# THE SHAPE OF LIGHT: AN INTERACTIVE APPROACH TO SMART MATERIALS

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## Abstract

The research is focused on designing interactive products, in particular on the process that leads to the conception of innovative interfaces. The interfaces discussed are tangible interfaces, which exploit their physicality and their material characteristics as input and output mechanisms in the human-product interaction process.

The objective of the research is to investigate the use of interaction design methodologies in the design of Smart Material Interfaces: interactive tangible products consisting primarily of smart materials.

The overlapping between the discipline of interaction design and the world of smart materials generates new design opportunities. Thanks to this overlapping, objects of daily use become able to convey information through their physical properties and use the material they are made as a communicative medium.

The paper is divided in three parts. The first part investigates the role of materials in interaction design, the second part presents the brief of the research and the third one reports an experimental workshop conducted in order to elaborate new interactive metaphors for lighting design.

**Keywords**: Collaborative design, User centred design, Design methodology, Human behaviour in design, Participatory design

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## 1 INTRODUCTION TO INTERACTION DESIGN

Interaction is a fundamental characteristic of any design project, beyond the specific features or the disciplinary field of the project. The interaction term means, indeed, a reciprocal action between many entities: a phenomenon or a process in which two or more objects act on each other, influencing each other. This type of action does not relate to a specific type of product but concerns any artifact, system or service generally used.
The concept of interaction is not detected exclusively in electronics, but it is a feature of any design context: also an object such as a book, although entirely analog, takes the user to turn the pages, inducing interaction. Therefore, the interaction between man and object takes place through any kind of technology able to create a link between them, not only digital-electronics, but also analog (Davis, 2008).
Existing researches in this field propose to replace the previous archetypes of design with a new paradigm focused on interaction. The interaction becomes a tool to evaluate the relationship between people and objects and, therefore, a way to contextualize design activities. Any artifact provides opportunities for interaction and, consequently, each design activities can be considered for interaction (Buchanan, 1998). The same concept can be applied, not only to artifacts, but also to environments and systems.
Interaction design consists in creating a dialogue between people and products, systems or services. This dialogue is both physical and emotional, and it appears in the form, function and technology of products. Interactive products act on users through their features, and they influence feelings and perceptions. The product designed for the interaction becomes communication tool, and allows the designer to pay special attention to the user, supporting the dialogue between user and product.
Jon Kolko (2010) highlights another peculiarity of the concept of interaction design, defining the interaction designer as "shaper of behavior", that is who design and shape the behaviors. The designer, indeed, defines the interactions as semantic connection between technology and form that exists when someone uses a product. All the interactions together, form the behavior of the product.

### 1.1 Materials in interaction design

Considering the role of materials in interaction design, there are two connected but contradictory issues: the move towards invisible computing and at the same time a renewed need to understand computation and interaction as composed with and of materials. How might designers come to accept that interaction design materials may be both immaterial and a material at once? What kind of language and framing do we require for that to be possible?
In industrial design there has been great historical emphasis on a high degree of material knowledge in the processes of invention, such as actual production materials, e.g. plastic, metal, and wood.
To address the centrality of material understanding in industrial and product design, formalised methods of material testing have been developed. Industrial designers are familiar with instruments that can measure the “properties of materials and components using tension, compression, flexure, fatigue, impact, torsion, and hardness tests” (www.instron.it, 2012). This kind of testing involves the materials being unpacked, pulled apart, broken, reconstructed, and reshaped to build knowledge about the opportunities and constraints they may embody. Outside of practice however there is still “no common systematic approach for supporting designers in involving these [material] concerns into their selection processes” (Karana, 2010). In interaction design too, studies of material are relatively rare, as most research focuses on interfaces in use, on usability, and application (Arnall, 2014).
This work is focused on the study of the role of materials in interaction design, and in particular on intelligent materials.

### 1.2 Intelligent materials for interaction design

The term “behavior” refers to the complex of attitudes that a person takes in response to certain environmental stimuli or to personal needs (Arnall, 2014). The concept of “behavior” becomes the core of interaction design and can be the link between interaction design and the field of intelligent materials.

In general, intelligent or smart materials are able to interact with the environment and to respond to external stimuli changing one or more of their properties. Smart materials can be described as materials characterized by specific behaviors, which are comparable to living being. Indeed, the main objective of smart materials research is to confer to the inert material capability of reacting to external stimuli. Smart materials are active in the interaction with the environment.
Across the multitude of intelligent materials' behaviors, shape-changing materials are the one that, because of their dynamic nature, if influenced by direct or indirect electro-mechanical stimuli, undergo a mechanical deformation. In particular, Shape Memory Alloys (SMAs) represent currently the most versatile smart material which could be easily implemented in interactive systems and devices.
The increasing spread of smart devices and systems in everyday objects and in many daily activities, are setting a new artificial reality in which design takes intelligent materials as elements of a new design language. An approach focused on interaction design for product design practice, can be realized using the peculiarities of shape memory alloys.
SMAs are thermomechanical nickel-titanium alloys that, once treated to acquire a specific shape, have the ability to indefinitely recover from large strains without permanent deformation and remember their original geometry. Shape Memory Alloys, used as a single-wire linear actuator, could support the design of shape-changing surfaces, enabling designers to create three-dimensional transformable surfaces (Coelho and Zigelbaum, 2010).
Along this direction, the development of communicative and interactive artifacts is possible, and they can relate with human senses improving product performance and user experience. Considering interaction aspects, the design is oriented to values the materiality as well as intellectual, dynamic, emotional, and behavioral aspects.
The connection between interaction design and shape-changing materials in design practice, creates new opportunities and stimulates the emergence of new user behavior. Through this connection, objects of daily use become able to convey information through their physical properties, and they use the material they are made as medium.
This is how tangible and intelligent interfaces are generated, and in this way, the boundary limit between material properties and the computational functions disappear.
This type of approach in design practice is currently at the beginning of its development, and consequently its employment by designers still be poor of asserted techniques and little structured.
The present work is focused on the application of a co-design methodology, centered on the idea of conceptual models and metaphors, in order to inspire the development of material interfaces characterized by innovative aspects.
The aim of this research is the experimentation of methodology in order to design innovative smart products stimulating new opportunities for interaction.

## 2 RESEARCH PROJECT BRIEF

The integration between techno-scientific disciplines (Materials Technology, Computer Science, etc.) with social science (Cognitive Science, Psychology) and User Experience Design, allows designers to obtain everyday objects able to convey information through the material they are made. Communicative artifacts, able to interact with the environment through user senses, influence both the consumer experience with the product, and the acceptance of the product itself. As Karapanos (2009) underlines: "often, anticipating our experiences with a product becomes even more important, emotional, and memorable than the experiences per se".
This research focuses on the application of Interaction Design's cognitive aspects as mental models and metaphors. The practice of this methodology has the aim to generate innovative concepts of material-based tangible interfaces. This kind of interfaces are characterized by the integration of an important quality of tangible user interfaces: objects materiality is used for the interaction (Doering, 2011).
At first, the present research investigated concepts of interaction and interface (Kolko, 2010), by analyzing the evolution of the different interaction paradigms, and identified the project aim on the vision of ubiquitous computing (Weiser, 1991). After that, the project followed the direction indicated by the operational vision of Radical Atoms and tangible interfaces (Ishii et al., 2012). After exploring the field of Smart Materials and programmable surfaces for the design of tangible interfaces (Coelho et

al., 2008), the work focused on Smart Material Interfaces (SMIs). Taking advantage from Smart Materials unique properties, the aim of Smart Material Interfaces' is to overcome limitations of Tangible
User Interfaces, coupling the "digital feeling" of interaction in a more analogic space of physical interaction (Vyas, 2012).
The interaction process needs input and output in order to create dynamic affordances between the user and the product. SMIs allow designers to couple input and output mechanisms, through material and physical changes. In this research, shape change was identified as the mechanism of input and output for the design of Smart Material Interface.
Placed in the wider context of tangible interfaces, the research goal is to test the methodology to develop an interactive product with a morphogenetic interface structured as a programmable surface, able to exploit the change in shape as primary mechanism of input and data manipulation. In order to proceed in the project, a specific area of design, specifically lighting design, was selected for the work.
Summarizing the brief of the research project through three main points:

- What: design an interactive lighting product applying shape memory alloys in order to exploit the change in shape as mechanism of input and output. The user, manually changing the shape of the lamp, could control light performance.
- How: design a lighting programmable surface, made of SMA units, characterized by a change-shape behavior.
- Why: explore formal and expressive possibilities offered by shape changing interfaces through materials, and verify the interfaces potential applications in light interaction.

The design process applied reflects the methodology proposed by Peerce (Peerce et al., 2004): shown below, all the steps for the formulation, design concept and physical design process are reported.

## 3 TOOLS AND METHODS: USER EXPERIENCE AND CO-DESIGN

Starting from the Nineties, the offer of everyday products, functionalized through interactive components, has constantly increased. The development of the "info-products", which incorporate digital intelligence, includes the growth of the level of complexity, the available functions, and consequently, the type of experiences that users can enjoy with products.
Placing the user in the center of the design process, it is possible to examine user needs with a structured and systematic approach (User Centered Design). This approach takes advantage from survey instruments used to study consumers, products, experiences, context, and all the elements that can provide useful information for the design process. That contributes to make the artifact perfectly designed to perform user desire actions in a natural way.
In this context, the user experience underlines the emotional and interactive aspects of the product, as well as human-computer interaction have emphasized cognitive and functional aspects of "info-products". The user experience analysis (what user thinks about the product, what he/she does, how he/she uses it, how user communicates the experience) allows designer to understand the essence of the experience with products. Integrating user experience in the design process, it is possible to understand the relationship established between user and product: how the artifact is in a reflexive connection with people and how consumers understand themselves in relation with products.
While user experience emerged as a new unit of analysis in the design process, methods related with social sciences (as ethnography) have been investigated to explore the project open issues. These two strategies allow users to play an active and central role, not limited to highlight consumers' needs or to verify product usability. In this context, the phenomenon of co-design, as a form of creative collaboration between users and designers, begins to take place. This method of collaborative designing is an innovative approach to get new products into an already overcrowded marketplace (Sanders et al., 2008).
Thanks to their inspirational function, to the constant attention at user needs, and to the role of user experience in the project, co-design methodologies can be considered adequate for this research purposes, especially in the phase of definition of product requirements. Moreover, research methods used in co-design sessions allow people to share personal experiences, they also contribute to the generation of new design concepts, and they permit to improve the process of analysis, interpretation, decision-making, and project evaluation (Hagen and al., 2011).

In particular, the co-design workshop was identified as the most appropriate instrument to generate metaphors and design new concepts. In User-Centered Design, co-design workshop represents a useful tool because it focuses, in particular, on how people conceive artifacts, and recognize their functions and their symbolic meanings. Furthermore, this tool permits to share the content of the co-design activity, using information to inspire directly the design phase.
The use of metaphors can affect the experience of user with products. Metaphors, indeed, have a direct and substantial influence on the meanings and values we attach to products, and their use leads to rich sensorial and emotional experiences (Cila, 2013).
The creative power of metaphor generation is of particular interest in this research which calls for the integration of innovative materials in an interactive product. Metaphor application can get insights about how to communicate designer intentions better with users and create more innovative design solutions. For that purpose, metaphors could encourage the designer to see things in a new light and bring novel perspectives to develop new concepts and products.

## 4 EXPERIMENTAL PHASE: WORKSHOP “THE SHAPE OF LIGHT”

This research project exploited the potentiality of a co-design workshop in order to inspire the design of new lighting interaction systems, characterized by a change-shape behavior as input and output mechanism and managing. Supporting different levels of participation, the co-design workshop was organized in different steps of creation, visualization and activities of experimental prototyping, in order to build innovative scenarios of physical interaction with light. In the following paragraphs, the development of the co-design workshop is explained in detail.

- Objective: the workshop objective is the generation of new metaphors and gestures of dynamic interaction with light. Co-design methodologies allow participants to manage spontaneous and intuitive gestures, which can be used as facilitator in the “dialogue” between user and product. The workshop has been useful to develop intuitive gesture-based user interfaces that integrate change-in-shape function in order to better control user gestures and to enable physical interaction.
- Participants: workshop members were 12, characterized by different cultural backgrounds. For the participation to this co-design workshop, any specific competence has been requested. Workshop members did not have knowledge about Smart Materials and Shape Memory Alloys and their potential use in the lighting product.
- Time: the workshop session lasted about 2 hours. Each activity was developed with different duration, from 5 minutes to 30 minutes.

*Table 1. Workshop activities’ description: time and type of activity*

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- **Introduction** | *5* | | | | | | | | | | | | | | | | | | | | | | |
| 2- **Brainstorming I** | | *10’* | | | | | | | | | | | | | | | | | | | | | |
| 3- **Brainstorming II** | | | | *10’* | | | | | | | | | | | | | | | | | | | |
| 4- **Clustering** | | | | | | *15’* | | | | | | | | | | | | | | | | | |
| 5- **Theoretical** | | | | | | | | | *5* | | | | | | | | | | | | | | |
| 6- **Roundtable** | | | | | | | | | | *30’* | | | | | | | | | | | | | |
| 7- **Metaphors selection** | | | | | | | | | | | | | | | | *10’* | | | | | | | |
| 8- **Bodystorming** | | | | | | | | | | | | | | | | | | *30’* | | | | | |

Desctriptive phase
Divergent phase
Convergent phase

The design researcher guided the workshop instructing members on how to participate and interact with the other participants, explaining for example which questions using, which language/words, etc. The workshop was set up as an experiment of envisioning, in order to inspire the design concept, rather than a systematic analysis of a real context of use. Following, each activity of the workshop is described.

- Phase 1 - Introduction (5'): explanation of rules and objectives to the workshop participants.

The aim of the introduction phase is to create a relaxed atmosphere, clarifying the purpose of the activity and explaining brainstorming rules. This phase it is necessary to remove inhibitions.

- Phase 2 - Brainstorming I (10'): association of ideas starting from the words "light" and "shape"
- Phase 3 - Brainstorming II (10'): association of ideas considering the words "light" and "movement"

Brainstorming activity represent the first divergent phase of the workshop; its aim is to map the context of human-light interaction and the relationships between light, shape and movement. The choice of the terms refers to interfaces implementation of shape changing behavior.

- Phase 4 - Clustering (15'): grouping of terms obtained from the two previous brainstorming in semantic fields or conceptually homogeneous groups

The clustering activity is the first convergent phase of the workshop; it allows users to explicit knowledge of the context analysis by creating logical connections between words. Terms obtained by the two brainstorming are categorized in order to form homogeneous group of meanings.

*Figure 1. Brainstorming (left) and clustering activity (right)*

- Phase 5 - Theoretical explanation (5'): definition and explanation of metaphors
- Phase 6 - Roundtable brainstorming (30'): metaphors formulation about light from the groups of terms identified in the phase 4

During this activity, participants are invited to analyze each group of terms (identified in the phase 4) and to write metaphors associated to the words in object. Participants are invited also on working on the ideas of the other members, tying to expanding them. This activity constitutes the second divergent and generative phase.

- Phase 7 - Metaphors selection (10'): identification of the more significant metaphors

The selection phase is a convergent activity that permit to choose the most promising ideas (metaphors generated) which could be applicable to the product.

- Phase 8 - Bodystorming (30'): experimentation of body gestures that express and symbolize the selected metaphor

In turn, each participant shares with others his/her idea of interaction that correspond to a given metaphor, and tries to translate it into a body gesture. During this divergent phase, the group contributes to the generation of body gestures. The bodystorming constitutes a type of nonverbal brainstorming activity, in which gestures and body movements replace words in displaying the ideas generated during the metaphors selection phase. As a result, this activity produces the first models of interaction prototypes, which can be used to inspire the concept design process.

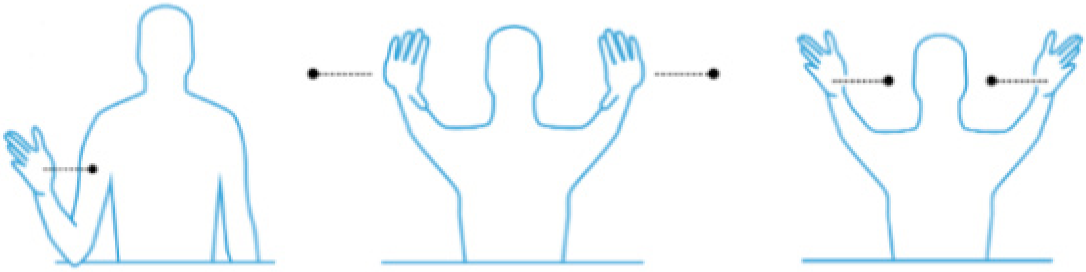

*Figure 2. Bodystorming: examples of basic gestures that represent full-hand, touch-free translations of finger-sized touch gestures.*

## 5 RESULTS: "THE LIGHT IS A SHEET"

The co-design workshop activity has been useful in mapping the project context and in providing inspiration for the formulation of a conceptual model of tangible interaction with light. Analyzing the metaphors generated in the "Bodystorming phase", it has been noted that most of the terms and concepts linked to "light" refer to substances highly malleable (as water, clay, mesh, etc.) or to objects with a strong geometric character (e.g. knife, wire, sheet, etc.). Observing the two clusters, indeed, there is a greater link, in terms of intuitive interaction, to the concepts of body, geometry and boundary. Summarizing, the concepts expressed by the participants draw metaphors of interaction which associate light with a substance manually formable and, at the same time, characterized by a precise geometric and directional feature.

In particular, the metaphors of interaction that correlate the expansion/contraction with a displacement of a substance from one point to another in space (directionality) were extremely recurring in numerous bodystorming gestures.

Starting from the observations acquired in the co-design workshop activity, it has been formulated a conceptual model of interaction.

Having regard to the significance of smart materials and their properties, and according to Ishii's approach (Ishii et al., 2012), has been selected as model of interaction for this project the Material User Interface (MUI). This design approach is based on the tangible interaction paradigm, which enables to explore the project opportunities generated by the elimination of the distinction between input and output devices, and imposing their coincidence. The Material User Interface approach exploits the functional characteristics of smart materials: similar to a "digital clay", indeed, shape memory alloys are able to implement the change in shape in response to an external stimuli.

The most interesting metaphor selected is "the light is a sheet". It represents an interaction metaphor which includes a manual interaction with a flexible object, and, at the same time, it presents specific geometrical and directional properties.

The interaction metaphor "the light is a sheet" strongly affects the shape of the product and defines its use. In relation with the sheet, the concept of the light is characterized by a two-dimensional shape: the product must be flexible and light, dimensioned in order to be easily handled, and its front and back must be recognizable. The concept is represented in the Figure 3.

From the metaphor selected, the concept phase has been developed taking into account the origami art and some experiments conducted at the MIT Media Lab (Coelo and Zigelbaum, 2010). In particular, the work conducted by Jie Qi, from the High-Low Tech group at MIT, takes the first steps towards revolutionizing the Japanese art of paper folding, actuating a self-folding motion through Shape Memory Alloy's wire (Qi and Buechley, 2012).

The use of paper in light design allows to create a warmth and "human" light: the paper represents the envelope of the light. The integration of paper and light with Shape Memory Alloys make possible to approach to the concept of "human light" as a way of conceiving interactive lighting products, which could be easily handled and flexible to human's need in order to be molded by the user himself.

The light concept results as an intelligent surface that takes advantage of the change in shape as an input in the process of interaction. The user will be able to manipulate the output information (the light produced by the lamp).

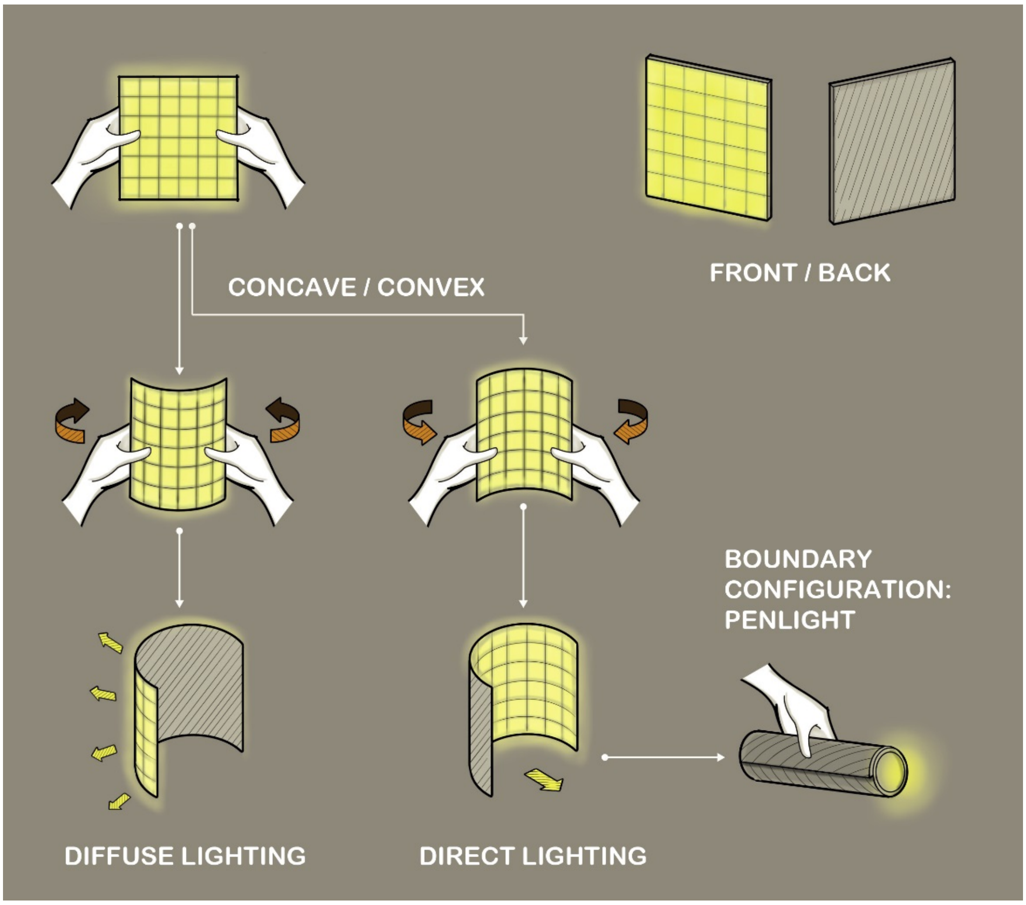


*Figure 3. Metaphor of interaction: the lamp is a sheet (Illustration by Giorgia Cavarretta)*

The Figure 3 represents the different configurations of the artifact, that correspond to diverse functions. For example, the function of directional light is linked to the geometrical concept of concave/convex. The lamp, as a sheet, has a front and a back. For this reason, it is possible to obtain a concave geometry flexing the surface with the front (the emissive part) to the outside. Flexing the surface in the opposite direction, it is possible to obtain a convex geometry. The concepts of concave and convex are associated respectively to diffuse lighting (ambient light) and direct lighting (functional light), in regard the backside surface has a physical limit because of the light source placement. A boundary configuration in direct lighting is penlight: wrapping completely the front surface on itself, light remains enclosed in a cylindrical geometry, forming punctual light.

## 6 CONCLUSIONS: SHAPE MEMORY INTERFACES IN LIGHTING DESIGN

The objective of the research, that is the investigation of Interaction Design methods in the design of Smart Material Interfaces, has been achieved. The Smart Material Interface concept was a light product, which shape has been inspired by a co-design workshop. It has been observed that the co-design methodology represented a very creative source of metaphors of interaction even if the participants at the workshop did not have knowledge of the smart materials (e.g. Shape Memory Alloys) properties. This has been made possible by the object of investigation: the light.
That point demonstrate that if the object of investigation is a familiar concept for all the users, it is possible to evoke spontaneously metaphors of emotional interaction. The power of this type of metaphor lies in the ability of the participant to relate distinct entities and to produce new and deeper meanings.
This potential allows users to associate the meaning of light and shape changing materials even if they are not aware of the material qualities of the object they are imaging to interact with. That behavior highlights the absence of a clear boundary line between the material properties of an object and the computational functionality that is supports.

The overlap between the discipline of Interaction Design and the use of smart materials in the design process is, therefore, an instrument able to generate new project opportunities, stimulating the creation of innovative behaviors. Indeed, through this overlap, everyday objects become able to convey information through their physical properties: the material becomes a communicative medium.

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