MATERIALS THAT MATTER
SMART MATERIALS MEET ART & INTERACTION DESIGN

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ABSTRACT

Dear reader,

"[...] Although the tangible representation allows the physical embodiment to be directly coupled to digital information, it has limited ability to represent change in many material or physical properties. Unlike malleable pixels on the computer screen, it is very hard to change a physical object in its form, position, or properties (e.g. color, size) in real time" [43]. Nowadays there are new (smart) materials that can change this situation and potentially influence the future of tangible technology.

This thesis will introduce you to a vision called Smart Material Interfaces (SMIs), which takes advantage of the new generation of these engineered materials. They are capable of changing their physical properties, such as shape, size, and color, and can be controlled by using certain stimuli (light, potential difference, temperature and so forth). We use the material property itself to deliver informations. We do this the context various experiments and contexts.

To facilitate the reading, we built a path within the structure of this thesis. It leads from the introduction through all the studies and all the experiments we made. We divided it into *parts* that try to reflect our experience. Beside the initial part (**A wide perspective** Part i) and the conclusion (**Conclusions and future** Part v) there are three main parts.

In **Design** (Part ii) we create the message through the design of our interface. In **Experience** (Part iii) we create a learning path for children, experiencing SMIs as part of their own stories. In **Growth** (Part iv), we delegate the duty of creation to older students, preparing the terrain where to build their own message for them.

More in details we present the content of each part.

Part I: A wide perspective

The SMIs are here. We introduce (Chapter 1) and develop the vision of Smart Material Interfaces (SMIs). We describe SMIs in relation to Tangible User Interfaces (TUIs). *The main idea is: SMIs can deliver a message using material properties.* This is the framework we will build on for the rest of this dissertation.

We introduce examples of interfaces that make use of smart materials, to cover a wide overview of existing works (Chapter 2). We divided them into two larger groups. The first is about entertainment and expression from the market and the artists point of view (*arts* and *design* domain). The second is focussed on the researcher side,

bringing up examples of different kinds (*interaction design* and *research* domain).

Part II: Design

We *create* the message using SMIs. The main objective is to create an interface that can help the users to orient themselves in a complex environment, such as a large campus or a wide museum. We start from the root (literally) of the problem and develop methodologies to implement movement and control over the interface from the design side and the technological problem.

So, we describe *Follow the Grass* (Chapter 3), a first design exploration of a possible SMI display that can convey directional information to the user. Follow the Grass is a concept of an interactive pervasive display for public spaces. The display is built out of "blades of grass" that are actuated using NiTiNOL muscle wires (i.e. a shape-memory alloy). We present a number of scenarios with varying scale of interaction, and different applications, followed by a description of the design and its actuated root. We walk the reader through the design process and development of our installation (Chapter 4).

Part III: Experience

Others (children) use SMIs to *learn* a message we designed. We expand the concept introducing the possibility of learning by experimenting with SMIs. We give tools for learning and work our educative path guiding young children in the use of SMIs to convey a higher level message: environmental awareness.

We describe our learning experience held with a class of primary school children who were introduced to a novel class of resources (smart materials) and the interfaces built with them (SMIs, Chapter 5). The pupils were guided along a multidisciplinary educational path in which traditional and innovative teaching methods were composed for educating while engaging the children. It led to the creation of 6 automated puppet plays focused on the themes of environmental awareness as a result. In this process, storytelling and visual programming acted as powerful means for merging different educational concepts and techniques.

During and after the experience, the children's engagement and the educational impact were evaluated revealing interesting results (Chapter 6). The data collected through the direct observation and the questionnaires indicate that the experience was perceived as positive and interesting. The post evaluation, held some months later, revealed skills and knowledge improvements in all the areas involved by the multidisciplinary experience, from the knowledge of the properties of smart materials and the programming skills, to the increase of the environmental awareness and the skills for text analysis.

Part IV: Growth

We give others (students) the *tools to create* a message to share. We allow others to learn how to generate their own messages through interactive installations based on smart materials. The use of SMIs conveys a message, involving the user in an artistic context.

We present our approach for the development of young artists (Chapter 7). We describe how we helped them to discover new expression methods and methodology. We guided them through the smart material jungle with Arduino as lantern. We describe the application and use of Smart Material Interfaces (SMIs) in the context of artistic installations. We organised an intensive workshop in the Fine Art Academy of Venice. The students, divided in groups, produced interactive creative works based on cheap traditional materials enhanced with the properties of smart materials. We use new materials to augment the degree of freedom of expressivity of traditional media. Through this experience, the budding artists had the possibility to learn technology and techniques for creating fun new interaction by surprising and amazing the user in unexpected ways. The experience itself stood for a growing point, it allowed them to give life to their static works. The possibility of augmenting objects with new properties allowed them to convey emotion and feelings, not just information.

Part V: Conclusions and future

We conclude with our considerations and reflections about the future (Chapter 8).

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ACRONYMS

BBC British Broadcasting Corporation

CNC Computer Numerical Control

HCI Human Computer Interaction

NiTiNOL Nichel Titanium Naval Ordinance Laboratory

RBI Reality-Based Interaction

S4A Scratch for Arduino

SMA Shape Memory Alloy

SMI Smart Material Interface

TUI Tangible User Interface

Part I

A WIDE PERSPECTIVE

In this first part we will give a general introduction to SMIs and related topics, showing similarities and differences with Tangible User Interface (TUI). This part includes a taxonomy of Smart Materials and an overview of the related meaningful works.

The SMIs are here.

"The medium is the message,
therefore the audience is the content."

— Marshall McLuhan

1

SMART MATERIAL INTERFACES: A VISION

In this chapter, we introduce a vision called Smart Material Interface (SMI), which takes advantage of the latest generation of engineered materials that have a special property defined "smart". They are capable of changing their physical properties, such as shape, size and color, and can be controlled by using certain stimuli (light, potential difference, temperature and so forth). We describe SMIs in relation to TUIs to convey the usefulness and a better understanding of SMIs. We also cover a small taxonomy of Smart Materials.

This chapter is mainly based on [73] and [71].

Although the tangible representation allows the physical embodiment to be directly coupled to digital information, it has limited ability to represent change in many material or physical properties. Unlike malleable pixels on the computer screen, it is very hard to change a physical object in its form, position, or properties (e.g. color, size) in real time.

– Hiroshi Ishii [43]

1.1 THE NEED FOR NEW MATERIALS

Until the discovery of electricity as means of power (*light*) and transmission of information (*radio waves*), all the parts and the behaviour of everyday object were made possible mostly thanks to mechanisms. Starting from the far "Antikythera mechanism" [64] to predict astronomical positions, to Leonardo da Vinci's machines [61], mankind always looked for ways to reproduce behaviours of living things, repetition of movements, or program complex movement to fabricate amazing artistic pieces (as the example of an automaton in Picture 1).

Figure 1: An automaton: a device called "The Writer", built in the 1770s by a Swiss watchmaker, Pierre Jaquet-Droz (1721-1790), and his family: son Henri-Louis Jaquet-Droz and Jean-Frédéric. This automaton could write sequence of letters composed thanks the the mechanical interface on the back of the doll [50].

The complexity and resistance of these mechanism started to be more critical in the last century, when electronics became the new

Electronics as new mechanics

mechanics, the computers stepped from metal mechanisms (as the old computer for calculating trajectories were made of stainless steel gears aboard ships) to integrated circuits. But computers are often closed in their digital world and it is not always easy to create actuation.

An example of mechanics that might change in the future are wings. Traditionally speaking, leading and trailing edges of wings move with hydraulic actuators. However, this is bulky with many mechanical parts, and hydraulics can leak, hinges and joints need maintenance and so forth. With the use of smarter materials, as electromagnetic actuators, wings can become a continuous flexible form. This can improve the structural integrity of the control surface, while maintaining its multi-functionality[1].

1.2 INTRODUCTION TO SMIS

TUI as the future of interfaces is not enough

Mark Weiser's [129] vision of Ubiquitous Computing (ubicomp) motivated researchers to augment everyday objects and environments with computing capabilities to provide Reality-Based Interaction (RBI) [47] and more natural interaction possibilities. One of the most promising sub visions has been the TUIs [44]. In TUIs it is proposed to use physical handles to manipulate digital information. Some of the known examples of TUIs are Urp [119], actuated workbench [83], Illuminating Light [118], MediaBlocks [117], Siftables [68] and SandScape [42]. One of the major limitations of TUIs is that they focus more on the input mechanism and less on the output. As Ishii [43] explained, the incapability of making changes in the physical and material properties of output modalities is a major limitation of TUIs. Building on this limitation of TUIs [43], we propose a sub vision entitled Smart Material Interfaces (SMIs) [73]. The main focus of a SMI is being able to make changes in the physical and material properties of output modalities. SMI proposes the use of materials that have inherent or "self augmented" capabilities of changing physical properties such as color, shape and texture, under the control of some external stimulus such as electricity, magnetism, light, pressure and temperature.

The purpose of this chapter is to draw attention to this upcoming field of research. In this section, we describe SMIs in relation to TUIs to convey the usefulness and a better understanding of SMIs. We first describe our motivation behind this work (Sec. 1.2.1). Next, we describe the vision of SMI (Sec. 1.2.2) with reference to TUIs.

1 NASA research: http://quest.arc.nasa.gov/aero/virtual/demo/research/youDecide/piezoElectMat.html

1.2.1 *Motivation*

There are three main motivations for introducing such a vision, in the ever growing field of ubiquitous computing.

First, we believe that there is a need to make the vision of ubicomp, as conceived by Mark Weiser [129], more relevant. We see a trade-off in the ways this vision is applied in the current research. The central idea behind the vision of ubicomp is to seamlessly embed computing in the everyday used objects, both socially and procedurally. The material qualities of these everyday objects play a big role in the social and procedural practices of people. In the current ubicomp research, the material and the computation are seen detached from each other [120]. As Buechley and Coelho [17] suggest, electronic components are seldom integrated into objects' intrinsic structure or form. We believe that there is a need to highlight the blurring boundaries between the material qualities of an object and the computational functionalities it is supposed to support.

1st: embed computing in objects, socially and procedurally.

Second, the technology push from different fields of material sciences has provided new possibilities to integrate materials such as metals, ceramics, polymeric and biomaterials and other composite materials for designing products. A wide range of smart materials can be seen in the literature that can change their shape, size, color and other properties based on external stimuli. These properties of smart materials can be used to create new kind of interaction and interfaces. In section 2.1, we will provide a few examples of these materials.

2nd: the technology push is providing new possibilities

Third, with the use of smart materials, as designers, we can introduce a new communication 'language' to users. Use of screen-based interfaces has dominated the user interfaces for several years now. These use icons, texts, and other types of widgets to support communication with users. Smart materials can introduce new semantics to the human-computer interaction, which focuses on change of shapes, colours, size or positioning. Of course, the potential and semantic value of such a type of communication have to be explored and experimented further. However, the use of smart materials can be seen as a radical shift in the way we see our user interfaces.

3rd: use smart materials as a new common physical language

1.2.2 *The Vision*

The basic idea behind the SMIs vision is that it attempts to make use of readily-available, engineered materials as physical properties of an interface to convey information to its users. Additionally, following the ubicomp vision, SMIs attempts to close the gap between the computation and the physical medium – where the physical medium itself is capable of making changes. Computation and other external stimuli could help in this but it is not a necessity. This way our every-

Idea: convey information through material properties

Concept	Description	Material
	*SpeakCup* is a voice recorder in the form of a soft silicon disk with embedded sensors and actuators, which can acquire different functionalities when physically deformed by a user [22].	Composition of disk of platinum, cure silicon rubber (passive shape memory)
	*Sprout I/O* is a textural interface for tactile and visual communication composed of an array of soft and kinetic textile strands, which can sense touch and move to display images and animations [22].	Shape Memory Alloy (SMA) used as electrode for capacitive sensing and actuation soft mechanism.
	Concept that displays different information about safety and risk relative to the temperature of the content of the bottle. Designers: Hung Cheng, Tzu-Yu Huang, Tzu-Wei Wang and Yu-Wei Xiang [18].	Thermochromic liquid crystals

Table 1: In anticipation of Section 2, here 3 examples of Smart Material Interfaces (SMIs).

day used objects can convey informations by means of their physical properties and use the material itself as a medium of physical representation. SMIs emphasis on the medium used for the interaction, the object itself, instead of having a simulacrum giving the idea of interaction of another object augmented as input system.

To make the SMIs vision clearer, we will first provide a brief overview of the type of smart materials that are currently available and how they are used. Next, we will provide an informal comparison of SMIs with TUIs – that have been around for some time.

1.3 SMART MATERIALS

Before going further, we would like to explain what we mean by "smart materials". A smart material in general has at least one or more properties that can be dynamically altered in certain conditions that can be controlled from outside (external stimuli). Each individual type of smart material has specific properties which can be al-

Smart materials can change properties in a controlled way tered, such as shape, volume, color, conductivity, temperature, moisture, pH, electric or magnetic field, light etc... These properties can influence the types of applications the smart material can be used for. Smart materials are materials that "remember" configurations and can conform to them when given a specific stimulus[2].

The most common smart materials can have the form of polymers, ceramics, memory metals or hydro gels. These materials are engineered within the fields of chemistry, polymer sciences and nano technology. Importantly, these fields can offer specific kind of smart material that can be operated using specific external stimuli. For example, polymers can be activated through light, magnetism, thermally or electrically. Other smart materials: Nichel Titanium Naval Ordinance Laboratory (NiTiNOL) (SMA), used also for internal surgery; phase change materials [106] (heat is absorbed or released when the material changes state, used for mugs and clothes); chromogenic material [8] (changes color in response to electrical, optical or thermal changes, used in sunglasses and LCD); ferrofluid liquid [103] (becomes strongly magnetised in the presence of a magnetic field, used for Hard Disk and Magnetic resonance). In the Table 1, we provide a few examples of interfaces built using smart materials, more examples will be presented in the chapter 2.

NiTiNOL: Nichel-Titanium alloy

For a larger, more detailed and comprehensive list of materials with relative properties and effects, look at Sec. 1.4.

1.4 A TAXONOMY OF SMART MATERIALS

There are many possible categorisation under the wide term smart materials, here we group them by the effects produced (e.g.: movement) by material and subgrouping by family, e.g.: SMA. As we can see in this section there are many kind of materials that can achieve similar effects under different kind of stimulus (e.g.: color changes).

We will briefly show here some of the relevant categories of Smart Materials:

- Materials inducing external visual changes:
  - Changing color, transparency (Chromogenic Materials)
    - Electrochromic materials change color or transparency by the application of a voltage (e.g., LCD).
    - Photochromic materials change color in response to light (e.g., sunglasses).
    - Thermochromic materials change in color depending on their temperature (e.g., graphical thermometer).
  - Light emitting materials

Thermochromic materials will be used in the next chapters

2 NASA research: http://quest.arc.nasa.gov/aero/virtual/demo/research/youDecide/smartMaterials.html

        * Electroluminescent materials emit light on the application of voltage.
        * Fluorescent and Phosphorescent materials produce visible or invisible light as a result of incident light of shorter wavelength (e.g., fluorescent ink, phosphorescent ink).
    - Inducing movement
        * Materials that change shape:
            · Shape-Memory Alloys (SMA) and polymers are materials in which a deformation can be induced and recovered through temperature changes.
            · Magnetostrictive materials change shape under a magnetic field and also change their magnetisation under mechanical stress.
            · Ferrofluid is a liquid which becomes strongly magnetised in presence of a magnetic field.
            · Magnetic shape-memory alloys are materials that modify their shape in response to a significant change in the magnetic field.
            · Temperature-responsive polymers change upon temperature variation.
            · Photomechanical materials change shape under exposure to light.
        * Dielectric Elastomers (DE) are materials which produce large strains under the influence of an external electric field.
        * Polymer gel or pH-sensitive polymers are materials that change in volume when the pH of the surroundings changes.
        * Piezoelectric materials are materials that when a voltage is applied, will produce stress within the material. Systems made from these materials can be made to bend, expand or contract when a voltage is applied.

SMA will be used to create actuation in the next chapters

- Materials inducing other effects
    - Self-healing materials have the ability to self repair damage.
    - Magnetocaloric materials are compounds that undergo a reversible change in temperature upon exposure to a changing magnetic field.
    - Phase-change materials are capable of storing and releasing large amounts of energy. Heat can be absorbed or released when the material changes state.

- Smart Textiles
  - Smart Textiles are not always smart material by definition, but a special category that we want to include. It comprehends a variety of textiles that change colours, self-heal, transmit information or keep information all thanks to smart materials addition. They are engineered textiles with smart materials inside or a mix of compounds that gives them smart properties even if they are not smart materials at the bases.

The above list is not meant to be complete, there are more categories and many new materials are being created from one year to the next. The reader can find more technical information about such materials in [6]. As interaction designers and researchers of computer interfaces, we are especially interested in what we can use immediately to create interaction.

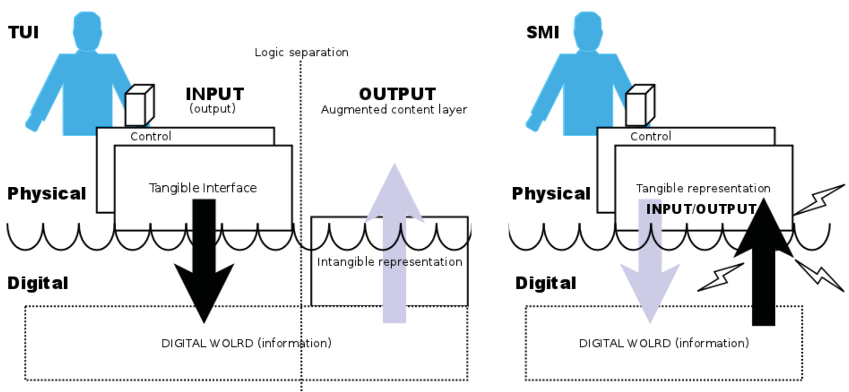


Figure 2: A comparison between TUI (left) and SMI (right), we want to stress the tight coupling of information and tangible interface, and especially the use of tangible elements as output of the system. This will take advantage of the smart properties that can be carried by the object itself as interface. The black arrow emphasise the focus of interest for the interface (as input in TUI, as output in SMI).

1.5 SMI VS TUI

Now that we have an idea of what is a Smart Material, we would like to proceed highlighting some radical differences of a system SMIs oriented and one that make use of TUIs. Figure 2 shows the architectural comparison between SMIs and TUIs and Table 2 summarises their differences.

TUI. As mentioned in [43], "the tangible representation allows the physical embodiment to be directly coupled to digital information", but the "limited ability to represent change in many material or physical properties" has been a drawback. As can be seen in figure 2 (left side), the user interacts with a tangible form of information (the object itself) to control the underneath mechanism – the object translates movements into commands and data in a digital form for the system (digital world). Once the computation has been done a different output is prompted to the user. The information returned (augmented content layer) can be presented over the tangible interface itself. The user can interact with the augmented layer by moving the physical interface. In TUI, we need to balance the intangible digital information (inside the augmented content layer) and the tangible representation (represented by the object itself) in such a way as to create a perceptual coupling between the physical and digital [43].

TUI: the information is presented mostly on a augmented content layer

SMI. With the use of smart materials, SMI attempts to overcome the limitation of TUI. SMI focuses on changing the physical reality around the user as the output of interaction and/or computation as well as being used as input device. SMI promotes a much tighter coupling between the information layer and the display by using the tangible interface as the control and display at the same time – embedding the augmented information layer directly inside the physical object. It uses the physicality of the object as a way to deliver information. Utilising smart materials' properties, SMI can support cohesive interaction by maintaining both channels (input and output) on the same object of interaction. The interaction constructed in this way will grant the user a continuous perception of the object and of the output with a persistent physicality coherent with the space.

SMI: focus on changing the physical reality around the user

1.6 SMIS: APPLICATIONS AND POSSIBILITIES

We believe that SMIs could have a wide range of applications, not limited to the field of computing. In fact, literature has shown how smart materials are used in surgery [77], architecture, art and engineering. SMIs do not need any kind of display, with materials being both the interface and input-output stimuli. Their physical characteristics may be enough to carry and convey information. In this way, SMIs propose a radical change in the way we see and understand common user interfaces as well as the way we interact with things, introducing a new space for research and development. We believe that in the future we will have a more seamless interaction between the real world and the digital world. This will provide a new meaning to augmented reality interaction that will have a more continuous, persistent and coherent feedback in relevant contexts.

The material is the display

We want to convey a message with an action, something that the user can sense directly, such as: change of shape, stiffness, colour or light emission. The only limit is our creativity.

TUI	SMI
sometimes incoherent in the relevant ambience (physical - digital)	coherent space of information (physical - physical)
information is represented as an augmented overlay on the object	information is part of the material/object itself
tends to separate input and output (distinction by physical - digital)	promotes a more tight coupling input/output
users can feel the difference from the "real" and augmented information	information added in a completely transparent way
output is felt non-continuous non-persistent	output physically present (not a digital representation), continuous and persistent
balances coupling the tangible and intangible representations	uses physicality of the object as way to deliver information
makes use of electronics and controllers	uses properties of smart materials

Table 2: Advantages of *SMI* in comparison with *TUI*

In the context of this thesis, we will focus on the physical action, intended not as variation of light emission in the traditional fashion, but as variation of material appearance, movement and surface change.

In [110] is stated that "the community has yet to identify important applications and use-cases to fully exploit its value" (referring mainly to shape changing interfaces). We can extend this question to the full set of SMIs. We will try to tackle this open question with the exploration of different aspects of the problem. We will evaluate the possibility of using SMIs for transmitting information according to various parameters and aspects. We will try to integrate smart materials in the interaction design process, both for design and teaching spanning through various domains, using (technological) proofs of concept and experiments.

In the next chapter (Chapter 2) we will proceed to show several existing category of interfaces that can be classified under the SMI definition, both in science and Art domain.

2

SMIS IN ART AND SCIENCE: RELATED WORKS

This chapter introduce several examples of interfaces that make use of smart materials. We partitioned them into two larger groups. The first is about entertainment and expression from the market and the artists point of view (*arts* and *design* domain). The second is focussed on the researcher side, bringing up examples of different kinds (*interaction design* and *research* domain).

This chapter is mainly based on [71] and [72].

2.1 SMIS ARE AROUND US

In this section we will focus on the use of SMI in Research and Arts, we will show examples from both fields. However, the idea of this survey does not include the use of smart materials in medicine, mechanics or other fields. All the examples will be presented for their relation with the User, might it be functional or just for aesthetic purposes.

2.1.1 *Poetry in the materials*

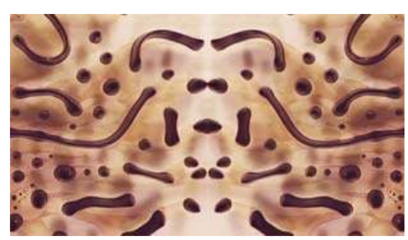
Many faces of ferrofluid

Often, walking by an installation, we are stunned from the beauty of the artwork we are looking at. It inspires us emotions and feeling. Some artists headed for the idea of using new materials as part of their artistic experience. They started to play with the aesthetics of the smart materials to communicate their emotion to the visitor. Some of them are from a very scientific background and applied their knowledge within an artistic frame. Sachiko Kodama is the first to start to employ ferrofluid in art installations with "Protrude flow" [54] in 2001, were the ferrofluid lift up from a plate, then creates a flower like shape balancing the wobbling spikes in between the two spaces. She created until now several installations, among others: "Morpho Towers – Two Standing Spirals" is an installation that consists of two ferrofluid sculptures that moves with the music [53](Fig. 3a). Many

(a) Morpho Towers, Sachiko Kodama.

(b) Millefiori, Fabian Oefner.

(c) Compressed2, Kim Pimmel.



(d) Ferienne, Afiq Omar.

Figure 3: Several examples of Ferrofluid installation in art

others started to follow her example, one of the most original we find the photographer Fabian Oefner breaking with this monochromatic tradition by throwing water colours into the mix and bringing in some luminosity and playfulness in his series Millefiori (video and photographs, Fig. 3b) [80]. After him: soap bubbles, ferrofluid, food colouring, and magnets, a mix in a video called "Compressed 02" from Kim Pimmel [87] (Fig. 3c). Also the artist Afiq Omar has been experimenting with ferrofluid and using the results to create frightening videos, they look like as they are lifeforms from another world. His experiments have seen him mixing ferrofluids with items from the weekly shopping list: soap, alcohol, milk [82] (Fig. 3d).

Figure 4: Magnetic Mind is a project that translates brainwaves into kinetic art, using a NeuroSky MindWave brain-computer interface headset, an Arduino, an electromagnet and suspended ferrofluid.

The last creation of this paragraph by Lindsay Browder, focuses on mind control, the poetry of changing brainwaves shown by a ferrofluid flask. The ferrofluid follows the user's mind activity, changes shape, grows tiny cones and relaxes again, doing this based on the user's real-time brain activity (Fig. 4, Magnetic Mind realtime BCI with Neurosky's headset) [15].

2.1.2 *Interactive background objects*

Another source of inspiration for artists and craftsmen is bringing up to the foreground, objects forgotten or that normally do not have any direct interaction with the user. The Brothers Mueller present an interactive wallpaper (Fig. 5). Their aim is to bring wallpaper back to the foreground. Viral (STD) Wallpaper is a damask print with stylised graphic versions of sexually transmitted diseases. By touching the wallpaper, the visitors can trigger the viruses to "infect" the wall. The infection spread thanks to Arduino connected sensors and thermochromic paint that allow the hidden pattern to appear [14]. Similar concept for "Chair of Paradise" (Fig. 6), the design of the chair is inspired by the mating behaviour of a bird, Superb Bird-of-paradise.

Changing surface properties (light and color patterns) to create communication

Figure 5: Viral (STD), Brothers Mueller

Figure 6: Chair of Paradise

This extravagant ritual is rather humorous when performed by a bird, which becomes nonsensical when it is done by a chair. This object and its behaviour exemplify the functional estrangement, in another word para-functionality, trying to achieve poetic language for electronic objects. The chair reacts to the proximity and it reacts with sounds and pattern change, thanks to thermochromic and Arduino [100]. Another outstanding work from Loop.pH research studio is Digital-Dawn (Fig. 7). It is a reactive window blind with a surface that grows in luminosity in response to its surroundings. It tries to emulate the process of photosynthesis using printed electroluminescent patterns that recharge during the day by means of solar powered textile. The darker a space becomes the brighter the blind will glow maintaining a balance in luminosity. A natural, botanical environment appears to grow and evolve on the window lamp [63]. Sometimes also nat-

Figure 7: DigitalDown, Loop.pH research studio.

ural creations wants to interact with the users passing by. The Robotany project (Fig. 8) by Jill Coffin, John Taylor, and Daniel Bauen is a sculpture in which the branches of a living tree sway when someone walks by. The branches are actuated by some SMA wire which is completely silent and hidden, so the tree appears to be moving to a virtual breeze [26, 25]. There are other objects that wants to communicate with the user, such as tables benches. Jay Watson of Oxfordshire decided to give voices from the past to its table and bench he designed, by using thermochromic finish on them (Fig. 9). It reacts to body heat by becoming transparent, temporarily exposing the wood underneath. It leaves an interesting ghostly print of either body parts or dinnerware for a brief amount of time that can stimulate intriguing dinner conversations [128]. Another interesting blend of science and art is Ferrocious [37]. Ferrocious is an electronic ferrofluid sculpture that responds to sounds. Different music will cause it to respond in different ways, leaving the ferrofluid jumping and spiking between the two magnets. Interactive Steampunk Ferrofluid stand

A temporal conversation among users and forniture

Figure 8: Robotany, Jill Coffin, John Taylor and Daniel Bauen.

Figure 9: Thermochromictable, Jay Watson.

(a) Ferrocious. (b) Steampunk concept.

Figure 10: Ferrofluid for entertainment and aesthetics.

concept (Fig. 10) by Geir Andersen [7] also shows how to entertain his spectator with electromagnets. Here, the aesthetics of steampunk design create all the interaction showing some hint of new perspective for Human Computer Interaction (HCI) design [114]. Patterned

Figure 11: Patterned by Nature, by Plebian Design.

by Nature [108] (Fig. 11) is a sculptural ribbon commissioned by the North Carolina Museum of Natural Sciences (naturalsciences.org), it represent an abstraction of nature's infinite complexity into patterns, it is made of 3600 tiles of LCD glass. It runs on roughly 75 watts, less power than a laptop computer. It brings to light the similarity of patterns in our universe, across all scales of space and time. Animations are created by independently varying the transparency of each piece of glass.

Transparency is another surface property

2.1.3 *Living Environments*

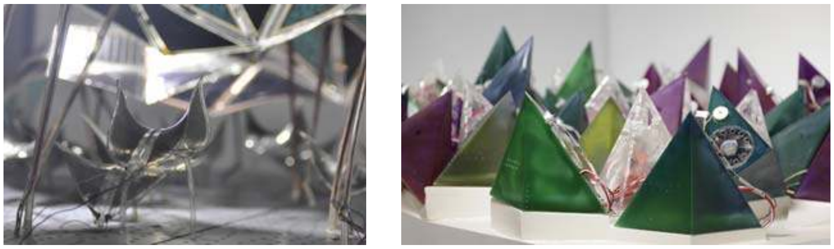
Living environments are architectures and environments that invite the user to participate, to be aware of some processing, or just experience and enjoy the result of the change made by the SMIs. A Shape-Shifting metal lets buildings breathe (Fig. 12) by using a thermobimetal [112], a laminate building material that changes shape as temperatures rise and fall, could enable structures that react smartly to their ever-changing environments. Hylozoic Series are a sculptural installation by Philip Beesley [9] (Fig. 13), it makes use of muscle wire to actuate portions of this living architecture. These installations are immersive, interactive environments that move and breathe around their users. The environment can both feel and intervene on the air, purifying the it, reacting to users, contracting and communicating with them by means of movements, light and chemicals. they are made to mimic a kind of synthetic biology, and uses interactive technologies to create an environment that is nearly alive. With this similar idea there are also the works supervised by Manuel Kratzer such as Phototropia [56] or Resinance [58] (Fig. 14a and 14b). Phototropia is part of an ongoing series on the application of smart materials in

Art, architecture and design fused in a common ground built on top of smart material

Figure 12: Breathing Metal, by Doris Kim Sung.

Figure 13: Hylozoic, byPhilip Beesley.

an architectural context. It merges self-made electro-active polymers, screen-printed electroluminescent displays, eco-friendly bioplastics and thin-film dye-sensitized solar cells into an autonomous installation that produces all its required energy from sunlight and re-



(a) Phototropia. (b) Resinance.

Figure 14: Phototropia and Resinance interactive installations, by Manuel Kretzer.

sponds to user presence through moving and illuminating elements. Resinance is part of the same serie, they are exploring the potential use of smart materials in an architectural context. The design of Resinance was strongly influenced by the behaviour of simple organic life forms, in particular the formation of cellular colonies. In its assembly it represented an ecology of functional units that could both work autonomously but also in coordination with their neighbouring units. It consisted of 40 active elements that were gradually changing their surface color in response to human touch. While this slow transformation as such couldn't immediately be perceived, each device had a second actuator, providing direct response through shivers and vibrations. Every four elements were connected through a control unit that formally resembled the rest of the objects but without the ability to change color. These units both choreographed the behaviour of the particular cluster and transmitted the current state of each element to its neighbours. Therefore the tactile input not only changed the touched element but was transmitted throughout the whole installation in a networked, swarm like behaviour.

2.1.4 *Interactive dresses*

Seeking the attention, conveying information to its wearer, smart textiles forms all sort of dresses and cloth, fashion oriented or not. Some of them have high and healthy purpose, so for example: teaching how to breath. It's the case of RUAH [116] (Fig. 15). RUAH is an interactive corset controlled by Arduino and actuated with NiTiNOL. This geometric corset helps the user to learn how to breath properly with diaphragmatic breathing. The stretch sensor detects the movements of diaphragmatic breathing and once elaborated the sends a signal to the muscle wire, inflating and deforming the centre of the structure. Through this interaction, the user becomes conscious about his body and his breath. With more trivial and playful intensions instead are created the Glow Thread t-shirt [115] (Fig. 16) and SquidLondon designs for rainy days [109] (Fig. 17). While the first is an interac-

There are more ways of interacting with your own dress than you expect

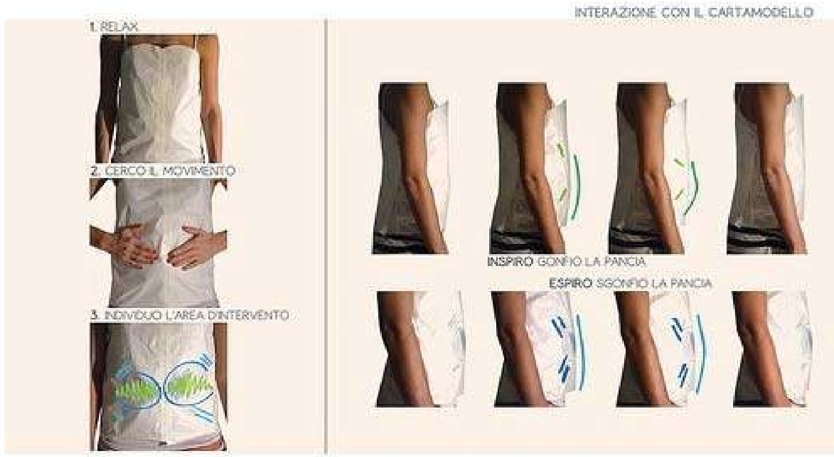


Figure 15: RUAH interactive corset, by Giulia Tomasello.

Figure 16: t-shirt by Glow Thread.

Figure 17: Color changing coat, by SquidLondon.

tive t-shirt that allows the user to create their pattern design on the spot, by using a UV light. It invite him actively to redraw the patterns when they fade away. The second is an entire line of design that became colourful when it gets in contact with water. It makes use of a hydrochromic ink print, that encourages the wearer to get wet to show its colours. The Kukkia dress [11] (Fig. 18) is an expressive

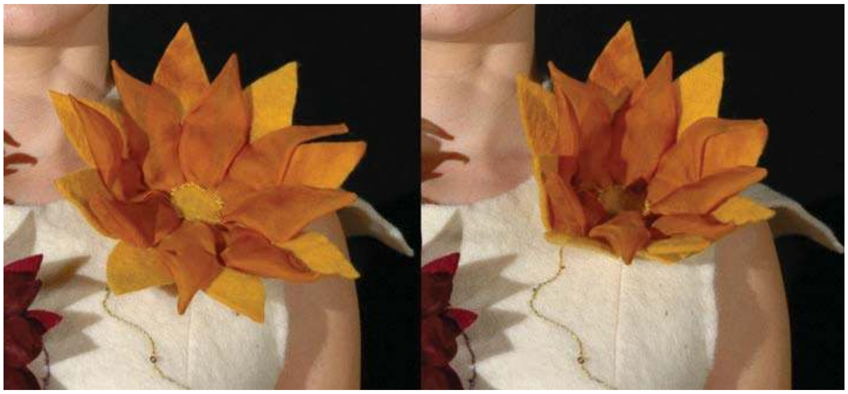


Figure 18: *Kukkia*, expressive and behavioural kinetic sculpture.

and behavioural kinetic sculpture that is decorated with three flowers. Each flower is animated. It opens and closes in a 15 second interval. The flowers are built with felt and silk petals, that provide necessary rigidity, and stitched NiTiNOL wires that create the animation. A more recent example of application of smart materials in wearable reactive garments is "Caress of the gaze" [33], by Behnaz Farahi (Fig. 19). It an interactive 3D printed wearable, which can detect other people?s gaze and respond accordingly with life-like behaviour thanks to NiTiNOL springs. A very small camera is place in the middle of the chest, when the system detects the gaze of a person staring, it responds by curling down and exposing the spikes.

Figure 19: *Caress of the gaze*, 3D printed interactive wearable augmented with SMA.

2.1.5 *Pure Entertainment*

This first example introduce us to another category for this section, even if it is made as cloth to wear, we still decided to classify it as a crafty interface for pure entertainment. Many people started to create minor works using smart materials, following just what their creativity suggested and giving the materials more or less expressivity. Product search studio created invites [81] for the Product Design MSc launch party that work also as musical instruments. The user

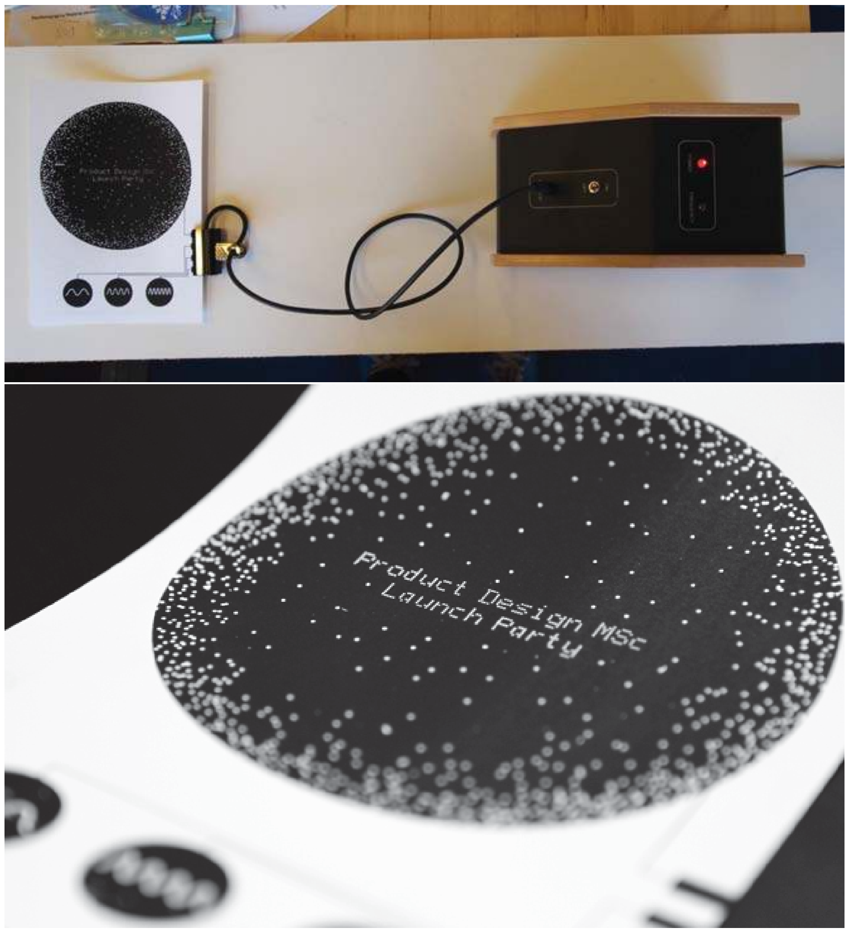


Figure 20: Invites, by Product search studio

could plug their invite into a box to make them become fully interactive 8bit music instrument. The user can control the pitch and the frequency of the beeping, using distance sensors made of conductive ink (Fig. 20). This all works with capacitance. Mazapy9teen-props which started to produce handmade Rorschach masks [66]. The mask change drastically from black to white and vice versa, reacting to breathing (heating the textiles painted with thermochromic ink) with pattern that change by the air coming in or out, emulating the original DC Comics character's face (Fig. 21). Also, several researchers

Diffusion of smart material as DIY component

Figure 21: Rorschach mask, by Mazapy9teen-props

started to give assignment to students and in workshops for creating new kind of interfaces or just for learning about prototyping, actually posing the bases for future evolution of interfaces, thinking outside the box. Several school organised workshop direct both at PhD and students, in many cases also to an outside academy audience. They shared their experience on the net, creating community of makers and produced more. This is the case for Qi Jie and Hannah Perner-Wilson, they created some of most interesting tutorial about smart material interfaces online yet, giving birth to pin prick sensor [85], animated blooming paper flowers [91] or cranes [90] (Fig. 22a-22c). Or students that followed their tutorial producing things like interactive animated snails [32] that react to the user's touch (Fig. 22d). This introduce us on the research side of the chapter.

2.2 A MATTER OF MATTER AND METHOD: SMIS AS A METHODOLOGY FOR INTERACTION

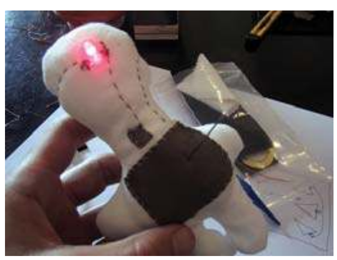
As introduced at the beginning of this chapter, the following examples show and draw attention to the methodology of application of the materials for creating interactive interfaces. Most of them not only give the idea on how to employ the material but also present a methodology for interaction and for creating new kinds of interfaces, in many cases for stimulating the creativity of the user, for prototyping or for pure entertainment.

We grouped the works in subsections by the kind of support mainly used in building the interfaces. Our interest is not only in the way it is done but also which and how the methodologies are used and what the pattern is behind the success of the interface itself. We aim to find out more about how to communicate using the material itself.

2.2.1 *Mainly paper*

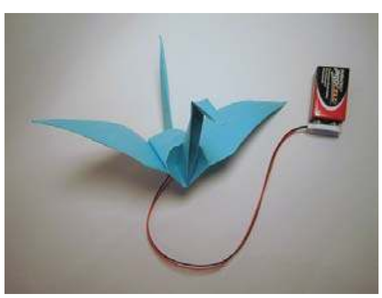
Many researcher studied how to augment paper using different techniques

Many researchers have applied smart materials by embedding them to create interactive new media for the public. We can spot several articles that focus their attention on creating frameworks or methodologies to engage the user, to make them play or unleash their inner creativity. These frameworks can also aim to support rapid prototyping for the researchers themselves. In '98 Wrensch and Eisenberg [132] started their initial efforts toward integrating computational and crafting media by creating a computationally-enhanced craft item, posing the bases for many future works as we will see in this paragraph. The Programmable Hinge they realised was firstly made with a normal motor actuation, soon after, improvements were made changing geometry and applying a SMA wire. Later on, many of them started to use cheaper and common office materials, such as paper or cardboard, for the support material. This is the case for Autogami [134] (Fig. 23a), where the authors present a toolkit for designing automated paper craft. AutoGami has hardware and software components that allow users to create physical animated paper crafts without previous knowledge of electronics. With the help of

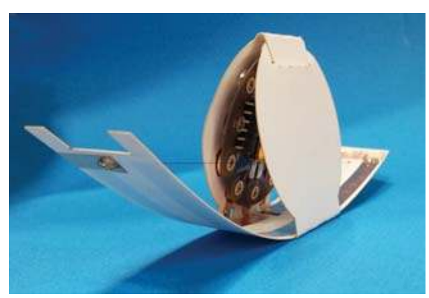


(a) Voodoo (prick) sensor-doll

(b) NiTiNOL blooming paper flower example



(c) Flapping origami crane example

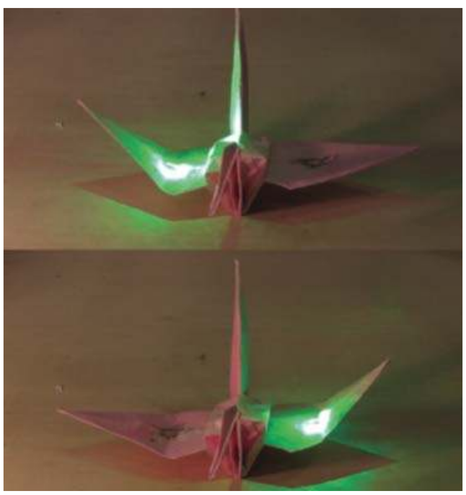


(d) Interactive animated snail

Figure 22: Workshop creation from Qi Jie and students

induction coils, the AutoGami set gives energy to the user's creations without power cords or cables. The user can animate his creation as he sees on the screen by applying SMA wires to the back of the paper shapes. Autogami also supports rapid prototyping. In 2009, Coehlo et

(a) Autogami



(b) Animated Paper for building toys

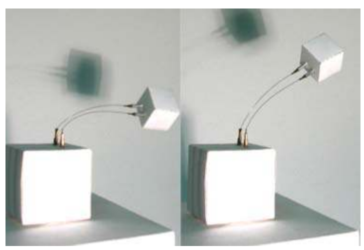
(c) Sonicinteraction, mechanisms

Figure 23: Several examples of SMIs applied with paper structures

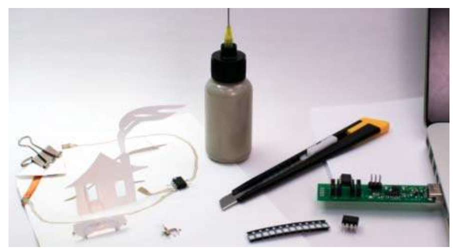
al. proposed the idea of pulp based computing [24]. Their aim was to develop an electronic paper composite, which combines traditional paper-making techniques with the interaction possibilities of smart materials. This is done by embedding sensors, electroactive materials and electronics into the paper itself to convey the affordances and tactile qualities of paper, while still keeping the potential of computers computing. Among the most innovative ways of paper-moving with smart materials there is the Animated Paper for building toys of Koizumi et al. [55] (Fig. 23b). By using SMA helix wire heated with lasers, Animated Paper represents another step to a wireless prototyping platform which combines paper, SMA, retro-reflective material and copper foil. They created flapping origami cranes and walking paper pandas, but because of safety measures, caused by the employment of a high energy laser, all the interaction needs to be made a-synchronically in a box, and it does not allow direct interaction. They also created an interesting flower garden that blooms when heated from concentrated sunlight (by holding a magnifying lens close to the flower). This represents an interesting real life application and provides a low-cost and eco-friendly platform for the user to develop and test new models.

Augmented paper based devices can be very cheap

In contrast to the expensive design set from the previous example, Greg Saul's Interactive Paper Devices are extremely cheap [102]. He describes a family of interactive devices made of paper and simple electronics such as paper robots (Fig. 24a), paper speakers and lamps. He developed software and construction techniques for supporting a do-it-yourself (DIY) process and a low-cost production. His robot "sleepy box" uses NiTiNOL for creating movements, it sleeps making its head nod slowly and it reacts instantly to noise or dance, making the head jump up and down. Saul describes a methodology to create contacts and interactive movable elements using magnets and copper tape.



(a) Interactive paper robot



(b) The untoolkit

(c) Interactive pop-up book

Figure 24: More examples of SMIs applied with paper structures

Qi and Buechley further develop the concept of paper based computing through an interactive pop-up book [92](Fig. 24c). They create and report the techniques for its development hoping to provide a reference for whoever would like to follow their steps. They use a mix of materials like piezo resistive elastomers, resistive paints, and SMA to build the pop-up book. By embedding components and SMA on the pages they create an intriguing combination of material experimentation, artistic design and engineering. They also show that function and aesthetics can be tightly coupled. After this experience they continued their research by organising workshops and testing the newly acquired knowledge about how to use SMA with paper [93], sharing information through both articles and online resources (for example with the crane tutorial [90]). With the "untoolkit" we can learn more on how to "frame the technology for the target audience" [67] (Fig. 24b), how it is important to adapt the complex materials, such as micro-controllers, conductive inks and smart materials and the contexts in which they are embedded. It shows the tight integration of craft and technology using both micro-controllers and paper. In Paper mechanisms for sonic interaction [29] we can also see mechanics for creating pop-ups with conductive ink to augment paper and creating sensors for controlling paper interfaces (Fig. 23c). It is similar to Qi's work but more oriented to producing sounds and effects. One last example for this part is [48] a recent experiment applying the techniques from above (with paper, controllers and conductive inks, mostly by using capacitive touch) with children to stimulate creative expression and storytelling. In the article the authors point out some interesting issues about how the children used the materials and how this some times caused problems on the final interface effectiveness. The participants in some cases created a "holistic combination of functional and aesthetic affordances that fit their specific needs" using the material as the medium both for expressing the functional desire and for fulfilling his aesthetic side. Last example for this paragraph, but not less interesting, is the work done over packaging solutions involving plain paper, properly cut, and carefully connected with thermoplastic polymers connections, creating a self-folding material [107]. The method allows to create folds that can produce 3D paper structures from ordinary 2D sheets of paper. When heated, the polymers shrink and lift the paper at specific angles, turning the paper into a predetermined 3D shape (Fig. 25).

Paper and SMIs become a framework for teaching target concepts

2.2.2 *Textiles and soft materials*

We can achieve similar creative result without paper: for example by using textiles or by making wearable interactive objects. This is exactly what Perner-Wilson does by creating the Kit-of-No-Parts [86] (Fig. 26a). She explores the concept of handcrafted electronics using e-textiles. She created a related site called "how to get what you want" [101] and over the years continued documenting all her activities and all her research, publishing step by step tutorials, materials reviews, videos and suggestion for anyone interested. She follows a DIY approach, with elegance and knowledge, experimenting and posting results. She has organised several workshops trying to convey

Knitted and handcrafted interfaces become smart materials

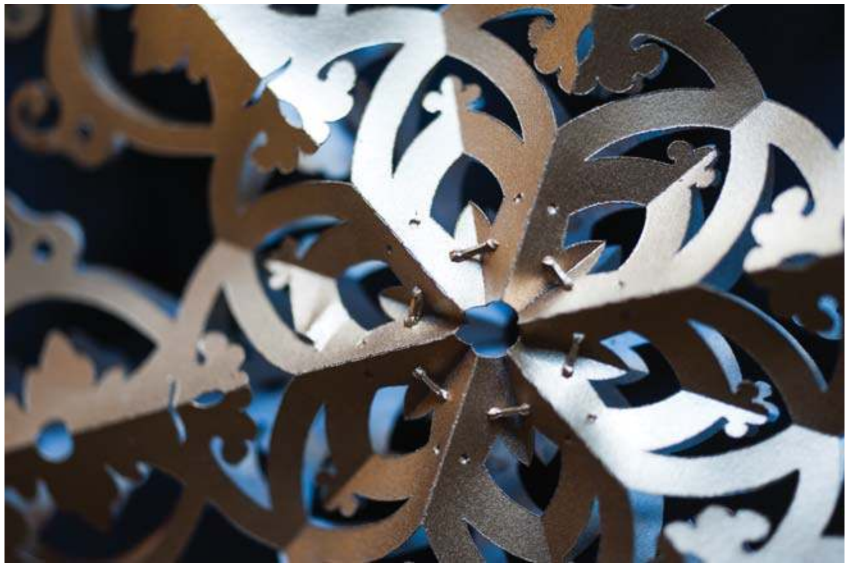


Figure 25: Self folding snowflake, by Ata Sina

a style of working that emphasise a creative use of (smart) materials. She describe how craft materials support a more understandable approach to creating technology and that the results of this process can be more transparent and expressive.

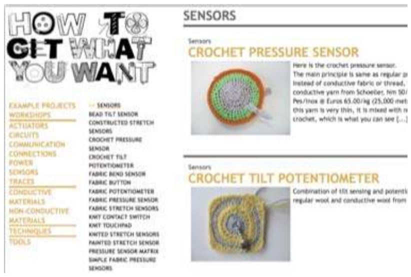
Even grass can be smart (on the backend)

A similar idea for managing NiTiNOL wires can be found in [70]. It is a tutorial-oriented technical paper, which shows the design history and the prototypes of Follow the Grass (Fig. 26b), a smart material interactive display shaped like blades of grass. It is rich of information on how to solve problems with the NiTiNOL wires and all the lessons learned through the mistakes made by the researcher. The SMAs here are the main motor that drives the motion of the blades of grass.

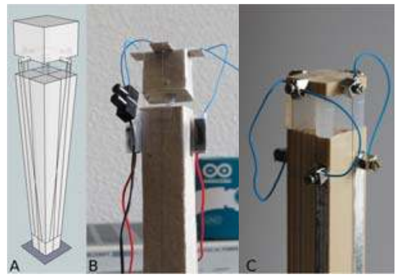
SMI as an element for creating soft prototypes

Surflex [23] (Fig. 26c) is a programmable soft surface for the design and visualisation of physical forms. It combines the physical properties of SMA and polyurethane foam to create a surface that can be electronically controlled to deform and come back to its original state. Although limited to homeomorphic shape changes, Surflex constitutes an interesting development for how to employ the new materials. The authors describe the implementation addressing the possibilities opened by the use of smart materials and soft mechanics in designing physical interfaces. Another interesting tool is Intuino [122], an authoring tool (Fig. 26d). The system enables the designers to concentrate on their essential work of interaction design making the prototyping process stronger and also facilitating it. It was created with the coordination of smart materials in mind and designed to allow an eased working with them, cooperating and coordinating the works with Surflex [23].

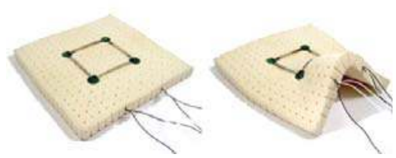
Successively, Parkes and Ishii [84] presented a more complete design tool for motion prototyping and form finding, named Bosu. Bosu



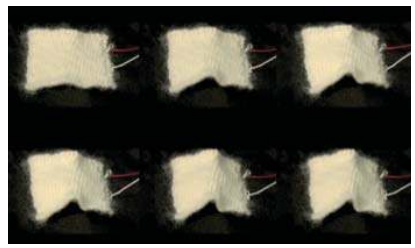
(a) Kit-of-No-Parts, tilt sensors on the "how to get what you want" site



(b) Growing grass, a SMI interactive display (see Chapter 4)



(c) Surflex a programmable soft surface



(d) Intuino, authoring tool

Figure 26: Examples of SMIs with textiles and soft materials

consists of a series of flexible elements that can be physically manipulated. They are composed of various materials, both soft and rigid: textiles, propylene or multiple layers of felt and polyester to allow bending and twisting. The physical manipulations can then be played back thanks to muscle wires embedded in the modules. Even if [125] does not include a methodology for interacting with the material, the authors introduce a possible way on how to incorporate SMA in 3D-printed (elastomeric) structures creating smart structures that can serve as sensor or actuator, by printing the material around the SMA or embedding them in a second time. This would open a lot more possibilities in the close future.

2.2.3 *Other support materials*

A more haptic oriented proof of concept for interaction is POC [127]. POC is a surface element made of addressable arrays of two-way SMA springs which can operate at a lower voltage and temperature compatible with mobile devices. The device is capable of changing into different shapes. It can simultaneously realise multiple methods for conveying information using dimension, force, texture and temperature. Wakita [124] takes a very different approach to the material, experimenting and describing his recipe to create a perfect match material for a rheologic interface. Programmable blobs is an actuated shape display. It is based on ferromagnetic fluids that by being at-

There are a number of studies that intersect two or more of the other categories tracted, connecting and dividing create a language for transformation control.

2.2.3.1 *Emotional interactions*

Interfaces for emotions and interfaces with emotional response

A notable sub section topic is also the creation of smart material interfaces for emotional purposes. It is possible to display, understand or elicit emotions through this kind of interfaces. This is the case of Wakita's work on Emotional Smart Materials [123]. In it the mood of the user is displayed by the change of color of a soft jelly keyboard. The system try to guess the mood of the user from what he write on tweets and display the change over the keyboard (see Fig. 27a). WeMe [65] (Fig. 27b) try to display the presence of the beloved person with a ferrofluid interface, it acts both as peripheral display and direct interactive interface.

Different idea is for the furry zoomorphic machine [35], where a smart textile made mainly of conductive thread is used as sensor for detecting affective touches (Fig. 27c).

(a) Emotional Smart Materials, keyboard interface, photochromic inc.

(b) WeMe, ferrofluid interface for displaying position of beloved persons

(c) Furry Zoomorphic Machine.

Figure 27: Examples of SMIs with emotional interactions

Part II

DESIGN

In this second part we will explore the possibilities and the design of smart material interfaces. The main objective will be to create an interface that can help the users to orient themselves in a complex environment, such as a large campus or a wide museum. We will start from the root (literally) of the problem and develop methodologies to implement movement and control over the interface from the design side and the technological problem.

We *create* the message using SMIs.

*"Prototypes are filters that traverse a design space
and are manifestations of design ideas
that concretize and externalize conceptual ideas."*

— Lim, Y.-K., Stolterman, E., and Tenenberg, J.[62]

3

FIRST PROTOTYPE

In this chapter we describe *Follow the Grass*, a first design exploration of a possible SMI display that can convey directional information to the user.

Follow the Grass is a concept of an interactive pervasive display for public spaces. We present a number of scenarios with varying scales of interaction, and different applications, followed by a description of the initial hardware design and its actuated root. We will give a description of the tracking system, and how it tracks users and is capable of identifying individuals.

This chapter is mainly based on [74].

3.1 INTRODUCTION

As we have seen in Part ii, for two decades researchers and designers have actively explored new methods of physical interaction with computer systems [34]. The seminal work of Ishii and Ullmer [44] helped spur the development of tangible interfaces; interfaces that allow users to manipulate physical objects that modify digital information. With technological advances, tangible interfaces have started to incorporate smart materials [46]. These materials are characterised by having physical properties that can be altered in a controlled way. Interfaces that incorporate such materials can be referred to as Smart Material Interfaces (SMIs [73]). In essence, where "traditional" tangible interfaces couple physical objects to digital information often displayed on a screen, smart materials allow the digital information to be represented by the physical state of the material. An advantage of this is that the information can be directly embedded into the materials of the physical environment. Furthermore, the use of smart materials allows for new forms of silent, energy efficient and more natural ways of actuating physical output (e.g. Sprout I/O [20]; Lumen [88]).

SMIs essentials, also Chapter 1.2.2

In this chapter we will present a concept of an interactive pervasive display that uses NiTiNOL (SMA) wires to actuate an artificial blade of grass in eight directions. These blades of grass can be thought of as physical pixels, and, when multiplied, can form a physical ambient display. Such a display can be employed for entertainment, indoor way-finding, or ambient persuasive guidance.

We will first review related work on ambient displays, ambient persuasive guidance and smart materials. Then we will present a detailed outline of the *Follow the Grass* concept, present a number of scenarios, and offer a description of the hardware prototype of the blade of grass and actuated root, and software design of the tracking system. We will conclude by providing suggestions for the further development of the hardware and software. In the next chapter (Chapter 4) will present a more detailed design history and technical development of the prototype.

3.2 RELATED WORKS

In the following subsections we will present three different relevant kind of application for our installation: ambient technology, persuasive ambient technology, and application of smart material for ambient displays and related SMIs applications.

3.2.1 *Ambient technology*

The interest in Tangible Interaction [44] is part of a development in HCI research that is moving away from the typical "window, icon, menu pointing device" (WIMP[1]) interaction [47]. RBI encompasses interfaces and interaction styles that support humans' existing knowledge about the physical world [47]. In this sense, the vision of *ubiquitous computing* is particularly relevant. Weiser's view [129] (as already discussed in Chapter 1) holds that computing can be unobtrusively integrated into everyday objects and environments. This proposes a direct coupling of computation and the "real" physical world, in an integrated natural manner. Furthermore, distributed networks and sensor technology can make such systems intelligent, resulting in objects and environments that can naturally adapt to their users [131]. Examples of such systems being used for presenting information or providing entertainment are plentiful. The ambientROOM [45] uses lights, sounds and movement to unobtrusively communicate a host of background information, such as the physical presence of others or the activity of an actual hamster. Similarly, Hello.Wall [89] consists of a grid of lights integrated into a wall, information can be presented by changing light patterns, that react to the proximity of the user to the installation. Another example is The Information Percolator [40], which displays information through air bubbles rising up in a number of transparent tubes filled with water. One application of The Information Percolator tracks people's movement along a corridor and represents this information in the ambient display. A more physical approach to ambient displays is implemented in Super Cilia Skin [94], which is a magnetically actuated display that makes cilia (i.e. individual actuators) move lightly to emulate the physical touch of a finger or a gesture trace. A similar approach has been used in the artistic installation Project Dune (Studio Roosengaard[2]), which is composed of large amounts of fibres that brighten according to the sounds, touch and motion of passing users, accompanying them along the walk. For an overview of similar ambient displays we refer the reader to Vande Moere [121]. What all of these ambient displays have in common is that they display information in an unobtrusive, yet aesthetically pleasing and fun way.

Making the ambient alive

3.2.2 *Persuasive ambient technology*

Recent evidence suggests that ambient technology can also be employed for persuasive purposes (for example Breakaway [49] and Twinkly Lights [98]). The fact that such ambient systems are inte-

The ambient can now tutor you

1 W.I.M.P paradigm: acronym for Windows Icons Mouse and Pointer interaction paradigm, coined by Merzouga Wilberts in 1980, developed at Xerox PARC in 1973.

2 http://www.studioroosegaarde.net/project/dune/info/

grated into the environment, means they do not explicitly tell people to change their behaviour. Instead they can suggest alternatives for a certain behaviour [98], or provide implicit visualisations of 'bad' behaviours [49]. The strength of this approach lies in the notion that people are not consciously aware of the ambient intervention, yet still adjust their behaviour [98].

There has been a substantial amount of research investigating the effects of static persuasive cues on the way people navigate public spaces. Such studies typically use textual [16] or visual cues [98] to guide people in a certain direction, for instance towards the stairs instead of the escalator. Examples of visual cues include lines that, when viewed from a certain angle, form guiding arrows [13]. Others used lenticular lenses to produce the illusion of lines moving to one side with the goal of guiding pedestrians [36].

Dynamic guidance

Compared to the use of static visuals, the advantage of using ambient technology for persuasive purposes is that the system can be dynamically adapted to the users' behaviour and to individual differences, as Kaptein says in [52]. This makes it more suitable for individual users, as well as allowing the system to adapt based on situational circumstances. For example a suddenly appearing obstacle that requires changing the direction in which pedestrians are guided. Here the use of smart materials is promising, because they offer both the ability to change dynamically as well as the ability to blend into the environment.

3.2.3 *Application of smart materials*

Shape for function

Considerable efforts have been made to explore the possibilities of applying smart materials in interfaces. For example, Surflex [23] consists of a foam with coiled NiTiNOL muscle wires embedded. The muscle wires can be used to reshape the foam. This principle has been applied as a way to use SpeakCup [22], a device used to record and replay messages by physically manipulating its shape (Shape-changing interfaces [22]). Another suggested application of Surflex is as a form of physical computer-aided design. Indeed, Parkes and Ishii [84] presented just such a design tool, for motion prototyping and form finding, named Bosu. Bosu consists of a number of flexible modules that can be physically manipulated (e.g. bent, twisted). The physical manipulations can then be played back thanks to NiTiNOL muscle wires embedded in the modules.

SMIs in ambient displays

Apart from design tools as Bosu, smart materials have been used in the creation of novel ambient displays. Shutters [21] is a curtain with a grid of shutters that are actuated by NiTiNOL wires. Shutters can be used to regulate the amount of light and air flow that enters a room, as well as serving as an ambient display by creating patterns using the grid of shutters. An ambient display that aims for a more tangible experience is Lumen [88]. A grid of cylindrical physical pixels are actuated to move up and down, using NiTiNOL wires. The physical pixels contain LED's that allow Lumen to display animations both visually, and physically.

While NiTiNOL is by far the most widely applied smart material, others have used ferro fluids and thermo-chromic materials to create physical ambient interfaces. WeMe [65] for example, is an ambient display that visualises the presence of members of remote families represented by bubbles of ferro fluid. Wakita et al. [123] note how, in the design of such interfaces, the materials and colours are felt as part of the emotional communication of the interface. Using the property (in this case colours) of the material directly, their aim is to communicate mood by changing the color of the Jello Display-Keyboard using IR-chromic material.

Emotional SMIs

The application of smart materials in interfaces enables designers to build interfaces that can take advantage of human tactile senses and perceptions of movement to improve interaction [51]. This allows for the complete abandonment of the digital display in favour of shapes and movements, creating a more direct way to communicate with the user and establishing a novel design language that could reduce the cognitive load (unlike WIMP interfaces which add new symbols interpretation).

Tangible smart interfaces make intangible tangible

In the next section we will present our idea of applying smart materials in an ambient pervasive display that can be used for entertainment, indoor way-finding and ambient persuasive guidance. The keys to communication here are the shape and movements of the artificial blades of grass. As was mentioned in [73] we want to try to keep the perception of the interface as analog as possible, experimenting with materials and shapes.

3.3 follow the grass

Follow the Grass is an interactive pervasive display made of artificial blades of grass. By moving individual blades of grass sequentially, it is possible to create animations (e.g. a Mexican wave-style animation[3]). Such animations can be used to communicate information to users. While the grass-pixels were designed for general use as an ambient display, their appearance and movement capabilities, make them particularly well suited for giving directions in indoor way-finding, or for ambient persuasive guidance and entertainment.

A waving environment

Follow the Grass mimics the way grass waves in the wind, not by representing only a single pixel but a mass of objects. In a large field installation it would be possible to emulate a virtual wind by moving the grass in waving patterns. Such a 'virtual wind' blowing through

See the invisible wind

3 Mexican wave-style: it is a large scale example of a metachronal wave. These movements produce the appearance of a travelling wave.

the grass field can be initiated by the presence of the user (see chapters Scenarios and following). Using a dedicated tracking system that follows and records the identity of users, it is possible to distinguish between different users, and to address them individually.

Convey information through the materials' properties, see chap.1.2.1

The grass-pixels were born out of the idea that, by using smart materials, we can create interaction in a less traditional manner (no WIMP) and convey information through the materials' properties (shape, position, colours, etc.). By using a muscle wire[4] we can accomplish a variety of movements allowing the blade to bend toward a specific direction (for now four cardinal point plus the four diagonals), with different speed to accentuate certain movement just by increasing the reaction time. Furthermore NiTiNOL wires are highly reliable and resistant to many kinds of stress. Compared to servomotors, the NiTiNOL wires operate silently, not drawing the users' attention to the hardware operating behind the scenes. This allows a more seamless experience of the grass, making it ideal for pervasive applications.

A silent way of moving things

Some examples

Some previous works involved display methods similar to the one used in the Follow the Grass concept. The Project Dune [99] has fibres with LED's embedded in the tips, that respond to sound. However, these blades of grass are not actuated and therefore lack the capability to address a certain direction. In Super Cilia Skin [94] the set of cilia creates a visual approximation of a contiguous deformable surface. Differently, the Follow the Grass concept attempts to make use of individually actuated blades of grass to address direction, or create a path by orienting individual blades of grass in unison. Compared to Coelho's work Sprout I/O [20] that uses NiTiNOL wires to bend a fabric grass in a linear movement (left-right only), we make active use of two degrees of freedom (see next sections for more details of implementation and movements). Sprout I/O was conceived as a remote control device and interactive actuated interface. The Follow the Grass concept, on the other hand, was conceived instead as an actuated pervasive display, envisioned to be mass produced and to be put in different public spaces. In addition Follow the Grass should provide interaction designers with a flexible infrastructure to develop animations to be depicted in the grass.

Unlike real grass, on which you can walk, it is not possible to step on the artificial grass at this stage, however, in the future we will be able to build a more robust base which would allow users to walk on the grass. But a limited number of blades can be put on a pedestal, or, in the case of a grass field, under a transparent floor, allowing the user to walk over the grass still perceiving its presence and animations.

We envision the interaction to take place in public spaces where the users are free to walk such as a hall of a complex building, a crossing

4 Flexinol or muscle wire is special kind of NiTiNOL wire that change shape by contraction its length.

of corridors or just the entrance of a building. The tracking system handles the path of all individuals that pass the installation, and adds a special profile to each one. Similarly, if you are in a hospital, and you need to know where the office of *Dr. Red* is, you can register your request at the reception desk. At this point the system can track your movements, and attach your request to you. By animating the grass in the direction of the office of Dr. Red, the only thing left to do is follow the grass distributed along the way.

Just follow the grass...

3.4 scenarios

For the application of our system we illustrate several kinds of scenarios. In each of the scenarios the hardware and software will be the same, but in some cases adjustments are needed to adapt to the specific interaction. In every scenario the individual roots and blades of grass are the same. In some scenarios we assume that we know the objective of the user (such as: path or game objective), for example an existing *Helpdesk* or a pre-filled user profile.

3.4.1 *Field*

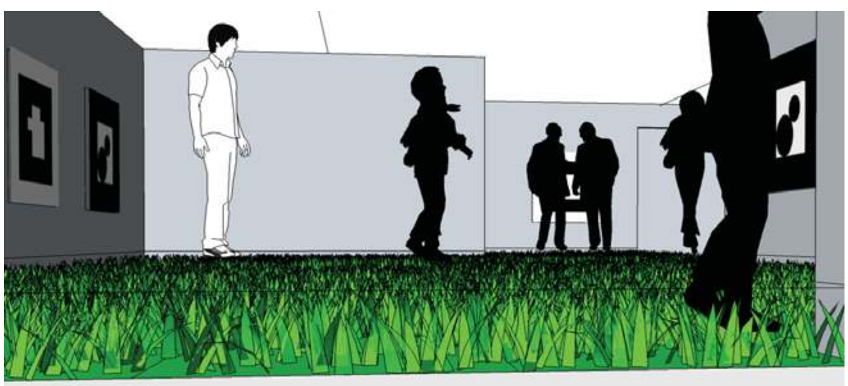


Figure 28: Concept of the scenario *Field*. The users are walking on a transparent floor over the grass.

In this scenario (Fig.28 and 29) we imagine a large-scale public installation, where a field of artificial grass is placed underneath a transparent floor. The users walk over the field without touching it, while the system tracks the identities of the users and produces personalised animation patterns under each user, by moving the nearby blades of grass. This can be used purely for entertainment purposes by simply displaying animations. For example a rippling effect, similar to a drop of water being dropped onto a water surface, causing concentric waves to form around the user. Another example is simulated wind that causes blades of grass all over the field to move

Immersive installation

Figure 29: Concept of the scenario *Field*. The grass bends creating a path from under the user to his/her goal.

in a natural manner. The field can also be used to guide individual users in a certain direction, by bending the blades of grass to form a path. A similar approach can be used to draw attention to specific objects in the space, by bending the blades of grass towards the object. Such an approach could be relevant for museum exhibitions or serious gaming purposes.

3.4.2 *Lawn*

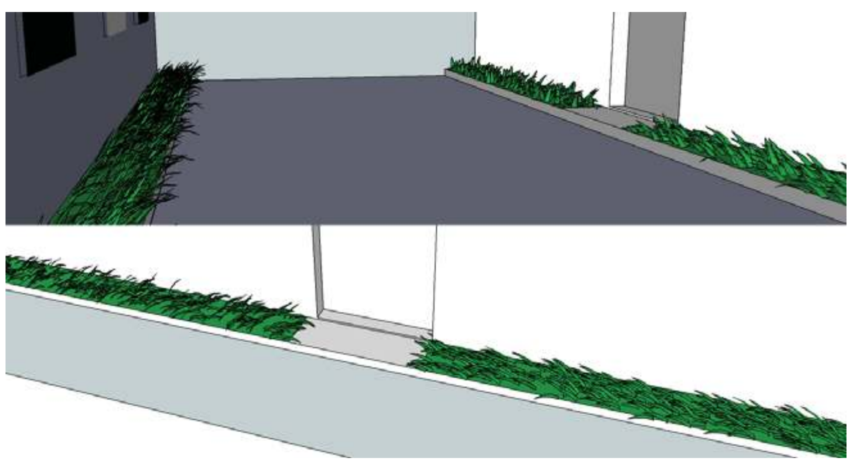


Figure 30: Concept of the scenario *Lawn*. On the top the grass bends toward the door on the right side and toward the corridor on the left. On the bottom the detail of the grass bending toward the door.

In the "Lawn" scenario (Fig.30) the total number of blades of grass is reduced by placing only strips of grass (lawns) along the walls of a public space. This approach preserves part of the entertainment possibilities of the "Field" scenario and maintains the possibility to provide personalised guidance to users. Users could simply follow the direction of the waving grass along the wall. Attention can be drawn to specific areas along the wall, for example the office of the person the user is looking for, or in a different context the artwork placed on the wall. This scenario presents a less immersive idea. The installation can be used both for suggesting information peripherally and attract the attention directly.

Surrounded by grass, a pervasive installation

3.4.3 *Map*

Here, a specific location is addressed using a scale model of an area (Fig.31 and 32), for example a university campus.

Figure 31: Concept of the scenario *Map*. Installation from the side.

The scale model will represent the surrounding area, with the space between the models covered in the artificial grass. Users can interact with the scale models through gestures (using the Kinect included in the system) in order to ask for directions. The grass will respond by forming a path from the users current location to the requested destination. This setup can also be used to highlight events in a specific part of the area, by playing animations that focus on the area in which the event takes place.

Scale model, a point for catching attention

3.4.4 *Patch*

The last scenario (Fig.33) is a small scale field (3x3 blades of grass) coupled with the tracking system. The patch of artificial grass can

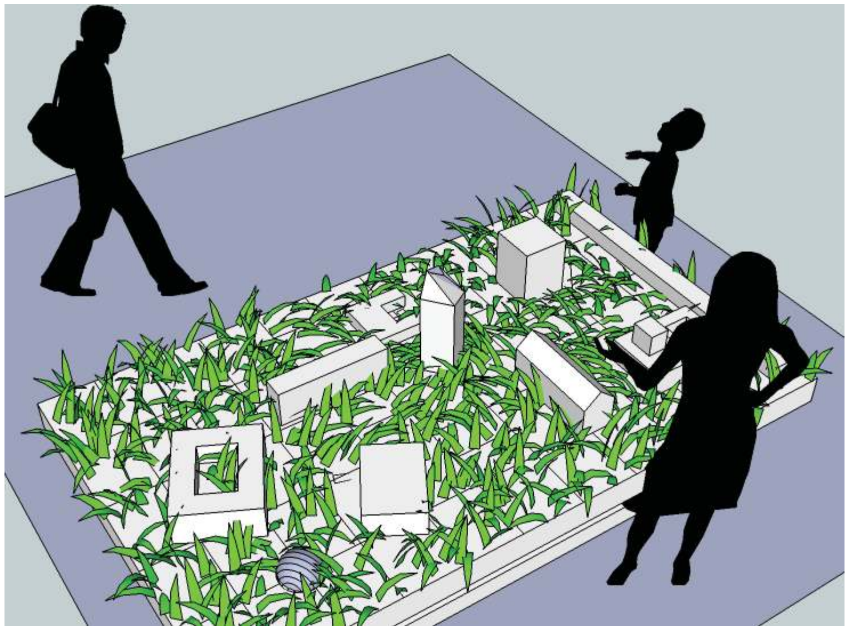


Figure 32: Concept of the scenario *Map*. The grass is bending toward the tower.

A small attraction point in the middle of the action

be placed on a pedestal at the place where a corridor splits. In the presence of the user, the grass will attract the users attention in *entertainment mode* (waving in different pattern or bending toward the user) and if profiled, address a direction in *guiding mode*.

3.5 system: tracking and actuation

The system is composed of two distinct components: one for the physical output (the grass) and one for the input, which is the presence of the users detected by the tracking software.

With the system, it is possible to track a specific person in a small group of people. This makes it possible to address this specific person individually, and provide him/her with personalised information, such as specific directions at the right time.

The interaction starts when people enter the area covered by the tracking system.

3.5.1 *Tracking software*

A Kinect[5]-based tracking system was developed to be able to address and track all the users in its sight. The Kinect(s) can be placed on the sealing or in high place to have a view of passage. This can be segmented and not necessarily be continuous. The idea is to have a

5 http://www.microsoft.com/uk/wave/hardware-kinect.aspx

Figure 33: Concept of the scenario *Patch*. The grass bends indicating a direction to the incoming user.

There is NO interest in identity, just on what your blob look like

system that is able to track identities from a simple blob tracker[6]. We intend to identify the user by knowing the tracking faults of the blob tracker itself and solving the problem in two phases. First, each time a blob merges with another we will trace and save the previous and the new relation (with related information), creating a sort of logical history of relation of blobs (with "AND" and "OR" logic conditions). Second, we will try to confirm the identity (between the observed ones) using logical operation and matching with hints that the software acquires from the behaviour and features analysis of each blob (in development).

The user can be identified in one of the specific checkpoints (if needed for giving personalised information) or just by entering the sight zone, a numeric ID is paired to the blob and tracked during the movements.

6 With BLOB we refer to regions with no fixed shape in the image that differ in properties compared to the surrounding. E.g.: brightness or color.

When the system is unable to track the user, there are three possibilities:

- The user is out of sight.
- The blob has merged with someone else's blob. In this situation we aggregate the information in "AND" until the system is able to address the blobs again.
- The blob has split into two or more parts. The information of the old blob is inherited in a doubt condition, i.e. an "OR" mode, on the generated blobs.

This way we generate blobs with some of the information precisely (aggregation of reliable information in "AND") and others in doubt (separation of blobs, in "OR" condition). To solve the "OR" condition we use a feedback loop that checks the features of the new blobs from time to time (shape, contrast, color, height, etc.) with the one from before, giving hints on which one is the most reliable solution. We then backward propagate on the other blobs to solve other pending doubt conditions.

There are limitations

The system has some limitations and can only be used in a controlled environment (at the moment, only inside the field of view of the Kinect). However, it is modular so that it will be further developed with other tracking features and the possibility to extend the field of view by connecting more units together.

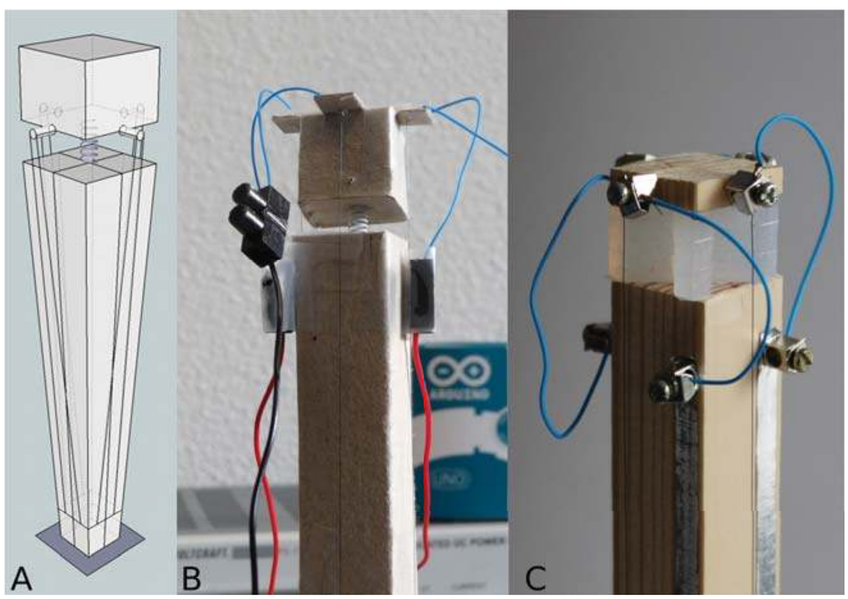


Figure 34: Physical actuator element, It is possible to see the movable head of the "root", where the blade of grass will be attached. A) the original 3D model for the project, B) the cardboard prototype with spring, C) latest prototype update with silicon"spring".

3.5.2 *Physical hardware for actuation*

Each grass-element is made of three parts: the controlling electronics, the "root", or the actuator base (Fig.34), and the externally visible blade of grass (in the next chapter, Fig.41).

The controlling electronics are just the elements (Arduino-based, see next chapter for more details) that controls physically the movement of the root, dosing time and power to get the best result.

Arduino powered

The root is the physical actuator that forms the base on which the blade of grass is placed. The root is hidden from the user view, leaving only the blade of grass visible. In Fig.34 (A) you can see our original concept for the root, that would allow the movement to be silent with the use of NiTiNOL.

The root is always invisible and silent

The blade of grass is affixed to the top part of the root, and is made out of a flexible material so that when the base moves, the blade of grass gently sways. The root need to move continuously and slowly to allow the blade to look more real and less mechanic. The blade of grass does not need to be a single blade, it can be also grouped to have more effect while moving.

Slow movements for more "organic" effect

3.6 TO THE FUTURE

Our aim in this chapter was to describe the work in building an interactive physical pervasive display, that can be used for indoor way-finding, ambient persuasive guidance, as well as for entertainment. Following the visions of ubiquitous computing and tangible interfaces, the Follow the Grass concept offers an engaging way for users to interact with their environment. As it has been demonstrated in [98] and [36] it is possible to change the behaviour of people by giving peripheral visual cues. Follow the Grass has the potential to have the same effect. Furthermore, the tracking system enables the interface to react dynamically to the users' presence, making it possible to give the correct information at the right time to the correct individual. This creates a more personalised experience for the user. The capability of the artificial grass to display animations adds to the expressiveness of the interface, and creates opportunities to engage and entertain the user.

A concept for an engaging and personalised experience

Future developments for the actuated root could include installing a tilt sensor on top which would reduce the number of NiTiNOL wires required, from four to three. The sensor would enable measurement of the angle of the platform to which the blade of grass is attached, allowing fine adjustments to be made using only three muscle wires. This would increase greatly the expressiveness of the interface but also increases control problems, complexity, and cost in the construction. The next step would be to make a serialisable version of the root for creating a larger field of artificial grass. Miniaturising the elec-

The future of this concept has space for improvements tronic components and constructing a dedicated controller module, would make the system more suitable for modular deployment. The tracking software will have to be improved and optimised for larger scale interactions (e.g. big rooms and halls).

In the next chapter we will go deeper into the details of construction and use of the root element. We will briefly describe the design process (decision making and structure) and show our consideration on the use of smart materials (NiTiNOL, in this case), before proceeding to the next part of the thesis (Part iii).

4

DEVELOPING GRASS

In this chapter we will present the design process and development of "Follow the Grass" (of which we discussed the concept in chapter 3), our smart material interactive pervasive display, with related technical detailed explanation. We will present the design steps and prototypes with the lessons learned for the use of smart materials (NiTiNOL) to create interaction.

This chapter is mainly based on [70] and [74].

4.1 INTRODUCTION

SMIs can be the filter to for a preferential information channel

Information needs to be filtered, slowed down to our level of comprehension, even changed and transformed to make the message reaching users effectively. We need interfaces to filter and represent personalised information at the right moment in the right place, the correct timing can be a key element in interaction. Technology offers possibilities to implement this type of interfaces, but technology alone is not yet user-friendly.

For for these reasons we introduced a new vision inspired by Weiser's vision of Ubiquitous Computing [129] and Ishii's Tangible Bits [44] [46]. We called our vision Smart Material Interfaces (SMIs) [73] (see Chapter 1), which takes advantage of smart materials to show a new way for the user to perceive the interaction and the message in it. SMIs use the physicality of the object as a way to deliver information, using smart materials' properties to convey the information directly to the user. We bypass the use of the traditional WIMP interfaces and prefer a tight coupling with both information and representation [73]. The communication by means of the material itself will open possibilities for new patterns of interaction. Modifying the world around the user, allowing the user to experience the information with just his presence as form of input provides freedom for design and interaction. In [74] (see Chapter 3) we presented the idea and application of "Follow the Grass", a concept born from this vision, in which we rethink the concept of display for information to address specific directions (we also forecast its use also for other purpose such as entertainment).

The interface is around the user, not just in front

Here we will present the design steps and prototypes with lessons learned from the use of smart materials to create interaction.

4.2 DESIGN AND PROTOTYPING

4.2.1 *Design idea*

Information and aesthetics are integrating part of the message [94]

With Follow the Grass, we wanted to apply the fundamental idea of SMIs [73] to construct a case study. The general idea of design behind Follow the Grass is to communicate with the user by means of the materials' properties, using the property itself to convey the message. As first exploration we focus our attention on the "shape": changes of shape, deformations and movements. Our idea is to communicate information by slightly moving objects or altering their geometry.

Persuasion by means of cues

As some studies made clear, it is possible to give the user visual [98] or textual [16] cues to guide him toward a specific direction. By using this metaphor we intended to help the user with constructing a mental model of the system, using these cues we will help to persuade him or to understand the right direction.

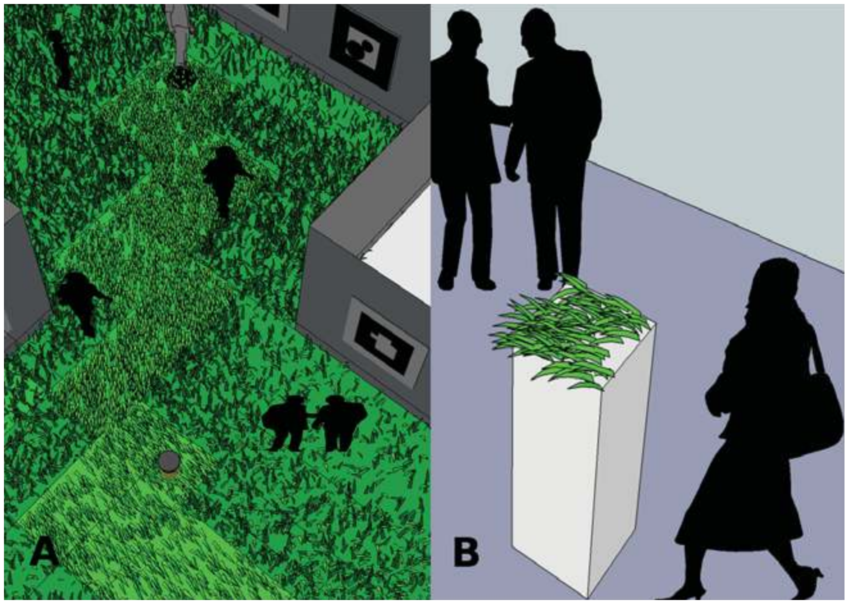


Figure 35: Section A) scenario *Field*, the user walks over the grass and can see through the transparent floor the grass animation creating a visible path. Section B) scenario *Patch*, the grass is on a stand and bends addressing the direction. All the scenario with full description can be read in the Chapter 3

Information must arrive when it is needed, appear in the right location, for example when a user reaches a crossing of corridors. At the same time, the interface should follow and reassure the user during the path.

Inspired by the surroundings nature, we chose the grass shape. The grass is an object that can easily adapt its shape by bending in a specific direction, in this way helping the users to find directions in an unknown environment (e.x.: as in the scenarios in Chapter 3 [74]). Using the illusion of the wind blowing on the grass to lightly "pushes" and indicates the user toward the right direction.

Nature teaches us in the strangest ways

It is also possible to use Follow the Grass as a display for more purposes.

4.2.2 *NiTiNOL*

The blades of grass are actuated by four NiTiNOL wires (muscle wires[1]) each. NiTiNOL wires create movement by contraction. Their advantage is that they operate silently, thus avoiding to draw unwanted attention to the hardware as it might happen in the case of motor-driven installations. If we consider an installation with a matrix of ten or more motor elements, the magnitude of noise can become a significant problem for the integration in the environment and for the expe-

Motors can be VERY noisy

1 Commercial version of the product http://www.musclewires.com/

rience of the users. Providing a more seamless interaction with nearly silent motion can help the user to perceive the installation presence as less intrusive and less disturbing.

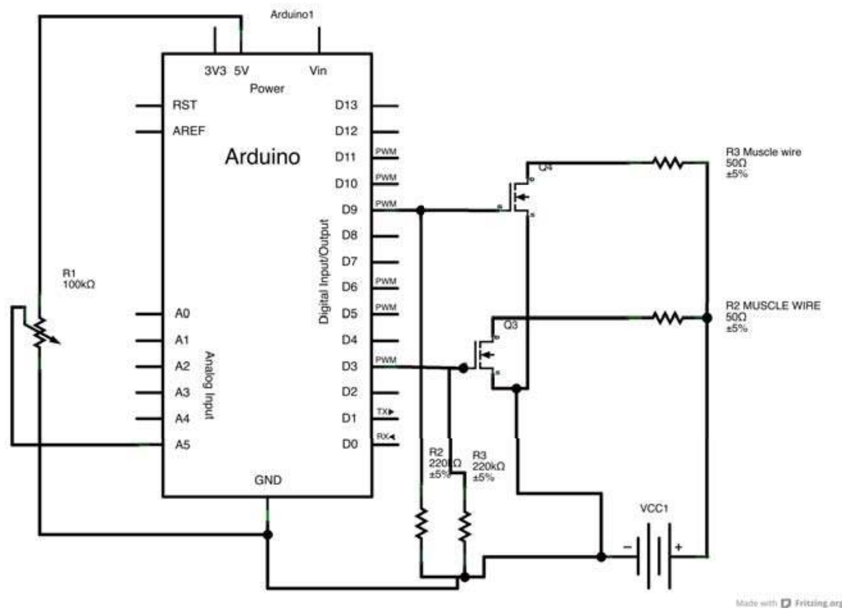


Figure 36: The circuit for the connection of 2 wires, Q3 and Q4 are mosfets to control the power for each muscle wire.

NiTiNOL is the moving soul of our grass

NiTiNOL is a class of memory shape alloys (MSA, as mentioned at the beginning of this dissertation), composed by Nickel and Titanium, it has the property of remembering the shape imprinted and restoring it under certain condition (depending on the specific kind), even after mechanic deformations. We are using a specific kind of NiTiNOL family: Flexinol. It is forged in different way than other MSA, during the austenitic phase (hot) it contracts and in the martensitic (cold) it relaxes, allowing to be mechanically pulled. This means for the contraction it needs to be heated (using itself as a resistance, with current depending on the thickness), and in the cooling phase it needs to be mechanically pulled to the original length.

It is all heat dependent

To reach this result we used an Arduino board[2] and some minimal component, such as resistances and mosfets (as shown in Fig. 36). The principle is to apply current to heat up enough the wire to reach 70°C but not much more (or it will overheat and loose the memory shape property). We did not want the process to appear unnatural so we used a PWM[3] to control and limit the amount of current given to the wire, slowing the reaction time when necessary. This way It is

2 http://arduino.cc, one board controls one blade of grass, but with some optimisation, the number of blades can be incremented.

3 Pulse-Width Modulation.

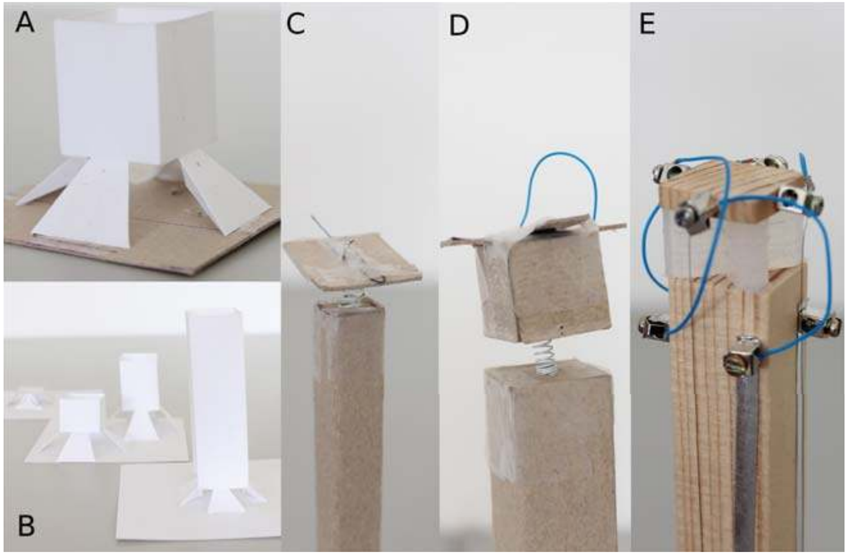


Figure 37: Several models for exploring design and mechanics, from the earliest prototype in paper and plastic to the latest. Section A and B are based on the material elasticity, in C and D we inserted a more powerful spring for allowing the wire to extend back to its original shape, in E we substituted the spring with a "X" silicon mold.

possible to vary the duty cycle to make the heating process faster or slower, resulting in faster or slower movement of the grass, allowing for controlled organic movements and animations.

The reaction time of the actuator is relatively fast, taking about half a second to contract. Here we refer to the complete contraction time, from resting position to the end of the animation. In order to avoid a "switch-click" effect (sudden movement from initial position to the final), we slowed down the reaction to a more "organic" contraction speed of around one second. Combined with a relaxation time of around one-and-a-half seconds[4], the animation of a waving piece of grass is nearly symmetrical. More details about use and problems can be found in Section 4.4.

It is too fast!

The base of our actuator need to measure enough to ensure enough contraction space. We estimated at the beginning that it should measure 20 centimetres in height. The wires, in fact, contract longitudinally about 4% of their total length.

It does not contract much

4.2.3 *Designing a Root*

The main goal to keep in mind was to create a grass element easy to multiply to be possibly controlled in batches or in larger matrix composition. The idea of a bending platform has been explored starting

4 This amount of time is required for relaxing without forcing the wire.

with the use of the materials itself. From the basic idea of origami grass it evolved in a functional way toward the actual prototype. At first the prototypes were made with paper and plastic, then with cardboard and wood (as is possible to see in Fig. 37). The early prototypes, even if promising, showed immediately limitations and replicability problems, both in movements and in the material used. Before arriving to the actual simplified shape we passed through several preliminary versions.

Each phase of development has its perks

Starting from the beginning, we used the stiffness of the material itself to allow the movement (Fig. 37 section A and B). The muscle wires were connected from the bottom inside the structure under the flaps, pulling them to make the whole structure to bend (Fig. 38). This has proven to be not a trivial challenge. In fact the material was not strong enough to allow the wires to be pulled back at their original length (even for the smallest size of wire, 75nm). The base design was made in this way to have the long part (as a straw) bending and to use the muscle wires for actuating the movement, allowing us to hide everything but the movement itself. The need for strength immediately led to a stronger structure and the use of springs of different dimension (Fig. 37 section C and D). This introduced new problems, such as: alignment of the wires and a more reliable way to fix the wire itself.

1st challenge: strength of the materials

The alignment problem has been introduced due to the new balancing mechanism for pulling back the wires to their original length, as one is contracted the opposite (fixed to the opposing edge) get pulled to its limit, making the spring compress and shift toward the pulled wire. If the wires were not precisely aligned all the mechanism was driving the bending in random directions. The use of the thicker wire also introduced the problem of attaching it with a more secure and stronger way: cardboard, strings and tape used before were not enough anymore to maintain the tension needed. We have been forced to explore other materials and mechanics. To have a better control over the movement we evaluated several alternative, including multiplying the springs (using one to include each wire or fixing one spring per corner). But it was making the construction more and more complex to assemble and calibrate with the right tension.

2nd challenge: alignment

3rd challenge: engineering the connection of the wire

4.2.4 *A better spring*

We explored different mechanism for making the grass bend, starting from the idea of using origami and the constructing materials' folds to allow only certain movements (mimicking hinges behaviour), using a small springs, to finally setting up a mould of a silicon with a suitable shape. We decided then for a dielectric gel, or a silicon, strong enough to sustain the top and the relative tension of four wires. We created different shapes for testing which one gave the best con-

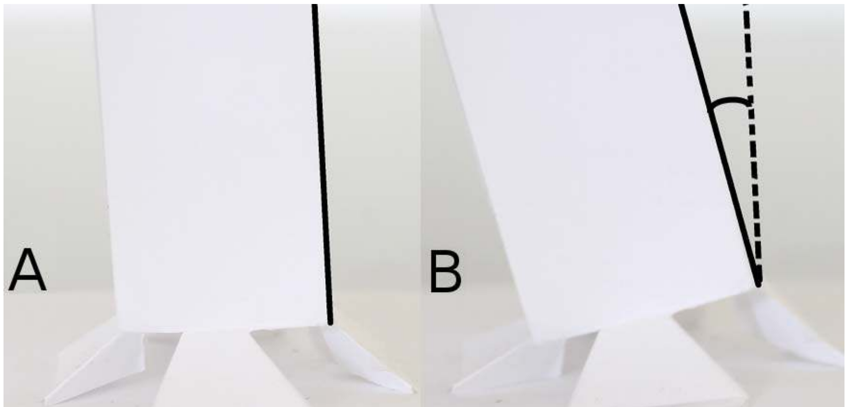


Figure 38: Original model's idea of displacement, paper deforming-hinge.

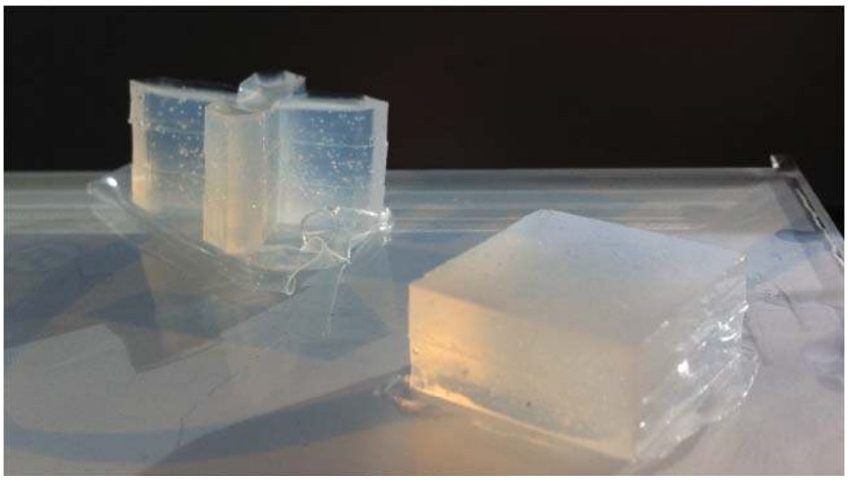


Figure 39: First batch of silicon mold, cross shape and flat square.

trol (square and diagonal cross Fig. 39). We tested different kinds of silicon to find the right consistency to have a material soft enough for our purpose. We chose the diagonal cross (for the mould shape) and placed it with the hollows parts facing the wires (Fig. 37 section E). This positioning allows a precise movement toward the wire. It corrects any possible problem of alignment of the wire connection, forces all the movement to converge toward the side, allowing to bend only in the main four directions. And it still enable to bend the platform toward the diagonals contracting two adjacent wires at time. We also chose the softer version of the silicon available on the market (medium-low stiffness) to allow wider movements of the top.

Stiffness contributes as much as shape for the spring

4.3 AESTHETIC SIDE

Up to now we discussed the root and the bending mechanism design, but all this parts will be barely visible to the eye of the user.

Grass should pleasant to watch and behave naturally

The most visible part will be the grass itself. Aesthetics of interaction has recently emerged as new area of research in the field of HCI [39], proposing the idea that the visual qualities of the object designed should try to valorize the transparency and the efficiency of the interaction itself [51]. In our case, the grass should be a form or material that could behave and look like a straw of grass, gently waving like under a summer breeze, and still come back to its original stand without putting too much strain on the mechanism underneath. The change of position should result in a fluent and continuos movement, therefore the material adopted should be a compromise to the best possible looking grass and the most manageable material.

Simpler grass behave better

We made several attempts with paper grass, origami grass as well as with different kind of synthetic grass. But the only one light enough to not compromise the stability of the element, and being able to show significant movement when bending, is the simplest one: a model made of two thin plastic stripes straws, rolled along the short side around a small stick (Fig. 40). More believable kind of grass has been tested but the material was always too heavy and, if not perfectly balanced, the grass blade tended to fall in one direction.

Animation and control are part of the aesthetics

We think that the aesthetic of the movements will be another key role in the interaction for large scale application (such as Fig. 35 section A). Creating an harmonious movement in the animation of all the grass blades together could be a difficult challenge to achieve (the speed of contraction could change with the ambient temperature variations, and different patterns could collide during the real action). It will also be needed to create different animations to capture the attention of the users in different way and communicate more information. To have a more natural movement we already slowed down the reaction time of the wires to avoid the "switch-click" effect, by powering the wire with less than 70% of the sustainable current. This allowed the wire to behave symmetrically, having the same speed for contraction and relaxation.

To further improve the appearance and the fluidity of movements, on some of the grass blades we added small origami flowers. This has a double effect: put some weight on the tip of the straws to make them sway in a more fluent and continuous movement, put an eye catching spot that can attract and lead the sight of the user toward the intended direction. Also for this improvement we tested different sizes and materials (see Fig. 41 and 42 at the end of this chapter).

4.4 MATERIALS CONSIDERATION

As a smart material NiTiNOL alloys should be controllable giving the right input to it. But there are many problems that an interaction designer have to face before really arriving to use the material.

NiTiNOL compared to motors is *cheaper*, *lightweight* and *more durable*. However, there are several potential problems we should be aware of:

The material does heat up. there are several different kind of NiTiNOL, some of them have the transition point at 70°C and others at higher temperatures 90-100°C. This fact has to be taken into consideration when the material touches sensitive parts, like skin or inflammable materials. In general, the higher the transition temperature, the higher the speed of transition. The temperature around the wire influences the condition of contraction: in a sealed enclosure, the temperature could rise rapidly.

It heat up a lot...

Overheating the wire is highly possible, especially without safe mechanisms. It is easier to avoid overheating using thinner wires (<100 micron). If fed with the normal (or a little more) amount of current, it is virtually possible to have it permanently contracted without overheating.

NiTiNOL might break with too much heat

The contraction time depends on both external temperature and thickness. As expected, thicker wires take more time to cool down. On the other side, sometimes the transition occurs quickly (especially in the austenitic phase), so it is better to use a PWM system to control the amount of power fed in the wires. Variation of the duty cycle of the PWM can also create interesting effects on the animation, changing the contraction time in favour of a smoother and continuos movement. With a feedback sensor (gyroscope, accelerometer, etc.. depending on the application) it is possible to regulate the contraction of the wire, allowing to be stationary around a specific length. The thicker the wire is, more unstable and difficult the operation become. If it is contracted for too long time, there is the risk of *overheating*.

Contraction time depends on power but also on wires

Contracting the wire at first can be a tricky task. The wire must be firmly connected to the power supply (more difficult for thinner sizes), and to be in tension (enough to straighten the wire). If not, the wire will be free to move and will not contract in the correct direction.

It must be carefully connected for making contact

Soldering NiTiNOL's wires is not possible. Traditional tin based solder and using high temperature will over burn the wire. It is mandatory to fix it with crimps or other contact solder free methods. Thin wires tend to slip out of their crimp when under tension. It is necessary also to always test the conductivity of the connection.

NO soldering

Connecting the wire in place is not trivial, because the wire is very resistant it tends to slip out of his place on the long run. So it needs to be firmly blocked between two solid metal press.

It must be sturdily fixed

Getting shorter is the main property of the Flexinol wires, but the total amount of length loss is around 4%. In most of the cases it is possible to use levers and other mechanical trick to extend the possible movement generated by the contraction. In our specific case the contraction constitute a variation of angle enough to show movements.

It shrinks only of 4%

Short-circuits are always behind the corner. Wires are often exposed to the possibility of contacts with other wires because they need to

It is easy to make short-circuits, that easily start fire be free to move for the contraction. In one of our early experiments with the material, we accidentally short-circuited two wires, causing one to fuse with a small sparkle that was actually over 600°C.

Fine tuning can cost a lot of time

Muscle wires (and in general all NiTiNOL wires) need to be calibrated in place for the right amount of tension, to balance the pulling force and the freedom of contracting. Each size of wire have a different strength that grows rapidly with the thickness, starting from 30g to 6kg for Flexinol[5]. This leads to the conclusion that most of the time, unless strictly necessary for rapid prototyping, it is simpler and still a good choice to calibrate the wires roughly by eye, because the calibration process can take a huge amount of time.

4.5 REFLECTION ON THE DEVELOPMENT OF FOLLOW THE GRASS

This chapter presented a first step for integrating smart materials in the interaction design process. Although the prototype developed up till now can still be refined, for example by introducing more efficient and ad hoc hardware, it still represents a good starting point for exploration.

Exploration and challenges, might make the designer grow

Applying smart materials in interaction design prototyping is not a simple matter. As demonstrated in our experiments, we met many technical difficulties. We needed to explore not only different design solutions but also nontrivial technological and mechanic complexities. The possibilities given by the new material offer new kinds of challenges for the traditional designer, but also open up to an unpredictable space for designing interactions. Coping with the new skills required to master the material properties is probably the biggest obstacle for the designer. It can involve skills and knowledge from different fields, and there is not a fixed methodology for using the material itself. Many researchers are experimenting and finding new ways for using it for interaction purpose, creating new case studies that can give hints and suggestions for developing different applications.

As this chapter is based on a technical paper oriented as guidance and inspiration, we hope that this experience and the knowledge acquired during the process can be of use to others when designing smart material interfaces.

5 Data sheet available on the producer site.

Figure 40: First aesthetically appealing grass model (V1), detail of the upper part, the only part the user is aware of.

Figure 41: Second aesthetically appealing grass model (V2), detail of the upper part. The model has been enriched with a set of origami flowers that bend the grass and sway the blades in a continuous way.

Figure 42: Third (minor revision) aesthetically appealing grass model (V3), detail of the upper part. The flowers material has been changed to give a more natural appeal. The reduced weight helps the swaying to have a more natural movement. The finger give the reference size o the origami model.

Part III

EXPERIENCE

In this third part we introduce the possibility of learning by experimenting with SMIs. We give tools for learning and work our educative path guiding young children in the use of SMIs to convey a higher level message: environmental awareness.

Others (children) use SMIs to *learn* a message we designed.

"[..] when you take off the screen,
information starts to act like a material,
a new material with new capabilities,
that can create new object or component."

— Mike Kuniavsky

5

SMART MATERIAL INTERFACES FOR EDUCATION: THE EXPERIENCE

This chapter describes a learning experience held with a class of primary school children who were introduced to a novel class of resources (smart materials) and the interfaces built with them (Smart Material Interfaces). The pupils were guided along a multidisciplinary educational path in which traditional and innovative teaching methods were composed for educating while engaging the children. It led to the creation of 6 automated puppet plays focused on the themes of environmental awareness as a result. In this process, storytelling and visual programming acted as powerful means for merging different educational concepts and techniques.

This chapter is mainly based on [69] and [76].

5.1 MOTIVATION FOR THIS STUDY

Time to update teaching

Educators should be able to offer up-to-date educational paths capable of integrating the novelties of science and technology with the engagement of the pupils for improved learning. Smart materials represent a novel and interesting technological topic to teach and learn. They can change their physical properties (for example color, shape, stiffness and so forth) and they can be manipulated and controlled through different hardware platforms (e.g. Arduino) for the creation of interesting and engaging interfaces (i.e. Smart Material Interfaces, SMIs). The interest of this exploratory study lays in the introduction of these complex technology topics in the Primary School and on the design of an interdisciplinary educational path supporting this goal. For reaching this goal the educational experience included scientific, technical, artistic topics and literacy skills, meant for engaging the children while educating them. It is important to underline that the topics that were introduced for stimulating the interest for the smart materials worked not just as a means but they were themselves a focus of interest.

The power of storytelling

Storytelling, which has long been recognised as a powerful means for engaging children in educational contexts, was used in this work as a glue for connecting the different educational topics. Storytelling provided an overall goal to the students' work: the creation of stories focused on environmental awareness themes. In this experience the children were challenged in the creation of origami[1] models as elements of a story. These elements were augmented with smart materials and programmed to act as the stories created by the children prescribed.

S4A+Arduino

A Scratch[2] based environment, Scratch for Arduino (S4A), was used as mediating tool for translating the narrative structures into programming blocks. It connected the models to an Arduino board[3] for triggering the actions of the associated smart materials. The Arduino-controlled stories were finally represented in cardboard theatres.

Data collection

The data collected during and after the experience indicate that the educational path was perceived as engaging and that the children improved their skills and knowledge. We collected these data during and after the experience using different means: direct observation, video recording, questionnaires and also replicating some tasks a few months after the end of the project. The engagement was positively evaluated through the analysis of various parameters [79] such as: perceived usability, felt involvement, focused attention, aesthetics, novelty and endurability. The educational impact was measured some

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1 Origami: the Japanese art of folding paper into decorative shapes and figures. From Japanese, oru, -ori 'fold' + kami 'paper'.

2 A visual programming tool `http://scratch.mit.edu` from MIT

3 Arduino is an open hardware platform `http://arduino.cc`

months after the end of the pedagogical path and revealed improvements in all the areas involved by the multidisciplinary experience.

In the next sections we will show an overview of related works (Section 5.2) and all the materials we employed (Section 5.3), then we will describe the teaching process through all the phases (Section 5.4). In Section 6.1 we will analyse and discuss our results and evaluation followed by our conclusions (Sections 6.2-6.3).

5.2 RELATED WORKS

There are many different ways to engage and attract the interests of younger minds. Some of these require the child to get more intrinsic motivation perhaps with the help of a new kind of interface.

Among the different ways to increase motivation, one is possibly making the task more enjoyable, for example by using novel interfaces instead of traditional ones. It is possible for example to use interfaces made of physical objects, often belonging to the everyday experience, instead of traditional ones based on the WIMP [41] paradigm. One of these novel interfaces is described in [111], where Sun and Han tested different kinds of input interfaces, such as: keyboards, aluminium foil pads and bananas. Even though the bananas scored as the worst in performance, they were also the best for engagement and enjoyment. Other possibilities are toys such as Makey Makey [27], that proved to be an interesting tool to create tangible interfaces with children [28]. Makye Makey allows the use of everyday (conductive) objects such as fruits or play-doh, to create interactive interfaces that can drive games made with Scratch[4]. This allows the children to have fun with games, but still to learn and improve their personal skills. In this context of development of games for children with Scratch we need to note that other visual programming environments have contributed significantly to the field, an example is Blockly [2]. Blockly is a similar visual programming editor (usable via browser, without installation of software or plugins) that allows children to learn programming while playing. Leduc et al. [60] evaluated accessibility in different fabrication tools for children, in particular for children with special needs. They pointed out interesting questions about accessible design. Jacoby and Buechley tried to make the children experiment a different approach to storytelling with new tangible technologies such as conductive ink [48]. They taught children about circuitry and conductivity with an interesting kit (StoryClip) to produce drawings that they could bring to life with their recorded speech, giving new life to paper with augmented properties. The same goes for Takegawa at al. [113], they involved and maintained children's attention by making them play with drawn musical instruments made with conductive

Making the task more enjoyable is a big task

4 Scratch is a visual programming language http://scratch.mit.edu developed at MIT

ink. The above studies also tended to ask the children to make things, to produce their own object of play.

Storytelling and visual programming: a possible children development method

As we know from [31, 38], "many studies [...] suggest that storytelling (meant as the capacity to listen, tell, and reflect on stories) is an extremely important developmental area for children, promoting a wide spectrum of cognitive functions and skills: expression, communication, recognition, recall, interpretation, analysis, and synthesis". Some experiences related to storytelling take advantage of visual programming languages. Different researchers have designed and experimented with visual paradigms for children, with the goal of teaching them to program. Alice [1], one of the most famous languages, allows children to program a 3D environment using a drag and drop style. Looking Glass [3], a successor, introduces children to programming by coupling 3D and storytelling. Scratch is a block based graphical programming language that permits children to build 2D stories and games. Jacoby and Buechley experimented with children a different approach to storytelling with new tangible technologies such as conductive ink [48]. They taught children about circuitry and conductivity with an interesting kit (StoryClip) to produce drawings that they could bring to life with their recorded speech, by enhancing traditional paper with augmented properties.

Creative environment where children use tangible objects

The educational project presented in this work takes advantage both of visual programming paradigms and augmented physical objects, for building an engaging storytelling experience. In our work the plain physical objects are augmented taking advantage of the properties of smart materials. A number of researchers involved in this research used just paper, in the artistic shape of origami, to engage the users. Boden et al. [12] describe a system designed to support augmented play and learning for children, that makes use of origami and augmented reality with fiducial markers. In [30], Do and Gross try to explore the possibility of creating creative environments by using interactive spaces, and also using origami as a means for teaching and learning geometry and spatial reasoning skills. For example in [133] Zhu tries to create a framework to facilitate paper-computing interactions, specifying new technologies for recognising and powering up augmented origami creation. And before him Coehlo [24] theorised about embedding materials in the paper making process to create sensors and interactive surfaces, or just computers. Other also in the past tried to couple new materials with toys, for example in [10] textile is described as a user interface for an interactive toy that responds at events by changing pattern or color.

As we have seen in the past chapters (SMIs, see section 1.2.2) the recently the increased availability on the market of new kinds of smart materials, gave a boost for creating interfaces for learning, teaching and most of all increasing and supporting creativity with many different techniques [71]. Some of these are more expensive, others cheaper,

Session	Lesson description	Survey	Main Focus	Duration
1	We taught the children how to make plain origami models and create stories with them(Sec. 5.4.1).		origami	1 half-day
2	We introduced SMIs with several small examples. (Sec. 5.4.2).		SMIs	1 half-day
3	The children modified their stories for adding smart materials to origami (Sec. 5.4.3).	First (Appendix A)	narration, SMIs	1 half-day
4	The children broke down their stories into narrative blocks, introducing symbols to come closer to a programming language (Sec. 5.4.4).		narration, programming blocks	1 half-day
5	We explained the basics of programming in S4A and taught how to create origami animations on Arduino from S4A. We asked the children to program their stories(Sec. 5.4.5).		S4A, Arduino	1 day
6	We prepared the setup for the final cardboard theatre representations (Sec. 5.4.6).		S4A, Arduino	1 half-day
7	The children saw the realisation of their work and filled in the second questionnaire (Sec. 5.4.7).	Second (Appendix B)	grading	1 half-day
8	We evaluated the educational impact after the end of the experience (Sec. 5.4.8).	Final (Appendix C)	evaluation	1 day

Table 3: General description of the time line of the experience, and focus of attention for each session.

but all of them try to interest and empower the user in making things, in participating in the creative process.

5.3 MATERIALS FOR THE EXPERIENCE

The smart materials used for this experience are of two different kinds, the choice was based on the most aesthetically and interesting properties: changing shapes and colours. We used thermochromic paints of various colours and SMA wires.

This thermochromic paint change transparency at 31°C

The thermochromic paint is a paint that has a thermic threshold, once this temperature limit is reached the paint becomes transparent and the color seems to disappear. Several colours were used, including the 3 primary ones. We decided to apply a serpentine made with a resistive wire to the back the paper to reach the necessary temperature gradient, this allowed us to "switch the color on and off" by command.

NiTiNOL actuators simplified for the purpose

The SMAs, as we mentioned in section 1.4, are a big family of materials: what we employed NiTiNOL. This specific kind has the property to contract once the temperature threshold is reached (Flexinol[5]). With the knowledge acquired with the experience and experiments, we created several actuators made with it to be applied to the children's creations. They were made following the implementation showed in [74, 70] (see Chapter 4) but with only one degree of freedom (a single muscle wire for each actuator). You can see an example with an origami model of a moving mouth in Fig. 43.

To control the temperature in both cases we used Arduino[6]and a small paper board made with conductive tape with a MOSFET[7] on it. Each board was used to control a single origami model and the related animations.

Paper for origami

We gave the children normal typographic paper and origami paper to create the elements for the story.

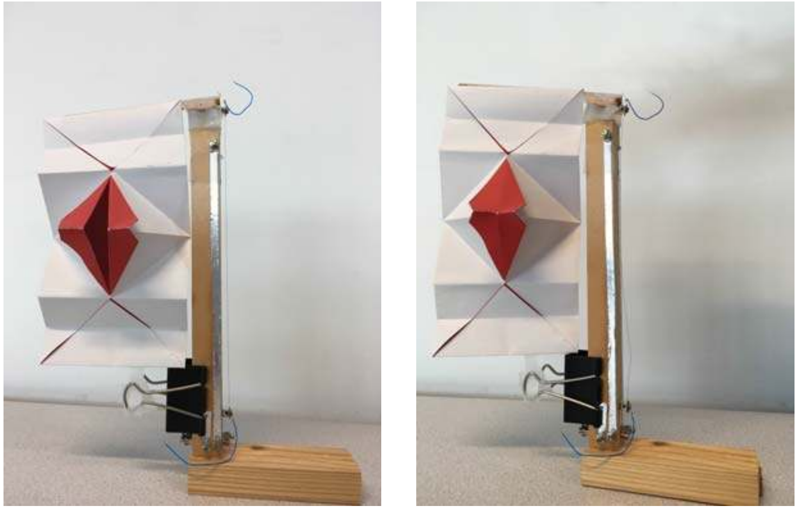
Visual programming for everyone

For the educational experience we decided to use a modified version of Scratch: S4A[8]. S4A allows the control of external actuators through the output pins of Arduino with the same language as Scratch. This way the children were able to program Arduino and to create the required animation for the smart origami models by themselves.

Big theatre cardboard theatres

Finally for allowing the children to enter, create and record the play in the proper condition, we built three, two sided, cardboard theatres: each one is about 1 m wide and about 1.8 m tall. Each side was historiated with decorations and colours inspired from the themes given to the groups (Fig.46). We also made use of a similar smaller ready made cardboard theatre (Fig.45).

5 Flexinol is the brand name of the wire employed. The wire stretches and shrinks longitudinally. More technical information can be found at `htt://musclewires.com`.
6 Arduino is an open hardware platform `http://arduino.cc`
7 A specific kind of FET transistor.
8 Realised in the context of the EU project Citilab `http://seaside.citilab.eu`.



(a) Actuator not contracted (b) Actuator contracted

Figure 43: Here is an example of the NiTiNOL actuator used during the experience for animating the the origami creations of the children. The support is made of simple wood with a floating head hooked to the NiTiNOL wire (so to be free to contract), the head is pressed from the wire tension and tape (to keep it in place) over the silicon spring. a) Not contracted, mouth open, b) contracted, mouth closed

5.4 teaching process

We experimented our learning path with a class of 19 Primary School children, all aged 9. None of them had any prior experience or knowledge about programming or visual programming. Some of them displayed partial knowledge about the use of the WIMP paradigm. The project was developed through 8 sessions held in the classroom and accompanied by additional homework.

All primary school children with no experience

During the whole process two researchers were in the classroom, assisted by the children's teachers. Most of the sessions included collaborative phases where the children were organised in 6 groups: 5 of which composed of 3 children and one of 4 (3 groups of boys, 2 of girls and a mixed group), that were maintained till the end of the project. During the experience we gave 3 sets of evaluations, the first two during the experience and one after its end. In Table 3 we summarise the timeline of the whole experience.

The children worked in groups and individually

In preparation for the experience the teachers debated with the children about environmental behaviours.

5.4.1 *Session 1: How to make origami models to tell a story*

Individual learning origami and group story telling

In the first session the children learned the basic techniques for making origami models. They were taught how to make simple forms for representing animals, trees and geometric shapes (Fig. 44). They worked individually for almost the whole session. In the same session we organised them into groups and asked them to create simple stories to be presented in a small cardboard theatre (Fig. 45). Here the origami models created in the morning would play the part of characters. At the end we assigned the first homework. We asked each group to create a narration inspiring positive environmental behaviours. The story had to be presented with origami models, as for the first presentation.

Environment friendly behaviour is the main connecting theme

A unique theme was assigned to each group: *energy consumption, light management, heating, mobility, water consumption and waste management*. We also gave each group a list of positive behaviours for inspiration, coming from the activity done before the start of this experience. The week after, before starting the second session, we listened to the stories that they had created. The children presented their stories in front of their classmates, taking advantage of one of the big cardboard theatres, also used for the final representation. One of the children read the narration while the other group members moved the related origami models by hand as puppeteers.

5.4.2 *Session 2: Explain SMIs the easy way*

This session was dedicated to introduce the children to SMIs. The children were given explanations about the meaning of SMI and they

Figure 44: Children making origami models during the first day.

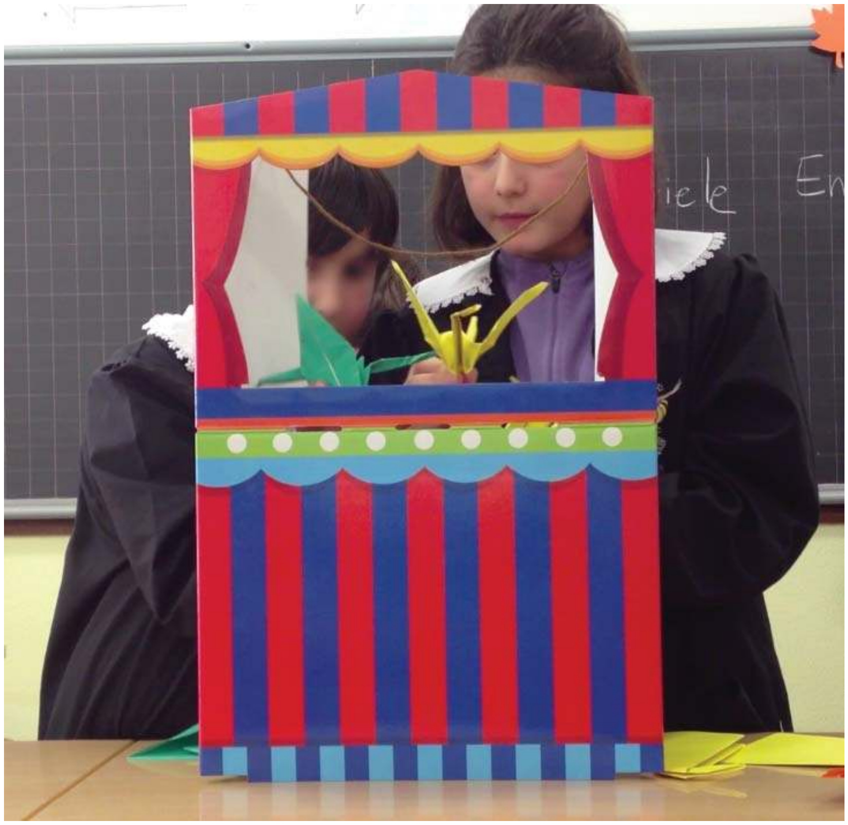


Figure 45: Children during their presentations in the small theatre.

were given practical demonstrations of origami models enhanced with smart materials. We showed them how the NiTiNOL wire could be used for generating transformations in the shape of an origami dog. We focused their attention on the fact that the wire, the origami model connected to it, could undergo transformations as a result of the activation of a battery. We experimented also the use of a proximity sensor for triggering the transformation. We then showed how the same NiTiNOL wire could be used to obtain simple rotations of another origami model, with a different connection. We showed the children examples of thermochromic paintings applied to origami representing a whale, a crane, a Christmas tree and a house. We focused the children's attention on the fact that the thermochromic inks disappeared when a battery was connected to a resistive wire positioned under the painted surface, as a result of the paper heating up. In some cases the activation of the battery resulted in simple chromatic effects, while in other cases it revealed hidden drawings. The activation of the smart materials was manually triggered by the researchers or by the children. After the practical demo the children had the opportunity to examine the smart materials. They experimented by heating the colours with the natural warmth of their hands.

Let's interest them with SMIs

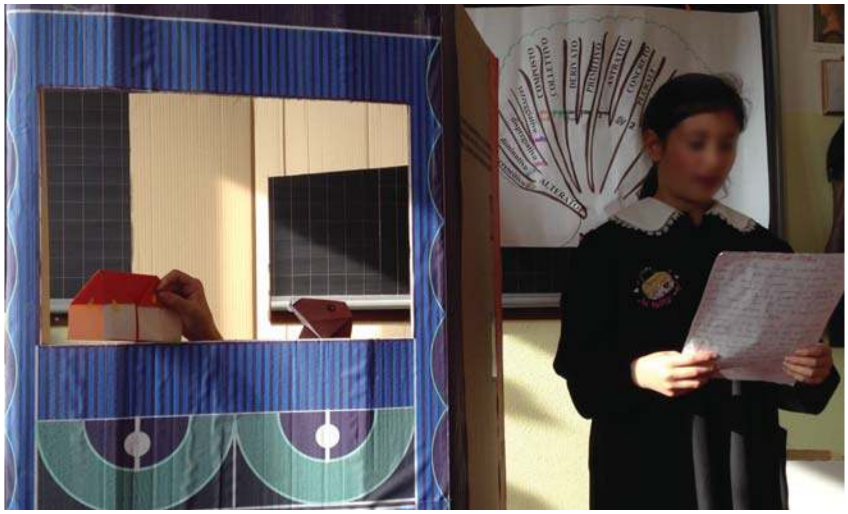


Figure 46: Theatrical play of one of the groups' stories. On the left the big cardboard theatre with two children inside, moving the origami model, while the third is reading the story on the right.

5.4.3 *Session 3: Let's modify the stories to make them animated*

Development of the stories for animation

First questionnaire (Appendix A)

At the end of the previous session the children were given their second homework. The groups had to modify the stories they had created to take advantage of the possibilities offered by the smart materials. The idea was to animate the origami models mechanically and to create dynamic effects with the smart paint. For technical reasons, we did not allow the use of more than three smart origami models, but we gave the freedom to choose among any combination of NiTiNOL wires and thermochromic paints. The children were given a questionnaire with both closed and open questions. We used it for assessing the children's opinions after the first contact with the smart materials. A week later, we analysed the children's homework. The groups had chosen different combinations of mechanical animations and chromatic effects, sometimes modifying the narration for adapting it to the introduction of smart materials. For example a group with a story about a dog and four frogs living in a house, took advantage of smart materials for animating the most dynamic character, the dog. The children decided to use thermochromic paint for revealing the content of one of the posters written by the dog. They also added a sequence at the end of the narration where the curtains, painted in thermochromic ink, disappeared to let the sunlight in (see Fig. 53).

We assisted the children in creating or modifying the existing origami models to support the edited narrations. Because of time constraints, we did not have the opportunity to let the children play with the resistive wire. However, we gave them the opportunity to apply the thermochromic paintings to their paper works, as can be seen

Figure 47: A child paints a peacock feather with thermochromic ink.

in Fig. 47, and we positioned the wire for them after the end of the session.

At the end of the session we showed the children how the puppet plays could be triggered not only manually, but also automatically driven by a software program, generating complex automated shows. We gave them a practical example of the final result, a play in the cardboard theatre of a story that we had previously written. In it, the smart origami models, that we had shown them in the previous session, acted as automated characters while a recorded narration was played (Fig. 48).

Learn by example

The story also included audio effects (e.g., the barking dog) that were inserted and sometimes iterated in the narrative flow.

5.4.4 *Session 4: Analyse the story and split in narrative blocks*

At the end of the previous session, the groups were assigned their third homework: to analyse the story that they had created and identify its basic components. We asked them to identify with arrows the different sentences, distinguishing the parts played by the narrator and by the different characters.

We asked the children to introduce or identify the audio effects that they wanted in the story by using additional arrows and to use a circular arrow with a number for identifying the repetitions (e.g., a triple barking should have been represented with the label *bark* preceded by the circular arrow and the number 3). We introduced the green flag symbol for specifying the beginning of the story and the red signal with the label *stop* for identifying the end of the story

This is the base for programming easily later on

Figure 48: This picture has been taken during the demo of the story the researchers created to show how the smart origami models worked with the story. From the left: 1) in orange, the barking dog, actuated by a NiTiNOL wire, 2) in the centre a crane with thermochromic ink on the wings and 3) on the right, a house with flowers hidden behind the thermochromic curtains of the windows. On the outside, in green, one of the cardboard theatres also used during the children's presentations.

(Fig. 49). The children could use the same symbol, accompanied by a numerical label if they wanted to introduce pauses in the narration (e.g., a pause of 2 seconds between sentences spoken by a characters).

For easing their work, we gave the them a complete analysis' example: the story text we had just played (Fig. 48) with the symbols.

5.4.5 *Session 5: Programming (in S4A) and record the story!*

This session lasted a whole day (8h).

During the first part, we showed the theatrical play of our story again, then we explained how everything worked. We showed how the smart origami models (SMIs) were connected to Arduino and how they could be controlled from S4A.

We explained commands, translating in Italian

We showed the children how the structures of our story had been translated into visual code that could be easily read and run by clicking a green flag placed at the beginning. We showed examples on how the narrative blocks and the other structures could be translated into visual programming entities. We focused on the programming entities that we could associate with the narrative blocks: the *play sound* block for playing the narration fragments and the special effects and

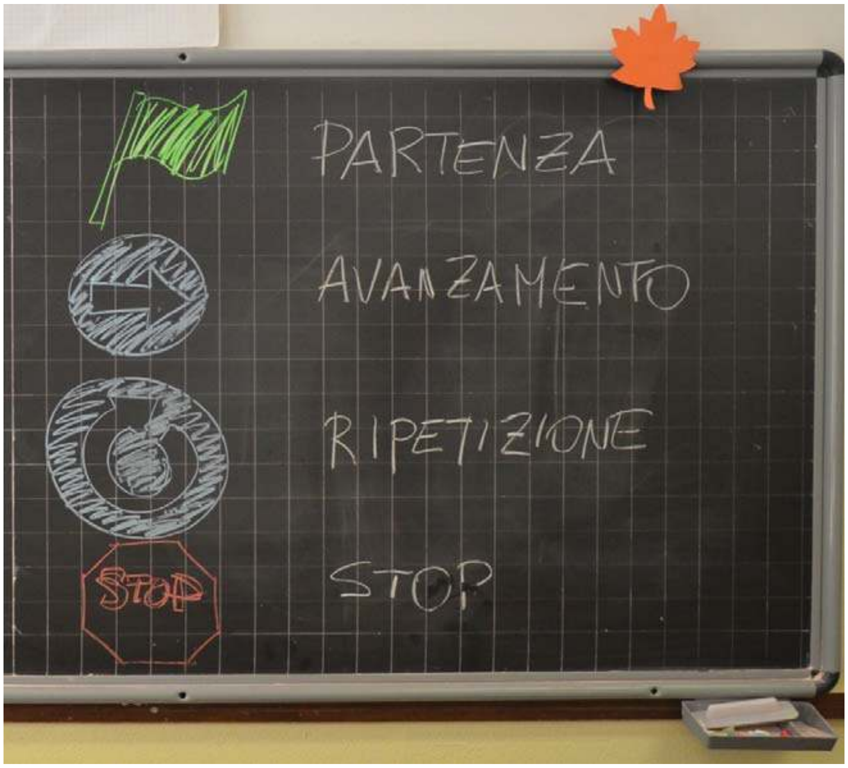


Figure 49: The instruction marks used by the children, from the top: START, STEP, REPEAT, STOP.

the *analog* block for controlling the smart origami figures. We also showed the different control structures that we had mapped to the narration (i.e., the sequence of blocks, *start* and *stop*, *repeat* and *wait*) and parameters.

After the explanation we organised the following work in separate sessions. Each group was followed by one researcher that assisted the children in the process of translating their stories into programming structures with S4A. After an initial checking of the correctness of the analysis done as homework, the process included the selection of the different blocks mapped to the narrative structures, the recording of the audio fragments of the story, the selection of the audio effects from a local repository and the specification of the parameters associated to the control structures. The children tested and ran the program till they reached a satisfying result.

We followed group by group all the work

Fig. 50 and 51 show the visual code representing the story of the dog and the four frogs. Because of space constraints the code has been split into two different columns. The children took advantage of all the different types of blocks described in our tutorials: the magenta *play sound* block, the blue *analog* blocks for activating and deactivating the origami figures (i.e., value 5 for the dog, value 6 for the poster, value 9 for the curtains). As this group also introduced a switchable

A good example of a story

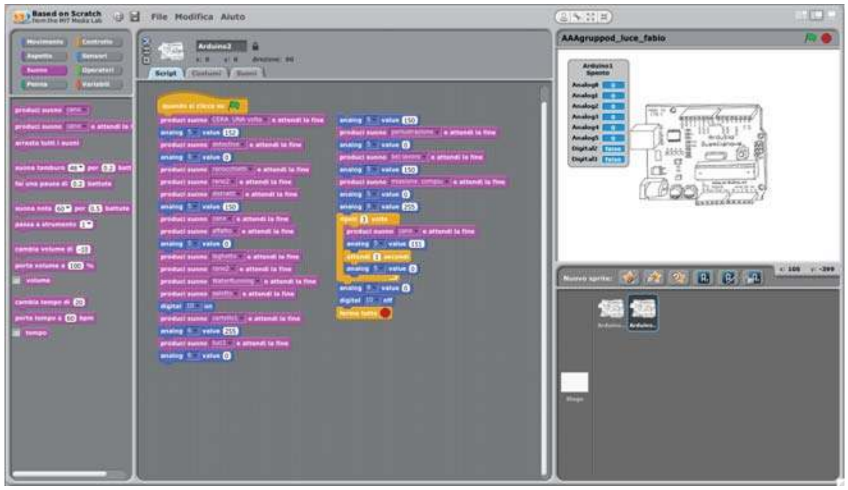


Figure 50: A screenshot of S4A. From the left: 1)the library for making animations and read/write to the pins of Arduino, 2) the actual program developed by one of the groups, with loops and animations and 3) the Arduino Area where it is possible to see the value read from Arduino in realtime.

lamp in their narration, we taught them how to control it through the blue *digital* block. The children also used the control structure for starting, pausing and ending the narration. The *repeat* was used to reproduce the barking sound and corresponding animation (repeated contraction and relaxation of the NiTiNOL wire).

5.4.6 *Session 6: Fix the scene! Proceed with animations*

After the completion of the story translations, we prepared the setup for the final representations of the stories. We used three, two sided, cardboard theatres. Each side was personalised for the environmental theme associated to the narration. After having positioned the background scenarios created by the children, we positioned the smart origami models on the scene and connected them to Arduino and to a laptop running Scratch. Because of the young age of the children, we discarded the idea of involving them in the implementation of the electric connections of the smart origami models, but we realised all the process in the classroom, so that they could see how the results of their efforts would have been translated into an automated theatrical representation. Unfortunately, for time constraints (the normal schooling hours of the class) we were only able to finish the setup and play one of the stories created by the children. This was sufficient to let all the children see the process of building the final representation, but prevented most of them for seeing their stories in the final shape. For this reason after the end of the session with the children, we proceeded on realising all the theatrical representations of the stories.

Time for rehearsal is ending

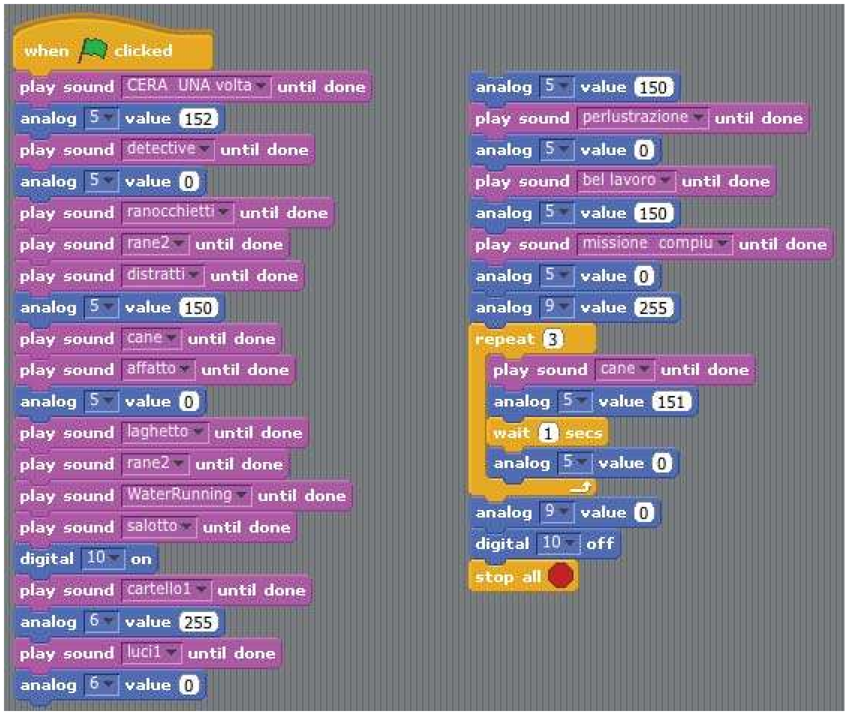


Figure 51: A screenshot of S4A with the split code of one of the groups' stories. The language of the interface was in italian for the children.

5.4.7 *Session 7: Watching and voting the stories*

This session was held in the classroom one week later. During this session the children had the opportunity to watch their stories on a large screen. An example of a final scene of the story of the four frogs and the smart dog can be seen in Fig. 53. In the same image it is possible to see the smart origami figures and how each single element works. Fig. 52 shows the front and back of the same theatre, all the wires are connected to an Arduino unit. At the end of each representation each child assigned a grade to the story. A post-test questionnaire ended the educational experience.

Second questionnaire (Appendix B)

5.4.8 *Session 8: Evaluating the educational results*

After the end of the experience, months later, we returned to check its educational impact.

Final questionnaire (Appendix C)

In the next chapter we gathered all the data analysis and the results for this experience.

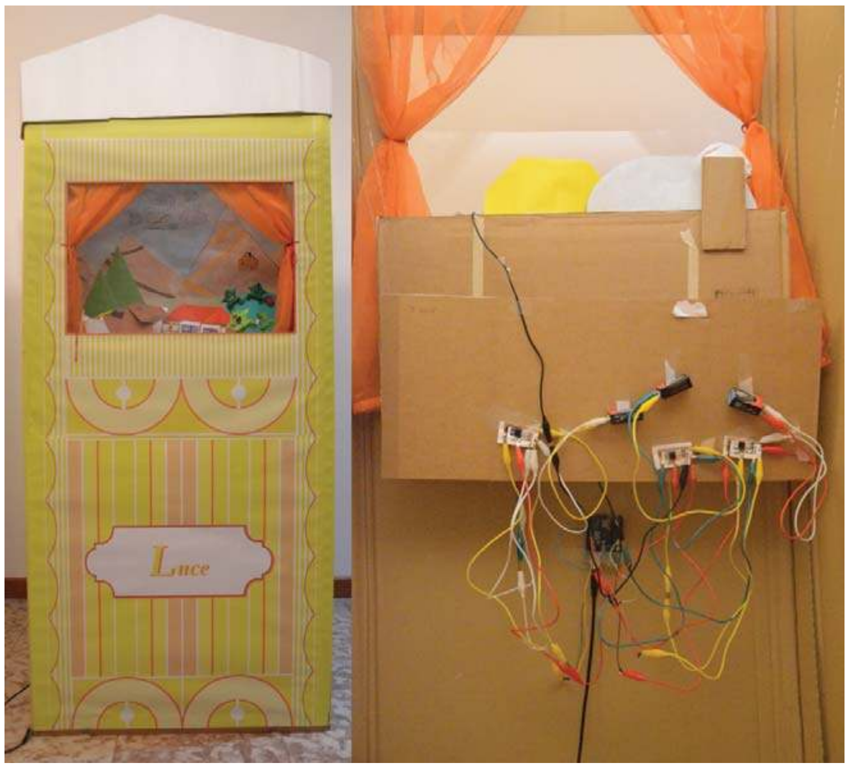


Figure 52: The cardboard theatre: front-end and backstage. On the right it is possible to see all the component to control the actuations. Arduino is the element on the bottom, in the middle there are the control switches and just over them the battery to power the animations.

Figure 53: The final version of the puppet play from the story about the four frogs and the smart dog living in the same house. The story of "the four frogs and the smart dog" living in the same house. The dog, expert on energy consumption, inspires positive behaviours and gives the frogs useful advice, exposing written posters when they forget to switch off unnecessary lights. The miniatures below the main scene represent: the animation of the dog (NiTiNOL powered), the disclosure of the word written on the poster (thermochromic paint with resistive wire), the switchable light (LED) and the curtains revealing the house's interior (thermochromic paint with resistive wire).

6

SMART MATERIAL INTERFACES FOR EDUCATION: EVALUATION

This chapter describes the evaluation of the our learning experience. During and after the experience, the children's engagement and the educational impact were evaluated revealing interesting results. The data collected through the direct observation and the questionnaires indicate that the experience was perceived as positive and interesting. The post evaluation, held some months later, revealed skills and knowledge improvements in all the areas involved by the multidisciplinary experience, from the knowledge of the properties of smart materials and the programming skills, to the increase of the environmental awareness and the skills for text analysis.

This chapter is mainly based on [69] and [76].

6.1 RESULTS OF THE EXPERIENCE

In the next sections we present all the cumulated results during and after the experience.

We tracked the educational process using several methods: direct observation, videos and questionnaires. The post evaluation, held a few months after the end of the experience, also included a set of individual and group tasks to check the educational improvements. We registered high levels of interest during all the phases, in particular for those activities that were perceived as new (i.e., origami models creation, demonstration and the making of SMI, demonstration and the making of visual programs). We measured our qualitative observations with 3 evaluations, after the first SMIs demo, at the end of the experience and a post evaluation some months later.

The evaluation is composed by many parts

Parameter	**Mean**
Overall interest for SMI	2.94
Int. for NiTiNOL wire (for moving objects)	2.61
Int. for NiTiNOL wire (for changing shapes)	2.50
Int. for thermochromic ink (for changing color)	2.67
Int. for thermochromic ink (for reveal. objects)	2.89

Table 4: First questionnaire (Sec. 6.1.1 and Appendix A) - Mean scores assigned by the children using a 3-points scale

6.1.1 *1st questionnaire: approaching SMI*

After our SMIs demo (Sec. 5.4.2), we captured the first reaction with the first questionnaire (Appendix A).

Table 4 shows the results of a set of closed questions targeted for the interest of the children for the SMI (overall) and for the possibility of experimenting again with the different types of materials. The mean results, measured through a 3-points scale (1=low, 3=high), display high interest for the SMI and especially for the use of thermochromic inks for revealing objects. We asked the children to imagine other uses for the SMIs and about two thirds of them expressed creative ideas beyond the simple extension of the functionalities we showed. Some of the proposals were focused on artistic uses of SMI, such as clocks and color changing shoes with the owner's preference or magical pencils capable of drawing in different colours. Many children proposed stimulating creative functional uses, such as glowing materials illuminating the path at night, smart books capable of turning their pages, or even super-smart materials capable of self-replicating or doing housework.

We asked about the 1st impression, and to use creativity

Parameters and Questions	Smileyom. all (a)	Smileyometer value per task (b)				
		1	2	3	4	5
perceived usability: how easy was it for you to perform the project activities?	4.14	4.2	4.32	3.89	3.79	**4.47**
felt involvement: how much did you enjoy to perform the project activities?	4.33	**4.74**	4.63	3.58	4.32	4.37
focused attention: how interesting was for you to perform the project activities?	4.15	4.32	4.42	3.63	3.89	**4.47**
novelty: how new did you find the project activities?	4.26	3.74	4.79	3.11	4.79	**4.89**
endurability: how much would you like to perform again the project activities?	4.16	3.84	**4.74**	3.37	4.11	**4.74**
aesthetics: how much did you like the stories created by your fellows?	3.81 *jury*	- not applicable -				

Table 5: Second questionnaire (Sec 6.1.2 and Appendix B) - Scores assigned by the children to the 6 parameters that define the engagement. Column (a) represents the overall mean scores, column (b) represents the mean of each task (the best task score is highlighted in bold). The list of the tasks: (1) make origami models; (2) enhance origami models with smart paintings; (3) write the stories; (4) enhance the story with smart materials; (5) transform the stories to visual programs for auto-play. For the sixth parameter (aesthetics) the mean score in column (b) derives from the votes of the jury of children.

6.1.2 2nd *questionnaire: the experience*

The second questionnaire (Sec. 5.4.7 and (Appendix C) was composed mainly of closed questions addressed to analyse different facets of the pupils' experience. We analysed the six different parameters that define the user engagement according to O'Brien et al. [79]: *perceived usability*, *felt involvement*, *focused attention*, *aesthetics*, *novelty* and *endurability*. This analysis is useful for measuring all those experiences that go beyond the working activity and whose success is also determined by parameters such as aesthetics or felt involvement. For this questionnaire we used a 5-point scale, with the *Smileyometer* for expressing the numeric values in a more friendly fashion. The Smileyometer [96][97] takes advantage of pictorial representations (smileys) for eliciting children's opinions. To be sure of the children's comprehension, we distributed the questionnaire in the classroom and read the questions one by one, evidencing the focus of each one and asking the children if they had any doubt about it. Table 5 shows the engagement parameters, the related list of questions and the resulting mean scores. We explored the children's opinions about the different active tasks that were assigned during the activities of the project. For five of the six parameters that define the engagement, we asked the children their opinion about each of the following tasks:

The focus is on the experience with detailed questions

1. make origami models;
2. enhance origami models with smart paintings;
3. write the stories;
4. enhance the story with smart materials;
5. transform the stories to visual programs for auto-play.

Column (a) shows the scores derived from the means of the different tasks, while column (b) displays the results for each task. The tasks are identified by a numerical label, referring to the numbered list that we have just described above in this section. For the aesthetics parameter, there are no analytical results for each task because we used the scores assigned by the children to each play when they saw them represented in the cardboard theatres. Column (a) displays positive results for all the parameters that define the concept of engagement. However, the analytic scoring emphasises that the use of smart paintings (2), the story enhancement with smart materials (4) and the transformation of stories into visual programs (5) obtained higher scores for all the parameters. The making of origami models performed well but with slightly lower values, especially for the novelty and the willingness to perform the activity again. Finally the story making activity worked as a glue for the whole experience and

They really loved the programming and painting

Block/Structure	Mean
start block	4.53
play sound block	4.21
analog block for activating SM	3.95
wait block	4.32
sequence	4.11
repeat block	4.11

Table 6: Second questionnaire (Sec. 6.1.2 and Appendix B)- Ease of use of the visual blocks and control structures (5 points scale Smileyometer).

gained positive values but lower for what concerned the novelty and the willingness to *write* stories in the future.

The questionnaire also included additional analytic questions about the ease of translating the stories into visual programs. The positive answers displayed in Table 6 confirm the results of the direct observation of the task execution, that was performed by all the groups nearly in autonomy after the collective demo in the classroom. While the ease of use gained high scores for all the blocks and control scores, the analog block was perceived as slightly less easy to use. This is because the meaning of the *analog* block is not intuitive. It requires one to map the SMI connected to the board with a pin number and another numerical value, the abstract duty cycle for controlling the energy fed to the SMI. A possibility for improving the situation is to change the digital (UI) and physical (Arduino) interface to a more matching and coherent meaning for the parameter choice. For example, Blockly introduced (for example on the online gaming part) a visual way to quantify the number of degrees to choose the proper value with a piechart. A complementary approach would see the Arduino interface to match colours with the S4A interface, simplifying the comprehension of the user on which is connected where.

The analog block was difficult!

6.2 final: learning evaluation

After the experiment we agreed with the teachers to come back in the classroom (Sec. 5.4.8) to check the results of the educational experience in the middle term. We had the opportunity to come back to the school a few months after the educational experience, just before of the end of the school's year (Appendix C).

The evaluation was structured into 4 tasks: two questionnaires, a text analysis task and a visual programming task. We examined several facets of the experience: the awareness for environmental themes, the knowledge about smart materials, the new skills for identifying the narrative structure and translating it into visual programs.

A very reach evaluation

6.2.1 *Tasks and goals descriptions*

A set of open questions about the experience

Task 1. The goal of this task was to verify the impact of the children narrations, on their personal environmental awareness after the end of the experience. We asked the children to fill in a questionnaire, a set of 6 open questions. For each question the children had to describe positive behaviours related to one of the thematic areas that were explored during the experience. The questionnaire was filled in in the classroom. The children had to complete the task individually in about 30 minutes.

A set of closed questions for the comprehension level

Task 2. The goal of this task was to understand the level of comprehension of the properties of the different materials. The closed questions (of the second questionnaire) were focused on the properties of the smart materials, met during the educational experience. In particular we asked the children to focus on the factors determining a change of state on the smart materials. The questionnaire was filled in by the children in the classroom in about 30 minutes.

A text to elaborate and split in narrative blocks

Task 3. The goal of this task was to verify whether the children had acquired the skill of performing a structured text analysis. We gave them a printed short story, asking them to do the same analysis they did for the stories during the experience (Sec. 5.4.4), splitting the narration in blocks and identifying them with the set of symbols that they used for their stories (Fig. 49). In addition to the symbols available during the experiment, we introduced the *Trigger* symbol, for specifying the start of the animations. Each child completed this task individually in about 30 minutes.

A visual programming test

Task 4. The goal in this case was to check if the children had acquired the skill of manipulating the entities of a visual programming language. For this task the groups' organisation was the same used during the experience. The children were asked to map the story blocks, from the previous task, to visual programming entities, as they did during the educational experience (Sec. 5.4.5). Due to practical constraints the task did not involve the real activation of smart materials. However we encouraged the children to use the proper functional blocks for activating the characters of the story. Due to time constraints we limited this task to the first paragraphs of the narration. The task was preceded by a 30 seconds recap about the categories of components available in Scratch. Because the children had worked individually in task 3, we selected only the most detailed analysis. The children then integrated it with more observations. For the execution of this task, we used a room where each group completed the task in sequence, on a laptop.

Parameter	Initial quest.	Final quest.
Electricity	24/0	**41/1**
Heating	4/21	**5/26**
Light	12/9	**16/11**
Transportation	19/9	*17*/**14**
Waste	21/0	**29**/0
Water	9/23	**19/28**

Table 7: Learning Evaluation - listing of positive behaviours related for thematic areas. The first number shows the number of answers related to issues evidenced in the stories, the second shows the number of complementary issues (in **bold**, positive increase of awareness, in *cursive* the negative).

6.2.2 *Results*

The evaluation confirmed the positive role of the experience for teaching the children new knowledge and skills. As stated at the beginning of the section, the time for coming back to the classroom and performing a post test evaluation was determined by the availability of the teachers. The results show that even after a prolonged period of time from the end of the experience (i.e. six months) and no intermediate recap, there was a high degree of retention of the knowledge and of the skills learned during the experience.

the children effectively learned a lot from the experience

Task 1. The results show that the creation of narrations focused on environmental issues had a positive impact on the personal awareness. Table 7 displays the number of positive personal behaviours described by the children for each environmental theme. It compares the results between the questionnaire filled in before the educational experience (Sec. 5.4.1) and the final post-test questionnaire. For each questionnaire and for each theme the first number displays the number of answers directly related to issues evidenced in the stories, while the second number displays the answers related to complementary issues. In most of the cases the final questionnaire reveals an improvement in the children's awareness (in bold). Only for a single theme (transportation) did the results display a modest reduction of the awareness. We think that this result might be due to the fact that the related story provided an example that was not immediately transferrable to the everyday experience (i.e., the bird flying with its own wings instead of using a jet).

There are improvements almost in all subjects

Task 2. The experience with the smart materials gave good results for the acquired knowledge, especially for those where the children had the opportunity to manipulate and not just observe them. The number of correct answers (Table 8) show that the children performed well in identifying how the two smart materials (NiTiNOL wire and

Topics	Correct answers
Factors changing appearance in the NiTiNOL wire:	
- ambiental noise (no)	17/18
- wire temperature (yes)	6/18
- room illumination (no)	17/18
- electricity (yes)	17/18
- proximity (no)	11/18
The NiTiNOL wire changed its appearance:	
- changing its length (yes)	16/18
- changing its visibility (no)	17/18
- changing its color (no)	14/18
Factors changing the thermochromic ink:	
- wind (no)	18/18
- ink temperature (yes)	16/18
- room illumination (no)	16/18
- electricity (yes)	15/18
- ambiental noise (no)	18/18
The thermochromic ink changed its appearance:	
- detaching itself from the sheet of paper (no)	18/18
- shrinking the underlying sheet of paper (no)	18/18
- changing its visibility (yes)	18/18

Table 8: Learning Evaluation - Properties of smart materials

There are improvements in all topics, but not all the details were memorised

thermochromic ink) changed their state and in understanding which were the factors driving the changes. About NiTiNOL wires, most children correctly identified the length changes and related these changes to the electric battery use, but some of them did not remember the associated temperature shift. We might relate this failure to the fact that it was not possible to let the children touch the wires during the demonstration. About the thermochromic ink, most children correctly identified the state changes and the causes that determined them. All the children had the possibility to test directly the influence of the temperature, by touching the painted objects and verifying the effect of the warmth of their hands.

Task 3. The results displayed relevant skills for the text analysis. Table 9 shows the number of symbols used for splitting each story into logical blocks, evidencing for each type mean and standard deviation. All the children placed the *Start* symbol correctly at the beginning of

Block	Mean	St. dev.
start symbol	1.0	0.0
go on symbol	8.3	4.9
trigger symbol	4.9	2.3
repeat symbol	3.1	0.8
stop symbol	7.4	4.5

Table 9: Learning evaluation - Story analysis: use of symbols for giving a structure to the whole story

the story and the majority of them used the *Go on* symbols correctly to split the text of the story into fragments. Only in 5 of the 19 the children used a very low number of *Go on* symbols (from 0 to 3 symbols). Most children identified the situations of the story that could be mapped to a cycle (e.g., repeated dog barks, noises and actions of animals involved in the story). The children appreciated the possibility to specify the animation of the characters with the *Trigger* symbol, recalling the experiments done with the smart origami. Most of them specified a high number of animations (mean 4.9, standard deviation 2.3, Table 9), related to the appearance of a character in the scene. The children also used the *Stop* symbol in different fashions. Some of them interpreted it as an entity that required an explicit restart and therefore placed a *Go on* block after each use of the *Stop* symbol, while others considered it as a temporary stop that did not require an explicit restart. In most cases we identified a precise logic underlying the association of the symbols to the text. Only in some of the cases (4 out of 19) were symbols not placed in a coherent fashion. The majority of the children did a good job for the text analysis.

The children got blocks concepts correctly, but there is room for improvement

Task 4. The results show that all the groups succeeded in creating a Scratch program of similar complexity (Table 10). Most groups did not have problems for mapping the Scratch components to the analysis. A single group, composed of children that did not give a detailed description of the structure in the previous task, needed additional support for improving the text analysis and the mapping work. The children had no problem in using the Scratch, even for the most sophisticated (i.e., the cycle that requires nested components), but still they needed time to adapt to the interface and mouse. They needed only simple verbal support for accomplishing complementary operational sequences, such as the creation and the use of audio tracks. All the groups succeeded in completing the visual programming activity, in 16 to 21 minutes (Table 10).

Good text analysis = no mapping problem

No problem using S4A

Group	time	start	play	repeat	wait	analog
electricity	19.0	1	4	1	2	1
heating	16.0	1	5	1	0	1
light	14.0	1	5	1	2	1
transportation	16.0	1	5	1	1	1
waste	21.0	1	4	1	1	1
water	18.0	1	4	1	0	1

Table 10: Learning evaluation - Time and use of programming entities for translating the story into a visual program

6.3 CONCLUSION

Many aspects to considerate

The final evaluation demonstrated that the design of the educational experience was successful in many respects. The children acquired new knowledge in relation to new technological topics, such as the properties of smart materials, and acquired new skills for programming interfaces based on them.

Loved Origami and visual programming

The results of the direct observation and the questionnaires show that the children learned new concepts, acquired different skills and were engaged both in cognitive and emotional terms throughout the experience. The children learned new methods of expression, they were very interested in origami and visual programming, and declared their willingness to try again the different facets of the whole multidisciplinary experience.

SMIs made stories fun!

About storytelling: we had a confirmation of its positive role for educational paths. This goes beyond the simple teaching of literacy skills and their use for connecting different educational topics and techniques. Storytelling itself received a positive boost from the definition of the innovative educational path. As can be seen from the questionnaires, the children were not very interested in creating stories in the traditional fashion, but they were happy to create them with the SMIs. The fact that the stories were played on a screen instead of the physical theatre, had probably some minor influence on the evaluation, but we expect that this would be worsening the results and not improving them. The results are instead all very encouraging. We designed this path focusing on the experience of creation.

Visual programming = best activity

With this S4A experimentation, we followed the tradition of Logo and visual programming, but added the role of children as makers. As can be seen in Table 5 column (b), rightmost task (5), transforming the stories into visual programs for the play, 4 out of 5 parameters gained the maximum scores among the other tasks. The introduction of a visual programming paradigm brought the possibility of automatically controlling the materials' transformation. In this educational experience, the shift from smart materials to SMIs allowed the move from the simple knowledge to the experimental activation of these materials. It is important to underline that the tools that were introduced for stimulating the interest for the smart materials, worked not only as a means but they were a focus of interest themselves.

acknowledgments

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THANKS!

Part IV

GROWTH

In this fourth part we allow others to learn how to generate their own messages through interactive installations based on smart materials. The use of smart materials interfaces convey a message, involving the user in an artistic context.

We give others the *tools to create* a message to share.

"Getting information off the Internet
is like taking a drink from a fire hydrant."

— Mitchell Kapor

7

SMART MATERIALS: WHEN ART MEETS TECHNOLOGY

In this chapter we will present our approach for the development of young artists. We describe how we helped them to discover new expression methods and methodology. We guided them through the smart material jungle with Arduino as lantern. We will describe the application and use of Smart Material Interfaces (SMIs) in the context of artistic installations.

We organised an intensive workshop in the Fine Art Academy of Venice. The students, divided in groups, produced interactive creative works based on cheap traditional materials enhanced with the properties of smart materials. Our idea was to use new materials to augment the degree of freedom of expressivity of traditional media. Through this experience the budding artists had the possibility to learn technology and techniques for creating fun new interaction by surprising and amazing the user in unexpected ways. The experience itself stood for a growing point of the students, it allowed them to give life to their static works. Also, the possibility of augmenting objects with new properties allowed them to convey emotion and feelings, not just information.

This chapter is mainly based on [72].

7.1 INTRODUCTION

Artists have always been author of their own tools

In this chapter we will present our approach for the development of young artists. From the beginning of time, artists have always made and selected most of their tools and materials themselves, from pigments to paint, from canvas to the best marble, and so forth.

now they are end-users

For newborn modern artistic disciplines, which we can address with the label of *interactive systems*, the artists are only end-users. They use methodologies and algorithms that have been conceived by others. In most cases these were highly skilled technicians that have nothing to do with arts or similar contexts and purposes. The artists have often no idea of how these artefacts work, nor how they are made. In these conditions, the artists' work is limited to what the artefact (hardware or software) can do, limiting the full extent of potential expression power in their poetic vision.

computation can be everywhere now

Thanks to Ubiquitous Computing, the computing context has shifted focus to real world tangibles, embedding computation in everyday objects. While some artists have taken advantage of these new opportunities (e.g., *The dangling string* [130], N. Jeremijenko, that materialised the data flux of a research centre) thanks to the cooperation of the technicians, others could not. In most cases this situation has enlarged the dichotomy between the artists and the possibility of building the tools for their creative work.

There is more in youtube than just cats

The modern movement of makers focuses on Do-It-Yourself (DIY), often inexpensive, implementations of interactive systems. Thanks to the tutorials and information posted online from this trend, and to the technologies now available at end user level, the artist can bridge the gap between technology and creativity. He can apply solutions and create everything on his own. He no longer needs the input or the role of technician that was necessary before.

There are teachers ready to share at each corner

One of the most interesting features of the new maker movement is the pedagogical opportunity of learning what is behind, how things work, and also the tendency to promote low-cost materials. They can learn new concepts through the experience of others, but they do not need to go too deep into the technical details if the do not want to. This allows a lot of people to get a first taste of experimentation with real systems.

We made a workshop for the Fine Art Academy of Venice

We focus our work on a category of (smart) materials that also fit well into the DIY philosophy. We will describe how we designed and conducted a workshop for a class of students of the Fine Arts Academy of Venice. The workshop focused on smart materials and techniques to create interaction in the Arts domain. The goal was to make the artists aware of the potential of the new technology, reducing the gap between technology and creativity by empowering their expressivity. Our purpose was for the students to develop interactions in the intersection between Arts and technology, by proposing the use of a development platform pair: *Arduino + smart materials*[1].

In this chapter we will briefly introduce some smart material (section 7.2),we will follow with the objectives and a description of our workshop (section 7.3). Then we will present a selection of some of the projects produced by the students (section 7.4) and we will have a look at the results of the data gathered during the experience (section 7.5) and discuss it (section 7.6).

7.2 briefly: some smart material

In this chapter we mention different families of smart materials, such as: ferrofluid, shape memory alloy and thermochromic pigments (for more details refer to Chapter 1, Section 1.4).

Shape-memory alloys (SMA) In particular NiTiNOL is a family of SMA that can be used for actuation. It is most commonly used in the medical domain.

Seen in Section4.2.2

Thermochromic materials change in color depending on their temperature. In the chapter, most of the themrochromic pigments cited are of two kinds: pigments that have a single threshold over which they become transparent, or liquid crystal based pigments that have a more precise threshold and can display different colours. They are commonly used in displays and various products both for entertainment and for communicating changes of temperature.

Seen in Section 5.3

You can find a deeper and broader analysis of the materials with specific characterisation in [6].

7.3 the experience

We organised a workshop at the Fine Arts Academy of Venice that consisted of 5 sessions of about 8 hours each, plus the exam and some remote consulting. The workshop was held in the context of the Interactive Systems course for the Master's degree in New Technologies for Art.

40h+ course about SMI

The number of students was 14, formed into 7 groups, but only 6 groups reached the final exam. Most of them were aged between 22 and 25, but there was also one of 55 and one of 63. They were all students from the first or second year of the Master's course, only one was from the third year of the Bachelor's course. None of the students had any previous meaningful experience with imperative programming. Some of them had partial knowledge of Max/MSP[2].

A very wide range of students, with no programming experience

The general idea behind the workshop was to give to the students different *bricks of knowledge*, minimal small useful elements of knowledge, to allow them to build new concepts with as few constraints

1 See section 7.2 for more details.
2 More info about Max/MSP:http://cycling74.com

Themese are made to challenge the creativity of students stimulating discussion

as possible. We offered the students three possible themes to choose from for the projects: *transposition of senses (synaesthesia)*, *object personality*, *picture feelings*. They were designed to stimulate discussion and allowed a lot of freedom without putting many constraints on their creativity. The *transposition of senses* theme tried to stimulate creativity by making them imagine how, for example, someone could perceive the sense of smell with touch. The *object personality* tried instead to give inanimate objects living qualities, and of course personal traits, for example how a chair would behave if it could move freely. The last theme was *picture feelings*, it focused on how we can transmit the feelings from the perspective of the picture itself, for example, how would a picture frame feel while being watched or laughed at. The students had the possibility to choose one or more themes to fit in.

Objective: build a SMI

The main goal, for them, was to develop an artistic working prototype installation of SMI in the context of their theme choice. The only other constraints were to create something tangible or physical that could be interacted with and to possibly make use of smart materials.

7.3.1 *Materials used*

We gave Arduino's kits + our components

Most of the material for the workshop was given to the students by the researchers (see Fig.54). Each group received a set of basic electronic components, accompanied by wires and an Arduino. To these was added a paper mounted MOSFET circuit, made with conductive tape, to ease the connections to and from Arduino. The students were encouraged to get personalised tools and materials for their future projects.

Each group used their own resources and material for the final project

We used Flexinol[3] for SMA actuator, a wire of NiTiNOL[4] that contracts as a muscle. We used thermochromic paint, both ready made and in pigments with the acrylic binder. For making origami models we used coloured office paper. Each project was characterised by the use of different materials, but all of them included the smart materials and Arduino.

Arduino is the key for construction

The smart materials used here were chosen for their different qualities and characteristics, one for making things move and the other for making colours change. These are also easily found on the market and can be bought from anyone without worrying too much about the expenses. The choice gave us also a very practical and immediate way of interacting with the materials through Arduino (using PWM, Pulse-Width Modulation, and the MOSFETs). This simplifies the creation of any interface that makes use of either NiTiNOL or thermochromic paint.

3 More info can be found at `http://musclewires.com`.

4 NiTiNOL: Nichel-Titanium alloy, a family of memory shape alloys. For more information see Chapter1 and section 4.2.2

Figure 54: In this picture: the main materials used by the students as base for their projects, in section 7.3.1 more details about use and development. Each group added other materials depending on their needs.

7.3.2 *Experience and activity description*

In this section we will describe the details of the teaching timeline and activities by day, also published in [75] with preliminary results (the Table11 show a short schematic view of the timeline of the experience).

1stDay: SMIs and Origami.

We opened the workshop with an overview of artistic interfaces made with smart materials and about SMIs. Then we asked the students to fill in an initial questionnaire (Appendix D), about their personal profile, previous knowledge and interests in the workshop. The lesson lasted part of the morning. A few hours were dedicated to the creation of origami models of various kinds and shapes. The lesson was a step-by-step tutorial. Each origami model was created altogether with the researcher. The origami models varied from basic shapes to more complex action models. The latter are origami models, such as talking fishes or barking dogs, that move if parts of the model are pulled. We then introduced Arduino and basic programming concepts, such as variables, conditional constructs and loops. At this point the students were divided into groups and several exercises were done.

First questionnaire (Appendix D)

SMIs, origami and Arduino

2ndDay: Arduino.

The second day started with the description of the Arduino I/O: the concept of *pin* and the methods to write and read from it. The rest of the session was dedicated to experimenting with Arduino, including hardware tests with LED and the other available components. We did experiments on how to control the properties of smart materials by using PWM (Pulse-Width Modulation). We then presented the three themes for the projects: *transposition of senses (synaesthesia)*, *object personality*, *picture feelings*. The students could choose one or more themes to fit. At the end of the day we asked the groups to bring in a conceptual proposal to the next session in the shape of a storyboard, that would contain the use of SMI in an art installation within the themes' scope.

Arduino programming, electronics

3rd Day: Thermochromic pigments.

The day started with the students presenting their proposals, that were discussed and evaluated. We showed a short demo about SMA and thermochromic paint. The first was an actuated origami barking dog with a distance sensor as activation. The dog barked when the sensor detected an obstacle in its range. We also showed several examples of thermochromic paint applications. We then moved on and explained how to use and how to make the thermochromic paint from pigments. The students applied it to the origami models they had created. As last teaching of the day we showed the students how it was possible to connect Arduino to social networks (Twitter).

Concepts discussion and thermochromic paint

4th Day: Actuators.

The students experimented with their first complete SMI. They applied a very small serpentine of resistive wire on the back of their painted origami models. They connected it to Arduino to power it up and make the origami model change color. Then, they learned how to create software switches for activating the SMI from Arduino. The students then built a small actuator with wood, NiTiNOL wires and ready made silicon springs. They connected it to Arduino with a MOSFET paper circuit and realised a light sensor based movement (to allow them to put in use all the notions learnt till now). At the end of the lesson we asked them to refine their proposal for the final project and to bring in anything they needed as external material to realise it. They also filled in the second questionnaire about the characteristics of their projects (Appendix E).

Resistive wire and SMA with experiments

Second questionnaire (Appendix E)

5th Day: Work in progress.

In the last session, the students started to work on their projects. All the lesson was focused on the development of the key features for their project. Each of them had its own peculiarities and different problems to solve, from mechanical to software related.

Project!

After the end of the workshop, several checks were made to supervise the development of the projects. The final versions of the works presented in the next section were realised after the end of the workshop, refining the initial idea and completing the technical realisation.

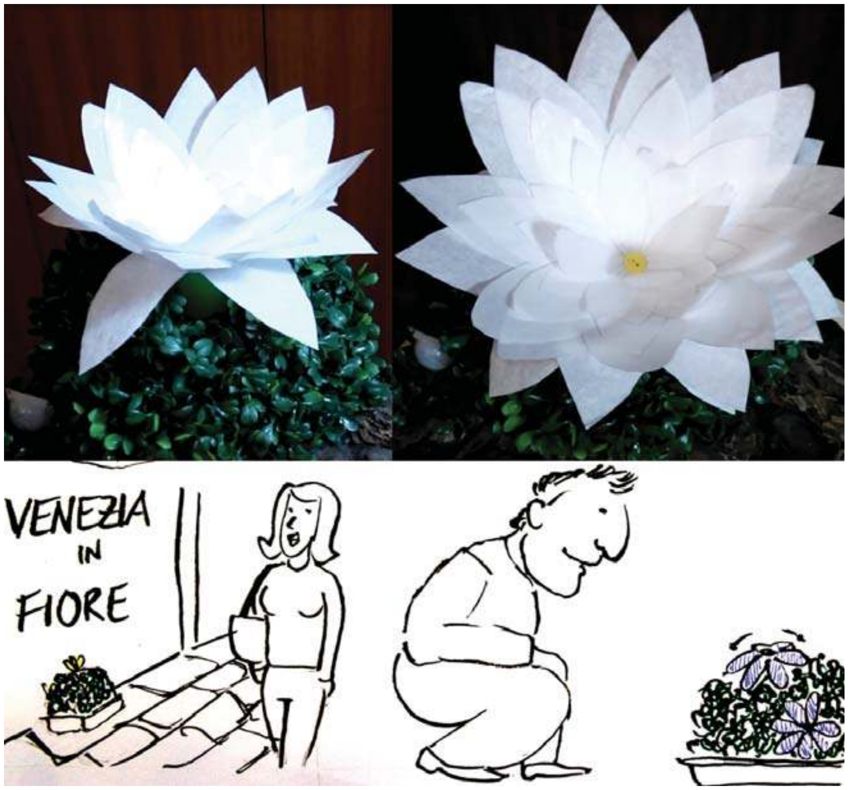


Figure 55: Development of project *Venezia in fiore*. On the top the final prototype in the two phases, open and closed, on the bottom part, the storyboard sketch for the installation.

During this phase the students worked mainly alone, but we organised periodic checkpoints for giving additional suggestions and for resolving technical questions.

After the official presentation of their projects, the students filled in the final questionnaire (Appendix F).

Third questionnaire (Appendix F)

7.4 PROJECTS

We have selected the best four projects (out of six) as a brief example of the products at the end of the lessons.

7.4.1 *Venezia in fiore*

One of the groups chose as theme *object personality* and produced a concept called "Venezia in fiore", translated: Blooming Venice (Fig.55). It is a small dome covered in fake green leafs and flowers. Every time a user approaches the art installation, or simply passes by, a flower blooms bringing surprise and interest. It will be located in a place without other green elements and just its presence will attract the

Connect people with their environment, mixing real and fake objects

Days	Lesson description	Survey	Main Focus
1st	The students filled in the first questionary, then we taught them about SMIs in general and origami. Introduced Arduino programming basics concepts.	first (Appendix D)	SMIs, origami, Arduino
2nd	We taught them Arduino programming and tested it, at the end of the day we asked to bring in a conceptual proposal the next lesson. We also assigned themes to help the production of the proposals.		programming, Arduino, electronics
3rd	The students presented their proposals and assisted to a demo session about SMA and thermochromic paint. They then learned how to make thermochromic paint and to apply it to the origami models created before.		future projects, thermochromic paint
4th	The students experimented with their first SMI, with thermochromic paint activated by resistive wire, then, learned how to connect electronic components and MOSFETs. At the end of the lesson we asked them to refine the proposal for the final project. The second questionary was filled in.	second (Appendix E)	resistive wire, experiments, SMA
5th	The students started to work on their project.		project
-	The students worked on refining their projects, periodically checked from the researchers.		project
-	After the official presentation of their works, they filled in the conclusive questionnaire.	third (Appendix F)	final thoughts, future

Table 11: Description of the timeline of the experience

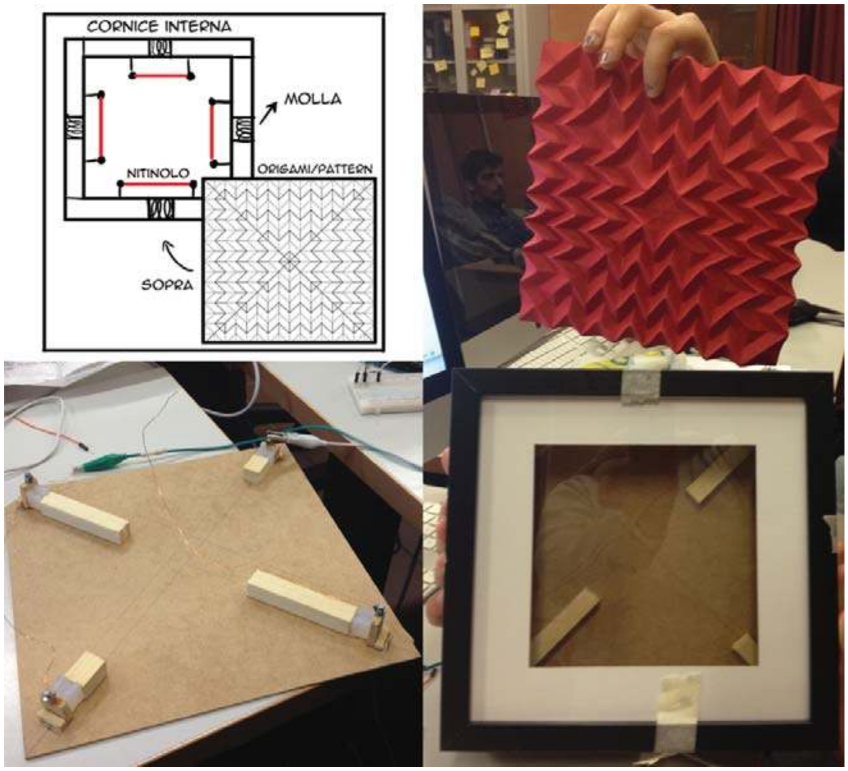


Figure 56: Development of project *#holy*, from the students' sketches and pictures from the exam. On the top left the initial schematics of the project, on the other parts, different details of the installation.

interest of the usual commuters who will be able to see the surprising unusual blooming among bricks and stones. The idea here is to awaken the environmental awareness of the users, by reminding them of the existence of nature and so doing, give them a reward by blooming. The NiTiNOL wires will create the movements from the inside, by contracting they will allow the flower to bloom.

7.4.2 *#holy*

#holy is the name of the installation (Fig.56) designed by a group that chose as theme *object personality*. The project is a picture frame with an origami tessellation inside, designed to be placed in a public gallery. Here, the idea is to invite the visitors to reflect on the concept of holiness and share their reflections on the social networks. The visitor will be invited by a small panel, placed next to the frame, to think about holiness and to tweet their thoughts with the hashtag *#holy*. Using the authors' words, "the cardiac muscle of the icon will contract as a sign of gratitude, for indicating that the concept of holiness has come back to life for a while in the hostile modern life". From a technical point of view, the installation involves a number of triggers

Relation between symbolic presence and communication in social networks

Figure 57: Development of project *Da mano a mano*, from the students' sketches. On the top the concept design and on the bottom picture of the aesthetics and the capacitive hand sensor drawn with conductive ink.

activated by an internet connection. NiTiNOL wires create the hidden silent motion from the back of the tessellation.

7.4.3 *Da mano a mano*

Connects the user with his presence in time

Da mano a mano (translated: from hand to hand) is the title of the installation (Fig.57) from a group that chose as theme *picture feeling*. It is a small square with hidden drawings and writing. The user will be invited to leave a mark on the installation by placing his palm on the square. As he does the action, the shape of his hand and a sign saying "I was here" will appear out of the dark. The idea is that people want to leave a mark behind them to become immortal. It will be realised with thermochromic paint, that becomes transparent when someone touches the installation showing up the hidden shapes.

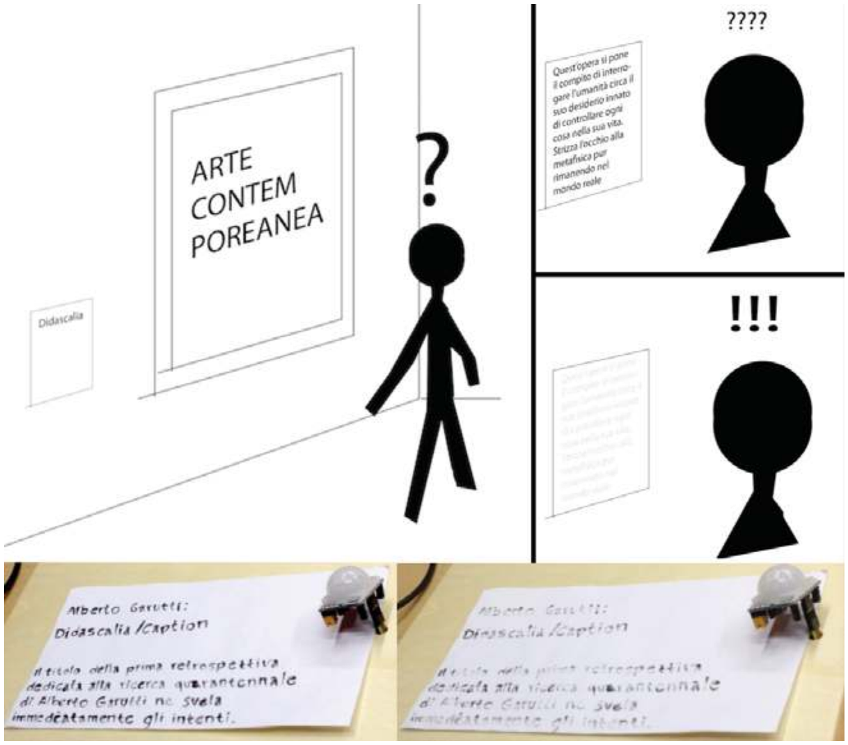


Figure 58: Development of project *Art-duino* from the students' sketches. On the top, the sketches of the student project (top left the user approaching, top right the user start reading the long description, but before the end the writings are faded out, centre right) and the final prototype, before (bottom left) and after activation (bottom right), where it is possible to see the ink fading out and becoming transparent.

7.4.4 *Art-duino*

The last project ***Art-duino*** (Fig.58) takes inspiration from the theme *transposition of senses (synaesthesia)* and creates a playful interface that takes advantage of the user's attention. This installation has to be located in an art gallery, close to an artwork (perhaps a painting), and is represented by a very long caption in very small size font. The caption fades away when a user approaches the artwork. All the writings are printed (in the case of the prototype hand painted) with thermochromic ink, with resistive wire on the back. As soon as the user reaches the proximity sensor range, the ink starts to disappear and before the reading ends there is nothing else to read. This project it is intended to provoke, "the caption is useless, the only important part is the artwork"[5].

Playing with the user expectations

5 Cited from the words of the group of students that made it.

Parameter	Mean
Level of expertise for assembly electronic components	1.33
Level of knowledge of the Arduino platform	1.17
Level of knowledge of programming language - Java	1.17
Level of knowledge of programming language - Javascript	1.17
Level of knowledge of programming language - Arduino	1.17
Level of knowledge of programming language - C/C++	1.0
Level of knowledge of programming language - Max/MSP	**1.41**
Level of knowledge of programming language - Processing	1.17

Table 12: Initial levels of expertise of the students. The scores are based on a 5 points scale.

7.5 QUESTIONNAIRES

3 questionnaires: previous knowledge, concept elaboration, and experience

As we mention at the end of section 7.3.2, after the end of the workshop, the students were working independently (excluding the checkpoints) on their own to prepare their exams. While it was difficult to measure the pedagogical path made by the students from a quantitative point of view, we tried to capture it from a qualitative point of view, through a set of questionnaires. We designed three questionnaires, focused on: the *initial knowledge of the students*, their *conceptual elaboration during the design* phase and the *final thoughts* at the end of the experience. For homogeneity, the data displayed in the following tables are related to the twelve students that completed their work and therefore filled in all the questionnaires.

7.5.1 *First questionnaire*

No past programming experience

The first questionnaire, presented at the beginning of the experience, included a number of closed questions for capturing the students' initial knowledge about smart materials and their application to the art domains, the Arduino platform and programming languages. Table 12 summarises the answers of the students, related to a 5 points scale. All the students declared a very low level of expertise and skills related to the Arduino platform, both for what concerns programming and the assembling of simple electronic schemes. For what concerns the programming skills, we asked the students about their knowledge of different languages, from traditional languages and scripting to visual programming environments such as Max/MSP. Even in this case the scores for most answers were very low (i.e means below 2).

Some smart material was known in artistic context

The students had no direct experience related to the manipulation of smart materials, but we wanted to know if they had at least the opportunity to see them in action. After having illustrated a number

Parameter	Number of instances
Application in artistic context	**6**
Application in architecture	3
Application in everyday objects	1
Application in educational games	2
Application in other contexts	3

Table 13: Applications of smart materials to different domains, highlighted by the students before the workshop. The number of instances is the number of students that picked that option, over a total of 12 students.

of examples in the classroom, we asked the students if they had seen similar applications. Table 13 summarises the answers of the students, in relation to a grid evidencing the different application domains. As it can be seen in the results, most of the applications were noticed for artistic and architectural contexts.

7.5.2 *Second questionnaire*

The second questionnaire captured their conceptual elaborations with a set of open and closed questions. The students were invited to describe the features of their proposal, putting in evidence the relations with the planned delivery context and the inspiring conceptual sources, if available. The students imagined different social situations (e.g., the road, the art exhibition) in which to place their artefacts. For four cases out of six (number of groups) these social situations were considered as essential components of the conceptual proposal. Only in one case was the context considered as unimportant.

Highlight the relation with context and works' features

In the questionnaire we also tried to map how the conceptual elaboration was mapped to the acquired technical knowledge, especially for what concerned the definition of the input and the output interfaces. Table 14 summarises these results. For the input interface, the students considered the use of the sensors that were experimented with during the lessons, but they also showed interest in additional sensors capable of capturing additional environmental parameters, such as the sound sensor (microphone not used for speech). For the output, the students demonstrated an interest in the two primary categories of smart materials that were experimented with in the classroom, but even in this case they also considered the possibility of experimenting with additional components, such as LED lights. Not all of the groups kept the original choices in the end.

Main interests and conceptual elaboration mapping

Sensor/actuator (I/O)	Number of instances
Input: light sensor	2
Input: sound sensor	1
Input: proximity sensor	4
Input: temperature sensor	2
Input: contact sensor	2
Input: Twitter message	2
Output: Paper/wood objects	3
Output: NiTiNOL wire	4
Output: Thermocromic ink	3
Output: Other output (LED/canvas)	2

Table 14: Usage of sensors and actuators for the input and the output interfaces. The number of instances is the number of groups that consider using that particular I/O, over a total of 6 groups.

7.5.3 *Third questionnaire*

O'Brien engagement

After having completed their works, the students were asked to fill in a final third questionnaire, containing both open and closed questions. According to the definition of engagement of [79], we tried to capture through the six parameters the different facets of the experience, from the ease of use to the aesthetics. We asked the students to express their evaluation of all the activities of the experience, from the conceptual design, to the creation of smart origami with the Arduino-based development. All the scores are based on a 5 points Likert scale.

Table 15 displays the overall score and, with the exception of the Aesthetics parameter, the detail for each activity that characterized the workshop.

All the manipulation activity scored high

Concerning the *perceived usability*, we registered a positive result (mean 3.51) with higher scores for the activities related to the manipulation of smart materials, the conceptual elaboration and, of course, the origami creation. The activities related to Arduino resulted more difficult, as underlined by the scores assigned to the realisation of the electronic scheme (mean 2.83) and programming (mean 2.58). The latter result is consistent with an additional question of the questionnaire (not displayed in figure) focused on the perceived level of acquired knowledge of the Arduino platform (mean 2.25). The students enjoyed performing the activities related to the project, as can be seen from the score assigned to the *felt involvement* (mean 3.83). Again, the activities related to the manipulation of smart materials and conceptual elaboration gained higher scores. However in this case the other activities were also rated rather high, above 3.5. The *focused attention* parameter, measuring the cognitive interest, gained even better scores with mean values above 4 for the activities related to the manipulation of smart materials, the conceptual elaboration, the project development and the creation of the Arduino-based circuity. Unsurprisingly, the origami models creation gained lower scores (mean 3.25). Most of the activities that were part of the project were perceived as novel (*novelty* parameter: mean 3.46), with values above 4.5 for those ones related to the manipulation of smart materials and to Arduino (both programming and creation of the circuitry). Again the origami model creation scored rather low (mean 2.17). The students showed a positive attitude towards the possibility of performing the project activities again (*endurability* parameter: mean 3.46), with a particular interest for the activities related to the smart materials manipulation, the conceptual elaboration, the project development and the creation of the Arduino-based circuity. Concerning *aesthetics*, we asked all the participants to express, through an anonymous vote, their opinion about the value of the works of art. The mean score, 3.94, shows a high degree of appreciation for the aesthetic qualities of the works of art.

The final questionnaire included an additional set of open questions that gave interesting results. The participants were asked to express their opinion about the usefulness of the experience in respect to their future artistic activities. Four out of twelve participants declared that the experience was useful for their artistic future. Only one participant declared explicitly that the experience would not have any impact on his artistic activity. The rest of the participants (seven students) declared that while they were thinking to direct their activities towards other technologies, the experience was useful for showing additional points of view on the possibilities of materials, circuitry and programming.

4 / 12 declared that the experience will be useful in the future

7 said they might move to technology for the future

The participants were also asked if the experience had changed their opinion about technology. While half participants declared that they were already aware of the importance of the technology, the rest participants stated that the experience was important for improving their awareness.

Everyone learned the importance of technology

7.6 discussion

The answers from the questionnaire seem to capture a positive pedagogical path. The students started from a situation of zero knowledge and arrived at the development of meaningful design and the final perception of the importance of the work done.

During the experience the students acquired new skills such as using previously unknown materials and components, soldering and programming. While at the beginning the students were guided, most of them demonstrated a good level of autonomy in using their new skills, when they worked on their projects.

From 0 to new skill, with autonomy

Activity	Perceived usability	Felt involv.	Focused attention	Novelty	Endurability	Aesthetics
Origami	4.00	3.58	3.25	2.17	2.42	n.a.
Arduino (Electronics)	2.83	3.67	4.00	4.67	3.50	n.a.
Arduino (Programming)	2.58	3.42	3.67	4.75	3.17	n.a.
SM (NiTiNOL)	3.67	4.25	4.17	4.83	3.67	n.a.
SM (therm. ink)	4.25	3.92	4.08	4.75	3.83	n.a.
Project concept	4.08	3.92	4.3	3.58	3.83	n.a.
Project development	3.17	4.08	4.17	3.92	3.83	n.a.
Overall	3.51	3.83	3.95	4.10	3.46	3.94

Table 15: Mean scores assigned by the students to the 6 parameters that define the engagement. The scores are based on a 5 points scale. The table displays the overall score and, with the exception of the *Aesthetics* parameter, the detail for each activity.

We supported them with periodic checks in person or through videoconference conversations. The level of support never went beyond the suggestion of how to operate to solve a specific problem.

All the design and practical operations were done by the students themselves. Most students described reasonable hypotheses for the technical realisations. They went beyond the set of sensors and actuators that they could experience directly in the previous days. Many groups demonstrated that they had acquired a methodology of work, visible since the selection of the components used in their projects. The students introduced capacitive sensors for the input and traditional canvas as a support for thermochromic paintings, experimented with new electrical circuits for composing their creations, seeking information on the web or asking teachers for advice. The students were not afraid of technology, they tried new solutions for implementing their concepts.

They introduced advanced sensing interactions with capacitive touch

The conceptual elaborations were made possible thanks to the knowledge of the technical mechanisms explained and experimented with in the workshop. The single mechanisms were in many cases creatively composed in the conceptual definition of the students' work, going beyond the schemes that had been used in the workshop, at the service of the expressivity of their work.

Creatively composition of technology

According to our initial expectations, the students shifted from the role of users to the one of makers. The students imagined different contexts in which to place their artefacts. These social situations were often the primary component of the conceptual proposal, that required a physical or a virtual presence as in the case of the use of the Twitter social network.

From user to makers

The students interpreted the relation between *materiality* and *digitality* in different modalities. Often the digital part of their proposal was hidden under the hood for the visitor, presenting the experience as a *magical* interaction between different materialities (the components of the installation and the user), for example in the *Da mano a mano* installation. Of course these conceptual proposals would not have been possible without the acquired knowledge about the sensors and actuators of a digital system. In other cases students mixed the materiality of origami models with the digital social world, imagining a sentient framed origami model reacting with a pulse to the messages received from the associated Twitter account. The practical demonstration of the properties of the materials triggered a positive interest towards the search for new components that could react to additional environmental variables, for augmenting the expressivity of the projects' design.

Materiality and digitality, connected by magic

Search for expressivity using materials' properties

The final recap questionnaire captured good results for what concerned the engagement. As stated in the previous section, the parameters that characterise the engagement capture different complementary aspects of the experience, from the *traditional* usability to the cognitive and emotional involvement and to the aesthetic values, particularly important for the specific educational context in which the workshop was organised. We obtained positive scores for all these parameters, as evidenced in the previous section (and in Table 15). For all the parameters, the highest values were registered for the smart materials manipulation. Also the Arduino-based activities gained good scores, with a preference for the activities related to the *concrete* realisation of the circuitry rather than to the *abstract* programming. The results are coherent with the tradition of the Fine Arts Academies in Italy, that emphasises the importance of the practical experimentation with physical materials vs. the theoretical speculation.

High result for engagement

Highest result for smart materials

The answers to the open questions show that the experimentation contributed to enlarge the possibilities of artistic expression, leading in a significant number of cases to identify the use of smart materials as a possibility for the future activities of the students. The answers to the questionnaire show also that, while in a number of cases the students were already aware of the importance of technology, the realisation of the workshop had a positive pedagogical role for increasing the perception of its role.

It had a positive pedagogical contribution

Part V

CONCLUSIONS AND FUTURE

This concluding part contains our consideration and possible view for the future.

It is based on [73], [71], [70], [74],[69], [76], and [72].

"I've had a wonderful time;
this wasn't it."

— [Anonymous online user[6]]

6 Possibly a paraphrase from a famous Groucho Marx quote.

8

REFLECTIONS AND CONCLUSIONS

8.1 THIS THESIS

This thesis is divided in different conceptual parts, the main ones are:

- Design
- Experience
- Growth

This structure reflects the evolution of our learning curve. We started to explore the field of Smart Material Interfaces by designing, learning difficulties and challenges with hands-on experience. In this phase, we experimented, we made mistakes and created interactive systems, *we designed the message* (Design, Part ii). With this experience we forged a basic set of knowledge. With it we designed a learning path and helped young children learn (external knowledge) through it. We allowed *others to learn* and experience an engaging pedagogical path (Experience, Part iii). We used SMIs as a means to deliver knowledge. We then moved to expand the message further by letting *others create* the message with their own interface (Growth, Part iv). We accomplished this with older students (bachelor and master level), challenging them to learn what we explored and expand under our guidance, creating engaging installations in the Arts domain.

A short description of the work

8.1.1 *Design*

As mentioned in Chapter 4, applying smart materials in interaction design and prototyping domains is not a painless matter. As demonstrated in our experiments, we met many difficulties (technical and non technical). We needed to explore not only different design solutions but also nontrivial technological and mechanic complexities.

There are problems

The possibilities given by the new materials offer new kinds of challenges for the traditional designer, but also open up an unpredictable space for designing interactions. Coping with the new skills required to master the material properties is probably the biggest obstacle for the designer. It can involve skills and knowledge from different fields.

Missing methodologies for use and for design

Unfortunately there is not a fixed methodology for using the materials themselves. Many researchers are experimenting and finding new ways for using them for interaction purposes, creating new case studies that can give hints and suggestions for developing different applications.

We held SMI Workshops in U.S.A. and Australia

In 2012 and 2013 we held workshops (during ICMI, International Conference on Multimodal Interaction) with guests from all over the world. The objective was to collect experience and gather knowledge on how SMIs can be and are used around the world. The workshops collected interest and publications spanning from the medical field to architecture, and from entertainment to teaching [4][5][78][59].

There is still interest in this field

Till today (while this thesis is being written) there are several new interesting publications about methodologies and interaction with smart materials. Many researchers have applied smart materials to rapid prototyping, coupling digital production and non traditional materials. This is the example of xPrint [126], where the authors collect design strategies for HCI researchers to standardise a tool set for extruding different kinds of (liquid) smart materials using slightly modified 3D printers. The idea is to have the precision of Computer Numerical Control (CNC) machines to deposit the smart materials where it is needed. The possibility to generate the patterns and effects generated by parametric models developed in high level visual languages (such as Grasshopper[1]) facilitate the approach to production from designers, scientific researchers, and/or artists.

More initiatives are born on the net

Communities such as "Materiability research network"[57] are growing educational platforms that provide open materials databases for creative applications. These gather more and more projects and methodologies for operating in a creative domain using highly technical materials, starting from how to create electroluminescent-panels to how to grow mushroom bricks.

EU projects about SMIs are still running

At the same time the interest in smart material interfaces grew in different contexts, for example through European founded projects: Light.Touch.Matters [105] and GHOSTs [104]. Light.Touch.Matters tries to bring together designers and material scientists to focus on products for care and well-being applications that can help consumers feel better, monitor or improve their health and increase comfort. GHOSTs (generic, highly-organic shape-changing interfaces) focuses on display surfaces made of malleable materials that can change into and retain arbitrary shapes so as to display output from the system or afford new actions.

All this effort to stimulate design and material scientists to get together to create new interfaces with material properties that can be programmed.

1 Grasshopper (http://grasshopper3d.com/) is a graphical algorithm editor tightly integrated with Rhino's 3-D modelling. It is not an opensource platform.

8.1.2 *Experience*

In [10] a possible way is shown to use smart materials to convey information to children. But at its end, several questions were still unanswered: could smart materials bridge the gap between the child and technology, could these materials be used in order to explain and communicate information technology to children, and if so, how. We addressed several of these issues, and we have positive answers for them.

Open questions and some good news

In our work at the primary school, the final evaluation of our learning experience demonstrated that its design was successful for several aspects. The children acquired new knowledge in relation to new technological topics, such as the properties of smart materials, and acquired new skills for programming interfaces based on them. They programmed (with S4A) what they had imagined and made. And they enjoyed doing it.

As seen in Chapter 5

We noticed improvements in all the areas involved by the multidisciplinary experience, from the increase of the environmental awareness to the skills for text analysis. At the end of the educational process the result of the children's efforts, thanks to their new skills, was both a working mechanism and a cultural artefact that was evaluated even for its aesthetic qualities.

The children worked and learned a lot!

We designed this learning path based on the *experience of creation* and we believe that giving the possibility of learning to create something new, can be a very rich experience, as mentioned in [19] a "maker's mindset [...] has a far greater impact than the teaching of any specific subject matter at the elementary grade levels".

A maker's mindset...

In this educational experience, the shift from smart materials to SMIs allowed the move from the simple knowledge to the experimental activation of these materials. We can observe that smart materials were not only the main focus of this experiment, but also a useful means for explaining and communicating information technology to children.

All the results and the children's responses indicate that the experience was perceived as a positive and interesting activity. The children were interested in origami and visual programming and declared their will to perform these activities again in the future. This shows how innovative research topics, such as SMIs, can be integrated into a pedagogical path for primary schools, merging the traditional learning and other techniques (assisted by suitable visual programming tools and physical technologies). We believe that this kind of application should be further explored and that the experience presented can be an interesting future path to look forward to.

The future is a mix

8.1.3 *Growth*

Hands on bricks approach

For the workshop ideation in Venice, we followed the traditional educational path of the Fine Arts Academy, directed to the production of works of art rather than to mere theoretical speculations. We introduced new technologies and allowed students to manipulate new materials, with the final goal of stimulating them towards new forms of artistic expression. We gave them brick of knowledge with which the students built their own interactive installation.

Aiming for independency

At the end of the project we may conclude, both from the observation of the work done and the comments expressed in the questionnaire, that we succeeded in reaching this goal. The students successfully took the lead and reinterpreted the technological bricks we gave them for their own purposes, making the new knowledge part of their own creational process. The workshop was also a confirmation of the role that smart materials and low-cost programmable platforms may have for expressing creativity in new shapes.

8.2 CONCLUSIONS

This work has presented an initial step for integrating smart materials in the interaction design process both for design and teaching, spanning through Art, Design, and Research domain. We earned a lot of information through our experiments, and we brought this experience to the field, bringing SMIs to the Fine Art Academy and primary school.

Version update: laser cut

While writing on this thesis, we developed an updated "ready-to-use" version of the grass actuator. Not cheaper (for now) but easier to build and to put in tension, very easy to scale in number and dimension. Thanks to the use of laser cutting, it removes the burden of precision from the previous version, and it takes much less material (Fig. 59). The idea here is to aim for a quick assembly, possibly glueless and robust. It is designed to be light and easy to modify for future use. This gives the possibility of transportation in flat packs and assembly in place. This design and the tutorial for building it will soon be released online (thingiverse[2], Materiability and instructables[3]).

We need more high level strategies!

At the moment of writing this thesis, the topic of shape changing interfaces, where the materials are the informations, is still an open discussion. In [95] it is highlighted "as we lack studies of how such interfaces are designed, as well as what high-level strategies, such as metaphors and affordances, designers use". As we mentioned before (Chapter 1) it is stated in [110] that "the community has yet to identify

2 Thingiverse is a repository for opensource models for 3D printing and laser cutting. http://thingiverse.com/

3 Instructables is a very popular online community for tutorials and free resources. http://www.instructables.com/

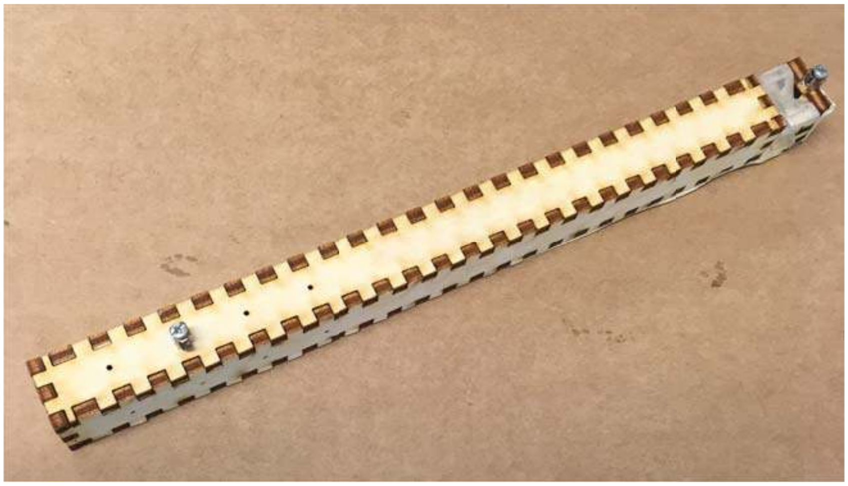


Figure 59: The root actuator, final version, is catted from a plate of 3mm poplar wood, the operation of cutting require about 3 minutes, and so the assembly. The silicon spring is casted from a batch mould made of perspex also laser cut. The total size is comparable the older one. The hinge mechanism is still made of tape (perfectly functional, cheap and easy to connect).

important applications and use-cases to fully exploit its value". It is clear that there is more to discover on many different levels, from design to methodology, and also new ways of technically applying this great amount of innovation that is not spread, yet.

Even if the interest for smart materials and interfaces built with them is recognised, it is dispersed across multiple fields. Material scientists have interest in developing new materials, and that these materials will be employed for some application, but trying to reach them was extremely difficult. Same goes for industrial designer and artists that are involved in the creation of concepts using new materials. Each of them have a different incompatible objective with the others. We have clearly seen these difficulties while organising the various edition of our workshop about SMIs. For this reason the third edition of our Smart Material Interfaces workshop did not go through.

Everyone has their own interests

Part of the european projects, among which the mentioned ones, aim to make practical use of these new materials. This does not necessarily means that there will be a common interest between the different communities. There is a need for a mediator that can translate and understand the needs of both sides and help them to meet over a common ground: interaction design. Unfortunately being the field very cross disciplinary, it is also very fragmented. To solve this we do not have an easy solution. Probably, we need another Ph.D. focusing on it. Interesting initiatives as Materiability [57] might have a good opportunity as a meeting point, but there is still space for growth.

More common multidisciplinary ground is needed

Difficult to predict future

What we have seen in our experiments and along our path is that it is possible to make use of smart material for many different purposes, many more than what was designed in the original intention. When NiTiNOL was invented no one would have probably thought that it would have made children happy by making an origami dog bark. The prices of these material are constantly dropping, making them more accessible every day. They can be, as demonstrated in this thesis, a great resource to stimulate and encourage learning in different levels.

New initiatives are born

British Broadcasting Corporation (BBC) recently started a program distributing a new board (micro:bit[4]) among children, aged from 9 to 11. The board is Arduino compatible and equipped with several kind of sensors and LEDs. The introduction of this board means easier way to get children interested in programming and science. The transition to SMIs would be a natural step to enrich the environment and start to make physical changes in the real world from a digital one.

We can not, but we can at least try

We live in a society where the users do not know anything about what they are actually using, if we can build up just a little curiosity by teaching the basics of technology, we can rise awareness and foster creativity in ways that we still cannot immagine.

4 `https://www.microbit.co.uk/` micro:bit hub for writing code and sharing creations.

Part VI

APPENDICES

A

FIRST CHILDREN QUESTIONNAIRE

The following is the questionnaire given to the children of the primary school, in its original form, just after the presentation about smart materials. Some minor translations in the text have been added to facilitate referencing.

Nome bambino ____________________________ Gruppo ____________________ Età ______

1) **Questa mattina ti abbiamo mostrato alcuni nuovi tipi di materiale, che si chiamano smart materials cioè materiali intelligenti. Li hai trovati interessanti?** (today we showed some new smart materials, did you find them interesting?)

Poco Abbastanza Molto

Che cosa hai trovato di interessante in questi materiali?
(what did you find interesting in the materials?)

………
………
………
………

2) Pensi che siano più interessanti gli origami semplici o quelli che con i materiali intelligenti? (Which are more interesting, the simple origami model or the one with S.M.)

Gli origami semplici Gli origami con i materiali intelligenti Entrambi

Perché? (why?)

………
………
………
………

3) Pensi che siano più interessanti i disegni con i colori normali o quelli in cui si usano anche le vernici intelligenti?

I disegni normali I disegni con le vernici intelligenti Entrambi

Perché? (Which are more interesting, drawing with normal colours or the S.M.? Why?)

………
………
………
………

4) Questa mattina hai utilizzato i materiali intelligenti per modificare una storia che avevi creato con il tuo gruppo. Ti è piaciuto utilizzarli in questo modo? (today you used smart material to modify a story made from your group. Did you like to use them in this way?)

Poco Abbastanza Molto

Perché? (why?)

………
………
………
………

5) Pensi che usando i materiali intelligenti la storia sia diventata più interessante? (do you think that by using smart material the story has become more interesting?)

Si No Ne più ne meno interessante

Perché? (why?)

....
....
....
....

5) Ti sarebbe piaciuto utilizzare i materiali e le vernici intelligenti in modo diverso? Anche per costruire cose diverse da una storia? Ad esempio?
(would you have liked to use the smart materials in a different way? Something different from a story? for example..)

....
....
....
....

6) **Scrivi se ti piacerebbe usare i seguenti materiali intelligenti:**
(write if you would like to use the following smart materials)

Filo che fa muovere un origami	Poco Abbastanza Molto
Filo che fa cambiare la forma di un origami	Poco Abbastanza Molto
Vernice che fa cambiare il colore di un origami	Poco Abbastanza Molto
Vernice che fa cambiare il colore di un disegno	Poco Abbastanza Molto
Vernice che fa comparire un disegno	Poco Abbastanza Molto

7) Se tu fossi un inventore, quale altro materiale intelligente ti piacerebbe creare? (if you were an inventor, which smart material would like to create?)

....
....
....
....

Per che cosa lo useresti? (for what purpose would you use it?)

....
....
....
....

B

SECOND CHILDREN QUESTIONNAIRE

The following is the questionnaire given to the children of the primary school for the final evaluation, in its original form, filled in just at the end of the experience. Some minor translations in the text have been added to facilitate referencing.

Questionario – Scrivi il tuo nome e cognome ____________________________________

1) Quanto è stato facile per te partecipare alle fasi di questo progetto (costruzione origami, creazione storie, applicazione vernici intelligenti, trasformazione di storie in programmi)? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio.
(how easy was it to participate in the various part of the project? Underline one of the sentences for your mark)

Per niente facile Non molto facile Abbastanza facile Facile Molto facile

2) Quanto ti è piaciuto poter partecipare a questo progetto? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio. (how did you like to participate in this project?)

Per niente Poco Abbastanza Molto Moltissimo

3) Ci sono state delle parti del progetto che hai trovato NON interessanti? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio.
(Was there part of the project that were NOT interesting?)

Tutte Molte Qualcuna Pochissime Nessuna

4) Quanto nuova è stata per te questa esperienza? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio. (how new was this experience for you?)

Per niente nuova Non molto nuova Abbastanza nuova Nuova Molto nuova

5) Quanto belle (o brutte) hai trovato le storie rappresentate nel teatrino? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio.
(how good or bad, did you find the stories presented in the small theatre?)

Molto brutte Brutte Né brutte né belle Belle Molto belle

6) Ti piacerebbe avere di nuovo la possibilità di fare di nuovo questa esperienza costruendo un'altra storia con gli origami per rappresentarla in un teatrino? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio.
(would you like to participate again in this experience to create another story with origami models and present it in the theatre?)

Per niente Poco Abbastanza Molto Moltissimo

7) Durante l'esperimento con Andrea e Fabio avete fatto molte attività diverse. Quali di queste attività ti è PIACIUTO svolgere? Dai un voto da 1 a 5 facendo una crocetta sulla faccina (da *=non mi è piaciuto per niente* fino a *=mi è piaciuto moltissimo*)
(which activities did you LIKE to take part in?)

Costruire origami

Potenziare gli origami con le vernici intelligenti

Scrivere la storia

Cambiare la storia per usarla con i materiali intelligenti

Trasformare la storia in blocchetti di un programma

Vedere la storia rappresentata nel teatrino

8) Durante l'esperimento con Andrea e Fabio avete fatto molte attività diverse. Quanto è stato DIFFICILE o FACILE fare queste attività? Dai un voto da 1 a 5 facendo una crocetta sulla faccina (da *=molto difficile* fino a *=molto facile*)
(How DIFFICULT or EASY was to take part in these activities?)

Costruire origami

Potenziare gli origami con le vernici intelligenti

Scrivere la storia

Cambiare la storia per usarla con i materiali intelligenti

Trasformare la storia in blocchetti di un programma

9) Durante l'esperimento con Andrea e Fabio avete fatto molte attività diverse. Quanto INTERESSANTI hai trovato queste attività? Dai un voto da 1 a 5 facendo una crocetta sulla faccina (da *=per niente interessante* fino a *=molto interessante*)
(How INTERESTING did you find these activities?)

Costruire origami

Potenziare gli origami con le vernici intelligenti

Scrivere la storia

Cambiare la storia per usarla con i materiali intelligenti

Trasformare la storia in blocchetti di un programma

10) Durante l'esperimento con Andrea e Fabio avete fatto molte attività diverse. Quanto NUOVE hai trovato queste attività? Dai un voto da 1 a 5 facendo una crocetta sulla faccina (da *=per niente nuove* fino a *=molto nuove*)
(How NEW did you find these activities?)

Costruire origami

Potenziare gli origami con le vernici intelligenti

Scrivere la storia

Cambiare la storia per usarla con i materiali intelligenti

Trasformare la storia in blocchetti di un programma

11) A quali delle attività del progetto ti piacerebbe dedicare altro tempo in futuro? Dai un voto da 1 a 5 facendo una crocetta sulla faccina (da =*non mi piacerebbe per niente* fino a =*mi piacerebbe moltissimo*)

(to which activities of the project would you like to dedicate time in the future?

Costruire origami

Potenziare gli origami con le vernici intelligenti

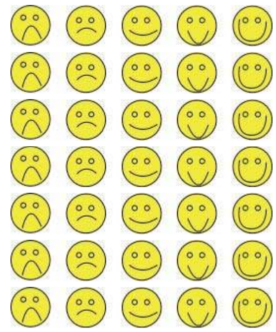
Utilizzare il filo intelligente per far muovere gli origami

Scrivere la storia

Cambiare la storia per usarla con i materiali intelligenti

Trasformare la storia in blocchetti di un programma

Rappresentare la storia nel teatrino



12) Durante l'esperimento abbiamo usato il computer per trasformare la storia in un programma. Quanto è stato facile per te usare i blocchetti per costruire un programma? Sottolinea una delle frasi qui sotto per esprimere il tuo giudizio.

(How easy was to use the blocks to create the program?)

Usare il blocchetto con la bandierina per far partire la storia

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Usare i blocchetti fuxia "Produci suono" per far sentire le registrazioni della tua storia e altri suoni

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Usare i blocchetti blu "Analog" per comandare gli origami

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Usare i blocchetti gialli "Attendi" per dire al computer di aspettare 1 o più secondi

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Mettere i blocchetti in sequenza

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Mettere insieme i blocchetti per creare ripetizioni

Per niente facile   Non molto facile   Abbastanza facile   Facile   Molto facile

Scheda della Giuria. Scrivi il tuo nome e cognome ___________________________

(Evalution of the stories)

Storia ACQUA (water history)

Molto brutta Brutta Né brutta né bella Bella Molto bella

Storia FORZA MOTRICE (power story

Molto brutta Brutta Né brutta né bella Bella Molto bella

Storia LUCE (LIght story)

Molto brutta Brutta Né brutta né bella Bella Molto bella

Storia RICICLO (Recycling story)

Molto brutta Brutta Né brutta né bella Bella Molto bella

Storia RISCALDAMENTO (warming story)

Molto brutta Brutta Né brutta né bella Bella Molto bella

Storia TRASPORTI (Transportation story)

Molto brutta Brutta Né brutta né bella Bella Molto bella

C

THIRD CHILDREN QUESTIONNAIRE

The following is the last questionnaire given to the children of the primary school for the final evaluation, in its original form, filled in a few months after the end of the project. Some minor translations in the text have been added to facilitate referencing.

Maggio 2014 – Questionario finale Smart Materials - Nome e Cognome ________________________

Come dobbiamo comportarci per rispettare l'ambiente?
Ripensa anche alle storie con gli origami che abbiamo inventato in classe!

(how should we behave to respect our environment? Think about the stories and origami models we made in the class!)

1 L'acqua – Come ci si dovrebbe comportare per non sprecarla?
(water - how should we behave to not waste it?)

2 La forza motrice (l'elettricità per far funzionare gli elettrodomestici e altri oggetti) - Come ci si dovrebbe comportare per non sprecarla?
(electricity, for moving and starting applieances - how should we behave to not waste it?)

3 La luce elettrica - Come ci si dovrebbe comportare per non sprecarla?
(electricity, light - how should we behave to not waste it?)

4 I rifiuti - Come ci si dovrebbe comportare con i rifiuti?
(garbage - how should we behave with them?)

5 Il riscaldamento - Come ci si dovrebbe comportare per non sprecarlo?
(heating - how should we behave to not waste it?)

6 I trasporti - Come ci si dovrebbe comportare quando si viaggia?
(transportation - how should we behave traveling?)

I materiali intelligenti (smart materials)

Nei mesi scorsi abbiamo visto insieme alcuni esempi di materiali intelligenti applicati agli origami.
(in the last months we have seen some examples of smart materials applied to origami models)

Sapresti descrivere brevemente come si comportavano questi materiali?
Rispondi mettendo una crocetta sopra le risposte corrette.
Le risposte corrette possono essere più di una!
(would you descrive briefly how the materials behave? Answer with a cross over the right answers, they might more than one)

Il filo intelligente collegato all'origami a forma di cane.
(smart wire connected to the barking dog origami)

Quando cambiava forma **il filo**? (When was the wire changin?)
SI NO Quando qualcuno parlava a voce alta.
SI NO Quando aumentava la temperatura del filo.
SI NO Quando c'era più luce nella stanza.
SI NO Quando veniva applicata corrente elettrica con la batteria o Arduino.
SI NO Quando ci si avvicinava al cane.

In che modo cambiava forma **il filo**? (how was it changing?)
SI NO Il filo si restringeva.
SI NO Il filo diventava più lungo.
SI NO Il filo diventava invisibile.
SI NO Il filo cambiava colore.

La vernice intelligente spalmata sui disegni.
(smart paint over the drawings)

Quando cambiava aspetto **la vernice**? (when was it changing characteristic?)
SI NO Quando c'era vento.
SI NO Quando veniva riscaldata.
SI NO Quando c'era più luce nella stanza.
SI NO Quando veniva applicata corrente elettrica con la batteria o Arduino.
SI NO Quando qualcuno parlava a voce alta.

In che modo cambiava aspetto **la vernice**? (how was it changing characteristic?)
SI NO La vernice si staccava dal foglio.
SI NO La vernice restringeva il foglio di carta.
SI NO La vernice diventava trasparente.
SI NO La vernice cambiava colore.

Suddividi una storia in blocchi (dived the story in blocks, using the symbols)

Suddividi la storia in blocchi, mettendo sopra alle frasi i simboli che vedi qui sotto:

PARTI **VAI AVANTI** **ANIMA ORIGAMI** **RIPETI** **ATTENDI**

C'era una volta un gatto, di nome Mario, che aveva un amico, un uccellino di nome Vittorio. I due amici tenevano molto a far sì che tutti gli abitanti della loro città rispettassero l'ambiente e tutti gli esseri viventi che lo abitavano.

Un giorno, mentre passeggiavano per le vie della città sentirono un rumore molto forte:

"Boom, boom, boom, boom".

Il rumore proveniva da una collina vicina. L'uccellino Vittorio disse:

"Presto, corriamo, sicuramente i cacciatori stanno sparando ai miei fratellini pennuti".

Arrivati in cima si trovarono di fronte un grosso animale che li accolse così:

"Bau, Bau".

Mario si rivolse al grosso animale, un cane pastore che conosceva da molto tempo: "Bernardo, devi farci passare, ci sono dei cacciatori che stanno sparando agli amici uccellini. Dobbiamo salvarli!".

Bernando li guardò con sconcerto e disse: "Cacciatori? Quali cacciatori?"

In quel momento si sentirono altri grossi boati: "Boom, boom".

"Ecco sentili, sparano ancora" disse l'uccellino Vittorio.

Allora Bernardo si alzò per 3 volte sulle zampe per guardare meglio da dove veniva il suono e poi si fece una grossa risata. Disse: "Ma non avete capito! Non c'è nessun cacciatore. Il mio padrone sta provando il cannone che permette di rompere le nuvole quando minaccia la grandine!"

Converti la storia in programma una storia in blocchi
(da svolgere con l'interfaccia di Scratch) (convert the story in blocks into Scratch)

Utilizza la suddivisione che hai fatto precedentemente per convertire la storia in blocchi, utilizzando i simboli che vedi qui sotto:

blocchetto con la bandierina per far partire la storia

Blocchetto fuxia "Produci suono" per registrare la storia

Blocchetto blu "Analog" per animare gli origami;
usa '5' per il gatto Mario
usa '6' per l'uccellino Vittorio
usa '9' per il cane Bernardo

Blocchetto '"Ripeti" per creare ripetizioni

Blocchetto giallo "Attendi" per dire al computer di aspettare 1 o più secondi

D

EARLY FINE ARTS ACADEMY QUESTIONNAIRE

The following is the questionnaire given to the students of Fine Arts Academy for the assessing the initial knowledge of the participants and general data collection for future evaluation. The original questionnaire was an online web form, this is a transcript of the questionnaire. Some minor translations in the text have been added to facilitate referencing.

Questionario Iniziale Accademia delle Belle Arti di Venezia, corso: Nuove tecnologie per l'arte. AA. 2013-2014

Cognome
Nome
età

e-mail
Anno di iscrizione
Indirizzo

Esempi di contesto in cui hai visto esempi di smart materials (Example of context in which you have seen smart materials)

In arte
In opere architettoniche
In oggetti d'uso quotidiano
In giochi educativi
Altro (specificare)

Specifica il contesto in cui hai visto qualche esempio di smart material (Specify the example of context in which you have seen smart materials)

Che tipo di competenze hai nell'assemblaggio di componenti elettroniche? (What kind of competences do you have in electronics?)

Quale tipo di attività hai svolto con la piattaforma Arduino? (what kind of activity did you do with Arduino)

Non conosco proprio Arduino
Ne ho sentito parlare
Ho già utilizzato Arduino, avvalendomi di script creati da altri
Ho già utilizzato Arduino, avvalendomi di script creati da me

Come definiresti il tuo livello complessivo di conoscenza della piattaforma Arduino? (scala 1-5)
(How would you define your level of knowledge about Arduino?)

Che cosa ti aspetti di imparare da questo corso? (what do you expect to lear from this course?)

Conoscenza linguaggi di programmazione (scala 1-5 per ogni voce) (Previous languages knowledge)

Java
Javascript
Arduino
C/C++
Max/MSP
Processing

Altri linguaggi? (specificare il linguaggio/i e il livello di conoscenza scalda 1-5) (Any more languages?)

Disponibilità personale di sistemi desktop (Operative system available)

- Nessuno
- Linux
- OSX
- Windows
- Altro

Disponibilità personale di smartphone e tablet (Smartphone or tablet available)

- Nessuno
- Android
- Blackberry
- iOS
- Symbian
- Specifica il tipo di tablet o smartphone

E

FINE ARTS ACADEMY PROJECT QUESTIONNAIRE

The following is the questionnaire is intended to collect the definition of the main characteristics of the SMIs the students were going to create during the course. It contains the description and the main features of the installations design. The original questionnaire was an online web form, this is a transcript of the questionnaire. Some minor translations in the text have been added to facilitate referencing.

Early-Questionnaire SMI Workshop Accademia delle Belle Arti Venezia 2013-2014

Tema scelto: (transposition of senses (synesthesia), object personality, Picture Feeling)

Titolo dell'opera/installazione:

Descrivete brevemente le caratteristiche della vostra opera/installazione

Come classifichereste in modo sintetico la vostra proposta?

Quale tipo di esperienza intendete proporre agli utenti/visitatori della vostra opera/installazione?

In quale contesto intendete proporre la vostra opera?

In che modo si relaziona la vostra opera/installazione con il contesto che avete scelto?

Quali sono le fonti/opere a cui vi siete ispirati per l'elaborazione della vostra proposta?

Selezionate le parole chiave che meglio identificano le caratteristiche della vostra opera
- emozione
- comunicazione
- conscio
- inconscio
- istinto
- ragione
- forma
- funzione
- altro (specificare)
- aggiungi altre parole chiave

Sistema di sensori
- luce
- suono
- prossimità
- temperatura
- contatti
- messaggi twitter
- altro (specificare)
- specifica quali sono gli altri sensori/sistemi di input che prevedi

Sistema di output
- oggetti in carta-cartone-legno
- utilizzo di nitinolo
- utilizzo di vernice termocromica
- altro (specificare)
- specifica quali sono gli altri sistemi di output che prevedi

F

FINAL FINE ARTS ACADEMY QUESTIONNAIRE

The following is the last questionnaire given to the students of Fine Arts Academy for the final evaluation. The original questionnaire was an online web form, this is a transcript of the questionnaire. Some minor translations in the text have been added to facilitate referencing.

Post-Questionnaire SMI WORKSHOP Accademia Delle Belle Arti 2013-2014

Quali di queste attività ti è PIACIUTO svolgere? (dai un voto da 1 a 5 per ognuna) (how much did you like to execute these activities?)

- Origami
- Arduino-elettronica
- Arduino-programmazione
- Smart Material/NiTiNOL
- Smart Material/colori termocromici
- Creazione dei concept
- Sviluppo del progetto

Quanto è stato FACILE fare queste attività? (dai un voto da 1 a 5 per ognuna) (how easy was to execute these activities?)

- Origami
- Arduino-elettronica
- Arduino-programmazione
- Smart Material/NiTiNOL
- Smart Material/colori termocromici
- Creazione dei concept
- Sviluppo del progetto

Quanto INTERESSANTI hai trovato queste attività? (dai un voto da 1 a 5 per ognuna) (how interesting were these activities?)

- Origami
- Arduino-elettronica
- Arduino-programmazione
- Smart Material/NiTiNOL
- Smart Material/colori termocromici
- Creazione dei concept
- Sviluppo del progetto

Quanto NUOVE hai trovato queste attività? (dai un voto da 1 a 5 per ognuna) (how new did you find these activities?)

- Origami
- Arduino-elettronica
- Arduino-programmazione
- Smart Material/NiTiNOL
- Smart Material/colori termocromici
- Creazione dei concept
- Sviluppo del progetto

A quali delle attività del corso ti piacerebbe dedicare altro tempo in futuro? (dai un voto da 1 a 5 per ognuna)
(which of the activities of the course would you like to do in the future?)
- Origami
- Arduino-elettronica
- Arduino-programmazione
- Smart Material/NiTiNOL
- Smart Material/colori termocromici
- Creazione dei concept
- Sviluppo del progetto

Dai un giudizio estetico alle opere realizzate dai tuoi colleghi (il giudizio rimarrà anonimo) (give an aesthetic rating over your colleagues work)

- #holy (origami quadrato, nitinol, twitter)
- Art-duino (didascalie che scompaiono, vernici termocromiche)
- Da mano a mano (filo resistivo, vernici termocromiche)
- Space invaders (origami organico, nitinol, pulsante)
- Un tocco di pensiero (Buddha, tecnica pittorica su tela, vernici termocromiche)
- Venezia in fiore (fiore di carta, nitinol, sensore di prossimità)

Che cosa ti sembra di aver imparato da questo corso?
(what do you think you learned?)

Come definiresti il tuo livello complessivo di conoscenza ATTUALE della piattaforma Arduino? (dai un voto da 1 a 5)
(how would you define your current knowledge of Arduino?)

Quanto è stato interessante il corso? (dai un voto da 1 a 5)
(how interesting was the course?)

Quanto utile è stato il corso secondo te per il tuo futuro creativo e lavorativo? (how useful was the course for your working and creative future?)

Come è cambiata la tua opinione riguardo alla tecnologia?
(how is changed your opinion about technology?)

Se ci fosse una seconda edizione più avanzata, parteciperesti ancora? (dai un voto da 1 a 5) (if there was a second more advanced edition, would you participate?)

Consiglieresti questo corso ad altri tuoi compagni/amici? (dai un voto da 1 a 5) (would you suggest this course to your friends/colleagues?)

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2011

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2012

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