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Between digital and physical. Envisioning and prototyping smart material systems and artifacts from data-informed scenarios.

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Abstract | Acknowledging the roles and potentials of data as activators of design processes within the domains of speculative design and prototyping, the authors are running a study fostering collaboration between the fields of smart materials, digital fabrication, interactive artifacts, and speculative design. This paper discusses the possibilities offered when data meets digital fabrication technologies for the construction of smart material systems. Integrating smart components and flexible electronics, novel materials with responsive behaviours can detect, process, and manifest data. Such nature and features make a speculative design approach key for contextualizing these materials in a social, environmental and ethical future dimension to define their purposeful applications. Situated in this cross-disciplinary design area, this paper describes the grounding theoretical framework for the setup of a 2-day hackathon where interactive materials possibilities and implications were addressed and unpacked. Finally, the paper discusses potentials, limitations, and future possible scalability of the experiments and models presented.

KEYWORDS | SMART MATERIALS, DATA, DIGITAL FABRICATION, INTERACTIVE ARTIFACTS, SPECULATIVE DESIGN

1. Introduction

It is nowadays acknowledged the paramount role that data plays in our lives, and as designers, in different ways and for different purposes, we also massively rely on data. For example, they allow us to build data-informed scenarios where to unpack phenomena and understand their features for extrapolating useful insights and suggestions. Given this premise, a team of design researchers from multiple design fields have started a joint research about how envisioning and prototyping can be informed by a conscious and sharp use of information as data, following a Research-through-Design paradigm (Frayling, 1993; Koskinen et al., 2011). Here, by *data* we refer to those related to existing imaginary as films, television programs, home videos, video games, streaming contents and other media that can be accessed because available online. As designers, we look at such relevant and valuable information because they can be seen as clusters of knowledge with the potential to play a key role in igniting and harbouring scenarios, elaborated in narratives and imaginaries (more or less wide and shared). Those data are often difficult to be retrieved, accessed, or identified as relevant because they are dispersed in the vastness of the online material.

Building on this, we launched InData (www.indata.polimi.it), a project aimed at investigating the role and potentialities of data as activators in the design process identifying speculative design and prototyping as its application fields. This project was born with the scope of enabling designers to better imagine possible futures, exploiting the collective knowledge coming from online open databases. The main practical output of the project is a Scraping Tool (Varisco et al., 2019) that plays an important role as a data collector and organiser, allowing access to knowledge that would otherwise be more distributed, or worse inaccessible. Within this project, we conducted several experimental activities, led by the research question: How envisioning and prototyping can be informed by data?

Here we discuss the possibilities offered by the encounter of data and digital manufacturing technologies for the construction of smart material systems in a perspective of envisioning and prototyping. Speculating about possibilities is indeed an empowering way of disclosing and discussing alternatives, considering both utopian and dystopian perspectives (Auger, 2013; Tharp & Tharp, 2019). Acknowledging that data and data-informed scenarios can be fundamental triggers when properly embedded in speculative design and prototyping, the experimental part of our study consisted of a hands-on activity, in the format of a design Hackathon to correlate the fields of smart materials, digital fabrication, and interactive artifacts.

In the following we discuss the benefits and implications coming from starting the construction of smart material systems from data-informed scenarios, presenting the outcome of a Hackathon where these premises were experimented.

2. Theoretical background

2.1 Interactive and smart materiality

The artifacts we use in our everyday life are becoming increasingly embedded with smartness, as the quality of an object to adapt to circumstances, reacting to different stimuli. Over the years we built complex and interactive systems that bridge together people, processes, data, things, and environments in a networked and responsive way (Evans, 2011, 2012). In doing so, data and information became central for crafting growingly seamless and integrated experiences (Castells, 2000, 2004; Giaccardi, 2015). To respond to this tendency, considering the urgency of connectivity, we should deepen the reasoning on which materials can be used to implement and support smartness.

The expression “smart materials” identifies materials with changeable properties responding to external inputs (Ritter, 2006). Smart behaviours can be transferred to materials by integrating micro-controllers, sensors and actuators into materials so that they can detect, process, and manifest data in very promising ways (Razzaque et al., 2013; Brownell, 2014; Vallgårda et al., 2017; Rognoli & Parisi, 2021). Furthermore, different technologies and materials with smart properties can be combined to create *Smart Material Composites* (Barati et al., 2018) and *Hybrid Material Systems* (Parisi & Ferraro, 2021).

The application of such materials unfolds many opportunities both from an aesthetic and functional perspective: enhancing multi-sensory experiences; monitoring and supporting body activities; making invisible data tangible and information more accessible. One of the main challenges regarding the implementation of smart and interactive materials is sustainability, e.g., using organic and biodegradable materials (Lazaro Vasquez & Vega, 2019; Ferrara et al., 2019; Parisi & Shetty, 2020; Kretzer & Mostafavi, 2021). The use of biopolymers from renewable resources emerges as an opportunity to exploit and test.

Therefore, the choice to work precisely on the transformation of bio-based materials into smart bio-based materials is a crucial critical aspect. From a side such materials have not reached a stabilized imaginary; from the other side the possibility to self-produce them in custom shapes, thicknesses, and haptic characteristics, offers great spaces for experimentation and application yet unexplored.

2.2 Speculative design

A speculative design approach is key in contextualizing these materials in a social, environmental and ethical dimension for defining their purposeful applications, by enhancing their potential in translating and delivering information. In fact, such hybrid materials are often materialized in the form of prototypes and experimental demonstrators, due to technological limitations in the case of scaled productions, scarce availability of fully embeddable components in some applications, and a lack of connection with the functional and emotional dimension to which they refer.

With a speculative approach, designers try to envision opportunities without the current limitations of technology, culture, and politics in mind, and seek to satisfy the emotional and intellectual needs of people. Everyday problems often take the shape of complex matters of investigation as *wicked problems* (Buchanan, 1992). Bridging the real and the fictitious into possible or alternative scenarios nurtures exploratory processes where opportunities and possibilities are investigated. These solutions act as a "catalyst for collectively redefining our relationship to reality" (Dunne & Raby, 2013, p. 2). Speculating about the not-yet existing technologies and objects, through the use of scenarios or tangible artifacts (diegetic prototypes), is opening new frontiers for exploration and inquiry – critical inquiry and creative exploration. In this way, design practitioners can focus on the new methods and applications through which they can envision a not-yet-existing artifacts and applications. Designers should take a look into the future to face the upcoming challenges. In the area of experimenting with interactive artifacts, intelligent materials, digital fabrication, and speculative design are performing a paramount key role in enabling designers to better imagine the future and to suspend disbelief about change (Sterling, 2005).

2.3 Digital fabrication as activators of new possible scenarios

The connecting element between speculative design and new possible application conception of bio-based materials is offered by the enabling nature of digital manufacturing technologies (DMT). These technologies, indeed, are increasingly accessible and pervasive, also thanks to the worldwide spread of places such as Fab Labs and makerspaces.
In the last ten years, this led to a change in reachability and exploitation of DMT. The ongoing growth of the maker culture through DMT filled the gap from "having idea" to "making idea" (Dormer, 1997). Nowadays, the importance of experimental practices is not being questioned: throughout design practices the use of makerspaces and fabrication workshops is being actively adopted worldwide, especially in high-education contexts (Carulli et al., 2017). The opportunities offered by making processes not only affect the prototyping phase but can also become a driver of design innovation. Above all, making practices could be identified as the first trigger for enhancing speculation in several fields, not only in Design.

DMT and making processes can lay the groundwork of design concepts that integrate design practices with engineering, art and science. Examples of this approach are "Design Taxonomy" by Ginsberg (2014) that visualized, through 3D-printed shells, a future scenario where vehicles mutate and evolve subjected to biological rules, and "Conus" of Vtol.cc Art Collective, a project that applied the study of a mathematical model to develop an installation that analyses a geometric pattern on shells and transforms them into control signals for the synthesis of sound and images. These artifacts represent singular cases of a wide nebula of conceptual trials and tests distributed in the centre of the *Krebs Cycle of Creativity* (Oxman, 2016), where the creativity drivers are entangled (Brockman, 2011). Consequently, providing the DMT – and more generally the context and knowledge of a university makerspace – the real turning point is channelling the speculative dimension of design that integrates bio-based materials, sensors, and actuators. A point that should be leveraged when attempting to apply an evolution of the experimental model already present in design schools.

3. Hackathon as a cross-disciplinary practice for envisioning and prototyping

As a demonstration of this cross-disciplinary design space, we present the case study of the 2-day hackathon "DATA < > MATERIALS - Design between Envisioning and Prototyping" involving 19 students from the different courses of the School of Design of the Politecnico di Milano (BSc and MSc). The hackathon relies on a research-through-design approach (Page et al., 2016) thus overcoming the limitations that occur when students have different backgrounds. Such an experimental approach represents a practical way to design where the students are able to first experiment and later quickly verify and iterate ideas extracting the necessary knowledge from the iteration itself through hands-on activities. Experimenting directly by building up ideas in quick prototypes gives the opportunity to fail and iterate quickly, thanks to DMT. When approaching intangible contexts such as future scenarios, the iteration of conceptual ideas in a tangible form is a key element to actualize intrinsic and critical elements. We took advantage of the practical and hands-on design activity as a final step for the InData project research (Varisco et al. 2019; Mariani et al., 2019). We used previously created data-informed future scenarios as a starting point for the student for the creation of concepts. The scenarios served as situational paradigms for the design and as a nourishment for the students' critical thinking on perspectives of future development and related ethical implications. In the following we present the setting and activities of the hackathon, critically discussing its outcomes and how the theoretical and practical framework nurtured the participants' knowledge.

3.1 Research methodology

Aiming to understand how data-informed scenarios and digital fabrication prototyping can empower designers in-training in envisioning smart material systems, the research follows a through-design approach (Koskinen et al., 2011). For grasping the benefits and also the implications of exploring bio-based interactive and smart materials from future scenarios and an array of sensors, we applied a mixed method approach, triangulating the results obtained. We monitored the hackathon conducting rapid ethnography (Millen, 2000) with participant observation. Moreover, we asked participants to provide us contextual feedback, explain which processes they were following and why. Further evidence was collected through online questionnaires and informal interviews. Also, we evaluated the experiment through the analysis of the outcomes in the form of the tangible artifacts. The purpose was comparing our initial expectations and hypothesis with the perceptions, thoughts, and experiences of those who partook in the design activity.

3.2 An experimental design method for the cross-disciplinary practice

For setting up the Hackathon, we defined a design method and structured the activities, preparing contents and a supporting toolkit for students. The method derived from the theoretical framework of the project, entangled as a systemic synergy of various outputs and knowledge from our individual research areas. It is a holistic design method involving future scenarios informed by data (Rosson & Carroll, 2009), bio-polymers do-it-yourself making (Rognoli et al., 2015), smart components programming and integration, and digital fabrication (e.g., laser cutting). In this method, three layers are mutually informed to provide design consistency to the designed artifacts: quality, shape, and behaviours (Fig. 1).

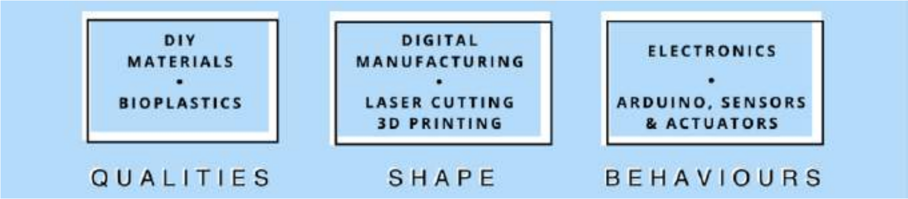

Figure 1. The three grounding layers of the method, and the related supporting technologies.

We involved a heterogeneous, multidisciplinary group of 19 students with various design backgrounds and previous knowledge on the hackathon's subjects. The brief was the creation of tangible artifacts as outcomes of the application of the method which involved different tools and elements as supporting material for the quick design process: data informed future scenarios, experimenting with bio plastics and digital manufacturing, and sensor and actuators embedding (Fig. 2).

Students were asked to create a concept of a tangible artifact that would set and act in a possible future – a diegetic prototypes – made in bio plastic, with embedded technology, supported by a kit containing a scenario, a board with sensor and Arduino code, recipes for bioplastics, and materials inspiration cards. Additionally, we provided ingredients for cooking bio plastics, and different tools such as moulds and laser cut frames.

Reference future scenarios with the additional support of a Scraping Tool developed by the authors (Varisco et al., 2019; Mariani et al., 2019) were provided as the starting point for students' creative process. Moving far from the present moment, the act of setting an idea, a concept, a provocatory element in the future allows designers to avoid constraints and boost imagination with a focus on critical elements and ethical involvement.

Moreover, aiming to materialize and iterating the conceptual ideas with hands-on activities, students learnt to create bioplastics with quick and easy recipes that enabled them to give shapes and material qualities to their ideas. The attribution of material qualities to bioplastic making was supported by introductory lectures, tutorials, and material inspiration cards that provided background knowledge and insights for embedding qualities of the material through different textures, thicknesses, densities, and so on. Students could take advantage of digital fabrication supports and electronics to be embedded in the biomaterials to give them behaviours and bring actions to life.

The first day of the hackathon was dedicated to the learning and experimenting with biomaterials and electronics that, starting from the data-driven scenarios provided, enabled the participant to explore possibilities and constraints of the creation and use of biomaterials and electronics extracting insights and iterating the design concepts. During the second day, students built the final prototypes.

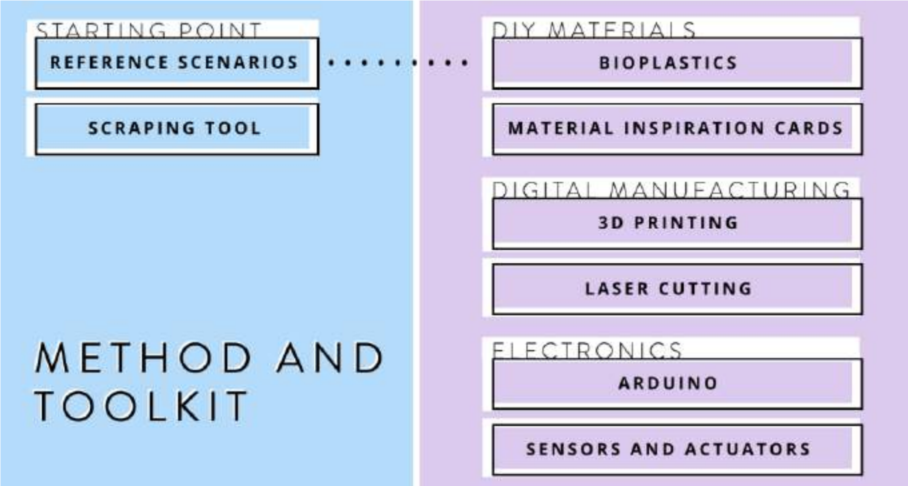

Figure 2. Overview of the Hackathon method and toolkit.

3.3 Elements of the toolkit

Reference scenarios. We provided participants with scenarios that were previously built relying on the knowledge base that later on informed the InData project itself. Starting from information derived from sci-fi, the scenarios are based on envisioning technological evolutions including not only technical, cultural and visual hints but also opening to social and ethical implications (Fig. 3): (1) Perfect Humanity, (2) Pervasive Monitor (3) Automatic Intelligence, (4) Alternatives (Varisco et al., 2017). This formalization of scenarios follows the same principles of the use of the InData Scraping Tool (Varisco et al., 2019), which has also been provided to students participating in the Hackathon as an additional instrument for refining and advancing the given scenarios.

Figure 3. The four scenarios used as a starting point.

These scenarios depict different futures with various extents of pervasiveness and ubiquity of information and technology, showing various degrees of access and use in societal context:

1. *Perfect Humanity*. Advanced technologies and access to high quantities of information enable us to enhance our potential, making us "perfect" but increasing social inequalities.
2. *Pervasive Monitor*. Measuring actions and people in relation to their data enables the hyper tailoring of services, while also raising perturbations on self-

perception, perception of others, and technocratic monitoring of society with political implications.

3. *Automatic Intelligence.* In completing everyday tasks and making decisions, we will rely on machines and robots capable of doing everything on behalf of people. In this setting, people become less and less aware of the actions performed by non-human actors.
4. *Alternatives*. The pervasive connectedness will delete the distances, altering the perception of time and space, and reducing the differences between reality and virtuality. This not only changes our reality but also allows people to become someone else through their avatars and digital representations.

We created a format containing all the scenarios, with mood boards, reference movies titles, and a list of keywords to use to expand the knowledge using the Scraping Tool.

Bioplastic recipes and tutorials. For “cooking” bioplastics, we selected a set of predefined recipes (Fig. 4). Participants could create new recipes changing ingredients’ proportions and adding fillers (as powders and pigments), exploring different properties of bioplastics, such as mechanical (elasticity, stiffness), optical (transparency, translucency, opaqueness), and physical (texture). Participants were equipped with laser cut wooden frames of various dimensions to be used for experimenting with first samples of bio plastics. Laser graved textured plastic sheets were also provided for this activity and participants had a half day for testing given recipes. Then they started to design their own frames, textures, and even recipes.

Figure 4. Experimentation with bioplastic recipes.

Fab Lab environment. Access to DMT such as laser cutting, 3D printers, and vinyl cutters allowed to shrink the time usually spent in the production and assembly of study models and prototypes, allowing to run several cycles of error tests until the ideal result is achieved. Without this type of infrastructure available, the duration of the hackathon would have had to be significantly revised.

Material inspiration cards. A set of 24 inspirational cards showing examples of interactive and smart materials was provided (Fig. 5). Each card shows an example through pictures and textual information, a short text describing how it functions and performs, and a graphical schematic representation of its components, inputs, and outputs (Parisi & Rognoli, 2021).

Figure 5. Participants using the material inspiration cards.

Arduino, sensors and actuators. A kit with an Arduino board, sensors, and actuators was provided for the embodiment of the technology in materials and designed artifacts. Based on the evaluation of the complexity and time that has to be employed for the realization of the artifact, we limited the selection to three sensors – sound, touch, and proximity– and three actuators – LEDs, vibration, and buzzers. Moreover, estimating possible uses, we provided basic codes (Fig. 6).

Figure 6. Arduino coding and experience prototyping.

3.3 Results

The activity resulted in four concepts of speculative interactive artifacts manifested by realizing a set of responsive material-based diegetic prototypes able to react to inputs and delivering information according to predetermined design scenarios. At the end of the hackathon, students presented their concepts making an open presentation to the community of designers, where the working prototype was shown and discussed. Here the four concepts are described.

Figure 7. Prototype of Secluder.

Secluder. Based on a society where virtual reality takes over and people live isolated in a parallel world (*Alternatives* scenario), the concept presents a visor-shaped device programmed to respond to noise overstimulation in public crowded environments by recreating a relaxing world of lights and colours regulated by chromotherapy, using sound sensors and LEDs as actuators (Fig. 7). The translucency and the use of colours and gradients recreate a relaxed immersive environment. The light-emitting behaviour and the material qualities are intrinsically dependent, while the texture enhances the interaction between the light and the material.

h.ID.e. The team contextualized the concept in a near future scenario where facial recognition takes over and governments have access to all data and control any action (*Perfect Humanity* scenario). In such a scenario, they imagine a part of the population that does not accept giving away their identity for security. h.ID.e is a DIY wearable device to circumvent facial recognition technologies in the form of a mask hiding facial expressions and preventing facial recognition thanks to the material texture and embedded lights activated via touch sensor (Fig. 8). The team exploited the potential of DIY bioplastics for generating uneven surfaces, applying a foamy-effect increasing the number of irregularities on the surface

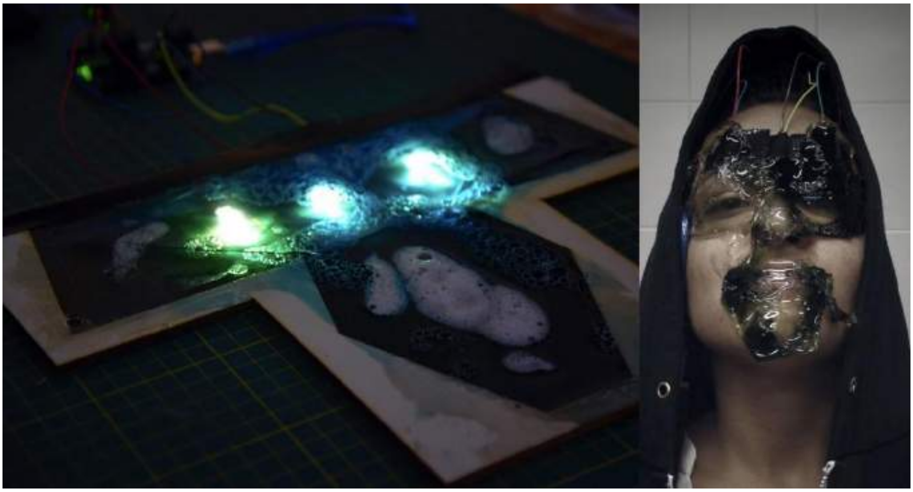

Figure 8. Prototype of h.ID.e.

Fig. 9. Prototype of Breasty.

Breasty. This device is conceived as a companion simulating human skin by touch and appearance (Fig. 9). The team worked on transferring the colour, translucency, and texture of human skin on a flexible bioplastic skin. The device detects the user's touch through a touch sensor situated on one side; it simulates the user’s touch, vibrating through a servo-motor situated on the other side. Users can interact with the sensing part of the object; in return, the responding part will generate the motion that AI elaborated they need (*Automatic Intelligence* scenario).

Zhuan. In the scenario, health and exercise become essential in people's everyday life, and they are often monitored or assisted by technology (*Pervasive Monitor* scenario). The concept is a wearable device designed in modules that detect physiological data and it provides light and colour feedback to make users more aware when training (Fig. 10). The team envisioned other opportunities to implement in the future in relation to IoT and communication with other devices for better program and time management. The device modules consist of two bioplastic layers with translucent and soft qualities, integrating electronics in between.

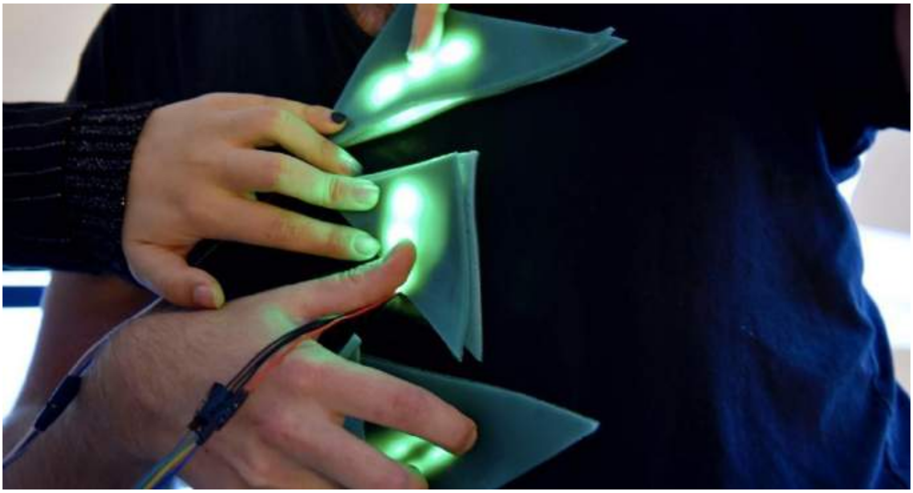

Figure 10. Prototype of Zhuan.

4. Discussion and conclusions

In this paper we presented the theoretical background and results of the hackathon. The method described is flexible enough to be extended or transferred to other fields and aims, and possibly to be scaled out in larger experimental actions. In this regard, we can trace a distinction between the methodology per se and how it was applied. Fundamental elements are data-informed scenarios and their use as triggers for both contextualization and inspiration. The playground in which this methodology was applied is that of smart materials, where scenarios contributed to envisioning the combination of materiality and technology, eventually delivering tangible demonstrators of interactive solutions. However, while in this hackathon the role of biomaterials was a central element, in further activities where the emphasis on this topic is limited, they can serve as a source of inspiration, ideas stimulation, or materialization of tangible demonstrators. The setup showed the versatility of the methodology, and its possible applicability/adaptability to other hackathons and experiences intended for speculating on times to come while relying on current expectations regarding the future, including societal, cultural, moral, ethical perspectives and implications. The methodology and its tools may be used in activities involving other disciplines or sectors than design or cross-disciplinary teams. Examples are sociology, research and innovation, media studies. In case of this extension to other fields, however, we recognise the possible need to adapt the tools in order to make them accessible and usable by non-designers, as to say researchers and practitioners from other disciplines.

The results confirm that the theoretical and practical framework of the research project can contribute to build knowledge, impacting on the projects' development. Stimulated by the set of future scenarios, participants developed unconventional and future-oriented ideas of interactive products or materials. The development of the future-oriented design ideas was a reflective process during which the designers were analysing potential societal issues and related ethical implications of the future world. The set of the future scenarios suggested different worlds with alternative social, political, cultural, and scientific constructions, with related implications. Such scenarios also embed several technological solutions that belong to those contexts, serving as the practical activators of the abovementioned implications. Building on this reasoning, the participants were able to explore the fictional worlds that paved the way for better understanding the potential of technologies. In our case experiment, one of the main topics was bioplastics, hence ruminations regarded their possible evolutions and applications, their social impact and ethical implications. The future scenarios and the hands-on activities encouraged the adoption of a reflective approach while facing future-oriented constructions and related idea generations.

All the participants capitalized on the opportunity to use digital fabrication, especially laser-cut applied to wood to obtain custom frames, and laser-engraving applied to plastic surfaces to add designed textured and form to the materials (Fig. 11). The combination of DIY bioplastics as an easily customizable material, and digital fabrication as a rapid prototyping technique supported participants in obtaining personalized tangible interfaces with meaningful user experiences. Finally, the potential of the bioplastic to embed technologies or serve as a layer with the purpose of containing electronics was exploited.

Figure 11. Custom shapes and textures are obtained by moulds laser-cutting and -engraving.

Although we suggested subsequent steps to facilitate unskilled participants, the method encourages a non-linear use of the toolkit's elements, prioritizing a holistic and flexible approach. Despite the positive feedback collected during the hackathon and in the evaluation questionnaires, some unexpected behaviours were observed, which are food for thought for future actions. In particular, the wide range of interpretative and implementation possibilities offered to students actually shifted the focus from the final output to the process. The experimental dimension is particularly persuasive for design students. As soon as they had the opportunity to confront themselves directly on bioplastics, they partially detached from the final goal of the activity, focusing on basic, extensive experimentation. Probably, the lack of integration of in-depth studies on self-produced materials in design courses was one of the reasons for the deep-rooted curiosity found in the creation of materials.

At the same time, there is the awareness that the acquisition of a process allows its replicability: participants mastered to manage the basic knowledge, potential and limits of bio-based materials, understanding some unconventional application potential of digital manufacturing technologies. In doing so, they learnt that integrating electronic components into a prototype presents unexpected complexities. In this case, thanks to the multidisciplinary structure of the experimentation, participants have been able to expand their knowledge in areas that are not usually tackled together. Therefore, experimentation combined with design practices has once again proved to be an effective and fast learning method.

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