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DOI
10.1007/978-3-031-32280-8_24

Publication date
2023

Document Version
Final published version

Published in
Developments in Design Research and Practice II

Citation (APA)
Papile, F., Bolzan, P., Parisi, S., & Pollini, B. (2023). Perceiving Grown Bacterial Cellulose: An Aesthetic and Sensorial Evaluation of a Bio-Fabricated Material. In E. Duarte, & A. Di Roma (Eds.), *Developments in Design Research and Practice II: Best Papers from the 11th Senses and Sensibility 2021: Designing Next Genera(c)tions* (Vol. 31, pp. 333–346). (Springer Series in Design and Innovation; Vol. 31). Springer Nature. https://doi.org/10.1007/978-3-031-32280-8_24

Perceiving Grown Bacterial Cellulose

An Aesthetic and Sensorial Evaluation of a Bio-Fabricated Material

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Abstract. Biofabricated and grown materials are an emergent trend in the design discipline. The push towards the re-search of innovative and sustainable material solutions has recently increased since there is a real necessity to find solutions compatible with sustainable production paradigms. In the presented work, bacterial cellulose (BC) from kombucha tea fermentation has been chosen for investigation. The biofabrication of this peculiar material enables the realisation of several textural and aesthetical features, giving the designer important freedom. However, to properly look for possible applications in products design, some precise characterisations must be observed and discussed. In this contribution, the authors analysed the sensorial and aesthetical dimensions of six different BC samples to highlight and assess the peculiar element of this promising material.

Keywords: Circular Economy · Growing Materials · Sensorial Material Characterisation · Bacterial cellulose · Material designer

1 Introduction

Linear production characterised the last fifty years production system, and this practice profoundly modified Planet Earth on several levels [1, 2]. As a response, research in diverse fields moved towards finding new paths to overcome the linearity and embrace more holistic production practices. From an economic perspective, new models have been widespread over the last years [3–5]. Consequentially, the design discipline evolved in the same direction, looking for new practices to respond to the transitional urgency toward new modes of designing and producing goods. Hence, many different possible approaches to shift productive paradigms arose. Design activism [6], eco-design [7], design for sustainability [8] are just a few examples of the different focuses design discipline is envisioning as possible solutions to promote shift.

Another significant trend emerging in design research seeks to join design and other research fields, with the specific objective of emulating and designing with Nature [9]. In 2012, Myers described for the first time Biodesign as an "approach to design that draws on biological tenets and even incorporates the use of living materials into structures, objects, and tools" [10]. In recent years, design academics have shown an increasing

E. Duarte and A. Di Roma (Eds.): Senses 2021, SSDI 31, pp. 333–346, 2023.
https://doi.org/10.1007/978-3-031-32280-8_24

interest in bio-manufacturing, understood as a process of materials production - e.g., growing materials (GMs) and complex objects through the growth of living organisms - based on the dialogic exchange between the world of design and that of applied sciences. Biodesign's origin and community are characterised by a DIY and open-source approach [11], contributing significantly to the new perspective of creating experimental materials through innovative, productive processes. In recent years, in the context of material education and design, direct experimentation with material samples has been widely implemented. The importance of the materials' sensoriality and the direct involvement between the designer and the physical samples of the materials were therefore recognised [12–14] as a way to encourage creative practise and experimentation. In this process, emerging practices of Material Tinkering [15] arises as a hands-on, creative and imaginative approach to material exploration, understanding, and development. We can easily apply this direct and creative way to experiment with materials for self-produced, underdeveloped, and low-tech materials, i.e., Do-It-Yourself (DIY) Materials [16, 17]. As a new way of crafting, the self-production of materials allows designers to control the whole process independently and make technical and sensorial material customisation according to their visions and creativity.

These activities result in a multitude of different material outputs that have powerful experiential potential. Therefore, it is necessary to map in a univocal way the materials sample properties, allowing practitioners and designers to apply them to design projects properly. Hence, the objective of the presented work will assess the aesthetic and sensory characterisation of diverse biofabricated material samples. Since GMs [18, 19] can be considered inherently sustainable as they are renewable and biodegradable, current studies in terms of circularity are just at the beginning. Good examples to mention are the grown fungal biotechnologies [20] or kombucha-based leather alternatives [21]. In the frame of the project DE_FORMA, funded by Design Depertment of Politecnico di Milano with research grants, the authors are trying to highlight the potentiality of the development through hands-on experimentation of bacterial cellulose (BC). In this study, BC is obtained from a by-product of Kombucha tea fermentation, using the SCOBY, a biofilm of cellulose that contains a symbiotic culture of bacteria and yeast.

Authors in this work are focusing on the programmability and assessment of the aesthetic features of the BC, finalised to envision its possible application in the initial design stages. The aesthetics dimension is closely dependent on both functional aspects and sensory perception. Therefore, designers usually analyse it while selecting raw materials for their projects. Working on the intrinsic characteristics of a "living" and "growing" material is a significant and attractive challenge for designers, who can operate on colonies of bacteria/yeasts to encode the aesthetic aspects of the final biofabricated material. The aesthetic elements on which it is intended to intervene because relevantly perceived by users in contact with the finished product are mainly: a) surface qualities, e.g. consistency, flexibility, texture; b) optical qualities, e.g. transparency, colours, photoluminescence. In the presented work, the authors will assess the aesthetic and sensorial evaluation of a selection of grown BC samples produced within the project DE_FORMA, considering users' tactile, visual and combined experiences to define their perception upon materials samples, through a designed protocol.

2 Methodology

Relatively unknown materials, like BC, imply complex and novel experiences and aesthetic-sensorial patterns that designers need to comprehend and master to design or integrate them into applications that foster people's appreciation and acceptance. The aesthetic-sensorial evaluation of materials has a long tradition in the design discipline [22–24]: at least four different analysis levels have already been studied and framed within the notion of Materials Experience. Since materiality contributes to the definition of product experience [25], the concept of materials experience, introduced by Elvin Karana [26] and then further investigated, developed and extended [27, 28], is defined as the experiences that people have with, and through, the materials embedded in a product. It describes a holistic view of materials for design, emphasising the role of materials as simultaneously technical and experiential. By taking materials experience as an entry point, it is possible to understand and describe how people experience materials and how physical, biological, social, and cultural conditions constitute these experiences. These four levels are not separated, but they actually interrelate each other and collectively constitute our ultimate experiences. As studied by Karana [29] and subsequently integrated by Giaccardi & Karana [27]:

- The sensorial level concerns the experience that originates from perceiving and noticing material sensorial information by senses. The sensory experience of a material is related to sensory information, e.g., material softness or roughness;
- The material interpretive deals with meaning attribution to the materials (e.g., it is modern or nostalgic);
- The affective level relies on emotions provoked by the user-material interaction (e.g., it is surprising, disgusting);
- The performative one suggests the interaction modalities (e.g., invites me to touch).

Meanwhile, sensorial material characteristics could be led back to numerical, quantitative values, meaning attribution, affective and performative levels of analysis strictly depend on personal's users' culture and, in a broader perspective, in the referring application context (e.g., a specific market or a particular application).

The following methodological path has been adopted in the presented work to collect information on mainly sensorial and interpretative levels of material samples. A panel of design students has been allowed to interact with the material samples at a given time. The samples have been developed to show different aesthetic and sensory characteristics, implicitly communicating the potential customisation of the grown materials in terms of sensorial (e.g., tactile and visual) and aesthetic properties (e.g., colour, material and finishing).

In the framework of descriptive test typology [30], the scaling method will assess the samples' specific material aesthetic and sensorial properties [31]. According to traditionally coherent sensory vocabulary, the scales have been elaborated to evaluate specific perceived qualities, as for the semantic differential methods [32]. The descriptive test typology has been preferred for the possibility to assess qualitative sensory profiles in a measurable output [33]. Moreover, this methodology is going to allow researchers to evaluate properties linked to different sensorial registers (as sight and touch). BC, as a semi-unknown material - or in any case little used in design applications-, can be qualitatively evaluated also through the structuring of "sensory path" for the survey participants. This approach incorporates the study already carried out on the evaluations of innovative materials [34] that underlined how important it is to pay attention to the relationship between optical qualities and tactile expectations related to them. To facilitate data collection processing, the authors paired the in-person testing session with an online data collection form to allow participants to respond consistently and not interrupt the perceptual assessment by altering it through contact with other materials to be manipulated (e.g., paper).

2.1 Test Protocol Design

A specific protocol has been designed following guidelines found in literature to collect data uniformly.

Safety Rules. To realise the sensorial test in total security and within respect for COVID-19 health security restrictions, the protocol includes safety measures as:

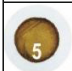
- Hands and personal electronic device sanitation with alcohol-based sanitiser;
- Face mask requirement;
- One person per time evaluating samples.

Test Development. The test room has been set to introduce test attendants in a sensorial iter. At the entrance of the test room, a hands sanitiser has been provided, and a QR Code has been shared to directly guide personal electronic devices (Cellphones, Tablets) to the online evaluation form. Once accessed, some questions upon the test attendants' profiles have been asked, in particular:

- Gender Identity Information: Sex (Non-binary/Female/Male);
- Test Attendant Background (Professional/Student);
- Nationality.

The survey attendants have been then invited to start the test through a tactile evaluation, followed by a visual assessment and, finally, a visual-tactile evaluation of the six different samples among the various produced within the DE_FORMA project, carefully selected to represent a wide range of variations, both visual and tactile in terms of colour, texture, thickness, opacity, etc. The samples selected and tested have been chosen for their aesthetic and sensorial properties, strongly determined by the production processes and surficial treatments adopted. In Table 1, a resume of the different production processes and subsequent samples are presented.

Table 1. Samples Description.

Sample n°	Production process	Ingredients	Color	Texture treatment	Inclusions (perceivable at touch)
	Grown, Dried	Green Tea + Vinegar +Sugar + Food Colouring	Green	None	None
	Grown, Cut & Mixed, Dried in mould	Green Tea & Karkadè Scoby + Textiles fibers	Grey/ Blue	None	Fibre chops
	Grown, Cut, Dried in mould	Karkadè Scoby + Glycerine	Dark Red	Glycerine	None
	Grown, Dried in mould	Karkadè + Vinegar + Sugar	Red	Impressed texture	None
	Grown, Dried	Green Tea + Vinegar + Honey	Brown/ Yellow	None	Honey
	Grown, Dried	Water + Vinegar + Sugar + Pepper Powder	Light yellow/ Avana	None	Pepper Powder

The descriptors used in the test, inspired by referring literature [33], have been adapted for activity purposes. Descriptive tests are usually carried out using scaling methods to assess the material samples' specific aesthetic, sensorial and intangible properties [30]. Therefore, the test attendants evaluated different sensorial properties through five-point scales, providing a neutral evaluation value. Coherently with Osgood et al. [32] Semantic Differential Method, unstructured scales with verbal anchors at the extremities, were provided in the questionnaire. The verbal anchors have been defined through adjectives for each specific sensorial, aesthetical or intangible material characteristics (Table 2).

Table 2. Attributes and Descriptors

Survey sections	Sensorial property	Descriptor
A - Tactile Evaluation (Blind)	Roughness	Rough - Smooth
	Warmth	Warm – Cold
	Stickiness	Sticky – Non Sticky
	Flexible	Rigid
B - Visual Evaluation (No Touch)	Glossiness	Shiny - Matte
	Surface Evenness	Uniform – Non Uniform
	Colour Intensity	Intense – Light
	Transparency	Transparent – Opaque
C - Intangible Evaluation (Free interaction)	Quality	Premium – Poor
	Elegance	Elegant – Cosy
	Innovation	Modern – Traditional
	Cost	Expensive – Cheap
	Pleasure	Like – Dislike
	Naturalness	Artificial - Natural

For the tactual and visual experience (sections A & B of the survey), vision and touch have been respectively isolated to allow a better focus on a specific sensory register per time. In doing so, physical supports were needed to assist the evaluation. For the tactile analysis, the samples have been inserted one per time in an especially designed box, ideated and fabricated by one of the authors, allowing the tester to touch the sample without looking at it (Fig. 1).

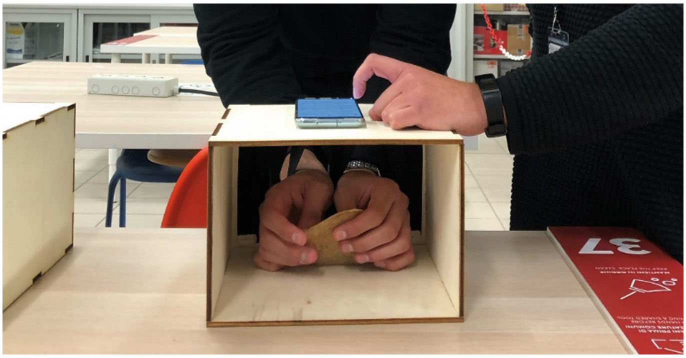


Fig. 1. Touch blind evaluation through masked boxes

For the visual experience, samples have been positioned on plexiglass stands to allow the user to look at the material and perceive its translucency. According to literature [33], the stands have been inclined of 45° to guarantee the same incident light on the material's surface (Fig. 2).

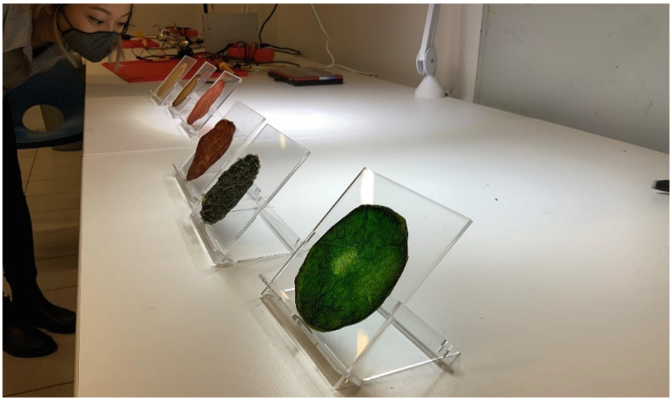


Fig. 2. Visual evaluation, no touch allowed.

On the contrary, for the samples' intangible evaluation (survey section C), since it comes to meaning and appreciation of presented material samples, authors identified the interaction with touch and sight together as the most effective registry combination to introduce intangible evaluation of the samples (Fig. 3).

Fig. 3. Visual-tactile evaluation

3 Results

A total of 35 students took part in the test activity (Fig. 4). The majority of participants were students (34 on 35 attendants) and of Italian nationality. However, a symmetric balance between males and females has been reached (respectively 16 and 19).

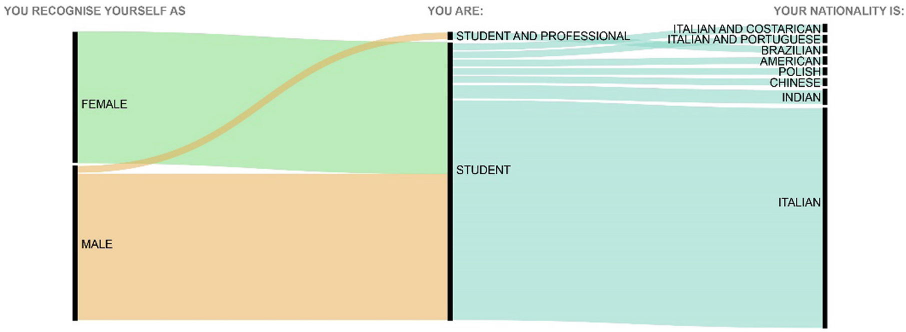


Fig. 4. Participants' Profile

Thanks to their participation, a precise aesthetic-sensory profile of the six different BC samples has been retrieved through average values (Fig. 5).

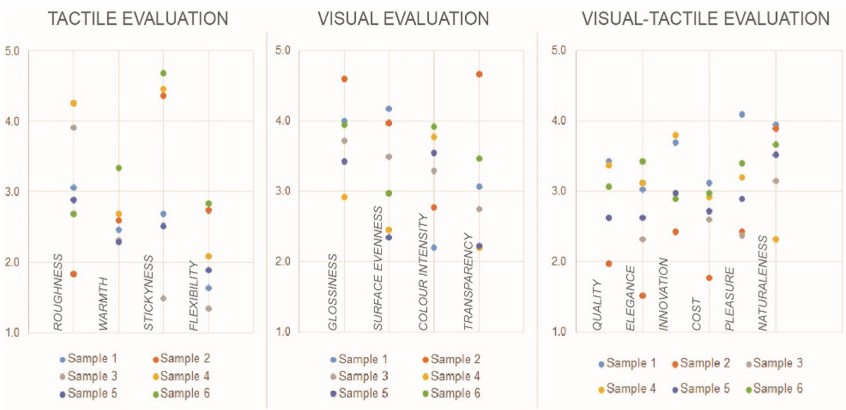


Fig. 5. Cumulative collected data per test section (ROUGHNESS: 1 = Rough and 5 = Smooth; WARMTH:1 = Cold and5 = Warm; STICKYNESS: 1 = Sticky and 5 = Non-sticky; FLEXIBILITY: 1 = Flexible and 5 = Rigid; GLOSSINESS: 1 = Shiny and 5 = Matte; SURFACE EVENNESS: 1 = Uniform and 5 = Non-Uniform; COLOUR INTENSITY: 1 = Intense and 5 = Pastel; TRANSPARENCY: 1 = Transparent and 5 = Opaque; QUALITY: 1 = Poor and 5 = Premium; ELEGANCE: 1 = Cosy and 5 = Elegant; INNOVATION: 1 = Traditional and 5 = Modern; COST: 1 = Cheap and 5 = Expensive; PLEASURE: 1 = Dislike and 5 = Like; NATURALENESS: 1 = Artificial and 5 = Natural).

The authors analysed and collected numerical data emerging from the survey responses to give numerical dimensions on specific aesthetic and sensorial attributes of the analysed material samples. No univocal associations emerge from analysed results (e.g., numerically, an elevated stickiness does not directly generate a poor perceived quality). Sample 1 is considered very flexible, quite matte, with a non-uniform surface at sight, and a high evaluation in terms of pleasure. Sample number 2 is less elegant, considered with lower quality and less loved by the users. On the contrary, Sample 1 and

6 are the most appreciated at visual-tactile evaluation average. Sample 3 is considered pretty sticky and flexible, despite to author's beliefs: if fact, by suppositions, the sample number 5 containing honey was supposed to be the stickiest material, but thanks to its major rigidity, probably has been sensed ad less sticky. Sample 4 presents one of the smoothest surfaces at touch, meaning that the impressed texture does not affect surface irregularities. Sample 5 has no particular excellences, resulting as the most anonymous profile by data analysis. Sample 6 is the less sticky and the second in pleasure, according to test attendees. Almost half of the test attendees (16 on 35) admitted not knowing what the analysed samples were made of, affirming having nearly no experience with similar materials (Fig. 6). On the other hand (19 on 35), the second half of the test attendants affirms recognising the materials but not having high experience with them. This insight is particularly interesting since design students who attended the experimentation proved to be not confident in general with biofabricated BC overall, even if some perfectly recognised the presented materials.

Fig. 6. Identification of presented material samples

From the free comments collected at the end of the test during an informal interview, SCOBY-derived materials appear to be still unfamiliar for designers. It is evident in some participants' comments describing the samples with conflicting definitions, such as stating them look and feel like "synthetic gums or natural materials". Various associations have been made with foods (e.g., salami, nori algae, pomegranate, among others). Also, natural elements, such as leaves or bio-based materials (paper, leather, bioplastic), have been quoted in the attempt to describe the samples. Sight and touch seem to give the most conflicting sensations: at sight, the samples were defined as "weird", "futuristic", and "beautiful"; while at touch, the stickiness is the most impacting sensation, being associated with cheapness, poor quality and dirt, but also cosiness and growth. A participant commented that the samples had a "good appearance but a bad tactile sensation". However, few candidates also related the stickiness (when not too excessive) to tactile satisfaction. Three participants associated sample n° 6 to the Moon, making an associate unrelated to the most recurrent "organic" and "edible" classifications.

Among the sensations aroused, a strong call with nature emerges and, in several cases, an association with childhood games. Several participants grasped the scientific world, the experimental and DIY side behind the creation of the samples, and some associations were made with the theme of innovation, also related to recycling processes. This may have been somehow influenced by the context and location where the test took place: a room - although neutral - belonging to the Prototype Laboratory of the School of Design; this may have produced preconceptions in students who are used to attend those spaces to carry out activities related to DIY.

The quantitative and qualitative data emerging from the experimental activity became fundamental and exhaustive for the authors since their systematisation conduced to realising the following sample ID cards (Fig. 7). ID cards like these are essential tools for characterising and documenting novel and underdeveloped materials. Indeed, they have a twofold objective. On the one hand, they are tangible tools for designers and makers to represent, interpret and comprehend the outputs of their material tinkering and experimentations – i.e., material samples – from the angle of the sensory and intangible qualities they integrate and express. By reporting the main features of each sample, they facilitate the material's author in identifying similarities and differences among the vast and varied collection of samples they fabricated, creating an idea of taxonomy in their

Fig. 7. Material Samples ID Cards

personal material archive or library. On the other hand, they can be used to communicate the inherited and unique materials qualities and identity to other people that may be involved in the process of materials development and application – e.g., other designers, engineers, companies, users. To keep track of the biofabrication processes and the possible interventions to determine some specific aesthetic-sensorial aspects of material samples, together with an efficient communication of this information, according to authors, represents a critical step to provide an efficient application in the design projects of these innovative materials.

4 Discussion

The experimentation demonstrated that with a biotinkering approach, it is possible to realise a wide range of different colours, finishes and textures can be easily obtained. Nevertheless, only through the application of a culture control and verification protocol it is possible to consciously ensure replicability of the finishes to ensure effective applicability in the industrial design domain. Some of the very different samples – belonging as well to the same material – have been recognised as very natural (thanks to the colour or the presence of veins). Stickiness, instead, has been identified as a primarily negative feature at the touch, so further research into treatments and finishes needs to be experiment. In particular, stickiness was primarily associated with the image of a poor material, not treated properly, or even merely not pleasant for subsequent design applications. This aspect is to be considered particularly relevant when designing a material not only as a mere sample, but also aimed at its scalability in productive contexts of circularity.

The majority of participants were able to associate a bio-based origin to the material samples, recognising their natural origins, even if rarely referring to BC, a material that is familiar in terms of knowledge of the literature but that very few have had the opportunity to interact with in practice. In fact, almost half of the candidates said they had no previous experience of the material, and in general, no one has declared to be an expert connoisseur. Sample 6, among others, demonstrated to be the most interesting since it strongly detaches from other material samples for both tactile and visual evaluations, often generating surprising expressions during the blind evaluation. The inclusion of textiles has been evaluated negatively in respect of different samples, probably due to two elements: on the one hand the presence of a very rough surface generated by the inclusion of textile fibres, on the other hand the loss of transparency of the material, which therefore appears very dark compared to the others.

Since some of the samples created a certain disambiguation between tactile expectation and visual feedback, some tests with some swapped phases [34] could be experimented in future to enrich the evaluation. The accordance or discordance between the expectation of tactile qualities by vision compared to the actual ones by touch may be significant for relatively unknown materials like BC, in order to unfold people preconception and sensory associations with familiar or well-known materiality, to stimulate other sensory interplay and better define perspective on BC perception.

The test attendees, as mentioned, were mainly coming from Italy or, however, they were friendly with both English and Italian language. Imagining widening the test evaluation to different audiences, the introduction of different anchors at end of the scales

-that can be complemented with pictures [34–36]- could facilitate in setting approximate standards for the minimum and maximum values and mitigate eventual linguistic misunderstanding or cognitive overload.

At the end of the test, everyone wanted to know what materials they had interacted with: according to the authors, this phenomenon is probably driven by the modality of carrying out the analysis in the presented sequence (blind, view without touch and final interactions). This modality created a particular curiosity during the initial phase of the test and aroused the participants in the following steps. This interest can also be traced back to the type of participants' training: the desire for knowledge and in-depth analysis of the nature of materials and objects with which one interacts is an intrinsic characteristic at the basis of designers' training.

In future developments, to provide a complete characterisation of the grown BC, the research group will further analyse the material's functional properties. In this way, it will be possible to evaluate the proposed material by its characteristics and properties so that design practitioners and students will have complete and integrated [33] information to embody the material into their projects. Ultimately, this aesthetic and sensorial information can be interpreted by designers to enhance meanings and positive experiences in material development, fostering their appreciation and acceptance by people. It should be pointed out that BC is in fact a highly explored material in terms of research and experimental applications, but at the same time, it has not yet found stabilization in large-scale applications. At the moment, most of the evidence in the literature [19, 37–39] proposes an interpretation of this material in comparative terms, in relation to other already known materials that occur in sheets, such as animal leather. However, it should not be forgotten that BC is in fact a completely different material, both in terms materials class and in terms of its production system, as well as its intrinsic qualities. The approach to this material from the point of view of its perceptive qualities is certainly a necessary step to be able to give the right peculiarities to BC: in this way BC deploy can become a conscious choice to be approached not in terms of replacement, but for its actual technical and perceptive characteristics. It is important to emphasise how a study on the quality of materials can open the door to other possible project impacts in which environmental, economic, social and cultural circularity are central. In particular, starting from studies on the quality of materials to be optimised in terms of reproducibility and scalability, creating new production processes, also to be designed, prototyped, tested and evaluated, is also advisable. Therefore, a fundamental role can be played not only by, e.g., virtual prototyping technologies but also rather by the designer as the planner of a visionary future aimed at plausible sustainability.

Aknowledgments. The DE_FORMA (Design Explorations on bio-Fabricated Organic Materials) is funded by FARB (MiniFARB section) funding programme for the fundamental research, by Design Department of Politecnico di Milano. We are thankful to all the colleagues of the project DE_FORMA who did not participate in the activity and the writing of the paper, but supported us in the initial discussion: Carlo Emilio Standoli, Daria Casciani and Erminia D'Itria. We thank Arianna Regaglia for the support in realising photos and samples. We thank all the participants of the study and also the Prototype Lab of the Politecnico di Milano School of Design for hosting the activity.

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