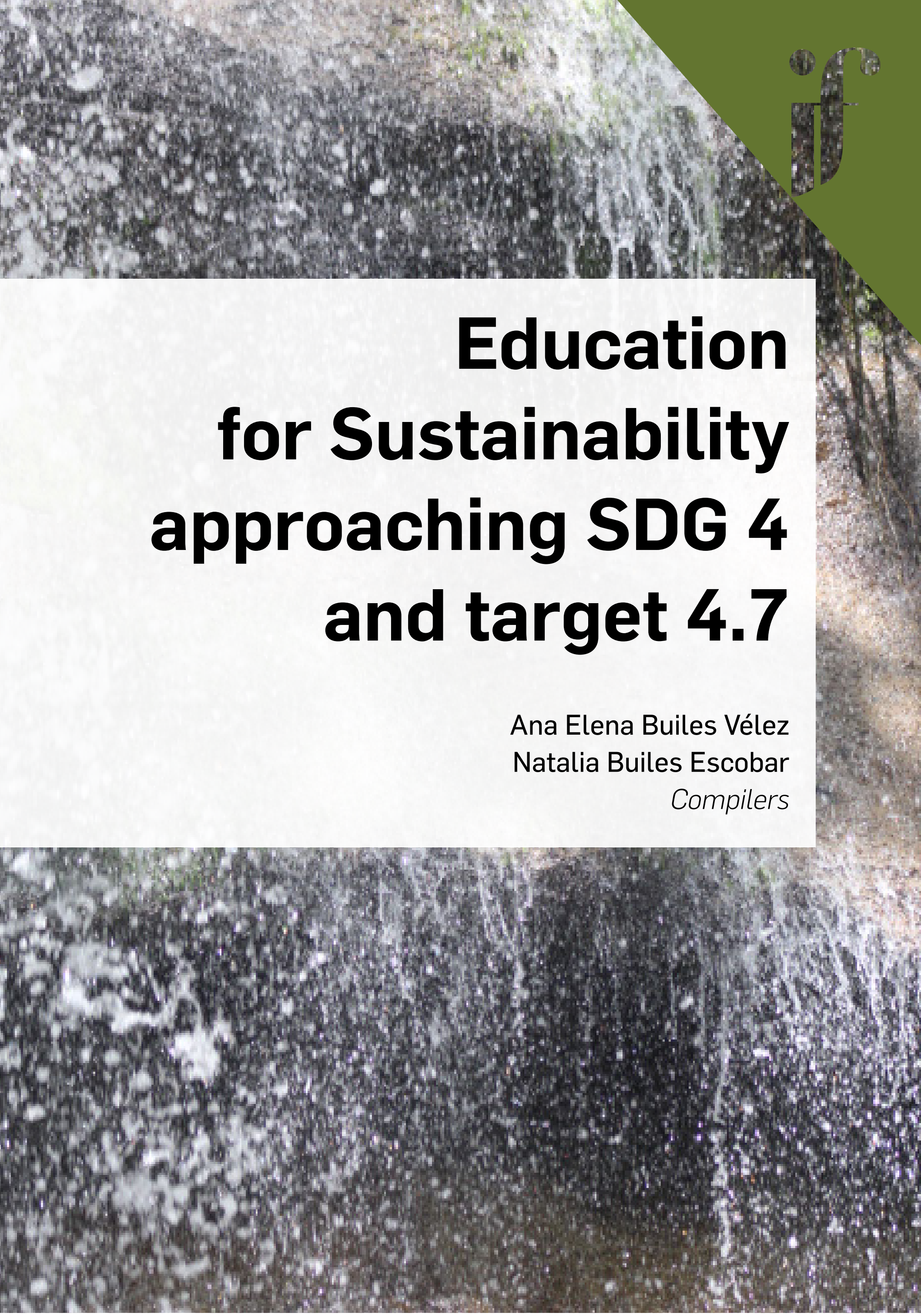

Education for Sustainability approaching SDG 4 and target 4.7

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Builes Vélez, Ana Elena, compilador
Education for Sustainability approaching SDG 4 and target 4.7/ Ana Elena Builes Vélez y otros veintiocho -- 1 edición– Medellín: UPB, 2022 -- 231 páginas.
ISBN: 978-628-500-077-5 (versión digital)

1. Sostenibilidad 2. Medellín 3. Diseño de producto

CO-MdUPB / spa / RDA / SCDD 21 /

Education for Sustainability approaching SDG 4 and target 4.7
ISBN: 978-628-500-077-5
DOI: http://doi.org/10.18566/978-628-500-077-5
Primera edición, 2022
Escuela de Arquitectura y diseño
Facultad de Arquitectura
CIDI. Grupo: GAUP. Proyecto: Educación para la sostenibilidad en las disciplinas creativas. Radicado: 718C-02/22-61.

Gran Canciller UPB y Arzobispo de Medellín: Mons. Ricardo Tobón Restrepo
Rector General: Pbro. Julio Jairo Ceballos Sepúlveda
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Coordinación de Producción: Ana Milena Gómez Correa
Diagramación: Transparencia duo
Corrección de Estilo: ProWrittingAid - Ana Elena Builes Vélez
Imagen portada: Ana Elena Builes Vélez

Dirección Editorial:
Editorial Universidad Pontificia Bolivariana, 2022
Correo electrónico: editorial@upb.edu.co
www.upb.edu.co
Telefax: (57)(4) 354 4565
A.A. 56006 - Medellín - Colombia

Radicado: 2235-19-10-22

Teaching sustainability through materials: bridging circular materials and bio-design for new design curricula

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Abstract

This work presents the pedagogical approach and the outcomes of a course aimed at teaching sustainability through the lenses of materials. The last decade has been crucial to finally reach a mature state of awareness of how the material side of our productions and its poor management is at the base of many environmental problems. Such awareness pushed the emergence of new materials, motivated by the search for more sustainable alternatives and a re-evaluation of biological processes capable of creating materials and artifacts through bio-based and bio-fabrication techniques. The clear environmental crises also pushed the design field to pay more attention to materials; but to date, for designers, understanding the sustainability of materials and their real impact on life cycle products is still not trivial; new biotechnologies are opening up the possibility for designers to experiment with organic sources and living materials. The academic course described in this study focuses on a didactic method based on a practice-based approach; the students are guided to learn the key aspects that can define a material in a sustainable context, improving their material development knowledge and lab working skills. A learning-by-doing path is developed in three workshops tackling material sustainability with an increasing difficulty and understanding. The learning journey starts with an analysis of local wastes for the development of new DIY circular materials. The second step introduces the living variable of bio-fabricated materials, amplifying the complexity of the project and adapting to nature's time scale. The last step requires a higher understanding of the synergistic mechanisms between biotic and abiotic agents in an ecosystem by exploring bio-receptive materials. These three material approaches have been selected for the design methodologies and sustainability principles they have in common. Using classroom observations and a survey, the authors examined student experiences and perceptions of the proposed syllabus in order to understand its efficacy in terms of the last student's material and sustainability awareness. This educational path has proved to deeply connect the students with materials' life cycles and local and natural resources, gaining a deeper understanding of regional environmental issues potentially having a material design solution.

Keywords: Sustainable materials, DIY-Materials, bio-fabrication, bio-receptivity, new design curricula.

The central role of materials in sustainable design

In the last decade, there has been growing attention to the material aspect of our lifestyles and our economies, and this was also reflected in the design field with increased attention to materials. While recent studies pointed out the inadequacy of the management, we have of the planet's resources (Circularity Gap Report, 2021), and how our production methods are still projected towards linear growth models on a finite planet (Elhacham et al., 2020); on the other side, the paradigm of circular economy (CE) has highlighted the central role materials play in an ecological transition (Ashby, 2021). The constantly developing discipline of eco-design (Ceschin & Gaziulusoy, 2016) has often highlighted the central role of materials (Michael F., 2016; Vezzoli, 2013); however, materials' environmental assessment and selection is not a trivial activity for designers, still lacking the right tools to manage material awareness within the project life cycle (Pollini & Rognoli, 2021a). The need for reasoning about sustainability from a material perspective seems urgent and effective at the same time. Materials are in the spotlight in the design practice: they are questioned, assessed for their sustainability, substituted with less impacting solutions, they even become more and more the subject of the design practice itself, for example, through experimental and explorative activities aimed at finding new material solutions with a DIY-Materials approach (Ayala-Garcia & Rognoli, 2017; Rognoli et al., 2015). The hands-on experimentation characterizing this approach for the development of new materials enact tinkering activity, a recognized educational practice grounding on experiential learning, from Bauhaus's didactic notion of learning by doing (Wick, K., 2000), to the more recent phenomena of DIY-Materials (Parisi et al., 2017). In the last years, the will to experiment with materials has been both a bottom-up phenomenon and an educational approach (Pollini & Maccagnan, 2017); designers have felt the need to criticize the choices of conventional materials for products, willing to better understand the production processes behind them and, as a counterpart, also redesigning them, creating new material possibilities, to open up future scenarios of more circular productions. This approach has been recognized as fundamental in material education since it allows to develop solutions at an intuitive level (Ziyu Zhou, 2022); through practical work with materials and tinkering, students can achieve what is called tacit knowledge, essential for design skills and to collaborate in multidisciplinary environments (Rust, 2004).

New sustainable opportunities arise for designers willing to experiment with materials, given by the recent democratization of science, in particular in biotechnologies. A DIY approach (and open-source philosophy) also characterizes the origin of Biodesign, a nascent hybrid discipline described for the first time in the homonymous book by Myers in 2012 as an “approach to design that draws on biological tenets and even incorporates the use of living materials into structures, objects, and tools” (Myers, 2012). In this design approach, materials gain a predominant role, being made of, with, or from living organisms (Ginsberg & Chieza, 2018), such as mycelium, bacteria, or algae, to name the most experienced ones in the bio-design field. Such bio-fabricated materials (Lee et al., 2020) are often claimed to be sustainable, stimulating a very interested audience (including both design academies and the market), thanks to the sustainable features associated with biological origin and bio-fabrication techniques (Camere & Karana, 2018; Esat & Ahmed-Kristensen, 2018).

Sustainability is, in fact, one of the primary triggers bringing designers closer to this discipline (Collet Carol, 2013; Ginsberg & Chieza, 2018; Oxman, 2010). The many sustainable features of biomaterials justify this aspect (e.g., fast renewability, processes that require little energy, water, and resources, life-friendly chemistry), although the life cycle assessment data for bio-fabricated materials are still few, given that many of them are still on a research stage and under development. However, bio-fabricated materials show potential also from a circular economy and bioeconomy perspective, not only for their organic origin but also because some of these organisms can be fed on agricultural waste, as showed both by mycelium-based materials (Meyer et al., 2020), and bacterial cellulose (Provin et al., 2021; Puspitasari et al., 2021) productions. In bio-design, materials that grow while alive provide the designer with unusual outcomes; the design process is highly influenced by the role and behaviour of the organism, affecting the tinkering activity, which became here bio-tinkering, taking the meaning of tinkering with materials of biological origin (Rognoli et al., 2021). Of course, the livingness affects this practice by adding non-linear outcomes (Figueroa & Carolina, 2018). Still, it also brings the abilities of life: consciousness, sensory abilities, and responses to external stimuli, adaptability, growth, change. All these aspects are peculiar to the living organisms, which become potent agencies affecting the design process in terms of its performance and aesthetic. Livingness (Elvin Karana et al., 2020) is not the only quality to be considered in the design process. From a bio-design perspective, inert materials support the living; therefore, the inert counterpart needs to be designed for the organism's requirements and the environment in which it is located. The importance of inert materials in bio-design have been highlighted in a recent study that expanded the definition of bio receptive design, suggesting its involvement "every time a material/artifact is intentionally designed to be colonized by life forms" (Pollini & Rognoli, 2021). Some material features, such as colours, porosity, composition and shape, can welcome living organisms, like lichen and mosses, algae, insects or mussels. These inert/alive assemblages can remediate polluted environments, increase biodiversity in depleted zones, or boost cities' biophilia (Söderlund, 2019). Bioreceptive materials can serve as a nursery for organisms able to positively interact with their environment; for example, MARS[1], a 3d printed ceramic modular structure, has been

[1] Retrieved 6 April 2022, from https://www.reefdesignlab.com/mars1

colonized by corals to restore damaged reefs; another example is H.O.R.T.U.S[2], designed by EcoLogic Studio and claimed to be the first 3D printed bioreactor, hosting algae and cyanobacteria for interiors air purification. Even though this approach is still a niche in design, the growing interest in living materials in the biodesign field makes the design of inert materials' bio-receptivity an essential counterpart to sustain life forms, while giving the designer the possibility to design for small scale living ecosystems, assemblages of inert and alive materials.

How to learn sustainability principles through materials hands-on experimentation

The three emerging material trends discussed so far can also be evidence that such materials experiments have pushed designers towards greater environmental awareness. The development of DIY-Materials forces designers to focus on sources, materials flow, and the expressive-sensorial potentials (Ayala-Garcia & Rognoli, 2017) of new materials derived from waste, supporting their applications in design. Designers, tinkering and creating new materials fully understand their life cycle, the input and output of the manufacturing processes, and their end-of-life potential. Besides this, an approach such as the Material Driven Design method (MDD), developed to facilitate designing for material experiences, is often associated to the DIY-Materials, since it helps to unveil the material's features to enable envisioning accordingly its applications (Karana et al., 2015). This approach brings a transition from a form-focused to a material-focused design process, which can help the designers make sustainably informed decisions in terms of material processing, finishing, and application; to where it is possible to talk about MDD for sustainability (Bak-Andersen, 2018). MDD can also apply to

2 Retrieved 6 April 2022, from https://www.ecologicstudio.com/projects/h-o-r-t-u-s-xl-astaxanthin-g

bio-fabricated materials (Parisi et al., 2016; Zhou et al., 2020); here the designer experience a closer collaboration with living and responsive organisms, capable of growing and giving life to renewable, biocompatible and circular materials and objects. With bio-receptive materials, providing a solid perception of the complexity of ecosystems and places, their design implies a deep understanding of the balance between different agents inhabiting a shared space. The authors, confident that these design approaches needs to be experienced hands-on to activate the intuitive and tacit knowledge leading to a deeper understanding of materials' environmental potentialities and implications, are presenting here the structure and the results of an elective course based on the hypothesis that sustainability principles can be taught through the lenses of materials. By experimenting with local and wasted sources, the students can map new local possibilities for circular materials by practically experiencing their life cycles as they try to create them. Dealing with and for living organisms (both living materials and bio-receptive ones), students need to face the dynamic abilities of life, eventually developing feeling of empathy and care (Camere & Karana, 2018; Keune, 2021); they can directly observe the growth of the materials, see their responses and behaviors to the environment they are exposed, learning about the physical and environmental parameters needed to co-design with the living. Trying to develop a bioreceptive project, aiming at its restorative potential, also gives students a sense of the ecosystem's dynamics and the relationships between biotic and abiotic in a system. The pedagogical approach suggested in this work aims to build a deep understanding of the relations occurring among materials and sustainable design, also providing practical skills and laboratory literacies to enable students to work with DIY, bio-fabricated and bioreceptive materials. The results of the course were analyzed through classroom observations, the analysis of student's projects, and a survey, confirming the efficacy of the proposed model in terms of final student's awareness and gained skills on the topics of sustainable design and the development of new circular, bio-fabricated and bioreceptive materials.

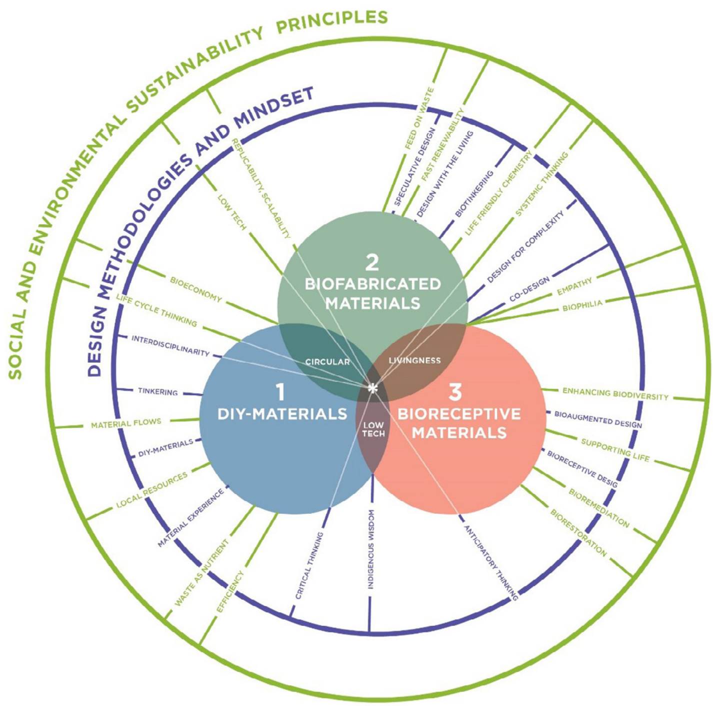
2.2 building new material design curricula for sustainable development

With a solid practice-based approach, aimed at guiding the students through three practical activities, the course focused on the possibility of creating sustainable materials in a crescendo of complexity: starting with the experimentation of DIY-Materials based on the analysis of local waste and resources, continuing with the experience of growing living materials such as bacterial cellulose and mycelium, and concluding a learning-by-doing path with bioreceptive materials, combining living and inert materials aimed at encouraging biodiversity, biophilia and bioremediation practices.

The course aims at improving students' understanding of the dynamic and innovative dimension of sustainability, by developing sustainability competencies in terms of materials evaluation, selection and design, which can meet the education aim of Sustainable Development Goal 4 (SDG 4); In particular, SDG Target 4.7 aim at Education for sustainable development and citizenship, pushing for knowledge, skills, values and attitudes, from local to global levels, to promote sustainable development. The proposed hands-on learning approach has among its outcomes the enhancement of some skills which have been highlighted as crucial competencies for sustainable development (Vallabh, 2018): systemic thinking, the ability to understand and design for complexity, anticipatory thinking (projection of solutions which might open new sustainable scenarios through a first speculative approach), critical thinking, co-design, empathy, interdisciplinary work.

The aim of the course was to build a syllabus to express the potentialities of material design in design education to foster sustainability awareness among young designers. The match between DIY-Materials, bio-fabricated materials and bioreceptive ones was built upon the observation of shared design methodologies and sustainability principles by these approaches (Fig.1); the sequence of the three workshops was built on difficulty that occurs for the development of the material by the designer, which also reflects learning of the basics of life principles of sustainability, from reasoning about circular materials flows to the material and energy exchanges occurring in the relationships of an ecosystem with multiple agents.

Figure 1 Diagram showing how the themes of DIY-Materials, bio-fabricated materials and bioreceptive materials share similar design methodologies and interconnected sustainability principles.



Source: Authors

Description of the learning path through materials

Like many developing countries, Mexico recognizes its role as a producer of raw materials, playing a significant role in the globalized economic system. Even if the concept of a CE is relatively new, public policy and researchers seeking to implement a circular economy model are proliferating since both the literature and national statistics show significant potential in adopting a CE model (Munoz-Melendez et al., 2021). The general attention to new materials is not as strong here compared to other countries, unless triggered by large global industries[3]. However, biodesign is also feeding a small niche of interest in Mexico: this is relatively new but slowly growing in different sectors, finally developing projects local-related to waste streams and social needs. The Mexican scene can fit into the broader South American one, where a Biodesign Challenge Hub has recently been established, showing interest and active participation[4]. To make some Mexican examples, Taina Campos[5] is working on biomaterials employing corn leaves among other sources, and accompanying her work with a narrative that promotes the protection of native corn, food sovereignty, as well as supporting local women producers; Biology Studio by Edith Medina[6], is studying the intersection among biology, design and ancestral knowledge to create textiles using raw materials from bacteria, fungi, flowers and vegetables; Polybion[7] is a company creating high-performance biomaterials from locally produced fruit waste to craft

[3] An example of this phenomenon is the materials design residency promoted by Space 10, powered by Ikea, to explore the local biomaterials of Mexico. Although these design synergies can open global connections favorable to economic development (also in terms of circular and sustainable products), they don't necessarily contribute to local empowerment, but risk remaining an isolated phenomena. Retrieved 6 April 2022, from https://space10.com/residencies-tomorrows-materials/

[4] Retrieved 6 April 2022, from https://www.biodesignchallenge.org/pressblog/2021/april-15-latam-hub

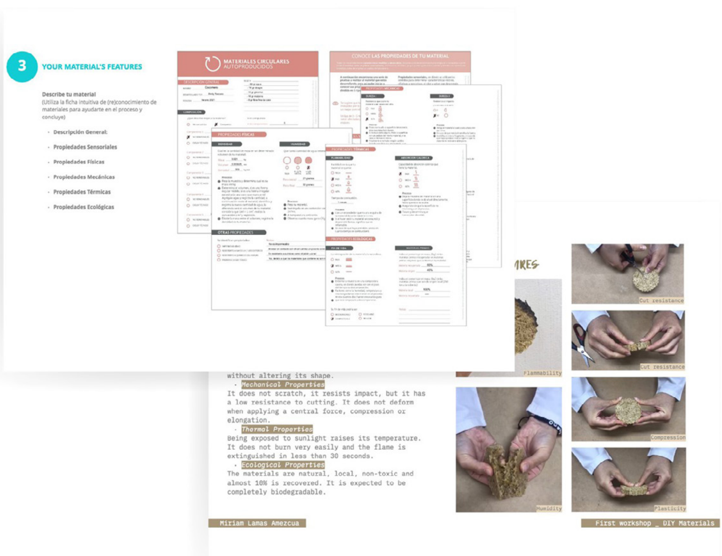
[5] Retrieved 6 April 2022, from https://www.tainacampos.com/

[6] Retrieved 6 April 2022, from https://edithmedina.com/

[7] Retrieved 6 April 2022, from https://www.polybion.bio/

a sustainable leather alternative. These examples show a turning point in the local design landscape, but it is important to highlight that in this area is more challenging to communicate the value of such projects, whose economic and environmental potential is still poorly understood by the design community and the industrial sector. Experiments in materials and biodesign are emerging trends in design. However, they are still little represented in the design of curricula in Mexico, as in the rest of the World when looking at the big picture, and not at some trendy niches in western countries. Some independent designers are working as pioneers in DIY or bio-fabricated circular materials. Still, the lack of knowledge in scientific disciplines could be a brake on experimentation in academic environments that are not yet highly interdisciplinary. For this reason, rethinking the designer's curriculum by including a theoretical and practical training on these emerging materialities can not only bring designers closer to the radical change that circular materials and biotechnologies can offer to the project, but it can also help them develop the skills needed to be professionals on a sustainable development trajectory. The course has been provided in Mexico as part of the ITESO elective International Summer course, and it lasted eight weeks. The aim of the course was to provide students with new ways of conceiving materials and their impacts. Taking circular design as a starting point, different methodologies for the development and application of new sustainable materials were discussed. The syllabus was nurtured by the authors' previous knowledge and teaching experience on sustainable design and materials. Having two different geographical perspectives, one European and the other Mexican, this difference enriched both the general method and the syllabus, creating a model that refers to the potential of the territory, but whose main educational structure can be applied anywhere in the World, precisely because it is based on the use of local resources and low tech processes. The topics covered by the course requirements are strongly interdisciplinary; in this sense, it was helpful to have a mixed class of designers and engineers who could cross-pollinate their previous knowledge for the design challenges proposed by the course. The development of new materials, as well as the growth of living materials, requires skills that are missing in the traditional training paths of designers; for this reason, a series of cards and worksheets, used as a guide, analysis, and reflection tools, have been developed for each workshop, to help students in the research and design process, but above all developing systemic thinking. The first week of the course has been introductory, discussing the leading theories of sustainable design with a broad understanding of its evolution, from the principles of the early green design to the last guidelines of circular design, passing by the life cycle approach as a fundamental aspect for understanding the impacts of materials within the design project. From the second to the seventh week, three workshops were dedicated to developing students' practical knowledge on three different material scenarios: DIY-Materials, bio-fabricated materials, and bioreceptive once. The last and eighth week was dedicated to wrapping up and preparing the latest materials and prototypes for the last exhibition. Each workshop started with one day of theoretical content to introduce the different topics, including an introductory lecture from national and international guests afferent to the circular and new materials scene. The DIY Materials workshop started with a research and analysis of local wastes in view of the possibility of being revalued for the development of new circular material considering: the abundance of flows, current uses, type of production industry, and production scenarios, as well as the processing methods with research of case studies showing existing applications worldwide. After initial experimentation with the most well-known and widespread bioplastic recipes (which made the students familiar with the possibility of actually creating materials), students experimented with local waste, appreciating sugar cane, coconut and pineapple scraps. All these resources are abundantly present on the territory as part of the local supply chain. In addition, tools developed by the authors were used to perform the design process and the final material assessment through an intuitive approach. A procedural thinking material scheme has been proposed to support students not to get lost in the many possibilities of experimenting with the material. Dedicated cards supported the intuitive analysis of the experiments carried out, to discover and appreciate material properties and applications. At the end of each laboratory, students were asked to identify the main characteristics of the new developed material through cards previously developed by the author for the ITESO Material Library (Fig.2), to recognize the properties of a material through the senses, referring to an intuitive approach, before using laboratory analyses. During the course, these cards were used on the most promising samples, guiding students through an intuitive knowledge of the material, so that they could change the design according to its current and desirable characteristics.

Figure 2. Intuitive materials analysis cards developed for Materioteca ITESO activities.



The second workshop was on bio-fabricated materials, here the students experimented the growth of two different growing materials (Camere & Karana, 2017), bacterial cellulose got from kombucha fermentation and mycelium. One of the most relevant aspects of this workshop has been the connection between local bio-designers and entrepreneurs. For this workshop the lectures and the starter kit with living materials were, in fact, provided by Radial biomaterials[8], a studio producing circular mycelium-based biomaterials from Agave residues, and Muutus biomaterials[9], a designer developing experimental materials and products based on bacterial cellulose from kombucha fermentation, especially for the textile sector of Aguascalientes, Mexico. The connection with designers operating on a market level, and showing the circular potential of bio-fabricated material from local waste streams, was a further aspect showing students the effectiveness of these materials for the regional bioeconomy. The worksheets supporting the second workshop focused on the organisms necessary for their growth, including a practical guide on how to work with living materials (basic wet lab skills). The third workshop introduced bioreceptive design, where the students were asked to think about inert/alive material assemblages to address local environmental issues related to polluted environments and biodiversity loss. The workshop started also in this case with research on the depleted or polluted zones of the territory; this helped make students aware of the area's environmental problems, looking for solutions in restoring the original environmental conditions through the project. Among the tools provided for the workshop, the bioreceptive material method (Pollini & Rognoli, 2021b) has been provided, supporting the work with worksheets dedicated to deepening the study of the organism and the environment to design the suitable artifact/material accordingly.

8 Retrieved 6 April 2022, from https://radialbio.com/

9 Retrieved 6 April 2022, from https://www.instagram.com/muutus.b/

Findings and results

To understand the adequacy of such a training proposal, correlating materials and sustainability and firmly rooted in knowledge through practice, the authors collected data during all the course through observation and field notes. Part of this analysis is related to a twenty-eight questions survey the students were asked to take at the end of the course to gather information about their overall experience regarding the presented topics and the three workshops' experiences. Ten students took part in the survey. The survey covered the students' background and their familiarity with the topics proposed within the course; in addition, for each workshop, the questions aimed to understand which aspects students perceived as more challenging, engaging, and valuable. Students were asked about the design methodologies and the practical knowledge gained through the workshops, and their perception of living materials in the design practice. Being the course an elective one, the students were asked about their motivations for taking the course; from the survey, the main trigger in subscribing appeared to be the will to know more about circular economy and sustainable materials alternatives. Students also referred to the practice of DIY and the emphasis on experimentation as key-point in deciding to take the course, while one student also valued the possibility of making it follow an entrepreneurial path. This answer confirms that sustainability, joined with a practice-based approach, is a powerful trigger for designers, who may even foresee taking an entrepreneurial way after a first educational stimulus. This path is, in fact, not new in material design and biodesign. Two significant examples are the dutch company StoneCycling[10], born as a startup based on Tom van Soest's thesis project on the upcycling of construction waste; in biodesign, the designer Maurizio Montalti, after a thesis on the use of mycelium as a "human-digestor" in a burial suite

[10] Retrieved 6 April 2022, from https://www.stonecycling.com/

with the project Continuous Bodies–Bodies of Change, continued his professional and working career designing with mycelium in various aspects (from speculative to workable), up to founding the first European company of products based on mycelium, Mogu[11].

The following three paragraphs will describe the student's feedback and the analyzed outcomes for each workshop.

4.1 Student's awareness and potentialities perceived in DIY-Materials

Regarding the first workshop, just over half of the participants were already familiar with the DIY-Materials concept. Among those who have declared themselves aware, just a few were already familiar with the process of bioplastic making. The answers were quite similar when the students were asked about the potential link between the practice of DIY-material and the concept of circular economy: all agreed on having realized the abundance of waste discovered by the first analysis of the territory. The students pointed out the potentiality observed while tinkering with those wastes, confirming the validity of the tinkering activity to envision new material possibilities. Asked about the major challenges in the DIY-materials process, students reported the challenge of not finding the right recipe and, therefore, feeling stuck in envisioning a application for the material. This initial frustration may derive from the feelings that designers experience in the path of trial and error typical of this approach (Rognoli et al., 2017), which does not aim at an immediate result, but it makes a value of the experimental and experiential path. However, most of the students successfully passed this first stage, reporting how the newfound ability to get samples of materials with an experimental practice was the most exciting aspect of the workshop. Many

11 Retrieved 6 April 2022, from https://mogu.bio/

students have referred to the MDD method presented in the introductory theoretical lesson as a valid approach to envisioning applications.

Figure 3. Use of the provided tools and selected materials outcomes showing the DIY-Materials workshop process.

4.2 Student's awareness and potentialities perceived in bio-fabricated materials

Regarding the second workshop on bio-fabricated materials, just over half of the students didn't know about bio-fabrication. Among those familiar with the concept, algae, mycelium and bacteria were known for their material potentialities, reflecting actually the most experimented organisms in biodesign: it was interesting to notice, though, that the majority mentioned algae. In this experimental path, students reported that the principal challenges have been understanding the bio-fabricated material's real potentialities, the need to follow clean protocol conditions, and the time factor affecting the length of the experiments. Interestingly enough, the primary concern turned out to be also one of the main valuable aspects of the workshop too; in fact, one third answered that understanding the bio-fabricated material's potentialities in design has been the real value of the practice-based activity, while the other participants referred to the possibility of creating something alive as the most triggering aspect. The students agreed that one of the most frustrating aspects was the uncertainty in the outcomes; many reported being afraid that something was wrong with their culture. Despite following the showed procedure, the growth variability was felt with a bit of anxiety that the organisms could not grow well. One student pointed out that "there is no specific pattern to follow, through experimentation and investigation is how you find out information, ", reflecting the uncertainty feeling also reported at the initial stage of the DIY-Material workshop. The class was composed of both design and engineering students: the authors noticed that while this explorative procedure might be enjoyable from a designer's point of view, from a more scientific and engineering one, uncertainty in the outcomes might be felt as frustrating. Once again, the survey reported the value of understanding the material properties through an experimental path: a student reported having particularly enjoyed "the liberty to be so creative and in charge of the process through all the course". A distinctive key concept here was the fascination of working with something alive and being able to follow its growth. The students positively evaluated the tools provided to guide them through the discovery of mycelium and bacterial cellulose as living materials (e.g., ID card, worksheet), declaring that they are likely to reuse them in the future.

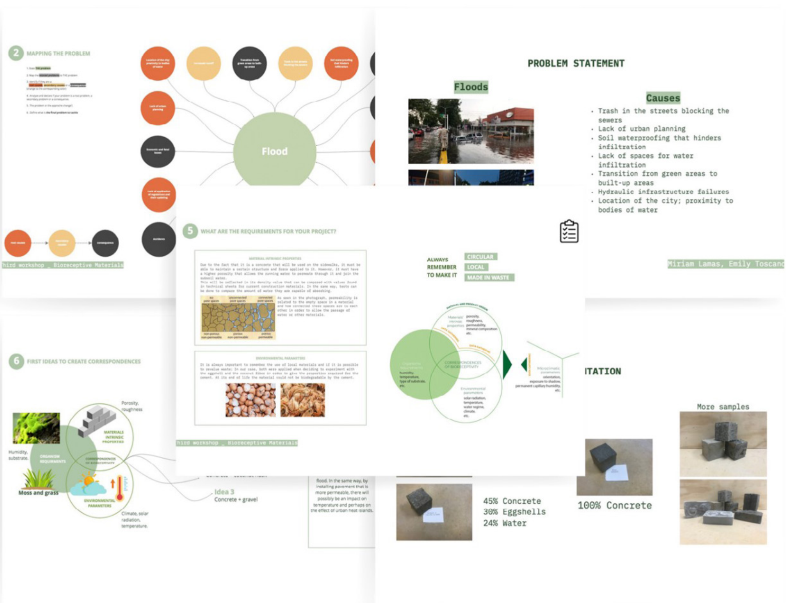
The students were also asked about their perception of these alive materials for design: on the answers they split in half, the once relating to them as functional materials for design, but the other admitting to perceive them more than living organisms. The students agreed that the material feature that primarily identifies a material as bio-fabricated is a "non-homogeneous aesthetic of colors and shapes that changes over time".

Figure 4. Use of the provided tools and selected materials outcomes showing the bio-fabricated materials workshop process.

4.3 Student's awareness and potentialities perceived in bioreceptive materials

Strangely enough (given the recent new definition proposed), two-thirds of the students stated to be familiar with the concept of bioreceptive design; however, the third workshop was probably the most challenging in design and planning. In fact, after two workshops in which the act of experimentation was guiding the design process, in the third workshop the students were asked to develop a project, choosing their basic materials and techniques to find a solution to a local environmental problem, taking into consideration the potential of bioreceptive materials for problems related to the loss of biodiversity and environmental pollution. The students saw in this "freedom", which required problem analysis and design planning, too little time to conceive a good idea. Also, in this case, the challenge reported turned out to be the most exciting thing in finding a solution. The students said the concept and potentialities of bioreceptive design as more attractive. Still, they also declared that they enjoyed the entire design process, from the analysis of the problem to the designed material solution. Most of the students claimed the proposed method to be useful, but sometimes difficult to apply; some complained about a technicality such as the microclimatic parameters to be considered. This feedback will be helpful for the authors to simplify the method in future workshops with limited time for deep reflection.

Figure 5. Use of the provided tools and selected materials outcomes showing the bioreceptive materials workshop process.



4.4 Student's general opinion on the course

From more general questions on the entire course, all the students have shown sincere enthusiasm in working hands on with the material, confirming their will to pursue it in the future.

This feeling was also clear from observing students' attitudes; in fact, even if the course was in hybrid mode and the students could decide how much time to spend in the laboratory, they always used all the time available to them to experiment with the materials there.

To the critical question of how much this didactic approach has changed their perception of the role of materials in design for sustainability, the answers were all encouraging, reporting an increase in the environmental awareness of materials and their life cycle, and an interest in learning new techniques and material possibilities starting from circular models and the revaluation of territorial wastes. Students stated they realized the countless sustainable material alternatives that this approach can unveil and help develop: one of them stated "I think that before I saw the creation of a material as something unreachable that I could not do, but after this course I broke that barrier". The authors also recognized the advantage of having a mixed class of two disciplines (engineering and design) who could compare and collaborate, even compensating for the general attitude of their respective classical study; one student declared "Sometimes is difficult to see a more creative way of being an engineer. This course has allowed me to expand my horizons and realize that indeed I can be creative". As general advice for improving the course, the only sign was related to time. The students would have wanted more time, which is reasonable considering the time needed for experimentation, especially when living organisms are involved.

Conclusions

The outcomes of the course and the inquiry attitude of the students showed how materials direct experimentations can increase awareness of materials' life cycle, bringing the designer closer to local and wasted sources, to low-tech processes, and to the rediscovery of ancient practices and designerly way of knowing. The recent democratization of scientific knowledge opens up the possibility for design to hybridize with other scientific disciplines and to experiment with living organisms, creating bio-fabricated materials generated through biological growth processes, or bioreceptive materials, able to support living forms for healthier and synergetic environments. To be grasped by designers and engineers, these emerging new materialities need to be considered in their classical training, to enhance a deep knowledge of the dynamics that relates materials to the impacts of design project, but also to introduce students to the basic techniques for the experiential knowledge of these new emerging materials. One of the key aspects of the course has been the connection with local resources and professionals in the field. The students started with a focus on the organic waste of the territory, realizing the linear management of valuable sources deriving mainly from the food supply chain, and being able to envision them in a circular economy perspective through design practice. The materials' samples showed them, experientially and experimentally, how a circular model could work and what potential (still unexpressed) their territory could exploit. In biodesign and bio-fabricated materials, knowing the local realities, allowed students to approach the topic in a rooted way with their territory, opening the possibility for them to refer or even join the local and regional biodesign scene that already actively contribute to innovation in biotechnologies. The last workshop allowed the students to approach local environmental problems. This analysis merged the fundamental aspects of the entire path, challenging the students to combine the World of inert materials with living ones for multi-species design projects where the living part could also contribute to the protection and healthiness of local ecosystems. The field observations and the results of the survey proved the effectiveness of this pedagogical approach in increasing students' environmental awareness, passing through an experiential study that helped them to focus on the dynamics that bind the material to the project, providing methods and useful tools to develop skills such as systemic and critical thinking, empathy and interdisciplinarity, that are fundamental to train capable professionals to lead sustainable development. Following the student's suggestions, further editions of the course should dedicate more time to the second and third workshops, while smoothing the learning path in bioreceptive design with additional supporting tools or avoiding technicalities is unnecessary for a first approach to this more complex theme. As a last consideration, the educational approach presented here is based on interdisciplinarity; therefore, it can find usefulness in the training paths of designers and engineers, who in equal measure can contribute to the development of the discipline of material design for the ecological transition.

References

Ashby, M. F. (2016). Chapter 14 - The Vision: A Circular Materials Economy. In M. F. Ashby (Ed.), Materials and Sustainable Development (pp. 211–239). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-100176-9.00014-1

Ayala-Garcia, C., & Rognoli, V. (2017). The New Aesthetic of DIY-Materials. The Design Journal, 20 (sup1), S375–S389. https://doi.org/10.1080/14606925.2017.1352905

Bak-Andersen, M. (2018). When matter leads to form: Material driven design for sustainability. Temes de Disseny. https://doi.org/10.46467/TdD34.2018.10-33

Serena Camere, E. K. (2017). Growing materials for product design. EKSIG2017 - International Conference on Experiential Knowledge and Emerging Materials, Delft, The Netherlands.

Camere, S., & Karana, E. (2018). Fabricating materials from living organisms: An emerging design practice. Journal of Cleaner Production, 186, 570–584. https://doi.org/10.1016/j.jclepro.2018.03.081

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. Design Studies, 47, 118–163. https://doi.org/10.1016/j.destud.2016.09.002

Circle Economy. (n.d.). Circularity Gap Report 2021. Retrieved 6 April 2022, from https://www.circularity-gap.world/2021

Collet Carol. (2013). Alive, New Design Frontiers. Central Saint Martins.

Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y. M., & Milo, R. (2020). Global human-made mass exceeds all living biomass. Nature, 588 (causes7838), 442–444. https://doi.org/10.1038/s41586-020-3010-5

Elvin Karana, Bahareh Barati, & Elisa Giaccardi. (2020). Living Artefacts: Conceptualizing Livingness as a Material Quality in Everyday Artefacts. International Journal of Design; Vol 14, No 3 (2020). http://www.ijdesign.org/index.php/IJDesign/article/view/3957/923

Esat, R., & Ahmed-Kristensen, S. (2018). CLASSIFICATION OF BIO-DESIGN APPLICATIONS: TOWARDS A DESIGN METHODOLOGY. 1031–1042. https://doi.org/10.21278/idc.2018.0531

Figueroa, R., & Carolina, P. (2018). Bio-material probes: Design engagements with living systems [Ph.D., Newcastle University]. http://theses.ncl.ac.uk/jspui/handle/10443/4110

Ginsberg, A. D., & Chieza, N. (2018). Editorial: Other Biological Futures. Journal of Design and Science. https://doi.org/10.21428/566868b5

Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A. (2015). Material Driven Design (MDD): A Method to Design for Material Experiences. International Journal of Design.

Keune, S. (2021). Designing and Living with Organisms Weaving Entangled Worlds as Doing Multispecies Philosophy. Journal of Textile Design Research and Practice, 9(1), 9–30. https://doi.org/10.1080/20511787.2021.1912897

Lee, S., Congdon, A., Parker, G., & Borst, C. (2021). UNDERSTANDING 'BIO' MATERIAL INNOVATIONS: a primer for the fashion industry. Biofabricate and Fashion for Good 2021.

Meyer, V., Basenko, E. Y., Benz, J. P., Braus, G. H., Caddick, M. X., Csukai, M., de Vries, R. P., Endy, D., Frisvad, J. C., Gunde-Cimerman, N., Haarmann, T., Hadar, Y., Hansen, K., Johnson, R. I., Keller, N. P., Kraševec, N., Mortensen, U. H., Perez, R., Ram, A. F. J., … Wösten, H. A. B. (2020). Growing a circular economy with fungal biotechnology: A white paper. Fungal Biology and Biotechnology, 7(1), 5. https://doi.org/10.1186/s40694-020-00095-z

Michael F., A. (2016). Materials and Sustainable Development. Butterworth-Heinemann, Boston.

Myers, W. (2012). Bio Design: Nature, Science, Creativity. MoMA and Thames & Hudson.

Oxman, N. (2010). Material-based design computation [Thesis, Massachusetts Institute of Technology]. https://dspace.mit.edu/handle/1721.1/59192

Parisi, S., Ayala Garcia, C., & Rognoli, V. (2016). Designing Materials Experiences through Passing of Time. Material-Driven Design Method applied to Mycelium-based Composites.

Parisi, S., Rognoli, V., & Sonneveld, M. (2017). Material Tinkering. An inspirational approach for experiential learning and envisioning in product design education. Design Journal, The, 20, 1167-S1184. https://doi.org/10.1080/14606925.2017.1353059

Pollini, B., & Maccagnan, F. (2017). Thinking with our hands. Renewable Matter N°19 (pp. 49–52). Edizioni Ambiente, Milano.

Pollini, B., & Rognoli, V. (2021a). Early-stage material selection based on life cycle approach: Tools, obstacles and opportunities for design. Sustainable Production and Consumption. https://doi.org/10.1016/j.spc.2021.07.014

Pollini, B., & Rognoli, V. (2021b, October 12). Enhancing living/non-living relationships through designed materials. CEES 2021, International Conference Construction, Energy, Environment & Sustainability. Section: Responsible Biotechnologies And Biodesign For The Built Environment, Coimbra, Portugal.

Provin, A. P., Dutra, A. R. de A., de Sousa e Silva Gouveia, I. C. A., & Cubas, e A. L. V. (2021). Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles. Technological Forecasting and Social Change, 169, 120858. https://doi.org/10.1016/j.techfore.2021.120858

Puspitasari, R. T., Irawadi, T. T., Santosa, D. A., & Alim, Z. (2021). Bioaugmentation in domestic and organic wastewater for plant fertilizers. 709(1), 012087. https://doi.org/10.1088/1755-1315/709/1/012087

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015). DIY materials. Materials and Design, 86, 692–702. https://doi.org/10.1016/j.matdes.2015.07.020

Rognoli, V., Pollini, B., & Alessandrini, L. (2021). Design materials for the transition towards post-Anthropocene. LEM Workshop Book series (pp. 101–130), Franco Angeli.

Rognoli, V., Pollini, B., & Santulli, C. (2017). DIY-Materials design as an invention process. DIID Disegno Industriale, Industrial Design, 62/63, pp.9-17.

Rust, C. (2004). Design Enquiry: Tacit Knowledge and Invention in Science. Design Issues, 20(4), 76–85. https://doi.org/10.1162/0747936042311959

Söderlund, J. (2019). The Emergence of Biophilic Design. Springer International Publishing. https://doi.org/10.1007/978-3-030-29813-5

Vallabh, P. (2018). Youth on the Move: Intentions and Tensions. Unesco Publishing, France.

Vezzoli, C. (2013). The 'Material' Side of Design for Sustainability. In Materials Experience: Fundamentals of Materials and Design (pp. 105–121). Elsevier Inc. https://doi.org/10.1016/B978-0-08-099359-1.00008-4

Wick, K. (2000). Teaching at the Bauhaus. Hatje Cantz Publishers. Ostfildern-Ruit, Germany

Zhou, J., Barati, B., Wu, J., Scherer, D., & Karana, E. (2020). Digital biofabrication to realize the potentials of plant roots for product design. Bio-Design and Manufacturing, 4, 1–12. https://doi.org/10.1007/s42242-020-00088-2

Ziyu Zhou. (2022). Meaning-Driven Material Education in Design. PhD Thesis, Polytechnic University of Milan.