1 INTRODUCTION

The very rapid evolution of digital technologies and the "Internet of Things" phenomenon are today some of the most important issues that product designers have to face during their design activities. While in the past digital technologies were only embedded in some product categories, nowadays these are used and spread in almost all commercial products. This enormous phenomenon produces a shift in the product designers' role: most products are, or have to be, "smart", and their functions can be improved via electronics, software, sensors, actuators and network connectivity that enable these products to collect and exchange data (Atzori et al., 2010). Consequently, today designers need to approach, understand and manage these new technologies in order to exploit their potential into innovative products. However, in many cases these technologies become the core of products, where the user interaction is fully based on content displays, or applications on smartphones and tablets. Besides, if users are more and more comfortable with these digital interfaces, the interaction with smart products cannot be merely based on "a screen", which is fundamental when the system is quite complex, but in many cases could be an unnecessary feature.

Therefore, it is recommendable that designers focus their activities on the design of the meaning and on the user interaction of products, in order to create smart products that are easy-to-use and enjoyable, as well as functioning and effective.

In order to address all these issues with a structured approach, the authors of this paper set up an experimental workshop in which students with different backgrounds in design-related disciplines were asked to collaborate, in multidisciplinary groups, to the design of a specific product. In particular, the topic of the workshop was to design a domestic product that allows new tangible interaction with live-data streams. In addition, students were asked to develop the functioning prototype of their design solution, by using rapid prototyping and physical computing techniques. In the last years these technologies are more and more spread in the design area, and prototyping is a valuable tool in the user-centred design of new "smart" products (Hall, 2001). The workshop was carried out at Polifactory, an interdepartmental research laboratory of Politecnico di Milano that offers the possibility to students to share their experiences and acquire knowledge about digital manufacturing processes and other technologies for the development of prototypes.

The students were able to develop working prototypes of products that are capable of communicating information derived from real-time data streams. Some of the most representative results of this workshop are presented in the paper.

2 LITERATURE REVIEW

The advent of Internet of Things (IoT) has revolutionised the way in which people live, creating networks of information, people and smart products, which share data among each other (Atzori et al., 2010).

IoT has applications in almost all industrial sectors and commercial products. While in the past digital technologies were only embedded in some product categories, nowadays these are used in almost all commercial products. In particular, if we focus on the personal and home areas, we can see a very fast spread of these technologies. Consequently, final users are becoming involved in the IoT revolution in the same manner as the Internet revolution itself (Gubbi et al., 2013). This impressive, enormous phenomenon produces a shift in the product designers' role: most products are, or have to be, "smart", and their functions can be improved via electronics, software, sensors, actuators and network connectivity that enable these products to collect and exchange data (Vermesan and Friess, 2011). Nowadays these "smart objects" are considered as the building blocks for the IoT (Kortuem et al., 2010), and can be classified according to the type, the hardware and software characteristics of the device (computer – sensor –actuator), the service provided, and other parameters (Fortino et al., 2014).

In the professional world many changes have been carried out to manage and exploit these new technologies and fulfil users needs, and this has influenced also the academic world and educational institutions. Likewise companies, educational institutions are faced with new challenges such as growing competitiveness, and rapid technological evolution, and are trying out specific design courses (Cross, 2001; Kroll et al., 2001) in which the two more traditional fields of engineering design and industrial design are integrated in the new concept of industrial design engineering (Cross, 2001).

The attempts to develop multidisciplinary degrees are carried out both from Industrial Design and Engineering Schools (de Vere et al., 2010; Wits et al., 2014). The cooperation among different Schools and Departments is the basic element to supply different knowledge to the students and, then, to develop and improve their multidisciplinary skills (Grimheden and Hanson, 2005). At Politecnico di Milano, the Design & Engineering Master Degree Course has been established by the School of Design in collaboration with the Mechanical Engineering and the Materials Engineering areas (Carulli et al., 2013; Selva and Carulli, 2007).

Within the Design & Engineering Master Degree Course, an "Interaction Design" track has been created, which is devoted to the design and development of "connected products". The approach of this track is based on the fact that, besides technological elements, the design of connected products has to include also knowledge and creative inputs from different disciplines, such as product design, engineering, user-experience design, etc. One of the most important benefits of this multidisciplinary approach is that designers can move beyond the focus on computers to physicality, namely from screens and applications on smartphones to tangible interfaces (Jensen, 2005). Indeed, users like (or dislike) products due to their usability and interaction, more than the data they collect and present (Rowland, 2015). Consequently, product designers have to become figures capable to conceive and develop innovative products that should exploit the potential of new technologies and, at the same time, provide a satisfactory user interaction (Rowland, 2015).

Therefore, also the design process is rapidly changing, and new technologies are more and more used for representing ideas and for developing virtual and real working prototypes of design solutions. Indeed, prototyping is a valuable tool in the user-centred design of new "smart" products (Hall, 2001), which allow enhancing physical interactions with the design idea (Georgiev and Taura, 2015) and evaluating in advance the products characteristics and the user interaction. In order to create real prototypes of "smart" products, product designers need to acquire skills in different disciplines in order to manage:

- the sources and streams of data from IoT networks;
- the physical computing technologies for elaborating these data and controlling the prototype, and
- the 3D modelling and additive manufacturing / 3D printing technologies for developing the physical components of the prototype.

Many universities in the world have introduced rapid prototyping tools and equipment to train students (Junk and Matt, 2015; Ford and Dean, 2013; Mostert-van der Sar et al., 2013; Sass and Oxman, 2006). Following this trend, at Politecnico di Milano the Polifactory maker-lab has been conceived and set up (www.polifactory.polimi.it). Specifically, Polifactory is an interdepartmental research laboratory that explores the relationship between design and new digital manufacturing processes. It is a container of services and activities designed to develop youngsters' multidisciplinary talent and their ability to materialize innovative solutions of product-services that integrate design and technology. Therefore, Polifactory is a making space that offers students the possibility to share their experiences with others, and acquire knowledge about digital manufacturing processes and other technologies for rapidly transforming design concepts into physical prototypes.

3 THE "TANGIBLE INTERACTION" WORKSHOP

On the basis of the literature review, the authors decided to experiment a new approach to the design process and carry out an innovative didactic experience based on it.

This approach is based on the observation of new trends in the design domains, where students are motivated to:

- work in multidisciplinary groups, where students have diverse backgrounds in design-related disciplines and collaborate in and contribute to the design process;
- design novel products, based on the most innovative technologies, focusing on the user interaction, as well as product functions and features;
- experiment the use of new technologies for developing virtual and real prototypes in a very early stage of the design process.

The test of this approach was carried out during a didactic activity named "Workshop", which is a one-week exam at the School of Design attended by the students of the Master Degrees, where a real working situation is simulated. Our Workshop, titled "From Mind to Reality", was attended by 30 students of the Master Degree in Communication Design and 20 students of the Master Degree in

Design & Engineering. The students were asked to independently create groups made of 5 members. Specifically, each group included 3 students of the Master Degree in Communication Design and 2 students of the Master Degree in Design & Engineering. The workshop lasted 5 full days, from Monday to Friday.
All groups of students had to work in the same-shared space, which is the Polifactory maker-lab. The students were able to use Polifactory facilities, consisting of machines for laser cutting, vinyl cutting, 3 axes CNC milling, 3D printing (ABS, PLA, resins, …), and also with physical computing boards and components. In addition, some materials and equipment were acquired specifically for the workshop, as MDF and plexiglass panels, consumables for 3D printing, Arduino boards, Particle Photon and Node MCU boards, sensors, actuators, LEDs, etc. Faculty members and Polifactory research staff were available for supporting students in the development of prototypes, by using all the above-mentioned facilities, components and software development tools.

At the beginning of the workshop (day one, morning), the authors of this paper (who were the coordinators of the workshop) presented the main brief to the students, which was: "*design a domestic product that allows new tangible interaction with live-data streams, and develop its functioning prototype*".
Specifically, students were asked to avoid using any kind of digital display in the final product. Conversely, they were asked to exploit and communicate digital data from the net by using real effects, like moving some parts of the product or changing its shape, or using lighting effects, sounds, smells, etc. Then, referring to Fortino's classification (Fortino et al., 2014), these devices should be "domestic devices", they should have an embedded computer (the Arduino - Particle Photon - Node MCU boards), sensors and/or actuators and should present information to users.
This brief is derived from the intention to stimulate students in conceiving and designing novel products, based on the most innovative technologies, in which new modalities of user interaction, based on the interaction design principles (Preece et al., 2011) can be exploited. Students, instead of designing user interaction based on "screens" and "apps", which currently is one of the most common approaches used for controlling function of any kind of product, were forced to be creative and "think differently".
Before letting the students start their activities, the Faculty members illustrated the main features of the various technologies to use for developing the real working prototypes. The first presentation about which kind of data students were able to acquire and use was given: these data can come from social networks, such as Twitter or Instagram, Spotify, from personal services, like online banking, or from websites and applications concerning weather forecast, maps (people and cars movements, traffic situation, …), air quality, and so on. The second presentation focused on physical computing techniques and the Arduino and Photon boards. Specifically, these boards present different characteristics, due to the fact that Arduino is multipurpose, while Photon is specifically designed for applications in cloud environments. Nevertheless, the programming language is the same and several applications, which do not need a continuous data stream, run also on the Arduino board. Finally, the third and last presentation was about rapid prototyping technologies. In particular, the professors presented the main characteristics of each technology (3D printing, laser cutting, etc.), the different production phases and materials, with the aim of teaching students how to select the most appropriate one for each specific purpose.
In the subsequent phase, each group started defining the "design problem" of their project. This phase consisted in identifying which data stream they intended to use as basis for a product that is supposed to help users in their daily life. The selection was based on an analysis regarding the kind of data that was expected to be useful for users, but that was difficult to understand by means of traditional presentations using numbers and graphs. This is also due to the fact that the amount of data that people can access is almost unlimited: this can be a great opportunity, but also an issue. Indeed, it is often quite difficult for an individual to distinguish between useful and useless data, and also between high and low quality data, and to convert them into practical information.
After this initial phase, which lasted one day, each group presented a set of alternatives to the workshop coordinators, in order to select together the one that deserved to be further developed.
Consequently, the students started focusing on the definition of "product concepts", where the meaning, the shape, the functions and the features of the *product to-be* were designed referring to the modalities used for communicating the selected data-streams. Again, at the end of this phase, which

lasted one day, the most appropriate product concept was selected jointly by the team members and the workshop coordinators.
Days three and four were dedicated to the project development, i.e. the definition and the development of the prototype main components. This was a cyclical process: each change of product functions, shape, interaction modalities, mechanisms etc. had impacts on the prototype and its development. In this phase, each group had to define rapid prototyping technologies to use for developing the prototype (physical computing boards and components, laser cutting, 3D printing and so on) and, consequently, prepare the necessary 3D models and program the boards. Once the components were manufactured, the students assembled them and verified the proper functioning of the prototype.
Finally, the last day of the workshop was dedicated to the presentation of the projects made by the different teams, consisting in showing videos developed on purpose to illustrate the concepts, and demonstrating the final working prototypes.
In total, ten projects and working prototypes were presented. In all cases real-time data streams were used as source of information and contents to communicate through tangible interfaces. In some projects data streams from social networks, mainly Instagram and Twitter, were used. In other projects data from weather forecast websites, online banking systems, apps for monitoring people health were used. The most representative and successful projects were then selected by the Faculty members. These three projects are described in the following section.

4 CASE STUDIES

4.1 Weather station for surfers

The first case study is a weather station, named BeWave, specifically designed for surfers (Fig. 1). In this project, the definition of the final user typology was a crucial element. Indeed, for most people the weather forecast is relatively important, due to the fact that many daily activities (such as reaching the office, go to school and so on) can be carried out with any kind of weather conditions (except for the most extreme ones). On the opposite, surfers need to check the weather forecast, as well as the sea conditions. Today these data are provided by different specialised websites specifically designed for surfers, but they are not so easy to understand.
So, the idea of this group of students was to design *a weather station that dynamically shows in real time sea conditions, such as wave height, wind direction and intensity and tides*. BeWave works with real-time data, where it is possible to select different surfing locations by using a dedicated app.
In particular, the product is designed so as to reproduce the waves height and intensity in a desktop "aquarium", where the water contained is moved by means of a specifically-designed device. Besides, on the left hand side of the BeWave station it is placed a lit wind star that is used for showing the wind direction, while on the opposite side a linear bar shows the wind intensity. Students analysed different data-sources and decided to use data-streams from the website *http://magicseaweed.com/*, where weather forecast dedicated to surfers is presented.
The design of the weather station looks like a basin. This shape is due the fact that it has to contain a certain amount of water, and its shape is elongated for allowing the creation of a wave effect. Regarding the interaction modalities, the users can immediately and naturally check the weather conditions, without having to interpret numbers or graphs, because the station reproduces, in a small scale, the real weather conditions. Referring to the interaction design principles (Preece et al., 2011), BeWave is efficient, effective and safe to use, has a good utility, is easy to learn and to remember how to use. Also, it is enjoyable and cognitively stimulating. Finally, its levels of mapping and affordance are quite high.
The prototype was developed using an Arduino board and a NodeMCU WiFi board for the acquisition of real-time data, for data processing and for managing the main technical components namely, the LEDs and two micro servo-motors used to move a shovel used to generate the waves (Fig. 2).
Finally, the external structure was manufactured by using the laser cutting technology for the flat surfaces (made of 5mm Plywood and 3mm Clear PMMA), and the 3D printing technology for manufacturing some connections.

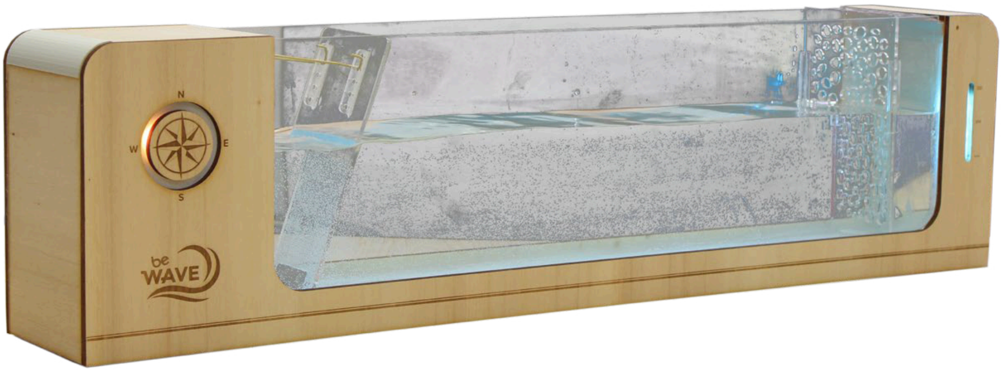

Figure 1. The BeWave prototype

Figure 2. Technologies and components used for developing the BeWave prototype

4.2 Weekly expenses display

The second project, named Budgy, is a system for visualizing daily and weekly expenses. Students started from observing that today daily economic transactions are usually carried out by using electronic cards or other electronic payment systems. Consequently, it is quite difficult to have a clear idea about daily expenses, and to control the actual cumulated expenses vs. a predetermined daily or weekly budget.

One can think of doing this by gathering data by accessing our online banking system and personal areas of electronic payment companies' websites.

The students' idea was to *help users in keeping under control economic transactions, which are often difficult and confusing*. To do this, they designed Budgy to transform a digital data from an abstract and mathematical entity to a physical and concrete product.

Firstly, they identified which visual processes people use to visualize "money", and they found out that one of the most common consists in a stack of coins. Students used this concept as inspiration and designed a product made of different vials: the upper and bigger one is the weekly budget, while the other ones, smaller and lower, represent the seven days of each week. The weekly vial is filled up at the beginning of the week with some small spheres, which represents the weekly total budget. Each sphere represents one euro. Then, for each bank transaction, Budgy drops the corresponding quantity of spheres into the daily vial, showing the daily activity. Every morning, according to the Greenwich time zone, the system moves the correspondent vial into the right position, in order for it to be ready to collect spheres for the daily expenditures (Fig, 3). With regard to the interaction design principles

(Preece et al., 2011), Budgy is efficient, effective and safe to use, has a good utility, is easy to learn and to remember how to use. Also, it is enjoyable, cognitively stimulating and motivating. Finally, its levels of visibility and mapping are very high.
The system works this way: the bank information system receives data concerning expenditures and sends these data to the user's mailbox. Then, a commercial software, named Mailparser (https://mailparser.io/), automatically extracts the data from the emails and create a CSV file. Then, the NodeMCU WiFi board gets the data from the CSV file and, via a specifically-designed software, turns them into inputs sent to three servo-motors. The first servomotor shakes the spheres, in order to avoid their aggregation, while the other two servomotors control the valve of the weekly vial, for dropping the spheres, and the rotating platform of the daily vials.
The prototype was developed by using one NodeMCU WiFi board for the acquisition of the data, their processing and for managing the three servo-motors. The physical structure was manufactured by using mainly the laser cutting technology for the flat sides (with Clear PMMA, 3mm), while a 3D printing machine was used for manufacturing the valve, leverages and gearwheels (Fig. 4).

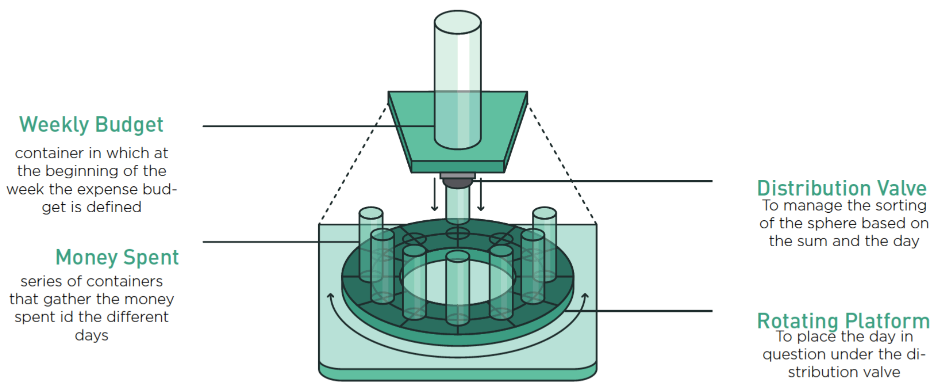

Figure 3. The main components of the Budgy prototype

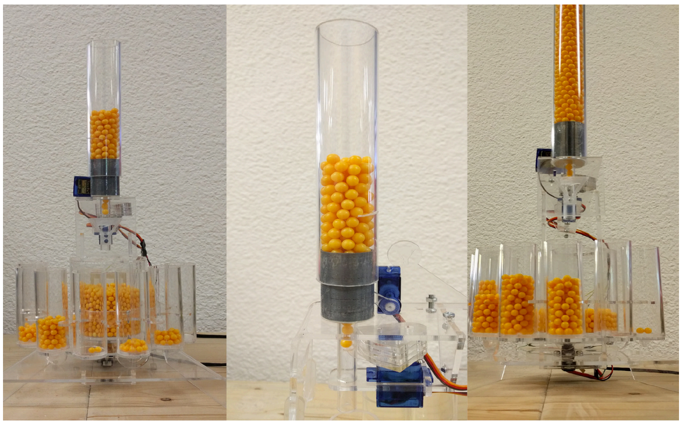

Figure 4. The working prototype of the Budgy

4.3 Pollution indicator

The third case study is a pollution indicator, named Pollenair. In this project, students took inspiration from the worldwide serious environmental problems, focusing in particular on air pollution. Even if it is usually an invisible phenomenon, air pollution kills 3.3 millions people every year. However, many people are not aware of the impact that air pollution has on their life and health. This is an underestimated problem, and some cities, if not entire regions of the world, are not even monitored. Moreover, also if data about air quality exist, few people check them and, even if they read them, they have not a clear idea of the potential risks caused by air pollution.
Consequently, the idea of this group of students was to design a real-time air pollution indicator, which can be used for visualizing the existing air pollution levels in contemporary cities in a tangible

way. The aim is to *increase people's awareness about the pollution issue and, at the same time, to warn them if the quality of the air is too low.*
In particular, the product was designed to modify its shape according to the Air Quality Index – AQI (Fig. 5). This index is based on the values of some PM, which changes according to the size of the particles. We have, for instance, PM 2.5, PM 10, Ozone, NO2, SO2 and CO. One of the most important values to consider is the PM 2.5 level, which measures the level of fine particles (less that 2.5 micrometres in diameter) and is believed being the most important health risk factor.
Students decided to use the live-data stream from the website https://waqi.info/, which is dedicated to monitoring the air quality in 60 different countries around the world. The data stream provided by this website reports the AQIs based on hourly measurements of particles in the air. Also, they used the traditional 0-500 AQI scale, based on the US EPA standard, for indexing the pollution according to six levels: Good, Moderate, Unhealthy for Sensitive People, Unhealthy, Very Unhealthy and Hazardous.
Regarding the shape, students decided to use a metaphoric language, consisting of a flower shape. The flower represents the heart of the city, which is affected by the air pollution level (Fig. 6). If the air quality is good, the flower is healthy and the light inside is green. If it is Moderate/Unhealthy for Sensitive People, the flower starts bending a little bit, and the light becomes yellow. If the quality becomes poorer (Unhealthy/Very Unhealthy), the flower is very bended and the light is blue. Finally, if the level becomes Hazardous, the flower is completely folded down on itself (which means "dead") and the light inside is red. The use of this metaphor is particularly effective, and the users can understand the air quality looking at the shape and at the colour of the flower. With reference to the interaction design principles (Preece et al., 2011), Pollenair is efficient, effective and safe to use, has a good utility, is easy to learn and to remember how to use. Also, it is enjoyable, cognitively stimulating, provocative and motivating. Finally, its level of visibility is very high.
The prototype was developed by using a NodeMCU WiFi board for the acquisition and processing of the real-time data, and for controlling the LEDs and two micro servo-motors used for bending the flower (Fig. 7). Finally, the external structure was manufactured by using mainly the laser cutting technology for the basis (made of Plywood, 5mm), while a 3D printing machine was used for manufacturing the main shape of the flower.

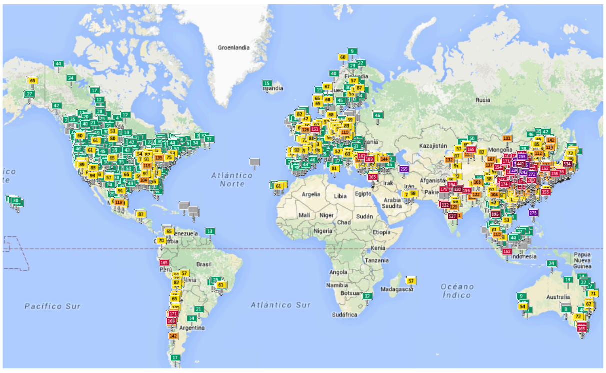

Figure 5. Graphical representation of the Air Pollution levels around the world based on the Air-Quality Index (AQI)

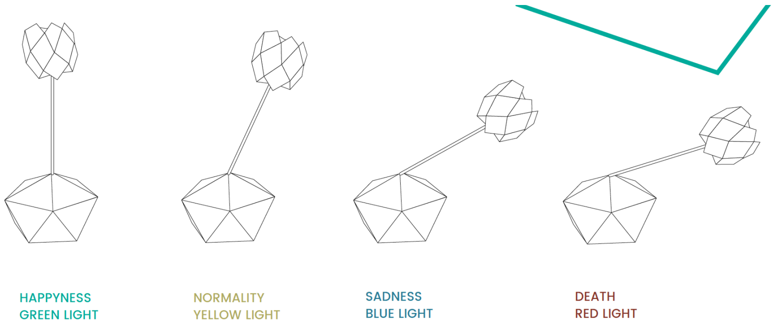

Figure 6. The four different configurations of the Pollenair system

Figure 7. The Pollenair prototype

5 SUMMARY AND CONCLUSIONS

Due to the advent of the "Internet of Things" and the rapid evolution of digital technologies, designers are facing new challenges in their design activities. Their role is to conceive and develop innovative products that should exploit the potential of new technologies and, at the same time, provide a satisfactory user interaction. Consequently, today design students need to develop skills that are useful to manage these new technologies, and to create new interaction modalities that go beyond the simple use of a display.

Therefore, the authors of this paper set up an experimental workshop in which students with different backgrounds in design-related disciplines were asked to collaborate, in multidisciplinary groups, to the design of a domestic product that allows new tangible interaction with live-data streams. In addition, students had to develop the functioning prototype of the product. The workshop was carried out at Polifactory, the maker-lab of Politecnico di Milano.

During the five-day workshop students defined the "design problem" at the basis of their project, which kind of data they would like to communicate, the product concept and its main features. Then, they started developing the product concept and prototyping it by using rapid prototyping and physical computing techniques and technologies.

At the end of the experimental workshop, ten projects and working prototypes were developed. Some general remarks can be made:

- in all cases, students were able to select real-time data streams as "contents" to be communicated through tangible interfaces and define a product concept;
- on the basis of the selected real-time data stream, students were able to define innovative interaction modalities, such as shape modification, lighting effects, sounds and so on, for conveying information;
- students were able to define the most appropriate prototyping techniques for producing the prototype;
- in all cases, the developed prototypes worked properly, and students and authors were able to verify the product features.

Moreover, the most representative case studies presented in this paper show that, also if the workshop duration was short, students were able to face complex problems, design novel project concepts and develop quite complex working prototypes. This result was obtained by using the global approach developed by the authors, which stimulates students in different directions resulting from the most innovative trends in the design area.

The evaluation of the workshop shows that students are enthusiastic about the course topic and approach, and about the possibility to experiment with innovative technologies. However, they thought that the time allocated for the workshop was too limited, given the objectives. In order to solve this problem and improve the final results, in the future editions, the authors are going to launch the workshop brief in advance (one week before the starting day), in order to give students the possibility to carry out a deep analysis about real-time data sources and typologies and acquire knowledge about rapid prototyping techniques. This should reduce the time needed to elaborate the product concept and, then, extend the time available for the prototypes development.

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