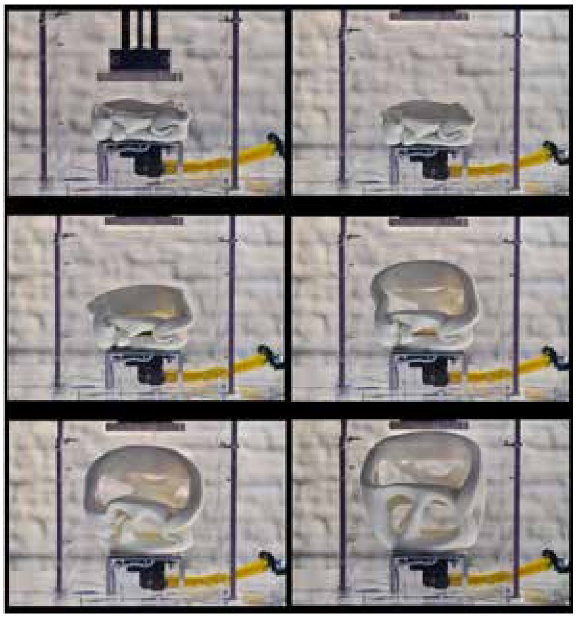
2.3 Shape memory jacket by Marielle Leenders

Designer Marielle Leenders developed shape memory textiles through the years 1999-2000. Thin nitinol wire is either woven into the textile or added later as one or more lines of stitching. Various uses were intended during the development of these textiles ranging from sleeves that automatically roll up and down to blinds that descend when warmed up by sunlight and roll back up when room temperature drops. The shape memory jacket is programmed to shrink at a temperature of around 45°C. When temperature is cooled down, the jacket resumes its initial shape.
A sense of playful surprise can be observed in the shape memory jacket with a hint of teasing (Fig. 2). The dynamic and smart attitudes of the jacket propose a simple tool for an expressive human body experience that extends and transmits information from the inside (the human body) to the outside (the cloth), making the changing body heat visible.

Fig. 2. Shape memory jacket designed and realized by Marielle Leenders for the Museum of Science and Industry, Chicago. Heating the jacket with a hair dryer causes it to shrink. Courtesy Marielle Leenders.

2.4 Chair by Carl de Smet

Carl de Smet is a Belgian designer and engineer who experiments with different types of SMMs. One of his designs involved a styrene-based thermosetting resin reinforced by E-glass fabric or carbon fiber twill weave. A shape shifting small chair prototype was produced with this material that transformed from a coil shape to the final chair shape at 75°C. However, certain problems such as low recovery rates were reported [12]. His recent efforts focus on polyurethane shape memory foams which have the advantages of low density and



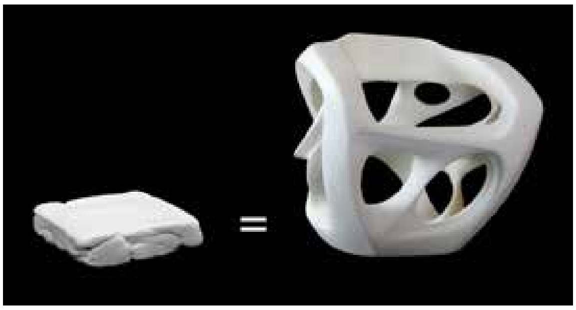


Fig. 3. Series of photographs showing how a compressed slab of shape memory foam recovers its original shape and becomes an armchair upon heating at 70°C. Shape memory polyurethane has the ability to grow up to 20 times and form soft but rigid furniture. Courtesy Carl de Smet.

extreme volume change from one state to another. The objective of his team's efforts is to develop a product which can be compressed into flat, lightweight slabs during purchase. The user will take them home, heat them up, and the armchair will recover its programmed shape (Fig. 3). De Smet is collaborating with researchers at several Belgian universities to upscale the prototype and create a feasible product for the market. The final product will have a flexible heating system; the customer will plug it in and the furniture will pop out. This experience might be comparable to purchasing a box of ready to bake cinnamon rolls, putting them in the oven, and watching them grow while they are baked. Through a project for easy packing and transport, this design proposes an "experience of creation" where a piece of furniture grows and expands right before the eyes and under the control of users.

2.5 Bloom by Doris Kim Sung

Today also architecture is beginning to implement new smart materials, contributing to the success of a new design strategy: kinetic adaptive architecture. This is an innovative strategy for the development of energy conservation through new structures and components that can be dynamic in order to react to environmental conditions, such as temperature shifts, performing as environmentally integrated living organisms that can learn from previous experiences, therefore evolving with embedded intelligence. Responsive skins and kinetic components are able to move without motors or mechanical parts. A design example of kinetic architecture is the project Bloom by Doris Kim Sung, an architect with a biology background, interested in developing and prototyping intelligent panel systems integrating thermo-bimetals[1]. The material curls when heated and blocks the sun's rays. A bimetal shutter system can be calibrated to completely block the passage of sunlight, if needed.

Bloom is a climate-controlled pavilion made out of about 14000 laser cut pieces (Fig. 4). The surface of this floor-to-ceiling installation acts as a sun tracking system that indexes time and temperature. When the temperature rises above 22°C, the metal sheets curl up and when it gets cooler, the sheets flatten out. This smart solution is useful to balance internal heat accumulation, improving the comfort level of the space. It reduces the need for airconditioning and saves energy, without the need for manual controls or additional power. "In houses now we don't need drapes or blinds" says the architect [13].

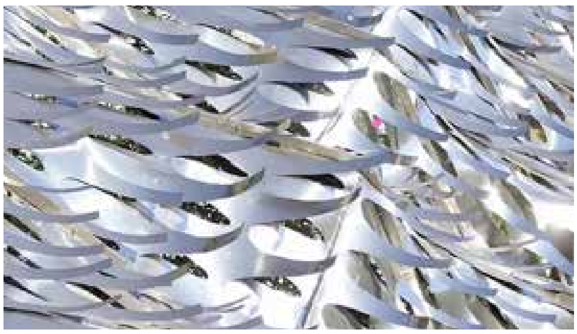


Fig. 4. Bloom skin detail, an architectural research installation displayed at the Materials and Application Gallery in Los Angeles, 2011. Courtesy Doris Kim Sung.

2.6 Hylozoic ground by Philip Beesley

Among the most surprising examples of kinetic architecture there is Hylozoic Ground[2], an immersive, responsive, interactive environment installation by Philip Beesley and his team. This installation explores the idea of an environment that lives[3], and reacts to the presence and actions of people who are in it with movement that imitates the interaction of physical bodies moving around, and behaviors like caressing and other empathic motions [14].
Mechatronics, synthetic biology, chemistry, art and design are embedded in this performance of an artificial forest that moves and breathes around its viewers.
The movement of the forest is being powered by muscle wire (electro active polymers). This wire is activated by a small amount of electrical power, and through leverages it is able to move. Organic power cells provide weak amounts of current in pulses like unconscious reflexes within a human nervous system. All elements work in concert.

3 Discussion on design approaches and new prospects

Various projects shown here make us predict that in the future our objects and architectures will no longer be rigid and stationary, but flexible and adaptable, active and responsive. With the emergence of new smart materials, like SMMs, the evolution of digital technologies and the availability of mass customization methods, technological products can now 'feel', 'hear', 'breathe' and react. However, there are many areas that might be developed before they are really useful to the user and ready for public consumption and standard architectural or product application. That's why the experimentation and the ability to design with smart materials embedded in products are becoming increasingly important for designers. This is becoming especially important since it has been shown that the realization of components and objects made of smart materials is feasible with advanced manufacturing technologies such as 3D printing and computer aided laser cutting.
The designs shown here, demonstrate many interesting elements that allow us to understand how these materials can change form and stimulate users' senses and emotions with surprising, expressive, erotic, comfortable and pleasurable experiences.
These issues generate new questions on the necessary evolution of design methodologies. The main question from the product designer is: how to design with smart materials for better user interaction and experience? Product design undoubtedly requires dealing with a greater technical complexity and organization seen that the materials have at least two states: an inactive and an active state. Furthermore the phase transition during the passage from one phase to the other needs to be accommodated by the design as well[4]. The design will have to manage various aspects or conformations of the object in its temporal dimensions. The variables involved multiply, considering the variability of the sensorial aspects in time and the time dependent form of the interaction between product and user.
Additionally, the design of material (or tangible) interaction requires a multidisciplinary approach that involves at least both product design and interaction design besides material science knowledge.
Interaction design started as a new field of design in the late 80s with the development of screen graphics and computer input devices by engineers. The initial concern of interaction designers was to make computerized devices accurate, easy to use, and pleasurable [15]. However the field of interaction design developed rapidly with the inclusion of computerless interactive products and many other aspects such as user experience, ergonomics, and sustainability.
Today, this field of design encompasses the design of all possible types of interactive products [16]. Thus, the original term is gradually replaced by the more specific term human-computer interaction (HCI) design. Interactive products cover all classes of interactive systems, devices, tools, applications, technologies, and services. Since smart materials, surfaces, and systems are inherently interactive, they are naturally the subject of interaction design [17].
In recent years new visions have expanded the boundaries of interaction design, from graphical user interfaces (GUIs) to tangible user interfaces (TUIs) and material user interactions (MUIs) [18]. The new visions assume that bodily engagement and tactile manipulation can facilitate a deeper understanding and more intuitive experiences. Some important capabilities of kinetic interaction have been underutilized such as motion's natural ability to draw our attention and convey information through physical change. According to Hallnäs and Redström, interaction design could be a real link between basic research in computer science and

product applications for new expressive design [19]. Various models exist that are related to the emotional aspects of interaction design. Such models could be useful reference points for designers of interactive products. One such model [20, 21] attempts to explain various channels of pleasure while interacting with products. According to this model, four types of pleasure can be distinguished, namely physio-pleasure, socio-pleasure, psycho-pleasure, and ideo-pleasure.
Physio-pleasure represents pleasure experienced through the senses, such as taste, smell, and touch. The caressing stroke of a soft fabric on the skin, or by a plume of the Hylozoic Ground is an example to tactile physio-pleasure. Such an emotion could actually be created on purpose by a shape-memory jacket or dress as depicted in Fig.2, although that was not the intention of the designer in this particular case. The tactile pleasure of kinetic surfaces or products that exploit SMMs is just one of the many possible fronts worth exploring by designers.
Socio-pleasure is defined as the type of pleasure that arises when we are socially interacting with friends, colleagues, and people we love. Interactive products can enhance social interaction or they can generate new channels of communication. Nowadays, friends of all ages use their mobile phones to show each other photographs or videos. The adoration of photographs and shared laughs while watching funny videos, are examples to socio-pleasure.
Using the idea of socio-pleasure, we generated a nucleus of a new application. A dynamic message could be an interesting way of sharing a sentiment with someone you love. In this concept example, a shape-memory wire is programmed by Sandra to express her feeling towards Piero. When Piero heats the wire with a lighter, the wire takes the shape preprogrammed by Sandra. Thus, Piero realizes her warm feelings towards him (Fig. 5).

Fig. 5. The Kiss by Sandra (a hypothetical interactive product shaped from SMM. Illustration courtesy of Soner Göksay)

Granted, the expressive potential of a single wire is quite limited and such a product would require a lot of imagination from the user. Still, it may be an interesting product for creative people.
Psycho-pleasure refers to emotional or cognitive satisfaction. For example, a user-friendly teller machine (ATM) would provide a higher level of psycho-pleasure than the one which causes errors due to misinterpretations.
In a product that employs shape-memory materials, the kinetic effect should not confuse the user or cause them to make errors while interacting with the product. Or when looking from the positive side, the designer should explore possibilities to give emotional or cognitive satisfaction to the user. A related example will be given under the discussion of experience design.
Ideo-pleasure signifies pleasure that is caused by an idea or by people's values. In environmentally conscious societies, using a product manufactured from biodegradable polymers may create appreciation by the society and satisfaction of the user. These feelings are examples to ideo-pleasure. Smart materials in general, and shape-memory materials in particular, possess a great amount of symbolic and real benefit for the society. They would also generate the added value of ideo-pleasure to users of products made of such materials.
Another design approach connected to our design discourse is *Experience Design*. This approach focuses on the quality of the experience of a specific user when interacting with a technical device. In addition to the simplicity and ease of operation during use, experience design studies the feelings and emotions of users through the involvement of all the senses, and the evolution of the values and significance of use, within a clear framework of social, material and cultural reference, with a holistic vision [22]. Experience design takes the quality of interaction into consideration and benefits from interdisciplinary research related to the analysis of phenomena that occur when a user interacts with an interface. Many disciplines such as cognitive and perceptual psychology, neuropsychology, linguistics, and semiotics may be involved in such research studies. Hassenzahl, created a link between psychological needs and human experience [23]. Sheldon and his colleagues

listed the top-ten psychological needs based on a review of theories about the content of motives [24]. These are autonomy, competence, relatedness, influence, pleasure, security, physical thriving, self-actualizing, self-esteem, and money. Hassenzahl claims that these needs could also be used as categories of experience. This hypothesis was supported by a survey conducted by his team, which analyzed over five hundred positive experiences of people that used interactive products such as mobile phones, mp3-players, and navigation devices [25]. Their study revealed a clear correlation between need fulfilment and positive affect and suggested that experiences can be categorized by the primary need they fulfil. The most pronounced needs that were linked to positive experiences were stimulation, relatedness, competence, and popularity.
We can use this model in order to dwell deeper into the ocean of possibilities through experience and kinetic interactive products. One of the drivers that possesses the potential of a positive experience is *stimulation*, here used to indicate the feeling of enjoyment and pleasure. We already proposed a possible application of shape-memory clothing that could stimulate the naked body of the person wearing it. We also discussed some examples where fashion designers Chalayan and Leenders used shape-memory garments to evoke eroticism and surprise, respectively. These are positive experiences for the majority of people. Other examples where the need of stimulation could be satisfied include products that cause some type of amusement, surprise, or playful action. Designers could explore the possibility of surprising the user with random reactions in products specifically aimed for enjoyment, such as toys or sports equipment. We suggest a random reaction in such applications because a single type of reaction or movement has the potential of surprising someone only once but a random reaction may surprise the user many times.
The second human need in the list is *relatedness-belongingness.* Relatedness represents the feeling of intimate contact with people who care about someone. A kinetic product experience that satisfies such a need could be an object used to teach a phenomenon to a child or an object that is modeled by a group of people who are peers or colleagues. A concrete example to the former case is a shape-memory wire that parents use to demonstrate the shape-memory effect to their child. When the wire is immersed in boiling water, it takes the shape of a fish. An example to the latter case is a clay-like shape-memory material with different colors. Design students work in groups to experiment with these materials, share ideas, generate interactive product concepts, and model it from the shape-memory clay. In both of these hypothetical cases, the shared experience would bring a sense of belongingness to all who lived through the same activities.
The third need we will discuss here is *competence*, which is described as being capable and effective in one's actions. Elderly people gradually lose some of their motor abilities, for example their dexterity. The former author's mother enjoys making embroidered pillow cases with different patterns. The pillow cases are supplied with the pattern stamped on them together with threads of different color. A beautiful pillow case can be embroidered if one follows the simple instructions. Many people who are not keen in this craft can get a sense of achievement when the embroidery is complete and a colorful pillow case is ready to be displayed.
A similar but somewhat more high-tech product could be an embroidery kit with thin shape memory wires and a targeted 2D or 3D pattern with the help of such wires. An elderly person (also a child or an adult) will now have the task of embroidering the shape-memory wire into the correct marking lines on a fabric. If the embroidery is performed correctly, the targeted shape will be realized when the fabric is heated with a blow-dryer. If not, the result will not be satisfactory, although you can try it once more. The successful embroidery would give the person a sense of satisfaction. The approach we used here is experience design since the user scenario is constructed aiming for a positive experience that will, at the same time, satisfy one of the human needs, namely competence.
As shown in these examples, the integration of product design, interaction design and experience design approaches can help to deal with the new design questions of kinetic interaction.

4 Conclusion

There are still many questions that designers will have to consider in relation to the meaning of the applications of SMMs and qualities of interaction experiences with the product that apply these. Current applications make use of the kinetic performance in terms of functionality, as well as the lead of novelty and sustainability of new materials. Designers are experimenting with the expressive, symbolic and aesthetic potentials of shape-changing materials.

Meanings change in relation to how the new products are designed, and to what emotional experience the user gets during the interaction with the shape-changing objects.

The performance in terms of interactivity could be enhanced by the awareness of the emotionality of visual and haptic sensations (physio-pleasure), psycho and ideo-pleasure of experience related to the meaning that it produce for the users. The designers have to invest and cultivate the imagination with regard to physical and psychological human needs, and link them to positive experiences such as stimulation, relatedness, and competence.

Surely among the research field of interaction design in the near future there will be new visions of experiences, and user interaction mediated by objects and architectures. Smart materials suggest a realm of interactive possibilities that can continually adapt to users' requirements and it seems logical that more open design methodologies that leave space for user input and meaningful appropriation may yield products that can have genuine everyday impact. The challenge for designers and materials developers remains working with shape-changing materials to exploit the materials' potential in perceptibly different ways that resonate functionally, aesthetically and emotionally, with users.

If design with the multidisciplinarity of skills and cross-fertilitation of methods (product, interaction, and experience design) could incorporate the potential of smart materials in our daily lives, our reality would be much richer in communication, powerful in sensorial engagement, more sustainable, and pleasurable for individual and social life.

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[1] Thermo-bimetal materials, used as shape-changing thermal actuators, are composed of two thin layers of metal with different thermal expansion coefficients. Thanks to the difference in the thermal response, each layer expands and contracts at a different rate. Since the two layers are mechanically connected, the difference in expansion rates causes the entire bimetal to curl as the environmental temperature changes.

[2] The term hylozoic refers to hylozoism, an ancient philosophical view that matter has life.

[3] Thousands of lightweight digitally-fabricated components (acrylic links, mechanical imitations of ferns, leaves and whiskers, kinetic valves, pumping systems meshed microprocessors and proximity sensors), contribute to create a 'metabolic' system in constant flux that replicate the processes of natural environments, such as filtering moisture and organic particles from the air.

[4] Design tools such Grasshopper and Firefly parametric software are needed to draw, control, and digitally simulate shapes, morphing patterns, and atmosphere.

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