Shybo – Design of a Research Artefact for Human-robot Interaction Studies

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Maria Luce Lupetti
Department of Architecture and Design,
Politecnico di Torino,
Turin, Italy.
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maria.lupetti@polito.it

ABSTRACT

This article discusses the role of Design Research in the field of Human-Robot Interaction (HRI). Notably, the Research through Design (RtD) approach is proposed as a valuable method to develop HRI research artefacts due to the importance of having a physical artefact, a robot, that enables direct interaction. Moreover, there is a growing interest in HRI for design methodologies as methods for investigation. The article presents an example of a design process, focused on hands-on activities, namely sketching, 3D modelling, prototyping, and documenting. These making practices were applied to the development of Shybo, a small sound-reactive robot for children. Particular attention has been given to the five prototypes that led to the definition of the current solution. Morphological, behavioral, and interaction aspects were investigated throughout the whole process. Each phase of the design process was then documented with the intent of sharing potentially replicable practices and contributing to the understanding of the role that RtD can play in HRI.

KEYWORDS

Human-Robot Interaction; Research Through Design; Prototyping; Robotic Toy; Design for Children.

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1 | INTRODUCTION

In human-robot interaction (HRI) studies a crucial aspect is represented by the physical presence of robots. In fact, even though simulations (Lemaignan at al., 2006) and video-based methods (Woods at al., 2006) can be valuable tools, most studies are more effective with the physical presence of the robot, since it can affect the types of social interaction that people will engage with it (Bainbridge et al., 2010).

Another relevant aspect that affects HRI studies is represented by the type of robot employed. Depending on the purpose of the study, the choice of the robot may vary. Some studies use commercially available products, as in the study with children affected by Autism Spectrum Disorder by Boccanfuso et al. (2016) who used Sphero, a spherical robotic toy that can be controlled via an application for mobile devices (smartphone or tablet). Other studies take advantage of open and customizable platforms, such as in the work by Bartneck et al. (2015). In this case the authors used an open source humanoid robot called InMoov (Langevin, 2014) to explore the use of Unity 3D Game Engine, an animation and interaction design tool, for controlling robots.

In other cases, the research implies the development of specifically designed robots, such as in the work by Lee et al. (2009). This last category is often adopted in the case of in-the-wild studies in which the robot is usually the result of a deep investigation on both technological and socio-cultural aspects. This is leading to a high interest for

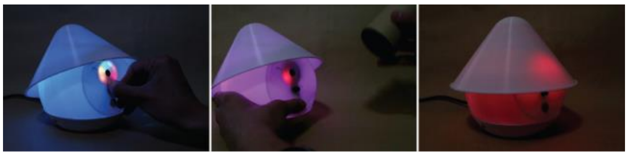

Figure 1 | Shybo robot. From left: colour selection in train mode; sound recording in train mode; scared status in play mode.

design methodologies among HRI practitioners. For instance, design methodologies may allow to explore the effects of different morphologies or behaviours through various design alternatives. In other cases, they may be adopted to get information as well as creative contributions from potential users, which can be used to design culturally robust robots (Šabanović et al., 2014a).

This acknowledged importance of having physical artefacts that allow direct interaction, and the growing interest in the design process as an investigation method, represent two key motivations for applying Research through Design (RtD) (Frayling, 1993) in the context of HRI studies. As explained by Zimmerman and Forlizzi (2014) RtD “is an approach for conducting scholarly research that employs the methods, practices, and processes of the design practice with the intention of generating new knowledge.”

Although methods and theories of RtD are still questioned (Zimmerman et al., 2010), there is a general agreement about three key aspects of RtD: getting in contact with the potential audience, exploring a wide spectrum of multiple potential designs, and considering the practice of making a route for discovery (Gaver, 2012).

The development of physical artefacts, robots in the case of HRI, is not only crucial because they significantly affect people in their types of social interaction, but also because they represent a relationship between a form and its context (Cross, 1999), and most of all, because they embody a thinking (Frayling, 1993).

Shybo (Figure 1), a small sound-reactive robot for children, was developed by adopting a RtD approach, paying particular attention to the artefact’s prototyping. The aim of this work is to contribute to the understanding of the role that RtD can play in HRI, by sharing lessons learned during the project.

2 | RELATED WORK

Although there are not yet explicit references to the adoption of the RtD approach in the HRI field, this may be found in human-computer interaction (HCI) literature. Zimmerman and Forlizzi (2014), in their article “*Research Through Design in HCI*” explain the connections between HCI and Design field and the ways RtD contributes to the production of research knowledge. They focus on two main contributions: a reflective practice of reframing the situation under investigation and the design goals; and a shift to investigating the future as a way to understanding the world that should be brought into being (Zimmerman and Forlizzi, 2014).

The adoption of the RtD approach in the HRI field should primarily be based on knowledge of the HCI field. In many cases, in fact, HCI theories have proven to be valid also in the HRI field. For instance, theories about robot’s acceptability are based on technology acceptance models (Beer et al., 2011) firstly applied in HCI (Dillon and Morris, 1996). However, as explained by Scholtz (2002) these two fields differ in at least four key aspects: there are different possible levels of interaction for humans; the physical nature of mobile robots requires them to have awareness of the physical environment; robots have a dynamic nature that can affect their functioning; finally, they might have to function in harsh conditions, depending on the environment.

Given their peculiar nature, robots’ design requires encompassing a variety of issues, related to both functional and perceptual aspects. On the basis of the robot’s purpose, these two aspects can be more or less related, affecting the design process. For instance, the design of a small jumping robot may be focused on mechanical design issues, rather than aesthetic factors, because of its purpose of suggesting an efficient strategy for fast locomotion in unstructured terrains (Scarfogliero et al., 2007). In contrast, the design of a social robot, aimed at supporting people in daily life activities, requires not only to build a technically robust solution, but also to consider issues of form, behaviour and social interaction (Di Salvo et al., 2002).

As mentioned earlier, in HRI studies it is difficult to find an explicit reference to the adoption of the RtD approach. However, many case studies show how the methodologies of the design practice are adopted as methods for investigation.

Vandevelde et al. (2017), for instance, applied a design approach focused on do-it-yourself (DIY)-friendly techniques to create an open-source robotic toolkit. The researchers faced the main project's challenges (e.g. the unpredictability of an open product and the need to be easy to build) through a series of design iterations that were regularly submitted to the judgment of non-expert potential users. A similar product-oriented approach was adopted by Hegel at al. (2010) for the development of the social robot Flobi. In this project, the designers developed a robotic character able to display emotions efficiently, using modular elements and a cartoon-like appearance.

These two examples appear to be mostly focused on productive aspects. However, the design of robots can address various factors, among which three key interrelated aspects: non-verbal behaviours, morphology, and interaction schemas (Luria et al. 2016). Luria et al. (2016) designed the robot Vyo, a personal assistant for a smart home, through a process characterized by the simultaneous and iterative development of both morphology and non-verbal behaviours, also affecting the interaction schemas. The design process was characterized by various activities, such as sketching, 3D modelling and simulating, low-fidelity rapid prototyping, embodied improvisations with actors, and movement simulations with professional puppeteers.

These few examples show some practices common in the design of robotic artifacts, such as sketching, 3D modelling, and prototyping. All these actions can act as tools for investigation and thinking, and tools for sharing, discussing and testing. Prototyping proves to be crucial for the design process. Thanks to their unfinished and open nature, in fact, prototypes represent a way to experience future situations, connect abstract theories to experience, support interdisciplinary discussions and storytelling (Stappers et al., 2014).

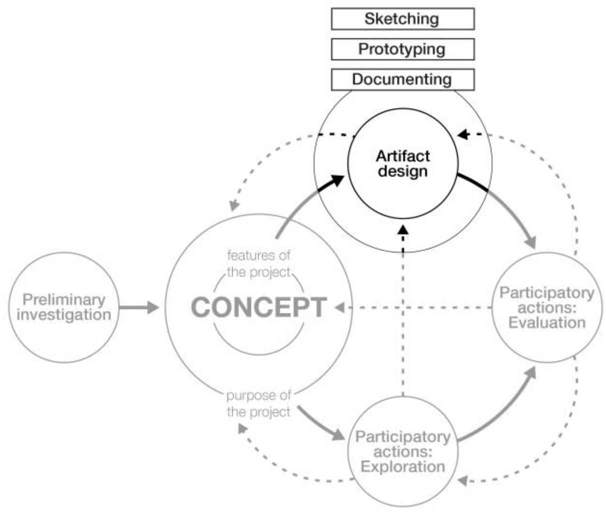

Figure 2 | Design process of the project with a focus on the design and development stage, discussed in this article.

3 | METHODOLOGY

Shybo was developed adopting a RtD approach and the design process was characterised by the combination of participatory actions and the design and development of an artefact. Figure 2 shows the main stages of the design process.

A preliminary investigation, consisting of literature review and scenario analysis, was previously carried out to define a concept and the design requirements necessary for the development of the project. Preliminary assumptions were also deepened through an exploratory study that involved children and parents (Lupetti et al., 2017). This article presents a focus on the making stage of the project in which morphology, non-verbal behaviours, and interaction schemas were investigated simultaneously, taking as reference the work by Luria et al. (2016). These aspects of the robot were investigated through three key actions: sketching, prototyping and documenting. Five different physical prototypes were developed: two paper prototypes and three interactive prototypes, with different levels of fidelity. Physical prototyping was also supplemented by 3d modelling, for both technical and aesthetical purposes.

The duration of the project was eight months. The first six were dedicated to the preliminary research, the definition of the concept, and the design and conduction of the exploratory study. The last two months were focused on the design, development and prototyping of the artefact, in parallel with the definition of usage scenarios and potential supplementary materials.

4 | PRELIMINARY AND EXPLORATORY RESEARCH

The robot's design process was anticipated by preliminary research, consisting of literature review and scenario analysis, and an exploratory study, which implied a questionnaire for parents and a hands-on workshop with children aged 7 and 8 years old (Lupetti et al., 2017). These two phases were aimed at identifying emerging needs and opportunities, both regarding potential users and edutainment robotics, useful to define the design requirements for the development of the robotic artefact. The design requirements were organized in three categories: non-verbal behaviours, morphology, and interaction schema.

Regarding non-verbal behaviours two main requirements were identified: communicate different *states through movement* and provide *explicit input-output relations*. The first requirement is motivated by the fact that the perception of animacy and causality spontaneously emerges with the visual processing of movement (Hoffman & Ju, 2014). The second requirement is aimed at providing children with actions and reactions related to one or more one of the five senses that can be used as starting point for experience-based learning (Andresen et al., 2000). This requirement was defined based on the findings of the questionnaire and the hands-on workshop, that revealed a need for an educational purpose in the play activities, and the opportunity to develop these activities based on children's direct experience.

Two other requirements were defined to guide the design of the robot from the morphological point of view. On the one hand, an *iconic appearance* (Dautenhahn, 2002) is suggested. This is due to the desire to provide lifelike features, such as a face, that can be attractive and can instil a sense of familiarity (Blow et al., 2006) avoiding, however, the emergence of uncanny feelings (Mori, 1970). On the other hand, it is a good practice to provide *physical affordances* (Hartson, 2003) to invite and facilitate the users to the interaction.

Two further requirements were defined regarding the interaction schema, which is intended as the modality in which a robot interact with humans, the sequence of actions required for obtaining the desired behavior from the robot. The two requirements were: using the *robot as a mediator* of the interaction, and to *giving control to children*. The first intends to meet the goal of allowing children to interact with the physical environment, a trend apparent in many projects (Wilson, 2016; Zund et al., 2015) and which emerged from the scenario analysis. The second requirement was based on the observations of the hands-on workshop (Lupetti et al., 2017). In this case the activities with sounds and colours revealed that, beyond finding the most expressive combinations of the two, it is extremely interesting to discuss with children different ways and reasons for creating these associations. Thus, giving control to children is aimed at supporting their reasoning.

5 | DESIGN CONCEPT

The project's aim to stimulate children's reasoning and the requirements guided the definition of the concept.

The first idea was to develop a set of robotic toys able to sense a physical quality and to react with a different quality. Three combinations were identified: sound-colour, texture-sound, and temperature-texture. These were aimed at letting children reflect on why a robot reacts in a certain way. The need for prototyping and testing at least one of the characters, in a limited time span, led to the choice of one combination: sound and colour.

This early idea was developed by reflecting on how to give control to children. Moreover, from the observations of the hands-on workshop the concept was re-defined, introducing the robot's ability to learn. The resulting concept consists of a sound-reactive robot that has no pre-set colour-sound combinations and that must be trained by children to play. Children are asked to assume the role of teachers and to train the robot. To do so, they must choose sounds, record them with Shybo and associate them to colours. By allowing children to establish their own rules and motivation, the robot promotes their spontaneous learning by teaching (Tanaka and Matsuzoe, 2012). Once they trained the robot, children can play with it in two usage scenarios. In the domestic environment, it can be experienced in a free play modality. This means that children can decide which sounds to record and why. For instance, children can train it to recognize different voices or to recognize different musical instruments. In the educational context it can be use as part of broader game experiences, for which additional materials are needed, aimed at creative learning (House et al., 2009). In both cases the robot is intended for children aged between 6 and 8 years old.

6 | ROBOT DESIGN

The characteristics of the robot were investigated and developed through three key actions: sketching, prototyping and documenting. The following sections provide an overview of the importance of each of these actions and how these were used throughout the design process.

6.1 SKETCHING

About the importance of sketching in the design process, Van der Lugt (2005) provided an extensive review study. In his article, he explains how sketching is used by designers to support creative thought, especially in the case of unstructured design meetings. Referring to Ferguson (1992) and Ullman et al. (1990), he provides a classification of four kinds of sketching that designers can use: thinking, talking, prescriptive and storing sketches. These four types differ in the purpose of the activity. On one hand, they can be self-reflective tools, as in the case of thinking and storing sketches. On the other hand, they can be a tool for sharing ideas, as in the case of talking and prescriptive sketches.

In this work, sketching was practiced as a tool to support an individual thinking process and to explore possible design ideas useful for future developments. The sketches produced in this work consists of thinking and storing sketches. Regarding the communication of design ideas, fast prototyping techniques were preferred over talking and prescriptive sketches. With regards to the requirements mentioned earlier, sketching was used as a preliminary activity to address all three categories, and to define possible strategies to

Figure 3 | A sketch about a preliminary idea of a robot's family.

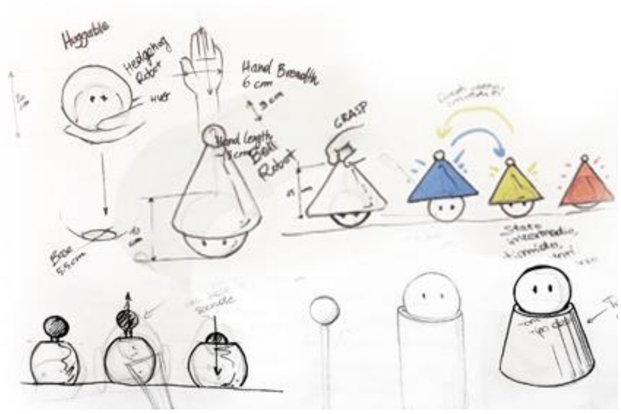

Figure 4 | A small set of sketches about the character's design and possible alternatives.

answer the requirements, that were subsequently explored through prototypes.

Figure 3 shows the preliminary idea of a robotic toy's set. Reflecting on this hypothesis of a set highlighted the need for designing the robot with a personality and helped to define a functioning principle. In fact, reflecting on the possible combinations of senses and reactions that could have been embedded on each robot of the set, allowed defining meaningful combinations (such as colour-sound, temperature-texture, and texture-sound). The need for prototyping and testing at least one of the characters, in a limited time span, led to the choice of one combination: sound and colour. Given this functioning, further sketches were made for thinking about alternative morphologies and non-verbal behaviours (Figure 4), and possible interaction schemas (Figure 5).

6.2 PROTOTYPING

Prototypes represent valuable tools for research-oriented design exploration in HRI (Šabanović et al.,

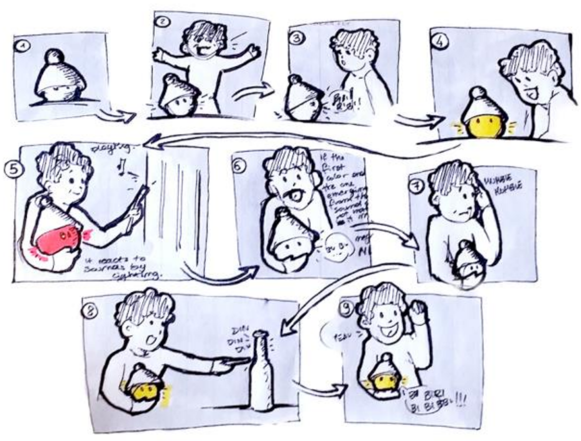

Figure 5 | Storyboard sketches of the artefact's concept. The sequence shows a child playing with Shybo, by making sounds and observing its reactions.

Figure 6 | First paper prototype. From left: active; calm; and scared.

2014b). Researchers can use them to conceptualize different aspects of an artefact, like appearance, functionality, interactivity and spatial structure (Lim et al., 2008). However, prototypes are not meant to satisfy requirements or demonstrate theories. They are rather intended to frame and explore a design space in which "what matters is to find the manifestation that in its simplest form filters the qualities in which designers are interested, without distorting the understanding of the whole" (Lim et al., 2008). Thus, the media or the technique used to develop a prototype is not significant. What is relevant is how a designer uses them to envision aspects of a future artefact (Houde and Hill, 1997).

In line with these statements, the prototyping phase of the project consisted of a series of different prototypes. Each prototype was developed with a different technique, chosen according to its purpose. Hence, a variety of paper models and physical computing platforms were drawn up to explore morphology, non-verbal behaviours and a possible interaction schema.

6.2.1 PAPER PROTOTYPES

The first two prototypes were aimed at investigating morphological aspects of the artefact. Both were focused on one element: the hat. The movement of the hat, in fact, is used to obtain three different states of the robot. According to its position, the robot might look active, calm or scared. Thus, the two paper prototypes were developed for observing the efficacy of hat's movement for obtaining the statuses. Furthermore, the purpose of the first

Figure 7 | Second paper prototype. The hat has the shape of a cone, rounded on top. The two elements are joint by providing the hat with two axes joint to the structure of the body though a pivot.

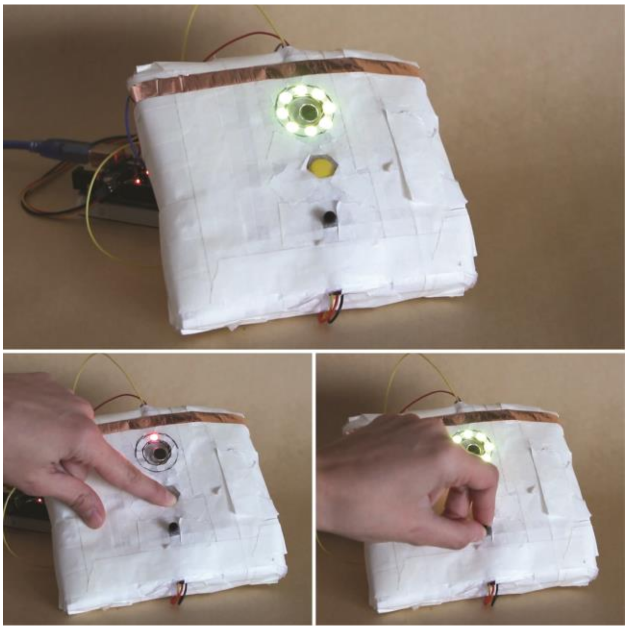

Figure 8 | Low-functioning and low-fidelity prototype. It allows to record a sound by pushing the button and to select a colour by turning the potentiometer. The touch-conductive copper band, placed on top, allows to save the training after recording.

prototype (Figure 6) was also to reflect on the preliminary aspects of character's design, defined by few minimalistic elements, answering the requirement of iconic appearance.

The second prototype (Figure 7) focused also on another morphological aspect, related to the need for providing physical affordances. Given the intent of designing a robot that invites children to the interaction, a rounded shape was identified to let them grab it and hold in their hands. This second prototype represented a way to investigate the formal relationship between the shapes of the hat and a rounded body, and on how to attach the two elements physically.

6.2.2 INTERACTIVE PROTOTYPES

A *low-functioning and low-fidelity interactive prototype* was characterized by the aim of developing and play with a preliminary interface for the training mode of the robot. Given the fact that the character design was not the crucial aspect of this stage, the prototype has a squared shape and it's made of foam. In this case, a key role is played by the hardware components: a button, a potentiometer, a microphone, an LED ring, and a touch conductive surface (Figure 8). These elements, connected to an Arduino board, enable to record a sound, select a colour and save the colour-sound association.

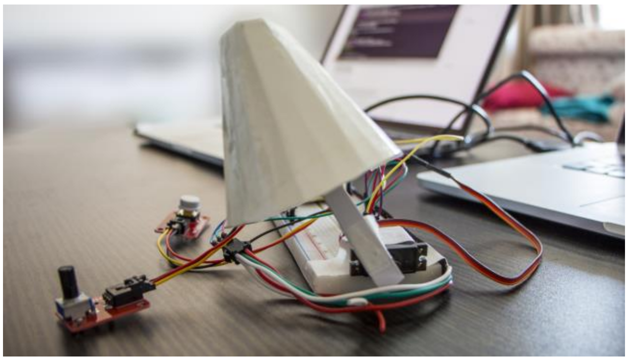

Figure 9 | Low-fidelity and semi-functioning prototype.

Morphological aspects were also addressed in this prototype. However, differently from the previous two, the intent in this case was to explore a way to provide physical affordances for facilitating the interaction in the training mode. On the other hand, the interaction with this prototype allowed an issue to be identified. The training configuration and the required sequence of actions that were initially hypothesized were too complex. Thanks to this observation, the sequence was subsequently simplified and reduced in the number of actions and elements required. This led to the current arrangement of the elements, which has the button as the mouth, the potentiometer as the nose and the LED ring and microphone as the eye.

This prototype was followed by a *low-fidelity semi-functioning prototype* (Figure 9) aimed at improving the training interface and developing the robot's behaviours. Given the focus on the functioning rather than morphology, the hardware components were roughly connected to a breadboard, without any sort of cover. The movement of the hat was developed and tested by sticking the paper hat from the first paper prototype on a servo motor.

At this stage, the two prototypes were mostly focused on the development of non-verbal behaviours and the interaction schema. The

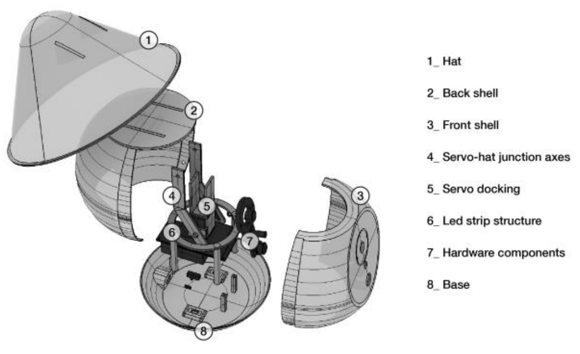

Figure 10 | 3D model of the robot's components.

Figure 11 | Shybo robot: a high-fidelity and semi-functioning prototype.

morphological and aesthetical aspects of the artefacts were investigated through 3D models. The 3D modelling, made with the Rhino CAD software, was fundamental for combining morphological aspects with constraints given by the hardware employed (Figure 10). By modelling various slightly different alternatives, it was possible to identify the simplest and efficient morphology for the robot, that would meet both technical and expressive needs. Furthermore, the 3D model was also animated using Blender, an open-source software for 3D computer graphic, to simulate the movement and the light behaviour.

A *high-fidelity and semi-functioning prototype* (Figure 11) was then printed using those 3D models (Figure 10) exported in STL (Stereo Lithography) format. The printing was entrusted to a professional 3D printing service, which allowed to save time and to achieve a high quality of finishing. The pieces were printed in PLA (150μm, White).

In this fifth prototype, the morphology and the main functioning were mostly defined, and the purpose was to play and test these two aspects. Nevertheless, the efficacy of the robot's behaviours is strongly affected by the details of its actions. For this reason, this prototyping stage paid great attention to the details of the robot's non-verbal behaviours, namely the hat's movement and the light animations, which answer to the requirement of having explicit input-output relations. The animations of the eye of the robot were designed to communicate the functioning in the training mode, while in the play mode the body lighting was improved by paying particular attention to the fade and the transitions between the various colours.

6.3 DOCUMENTING

Every stage of the project was documented through pictures and videos. The resulting archive represented a useful resource for storing, sharing and discussing design ideas. Like sketches, a complete photographic documentation, especially of the prototypes, allows creative thinking, discussions, and comparisons among different design ideas. However, of even greater importance than pictures are the production of videos.

Videos can be used as storing and thinking tools, but they also allow the integration of information, taking advantage of video editing and eventually adding effects, texts and animations. As a matter of fact, the unfinished nature of prototypes may sometimes result in partially effective tools, even if they are meant to explore just one aspect of the intended artefact. In other cases, it may be necessary to explain the functioning or purpose of a prototype to several people at the same time. In these cases, videos can represent a more effective tool than the real prototype. For this reason, every prototype, especially the interactive ones, was documented through photos and videos. A final video of the high-fidelity and semi-functioning prototype was produced to explain the robot's functioning (available at: https://vimeo.com/233640805).

7 | SHYBO ROBOT

Shybo (Figure 11) is a small low-anthropomorphic robot that allows children to explore and play with the physical environment through sound.

It perceives sounds and reacts by lighting up with different colours, and by moving its hat. Given the aim of promoting children's reasoning, it was developed without pre-set sound-colour combinations. It is provided with the ability to learn these combinations from a training that can be simply performed by children. They can select a colour category (yellow, orange, green, blue, purple) and associate sounds with it. After the training, Shybo can recognize the trained sounds and light up in the chosen colours. Shybo has only one pre-set behaviour activated by loud sounds, in which it gets scared: it closes its hat, lights up in red, and shakes. These robot behaviours, explicitly related to the perception of sounds, potentially allow to develop playful experiences, even in the form of real games, for educational context.

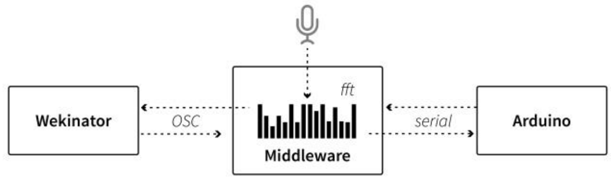

Figure 12 | Software architecture.

8 | ARCHITECTURE

The last Shybo's prototype is characterized by the combination of open source tools, both hardware, and software. An Arduino Pro Mini board is used to manage data from sensors (a potentiometer, a button, and a switch) and to control actuators (a micro-servo and addressable LED strips). Furthermore, the Arduino board communicate via Bluetooth with a laptop used to run a sound-analysis middleware and a machine learning software for classification, namely Wekinator (Fiebrink et al., 2009). The current architecture, in fact, does not include a functioning microphone.

The Wekinator is used to train a model and execute a classification algorithm using a deep neural network, while the middleware sends sound data to Wekinator and connect it to the Arduino.

As shown in Figure 12, the middleware, developed in Processing by Romagnoli (2017) and available on GitHub, has two functions. On the one hand, it analyses sound: it receives real-time audio data and performs an FFT (Fast Fourier Transform) splitting sounds in 250 bands. On the other hand, it allows the communication between the Arduino and the Wekinator. The middleware receives, via Bluetooth, input data from the Arduino, such as start recording, change class, and change mode, and forward them to the Wekinator via OSC (Open Sound Control). It also receives data from the Wekinator, which runs the trained model and send out the data about the classes.

The Wekinator is a tool that allows musician, composers, artists, and designers to train and modify many standard machine learning algorithms in real-time (Fiebrink et al., 2009). In this project it was used to build the robot's training interface, in which sounds are recorded and associated with classes, represented by colours.

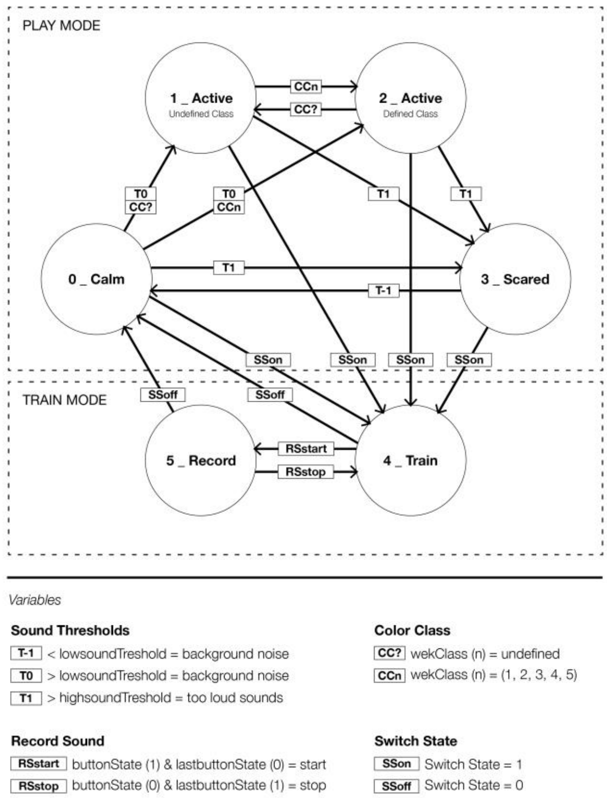

Figure 13 | Finite states machine.

Figure 13 shows the resulting robot's functioning developed as a finite state machine characterized by six statuses. The play and the train mode are determined by the status of the switch, located on the bottom surface of the robot. When the switch is on the robot enter the train mode. In *train mode*, the shift from state 4 to state 5 is determined by the button state. When the button (the mouth of the robot) is pressed, the robot enters the state 5 and starts recording. The *play mode* is characterized by 4 statuses: calm, active with undefined class, active with defined class, and scared. As previously mentioned, the robot gets scared when the sounds are too loud, namely when they exceed a certain high threshold. Regarding the active state, it is firstly determined by the presence of sounds greater than a low threshold. In this state, the robot lights up in different colours according to the training, and the classes that it receives from Wekinator. However, if the robot perceives a sound that was not trained, it goes to state 2 and lights up with a rainbow light animation.

9 | DISCUSSION

Thanks to its hands-on nature, this making process enabled a continuous investigation of morphological, behavioral, and interactive aspects. Despite its unfinished nature, the last high-fidelity and semi-functioning prototype embodies all those reflections and the knowledge produced through the process.

From the *morphology* point of view, the need for an iconic appearance and for providing physical affordances are obtained through both the essential volumes of the robot's body and the composition of the train interface. The robot's body and its hat are designed as essential volumes, which relate to each other thanks to the same origin point that their constructive lines share. The rounded shape of the robot's body is meant for inviting children to hold the robot in their hands and to provide them a comfortable grip. This way of blending functional and formal elements is observable also in other elements of the robot, such as the use of hardware components as face elements. Also, the flat surface that cuts the robot's spherical body is designed with a functional purpose, obtaining a flat surface to place the hardware components, and a formal intent, namely obtaining a face area.

Regarding the *non-verbal behaviours*, the robot can act in two main ways. On the one hand, it lights up in different colours according to the trained sounds. On the other hand, when there are loud sounds, and it gets scared, the robot closes its hat, light up in red and shakes. These two behaviours, which belong both to the robot's play mode, have a different nature. The scared reaction gives a sense of autonomy and personality to the robot, while lighting up in different colours may appear a mechanical behaviour. This mechanical nature, advisable also in the training mode in which the robot gives just small feedbacks on its eye, answer to the requirement of providing explicit input-output relations. This requirement is fundamental for building educational activities focused on how and why to train certain combinations to the robot. The robot's autonomy, in fact, was limited in favour of giving more control to children. In the case of free play in domestic context, however, further development of non-verbal behaviours may increase the robot's engaging potential.

Concerning the *interaction schema*, the robot requires players to train it firstly. It can be done through a sequence of small actions in the train mode. The need for being trained, however, does not only results in those small actions. Since the training pertains sound-colour associations, players are implicitly asked to interact with their real environment to find and play with real objects to make sounds. Thus, even the interaction schema was conceived as open and editable by the player.

The abovementioned characteristics of Shybo resulted from the development of early design ideas through a process grounded in making practices. Although this, as well as all creative processes, is determined by the individual peculiarities of the designer, it is possible to highlight some main advantages of the hands-on activities for the design process.

Foremost, by sketching, prototyping and documenting the design process results *fast*, since it is easier to visualize intended design ideas and features. Prototypes, in fact, allow to quickly bring out critical issues, introducing the need for design iterations. They also allow discussing effectively avoiding the misunderstandings that may arise when interlocutors are asked to imagine certain features. Finally, the process is also speeded by unpredictable solutions emerging from the problem-solving process carried out while making prototypes for different purposes. For instance, the low-functioning and low-fidelity interactive prototype (Figure 7) was meant to explore a possible sequence of actions for the training interface. However, by composing a functional prototype emerged the idea of using the hardware components as face elements, providing a solution for a morphological aspect.

Secondly, the process acquires *authenticity*. By directly experiencing the intended features of the designed artefact, it is possible to give a valid evaluation. As a matter of fact, it is not entirely possible to explain verbally features of the interaction such as timing, complexity, and attractiveness without experiencing them. This is particularly true in the case of artefact designed for play, like Shybo, since it is not possible to explain fun without experiencing it.

Finally, by directly making and playing, especially in the case of prototyping, the process results *enabling*, at two levels. From the designer point of view, prototyping firstly allows to reach more effective communication of the design intentions and to easily change and iterate. By allowing an effective communication, prototypes also enable other potential stakeholders to interact with the project, both to evaluate and to contribute creatively. This is particularly important because in most of the cases the stakeholders may not share the same skills and vocabulary of designers and even a partially functioning prototype can greatly facilitate the communication.

10 | LIMITATIONS

Despite the benefits mentioned in the previous paragraph, the process also presented some limitations. The making practice presented in this work, in fact, consisted mainly of an individual creative process.

The evaluation of the various prototypes consisted mostly in a personal reflection and lab presentations in which other researchers were invited to comment, highlight critical issues and propose improvements. Although these occasions greatly enriched the project, the various prototypes were never submitted to structured test sessions with potential users. Several studies, in fact, illustrated the importance of systematically submitting the prototypes to the judgment of potential users. This would allow to identify the appropriate design characteristics of the robot (Šabanović et al., 2006) and to get useful insights from the use (Vandevelde et al., 2017). Furthermore, participation is even more productive in co-design sessions, in which potential users can creatively play a role in the definition of all aspects of the robot.

11 | CONCLUSIONS AND FUTURE WORK

This article introduced Research through Design as a valuable approach for human-robot interaction studies. As shown by some examples, the physical presence of the robotic artefact is crucial for the understanding of human behaviours towards and our perception and acceptance of robots. This, together with the growing interest in design methodologies as investigative methods, represents an opportunity for RtD, which applies design practice methodologies for the production of new knowledge.

A crucial role in this approach and HRI studies is therefore played by the artefact. For this reason, some case studies were reviewed to identify common practices that can be taken as an example for the development of a research artefact. Among the most recurring design actions are sketching, 3D modelling, and physical prototyping, with different levels of fidelity. As mentioned in related works these actions are usually focused on investigating the three most important aspects of a robot's design: morphology, non-verbal behaviours, and interaction schemas.

Therefore, in order to provide further knowledge about the role and contributions design research methods can offer to HRI studies, especially in the development of novel robotic artefacts, a case study is provided.

Shybo, a small sound-reactive robot for children, was developed applying an iterative process based on hands-on practices which emerged from related works. Sketching, 3D modelling, and physical prototyping were also supplemented with photo and video documenting. The latter practice appeared to be extremely useful both for storing design ideas and for integrating missing details on prototypes, enabling more effective communications with possible stakeholders.

The design process undertaken led to a high-fidelity and semi-functioning prototype that can be used for tests and evaluations with children. The next steps of the project, in fact, will consist of play-testing sessions with children in an educational environment, most probably a primary school. In that occasion, Shybo will be part of a broader activity about sounds and colours that will also include the use of a board game about colour theory fundamentals. At the same time as the play session, some parents will be invited to fill in a brief questionnaire about Shybo and the related playful learning experiences.

The feedback obtained through the questionnaire, the comments from the children, and the observations during play will be the basis of future Shybo iterations.

From the technical point of view, future iterations will also include embedding all the software and energy supply inside the robot, making it a stand-alone artefact. Finally, further aspects that will be explored pertain to the robot's non-verbal behaviours. By providing proactivity, more motion abilities, and non-linguistic utterances (NLU), the robot could increase its engaging potential and become more suitable also for free-play scenarios.

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BIOGRAPHICAL INFORMATION

Maria Luce Lupetti is a PhD candidate in Design for Service Robotics, at Politecnico di Torino, Italy. Her research, focused on human-robot interaction and play, is supported by TIM. During her PhD she was Publicity Chair for HRI Pioneers Workshop 2017 and visiting scholar at X-Studio, Academy of Art and Design, of Tsinghua University, China.