FROM HUMAN-CENTERED TO MORE-THAN-HUMAN DESIGN

Exploring the transition

edited by Barbara Camocini and Francesco Vergani

D.I. FrancoAngeli
DESIGN INTERNATIONAL

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5. Design materials for the transition towards post-Anthropocene

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Abstract

Materials are considered fundamental elements of the design process and influence the era we live in, the Anthropocene. The chapter provides an overview of the leading researches on materials for design contributing to a sustainable transition.

We will consider the main aspects of new materiality emerging from processes of experimentation and sustainable innovation, highlighting those materials scenarios opening up solutions for a post-Anthropocene epoch. Yesterday, designers were focused on selecting the available materials; today they can design them for its own needs, helping to find and develop more sustainable solutions.

This chapter will focus on materials from organic waste, circular materials, and those bio-manufactured from living organisms as an emerging trend that design proposes as a helpful tool for planning the transition to the post-Anthropocene. Organic waste can be considered an alternative source in producing new biobased materials, improving sustainable development and promoting effective waste management. Nowadays, professionals' goal evolves in the diffusion of the circular bioeconomy through design thinking disclosing how materials play an essential role in this ongoing process. By selecting design case studies, we will highlight how materials can contribute to a

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more symbiotic relationship among industries and circular materials flow, acting as a key player in this transition.

Today, the word *biomaterials* can have multiple but slightly different meanings, reflecting material's differences in technologies, complexity, and potential impacts. An emerging trend in material design is related also to those grown from living organisms, thanks to a radical approach that draws on biology, incorporating the use of living materials into structures or objects. The growing interest in these materials lies in the possibility to biofabricate materials and artifacts from fast renewable and biocompatible little organisms, such as mycelium, bacteria, algae and yeasts. These and other sustainable features trigger designers willing to advance the transition from an oil-based and linear economy to a bio-based and circular one, designing post-Anthropocene futures.

5.1 Introduction

As argued by several scholars from different disciplines (Morton, 2018; Torres, 2017), the world as we know it is already over. All the changes we are experiencing at multiple levels force us to rethink and redefine almost everything to find sustainable solutions and the right direction.

Even if today the International Commission of Stratigraphy still classifies the current epoch in which we live as Holocene, that is the last part of the Quaternary period of the Cenozoic era, in reality, the concept of Anthropocene emerged and settled down into the scientific and intellectual debate. Especially since the beginning of the new millennium.

The entire historical development of human civilization took place within the Holocene, which in common sense, begins with the discovery of agriculture about 10,000 years ago, but it is the concept of Anthropocene that better highlights the impact of humankind on the environment. The term was spread in the eighties by the naturalist biologist Eugene F. Stoermer and adopted at the IGPB conference in 2000 by the Nobel Prize for chemistry Paul Crutzen. He announced that as far as he was concerned, the Holocene was to be considered

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concluded. The International Union of Geological Sciences and the International Stratigraphy Commission have not yet officially approved the term. The latter, however, established the Anthropocene Working Group (AWG) in 2009, a working group that, over the last decade, has worked to understand if there were the conditions for talking about a new geological era. The feedback was positive, and the AWG has decided that in 2021 it will formally propose to the International Commission of Stratigraphy to add the Anthropocene within the history of the Earth.

The new Era could begin with the mid-1900s, the moment from which, according to the AWG, it is possible to identify radionuclides in the rocks from the detonation of the first atomic bomb in history (Perasso, 2015). In the scientific community, there is still ambiguous agreement on the start date of the Anthropocene, but there is a point on which all scholars and theorists of the Anthropocene agree: the new Era started when humankind became a geological force capable of changing the systems of the planet. In fact, as written in the name, human beings reshaped the Earth in this new Era, modifying its entire systems and consequently obtaining a decisive influence on global ecology. The human being is the dominant force that influences the planet, creating all the now evident damage and perhaps irreversible. The detrimental impacts and degradation of human activities have accelerated and intensified in various areas. It includes the overuse of resources and overloading that is over the limits, which compromises the integrity of the fragile ecologies of planet Earth and its climate.

In addition to the well-documented environmental problems caused by this human domination, we can see how the world has also become more confused and with less certainty. Is it still possible to distinguish what is natural from what is artificial? What is the difference between products created from raw materials and those generated from waste? Between consumption and production? These dichotomies are evolving and dissolving, emphasizing at the same time the growing uncertainty of the blurred boundary between them.

Humanity is called to find and pursue new ways to interact differently with the environment, and design, as always, has the responsibility to facilitate the task. The Anthropocene, or rather the transition towards the post-Anthropocene, requires planning commitments that can question human domination's social, economic, and political implications. In other words, rather than being interpreted as an affirmative discipline, design can serve as a process-oriented critical tool (Gatto and McCardle, 2019).

The Post-Anthropocene is a neologism that is perhaps a bit ambitious to connote the Era in which humanity will be able to reverse the process, to make all forms of pollution and perverse sedimentation disappear. There are several theories for what will happen after the Anthropocene. Perhaps we will experience James Lovelock's "Novacene"[1] (2019), or Geoffrey West's "Urbanocene"[2] (2016), or Rachel Amstrong's[3] "Ecocene"[4] or the Era of ecosystemic egalitarianism (2016). Possibly the European Green Deal will show the world the right way. Or none of this because we will not have reversed course and will have become the only species on this planet to have self-extinguished.

The Anthropocene is characterized by the highest level of imbalance between humans and nature that was reached with the industrial revolution that began in the second half of the eighteenth century with the transition from renewable energy to fossil sources. A revolution that has changed the way of living and producing, bringing significant benefits to the community, but at the same time also increas-

[1] The Novacene hypothesis is the new Era of digital "superintelligence" that gets rid of human intelligence because it is not intelligent enough to follow the very rapid evolution of the artificial one. Human beings will find themselves, for the first time, having to share the planet with other beings smarter than themselves. This is why the Novacene is seen as the first true post-human Era.

[2] Begun with the first industrial revolution, the rise of cities seems to configure a transition from the Anthropocene to a new era that Geoffrey West, theoretical physicist and one of the leading experts of complex systems, he called "Urbanocene". Cities are laboratories of ideas, innovation, social cooperation and wealth creation, but they are also primarily responsible for the constant increase in environmental pressure and the consequent impacts on biosystems health.

[3] Armstrong, R. (2015) 'Keynote Presentation', Urban Ecologies 2015: A conference examining the future design of our cities, 18-19 June 2015, Toronto, Ontario, Canada: OCAD, Ontario College of Art - https://ecocene.wordpress.com/home/the-ecocene/

[4] The Ecocene refers to an epoch where humans and their design practices identify ecological frames of reference. An emergent Ecocene depends on creative transformations in all domains and on all levels from human subjectivities to political economies (Boehnert, 2018).

ing an excessive consumption of natural resources that had been accumulated on Earth for millions of years.
With the industrial revolution, materials have also become industrial materials, designed and developed to meet mass production needs (Bosoni and De Giorgi, 1983). If, for decades, designers have been fascinated by the continuous development of industrial materials that perform well on the application level and of inspiration on an expressive and experiential level, today, the situation has changed. In fact, in the last ten years, designers have returned to take care of the materials themselves, designing, developing and self-producing them. The term DIY-Materials (Rognoli et al., 2015; Rognoli and Ayala-Garcia, 2021) is now shared in the literature (Galentsios et al., 2017; Calinedo et al., 2019; Comino et al., 2021) to describe the phenomenon that sees the designers realize, thanks to experimentation and tinkering, material drafts and demonstrators (Rognoli and Parisi, 2021) that can be subsequently studied and further developed to meet the needs of contemporary production.

In particular, the experimental process with materials was referred to as "material tinkering" (Parisi et al., 2017). Material tinkering is linked to the Experiential Learning concept, which involves the creative exploration of the connections between experience, learning, and personal development. Going more into depth implies acquiring new knowledge through direct experience with phenomena observed: this can be applied to the development of materials. As suggested by Resnick and Rosenbaum (2013),

> The tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities.

Thanks to the democratization of technologies and processes brought about by the spread of the maker culture and the authorization that tinkering has given designers to handle materials, exciting things are happening that can positively influence by providing sustainable material solutions for the post-Anthropocene Era. Observing what is arising from these new practices towards design[5], we could say that there are two emerging phenomena regarding materials in the Anthropocene (Panneels, 2019; Dijkstra et al., 2019; Davidova and Zavolea, 2020).

The first is the one that investigates the increasingly blurred boundary between natural and artificial. Since plastic and other materials belonging to discarded objects have become part of the Earth's crust, it is no longer possible to distinguish which materials derive from natural resources and those from waste. Creating materials using waste is a pervasive practice and can be considered a driving force towards the transition to the post-Anthropocene Era.

Given the growing interest in the circular economy, all waste should be recycled most cost-effectively and sustainably. This is particularly important given the intensification of climate change and the increase in world population and urbanization. Due to the depletion of fossil resources and pressing environmental issues, the general interest in waste as a raw material increases. In particular, the EU must accelerate the transition to a regenerative growth model that gives back to the planet more than it takes, working towards maintaining the consumption of resources within the limits of the planet and therefore must do everything possible to reduce its consumption footprint and double the percentage of use of circular materials in the next decade (EU, Circular Economy Action Plan 2020[6]).

The European Green Deal[7], which consists of a wide variety of legislative initiatives to be pushed forward during the next few years to increase climate ambition and create a growth strategy for the EU, is also focused on the concept of circular bioeconomy.

[5] Some interesting references available at: https://www.designinfo.in/blog/fashion-design-revolution/2018/materials-of-anthropocene-era/900
https://www.cooperhewitt.org/2019/05/22/nature-salons-materials-of-the-anthropocene/
https://www.dezeen.com/tag/anthropocene/

[6] Available at: https://eurex.europa.eu/legalcontent/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

[7] Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

The circular bioeconomy is a circular economy based on renewable biological resources and sustainable biobased solutions. As defined by Stegmann, Londo and Junginger (2021):

> The circular bioeconomy focuses on the sustainable, resource-efficient valorisation of biomass in integrated, multi-output production chains (e.g., biorefineries) while also making use of residues and wastes and optimizing the value of biomass overtime via cascading. Such optimization can focus on economic, environmental or social aspects and ideally considers all three pillars of sustainability. The cascading steps aim at retaining the resource quality by adhering to the bio-based value pyramid and the waste hierarchy where possible and adequate.

Furthermore, scholars believe that the development of the bioeconomy reduces emissions and mitigates climate change, mainly thanks to the use of biological resources, this can include also living organisms, such as bacteria, algae, fungi, and plants to develop new materials. In fact, it is generally believed that using these resources reduces emissions compared to highly emission-intensive fossil products (Kardung et al., 2021). The second emerging phenomenon regarding post-Anthropocene materials is characterized by the transition from anthropocentric to anthropo-decentric[8], which sees the development of materials starting from living organisms, bringing the design closer to scientific laboratories and life science.

In the chapter, these two emerging phenomena will be explained and described in particular: we will focus on materials from organic waste, circular materials and materials from living organisms as an emerging trend in design for the transition to a post-Anthropocene Era.

5.1.1 The organic waste dual value for a new bioeconomy

The European Commission defines the bioeconomy above all by emphasizing the innovative potential it represents for the industry. In fact, he says that the bioeconomy is about

[8] The term is proposed by Valentina Croci (2017) in an article on Interni, which also presents post-industrial projects focused on the use of exemplary materials of the transition towards the post-Anthropocene.

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> the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling and industrial technologies, along with local and tacit knowledge[9].

A fully sustainable and symbiotic human-nature perspective finds a conceptual framework within a circular bioeconomy that manages and uses resources consciously. Nowadays organic resources are considered vital for the future of sustainable development (Vea et al., 2018). These play a central role in a circular bioeconomy because it aims to move towards a climate and nature positive economy not only through the replacement of fossil energy with renewable energy but also through the shift to fossil-free materials, substituting carbon-intense products like plastics, concrete, steel and synthetic textiles for lower-carbon alternatives (Bracco et al., 2018).

This shift also represents an opportunity to modernize and make industries more circular: renewable biological resources are, if managed sustainably, circular by nature and often easier to remanufacture. Several important sectors like chemicals, textiles, plastics or construction now need new conceptual business models and innovations to become more circular and lower carbon industries. It is urgent to develop business models and design products and services in new ways to decouple business prosperity from the mere consumption of products (Zihare et al., 2019).

In this context, organic wastes can be considered alternative sources in producing new biobased materials improving sustainable development and promoting effective waste management (Lundie and Peters, 2005). Organic waste is the oldest waste stream arising from human communities. We can include in its food and green waste, forestry and agricultural residues, animal waste, biosolids and sludges, as well as paper, cardboard and natural textiles (Lasaridi and Stentiford, 2011). Italy produces 10.8 million tons of organic waste, consisting of food and green waste (Buratti et al., 2015), which of this 42% is transformed into compost being put back in the soil. In

[9] Innovating for Sustainable Growth - A Bioeconomy for Europe (2012) https://ec.europa.eu/research/bioeconomy/pdf/bioeconomycommunicationstrategy_b5_brochure_web.pdf

recent years, a significant amount of research has been done to convert organic waste into valuable materials and products; strategies for producing sustainable materials and manufacturing processes for various applications are vital for sustainable development, but still little is applied.

Furthermore, it is necessary to consider that biowaste valorisation has received significant attention in recent years as sustainable alternative raw materials, exploiting the biowaste for producing high-value biomaterials (Dahiya et al., 2018). Repurposing waste materials into valuable products will not only improve sustainable development but promote effective waste management. In this regard, it has been proven that organic waste has a dual value if used within a bioeconomy framework. The first is that once the organic waste is disposed of, during the decomposition phase, it naturally produces gasses accelerating the greenhouse effect, like methane (CH_4), able to trap heat within the atmosphere more effectively than CO2 (Dilkes-Hoffman et al., 2018). The second advantage consists in the fact that upcycling organic waste avoids the extraction and use of new raw materials (Ghisellini et al., 2016).

For instance, a remarkable project done by a team of researchers from the Colorado School of Mines focused in extracting raw materials from organic waste taken from the local municipal site[10]. The lead researcher Ivan Cornjeo said that

> there's no reason to continue mining, destroying the environment, when we can find many of the materials we need from waste.

In fact, they demonstrated that organic waste from food leftovers could be a great source of precious minerals, like silica. The research team extracted it from 38 organic wastes to realize fully usable clear glass components. The team hypothesized that seeing the food waste amounts worldwide it will be possible to produce up to 36 million tons of glass from it (Cornejo et al., 2014).

Another organic waste used to extract raw materials is the citrus peel. In 2006, researchers from Cornell University showed successful results in extracting a potential alternative to fossil oil deriving sub-

[10] Available at: https://www.pbs.org/newshour/science/future-mining-resides-city-dump

stances from citrus peel coming from the fruit juice industry: limonene $C_{10}H_{16}$ (Byrne et al., 2004). Limonene has the potential to become an important component of the bio-based chemical industry; being a simple hydrocarbon, it shares many similarities with the chemicals we obtain from fossil fuels. Therefore, the technology we currently use on petrochemical feedstocks could be directly used on limonene to turn it into useful products such as bioplastics, potentially replacing polyurethane and yarnable polymers. Due to that during the juicing process the 50% in weight of citrus fruits goes to waste, it will be probably possible to extract roughly 125,000 tonnes of limonene per year worldwide[11].

MarinaTex is a UK based startup being developed by the designer Lucy Hughes[12]. Lucy tackled the problem of plastic pollution and new biodegradable polymers sourcing. For this reason, she developed a new compostable material designed as an alternative to single-use plastic films consisting of waste material from the fishing industry and sustainable algae. During the fish processing plant tour, she identified various waste streams to work with, including offal, blood, crustacean and shellfish exoskeletons, and fish skins and scales. After researching the different waste streams, it became apparent that the fish skins and scales had the most potential locked up due to their flexibility and strength enabling proteins. It took over 100 different experiments to refine the composition and process to form what MarinaTex is today.

As mentioned in the previous paragraph, one of the advantages of upcycling organic waste is to avoid the emissions produced during its end of life. Bio-digesters are nowadays the most diffused solution to trap the gasses produced, but that still must go through combustion to be transformed into energy (Pan et al., 2015). An innovative solution has been proposed by the Filipino student Carvey Ehren Maigue making him win the James Dyson Award 2020. Carvey and his project AuREUS, developed a compound made from new material from

[11] Available at: https://theconversation.com/orange-is-the-new-black-gold-how-peel-could-replace-crude-oil-in-plastics-47121
[12] Available at: https://www.jamesdysonaward.org/it-IT/2019/project/marinatex/, https://www.marinatex.co.uk/

vegetable leftovers which convert UV light into renewable energy[13]. He is currently planning to put it on the market, having his technology a wide variety of applications: windows, building facades and even electric cars.

These projects demonstrate that developing more and more efficient upcycling processes can lead to less primary resources exploitation. Solutions that look at organic waste from a different perspective are currently creating the basis of new potential bioeconomies representing the future in a world in constant demand of resources.

5.1.2 Innovations from below, organic waste DIY upcycling to sustainable bioeconomies

DIY-Materials practice is largely diffused among the projects developed by designers, often using organic waste coming from their own house or being locally sourced (Rognoli et al., 2015). Usually, this approach is adopted for two reasons: firstly, working within the private context doesn't allow the use of sophisticated instruments to process organic waste. Secondly, it gives the projects a potential educational purpose. With this, we can say that designers focused on the process itself to make it adoptable by the regular consumers in fostering better waste management, which will be an indispensable parameter for a hoped-for transition to a post-Anthropocene era. The intent of disseminating alternative organic waste upcycling practices could potentially create scalable phenomena starting from changing the habits of the single citizen until reaching more complex systems such as urban contexts and becoming new forms of potential bioeconomies (Santagata et al., 2021). In this regard, we could mention case studies like the work done by Weißensee Green Lab that designed a process to upcycled vegetable peel (such as asparagus) to create single-fiber[14]. As mentioned, the project focuses on making the process accessible to everyone and adopting technologies available in everyone's home, adding, in the end, the invitation to try with

[13] Available at: https://www.dyson.com/newsroom/overview/features/november-2020/interview-aureus-system-technology-jda-2020
[14] Available at: http://greenlab.kunsthochschule-berlin.de/archive/projects/100

more household organic wastes. Another project that started having a DIY approach to be a sharable process is the one realised by the designer Michela Milani and successively developed by Whomadeit studio[15]. They created tableware from organic waste from food leftovers like carrot peel and peanut shells, following a sharable process to be done at home. Many biodegradable tableware and food-related products have been recently developed, becoming startups using organic waste to create new materials that can be food-safe, resistant, and easy to break down once disposed of. A good example of a project that started as a DIY sharable process and then successively developed is Chipsboard[16]. The two founders, Rowan Minkleya and Rob Nicoll, realise structural material boards made of heat-pressed potato peel from industrially processed French fries. They started with a trial-and-error approach, until increasing the amount of production partnering with a bigger company such as the well establish French fries producer McCain Foods Limited.

Disposable containers inspired several startups in creating new solutions (Troiano et al., 2018), and some of them started from a DIY perspective making the process successively scalable.

Shellworks is a UK-based startup developed to work with organic waste from restaurant leftovers and extract chitin from crustacean shells to make biodegradable and fully recyclable containers. The project began in 2018, and now they developed an entire catalogue of new products encompassing food and cosmetic containers made to biodegrades.

5.1.3 Organic waste based socially organic bioeconomies

The attention in generating socially valuable projects is becoming part of the new designers' generation's DNA. New forms of bioeconomy from organic waste upcycling are increasingly giving attention to the three pillars of sustainability (Purvis et al., 2019) and its

[15] Available at: https://inhabitat.com/foodscapes-contemporary-compostable-tableware-made-from-recycled-food-waste/whomade-michela-milani-compostable-tableware-foodscapes-4/
[16] Available at: https://www.chipsboard.com/

social side. Regarding these aspects, fashion is one of the most impactful fields from an environmental (in 2015, more than 16 million tons of textile waste was generated only in the USA, according to the American Apparel and Footwear Association - EPA) (Shirvanimoghaddam et al., 2020) and social perspective, since it favours poor and developing countries women exploitation (in Bangladesh, the world's second-largest exporter of clothes, the 85% of the workers are women working from 60 to 140 hours per week for €62[17] per month). Designers and brands started to develop products and materials utilising textile fibers from organic waste sourced worldwide, being locally processed with the intent of creating all-around socially sustainable forms of business. For example, when banana fruits are harvested, the plant needs to be cut and disposed of creating a significant source of usable fibres (around 100,000 tons/year only from the Abaca type) currently used in a new generation of products aware of their impacts. Banana stem fibers made shoes have been developed by the Colombian designers' duo Diana Feliu and Iván Rojas. They choose to cooperate with 60 artisans using traditional techniques part of the local indigenous communities in the Andes mountains[18].

Bananatex is a Taiwanese Swiss brand realising natural fabrics extracting fibres from the banana plant trunks cut after harvesting. They involve local populations in all the artisanal activities on the field, such as the fiber extraction during the scutching process[19]. The Philippines is the biggest pineapple producer worldwide, 2.169.230 million tons in 2010, potentially producing around 72.000 tons of fibers from pineapple waste leaves per year (Hijosa, 2015). Pinatex is a pineapple-leaves-fiber based leather developed in the Philippines by the Spanish designer Carmen Hijosa working together with small cooperatives of local farmers that follow the whole fiber extraction process.

The above-mentioned good practices demonstrate how projects involving local communities in processing the organic waste are part

[17] Available at: https://www.fashionrevolution.org/exploitation-or-emancipation-women-workers-in-the-garment-industry/
[18] Available at: https://brightboys.org/2140-shoes-made-with-banana-fiber-local-and-sustainable-ar.html
[19] Available at: https://www.bananatex.info/index.html

of a new generation of businesses developed using waste and people from all over the world as precious resources.

5.2 Biodesign and biofabricated materials

The awareness of our impact on the planet (personally and as a species) is now reaching a mature state: in the last decade, design and art, as expressions of critical thinking, have profoundly questioned our relationship with Nature, rediscovering its involvement in the production of artifacts and materials as a powerful tool for reconnection, while proposing more sustainable production models. In terms of materials, one of the more evident signs of the Anthropocene epoch is the record reached in 2020, where the anthropogenic mass surpassed all living biomass (Elhacham et al., 2020); however, a re-evaluation of bio-based and circular materials is already in place, as previously described. In the context of materials for the bioeconomy, a new niche in design is bringing a radical vision of the project, including organic and living agents for sustainable and regenerative production models. Myers defined this new design field as Biodesign (Myers, 2012), a transdisciplinary approach incorporating the use of living organisms for the production of materials and artefact; the author highlight how this approach

> goes further than other biology-inspired approaches to design [...], Biodesign refers specifically to the incorporation of living organisms as essential components, enhancing the function of the finished work.

The terms defining this emerging approach are derived from the medical sector: Biodesign, biomaterial and biofabrication originally refer to medical tissue engineering. The glossary in the field of Biodesign is still under definition. Concerning materials, those obtained thanks to the involvement of living organisms have been called “biomaterials”, “growing materials” (Camere and Karana, 2017) or “living materials” (Gilbert et al., 2021); to date the most accepted definition was introduced in 2020 by the report *Understanding bio* (Lee et al., 2020), which, referring to the previous work of Mironov (Mironov et al., 2009) and Groll (Groll et al., 2016), stated that the

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more appropriate term for such materials would be "biofabricated", identifying with this definition materials made "of, with, or from living organisms" (Ginsberg and Chieza, 2018).

5.2.1 Leading research in the field of biofabrication

Biodesign has experimented with the most disparate life forms, but among the most promising in terms of scalable biotechnologies, we find mainly mycelium (the vegetative part of fungi), algae, bacteria and enzymes. Mycelium is experiencing a rediscovery as a species, given its importance in the origin and maintenance of ecosystems and being recognized as the protagonist of the wood wide web, a connecting agent of root systems entangling single plants in entire forests (Stamets, 2005; Sheldrake, 2020). The first experiments that saw mycelium as a material for design were aimed at the world of packaging, where the mycelium is grown in stamps on a substrate of agro-industry waste, growing similar to the polystyrene used in packaging[20]. The final material has insulating properties and can absorb shocks; for this reason, it has also been tested as a substitute for synthetic foams in bicycle helmets[21]. Given its physical properties, mycelium panels have also been developed to serve as thermal and acoustic insulation[22]. Even the fashion sector did not miss the possibility of experimenting with mycelium, giving life to a new type of leather[23]. Algae have been widely tested for biofuels and as a food thickener. The bonding power of some species has been used to develop new materials; their biocompatibility and easy biodegradability in water has made them the good raw material for the development

[20] The US Company Ecovative has been the first testing mycelium as a packaging solution. See also their dedicated web page: https://mushroompackaging.com/ (Accessed September 2, 2021).
[21] "Grow it yourself" helmet developed by NOS Design in conjunction with Polybion. Accessed September 2, 2021 at https://nos.mx/es/proyectos/
[22] As in the case of Mogu mycelium acoustic panels and flooring. Accessed September 2, 2021 at https://mogu.bio/
[23] The work of Mycoworks or the research of Pura by Mogu are both example of mycelium leather. Accessed September 2, 2021 at https://www.mycoworks.com/ and https://mogu.bio/pura-lab/

of food packaging, sometimes even edible[24]. Some materials act as fillers, thus avoiding a more significant amount of virgin raw material. Their filling ability has been tested in paper[25], plastic[26], and even in the development of new DIY-Materials for interior design, as in the case of the collection Terroir by Jonas Edvard (Cecchini, 2017). Bacteria are used to develop different materials too, for example, PHA bioplastics; while in the world of fashion, various biomanufacturing experiments are underway with enzymes modified to produce a fabric similar to leather[27].

The above-mentioned biofabricated materials have been produced by microorganisms and stabilized to become inert for the final production and use phase: still able to perform as materials, with textures evoking their natural origin through "nuances and imperfections as para-linguistic markers" (Pollini and Angelini, 2021), but inexpressive as life forms. Among the biofabricated materials, for the ones most devoted to feasibility, this seems an obligatory step. However, it is interesting to note that in Biodesign, there is also an opposite trend, which sees the living organism as an integral part of the project, able to manifest itself, mutate in time and perform "livingness as a material quality" among others (Karana et al., 2020).

Mycelium is among the most tested organisms to be employed as living architecture (Adamatzky et al., 2021) and tested as a living sensor for computing purposes (Adamatzky et al., 2021): the EU-funded project Fungar is exploring the possibility to develop "a fully integrated structural and computational living substrate using fungal mycelium for the purpose of growing architecture". Keeping alive the organisms within the entire life cycle of the artifact/material may sound still visionary and provocative, however, in some cases, it can bring the advantages of biological systems. One example is bacteria

[24] Evoware is a Taiwanese company producing edible algae-based paper-like material for packaging purposes. Accessed September 2, 2021 at https://www.newplasticseconomy.org/innovation-prize/winners/evoware
[25] Alga Carta by Favini. Retrieved September 2, 2021 on https://www.favini.com/news/alga-carta-sostenibilita-upcycling-venezia/
[26] An example is the company Bloom, collaborating with other brands by offering algae biomass as filler. Accessed September 2, 2021 at https://www.bloommaterials.com/
[27] To date, Zoa by Modern Medow and Mylo by Bolt Threads are the more feasible examples. Accessed September 2, 2021 at https://www.modernmeadow.com/zoa and https://boltthreads.com/technology/mylo/

producing CaCO3 embedded in concrete, able to fill the cracks occurring in the material by filling them with calcarean secretions (Stanaszek-Tomal, 2020). This form of "biological self-maintenance" has a sustainable counterpart in the durability of the materials and the consequent reduction of the need for new building materials. Algae can also be kept alive, benefiting from their ability to absorb Co2. Ecologicstudio[28] designs interior living systems: structures hosting living colonies of photosynthetic microalgae to purify and refresh the indoor air. This enthusiasm for living matter has overshadowed the role of inert materials in the field of Biodesign; however, the role non-living materials can play in hosting life forms is indeed a key aspect of those projects having as their ultimate goal the support of living organisms. A special material feature highlighting the active role of inert materials in Biodesign is the ability of a material to be colonised by life, namely "bioreceptivity" (Guillitte, 1995). This phenomenon has been studied mostly with negative connotations, and addressed as a material "biodeterioration", but recently this feature has been desired and designed to create the right conditions to host life. The work of Marcus Cruz at the Bartlett School of Architecture is, in fact, deeply exploring this material aspect, also with the potentialities of computational design and digital manufacturing, for the design of bioreceptive façades and tiles, able to greener the city. These tiles support autonomous systems of symbiotic building materials and cryptogamic and plants covers, precisely as it would happen in a forest. Widening this concept to the field of design, Material's bioreceptivity can be designed based on chemical composition and physical properties

responding to the host needs and preferable environmental conditions, thus enhancing a multispecies environment and a design of mutual interest (Pollini and Rognoli, 2021).

[28] Accessed September 2021 at https://www.ecologicstudio.com/projects

5.2.2 The role of DIY approach in the development of new biofabricated materials

Biodesign's origin is characterized by a DIY approach and open-source philosophy (Elsacker et al., 2020). The case studies of biofabricated materials were initially experimental and related to speculative design (Aldersey-Williams et al., 2008; Myers, 2012), but it's not uncommon that a designer's DIY approach became later a leading company in the field of biotechnologies[29] and, to date, the first dedicated study paths have been established[30]. Although this approach begins to be outlined in a more structured way, some of its early peculiarities remain, one above all is the necessity of a trans-disciplinary approach, functional to intertwine the practice of design with scientific knowledge and protocols. Myers in 2012 already described Biodesign as a

> cross-disciplinary collaboration and creativity prompted by scientific research [...], propelled by global imperatives such as the urgency to develop and implement cleaner technologies and the rise of do-it-yourself "homebrew" biology (Myers, 2012, p. 9).

Do-it-yourself (DIY) biology is one of the main definitions describing the growing movement that in the last decade is trying to push the democratization of life sciences and biotechnology (Walker et al., 2021). Within the movement, often a sort of "bio" extension of that of fablabs, the practice of DIY is not only linked to the development of bio-fabricated materials and artifacts, but also to the equipment needed to work with life forms, focusing on local resources and low-tech solutions, to make life sciences accessible and available to communities. If for DIY-Materials tinkering is an essential activity in developing new materials, for the development of bio-fabricated ones we can talk about bio-tinkering with almost the same

[29] Among the examples of companies established in the field of biotechnology after a student or independent research can be counted: Ecovative, Mogu, Mycoworks and Modern Meadow.

[30] MA in Biodesign at Central Saint Martins, Bio-Integrated Design (Bio-ID) MArch/MSc at UCL. Moreover many universities are implementing courses and Labs dedicated to this discipline: Simbiotica Lab at the University of Western Australia or the Material Incubator Lab, to name few.

meaning: tinkering with materials of biological origin. This practice was even mentioned in the DIYbio code, developed in 2011 as a framework to achieve a DIYbio community of practitioners across Europe and the US; among other principles, in the US code is possible to read about bio-tinkering "Tinkering with biology leads to insight; insight leads to innovation"[31]. Thanks to its open-source and DIY nature, this approach can also bring positive innovation in remote places, abundant in natural resources but scarce in technological ones. Palacios and colleagues (Palacios et al., 2020), in proposing a methodological procedure for self-sufficient biofabrication in remote territories, include tinkering activities as a fundamental step in the method, with the collection of samples, processing and material experimentation. Moreover, the study highlights activities that may lead to local and circular material solutions, guided by an "approach to the territory", to create a deep knowledge of the place, its materials and traditions, and allow an approach to biofabrication supported by territorial and cultural aspects.

5.2.3 Biofabrication for a sustainable transition

Curator Paola Antonelli, anticipating the theme of the 22nd Milan Triennale that she would have curated in 2019[32], wrote in the foreword of Myers' Book on Biodesign (2012) that

> if human relationship with nature is broken, this design approach makes us hope that perhaps we will be able to fix it from within (p.7).

Imagining post-Anthropocene scenarios, sustainability appears to be an important trigger for designers to start dealing with living matter (Collet, 2013; Camere and Karana, 2017), also thanks to the sustainable features of biofabricated materials, associated with fast renewability, processes that require little energy, water and resources, and life-friendly chemistry. For this reason, many biofabricated arti-

[31] From the DIYbio US community code. Accessed September 2, 2021 at https://diybio.org/codes/
[32] Broken Nature was the title of the 22nd Milan Triennale, curated by Paola Antonelli

fact are developed to replace objects often associated with environmental problems. If for mycelium and algae material experiments mainly have the objective of substituting plastic materials that are too polluting (especially because they are applied in contexts where they risk being dispersed, not recycled and where their performances are incompatible with the short life of objects), for bacteria and enzymes (but, again, also mycelium) there seems to be an open challenge to replace leather of animal origin, taken as a symbol of unsustainable material within the fashion system.

The complexity of sustainability is nowadays in the details of these new productions, mostly still at a research stage (Lee et al., 2020), therefore difficult to assess with standardized sustainability metrics (Bak-Andersen, 2021). To assess the environmental impact of bio-manufactured products, it is necessary to evaluate all aspects of their life cycle because they might be more sustainable for some impact categories (e.g., CO2 reduction) and less for others (e.g., water consumption) (Belboom and Léonard, 2016). Today LCA analysis remains the only way to ascertain the effective sustainability of productions, including those based on biological processes (Pollini and Rognoli, 2021); some early LCA studies suggest that sustainability must be analysed more in detail within the entire biomanufacturing processes, also considering the behaviour of consumers as a key factor for the effective sustainability of any type of new production with sustainable potential (Hildebrandt, Thrän and Bezama, 2021). Therefore, the intrinsic environmental characteristics of bio-manufactured materials are really promising but still dependent on processes that need to be increasingly assessed and improved for better sustainability standards and human habits. Biofabrication starts also to be mentioned for its potentiality in the context of circular economy: the white paper of Meyer and colleagues highlights how fungal biotechnology can be addressed as "solutions for securing, stabilizing and enhancing the food supply for a growing human population" (Meyer et al., 2020), since the mycelium grows on agro-industry waste, and bio-manufactured materials can return to fertilize the soil at the end of their life (if not treated with non-biocompatible materials/chemicals).

Regarding social sustainability it is important to highlight that biotechnology has always been synonymous with a quite rigid lab workspace, requiring scientific skills and expensive equipments, while Biodesign has always been characterized by a DIY/ experimental approach and open-source philosophy. This has also favoured the development of local and low-tech practices. A study by Palacios and colleagues (2020), proposing a "self-sufficient biofabrication protocol for remote territories", reports how bringing biofabrication "off-grid", can enhance the use of local materials, boosting circular models. The study also states that the enthusiasm for biofabrication can boost a rediscovery of the pre-existing relationship between natural resources and local culture, which are more robust in the memory of non-urbanized places; especially in isolated regions, where natural resources abound while technological ones are difficult to integrate, the authors state that

> in these territories researching biological resources from a biomaterials production perspective becomes necessary in order to establish local and self-sufficient production chains that provide tools for material sovereignty (Palacios et al., 2020).

5.2.4 Biofabrication as a paradigm shift in post-anthropocentric design

One of the main paradigms shifts to which the practice of Biodesign contributes is the old-new concept of the natural ecosystem, based on symbiotic relationships among the different agents of a system for their survival. Biodesign is proposing a more relational vision of the project, expressed above where the organism is alive during the whole life cycle of the artefact - pushing the idea of continuous exchanges of information and materials, taking place between designers and organisms, between anthropogenic activities and the surrounding environment, and between the different agents of a system. Exploring what post-Anthropocene futures will look like is a common trigger in Biodesign, as proposing new visions to overcome hierarchical and polluting production patterns of the past. When concerning living artefacts, one of the strongest links among Biodesign and post-Anthropocene is the fact that, among designers and users, also non-humans must be counted. Designers guiding the process of biofabrication, feel a sense of care for the organisms involved, which are often perceived as co-author of the project (Collet, 2013; Camere and Karana, 2018; Niinimäki, Groth and Kääriäinen, 2018), leading to a radical change in the perception of "the other". This inclusion implies transdisciplinary knowledge and non-anthropocentric reasoning (Pasquero and Poletto, 2020), which heavily affect the traditional design practice. Moreover, this declared act of co-creation questions the authorship of the projects, and often the outcomes are *open-ended*, subject to the multi-agents taking part in the process. The mutability of living artefacts, as well as of inert/living assemblages, is read in this context as an "aesthetic approach to socio-ecological issues", becoming a meta-language enhancing communication with the non-humans (Pasquero and Poletto, 2020). Within this vision, also technology is recognised as a fundamental mediator, becoming "a collaborative agency within nature's complexity and cross-species social networks" (Davidova and Zavoleas, 2020) in the post-human-centred co-design model, including technological, human and non-human agents (non-hierarchically but with continuous feedback loops of information). Embracing the nature of posthuman ecologies, Biodesign materials explorations reimagine what it means to be humans, and try to understand and embed in the design practice the point of view of other species, envisioning hybrid and dynamic environments, thus tracing new epistemological configurations (Oppermann, 2016).

5.3 Conclusions

Sustainability is a concept in continuous evolution and constantly updating. Therefore, it is legitimate to ask which principles can guarantee an effective transition to a sustainable post-Anthropocene scenario. The most common and shared definition of Sustainability is the one formulated by the Brundtland Commission in 1987, which describes sustainable development as:

the development that satisfies the needs of the present without compromising the ability of future generations to meet their own needs[33].

Such definition was then refined to include the three pillars: the environment, economic, and social factors. It is now widely accepted that to achieve Sustainability, these three pillars need to be balanced. Even in the discourse presented in this chapter regarding the materials that will help humankind for the transition towards the post-Anthropocene, the three pillars are essential elements since the materials themselves have wide repercussions on the environment and affect society and the economy. However, there is a gap in the literature concerning the three pillars as points of reference in the analysis of organic waste materials and biofabricated ones, which could help enrich the discourse on the topic, especially given the complexity to assess Sustainability for new and experimental materials and processes.

Good practices of designers and brands embracing the three pillars of sustainability in realising new forms of bioeconomy represent the ground to build a possible future in the post-Anthropocene. From the collected case studies emerged how innovative solutions to upcycle waste can match with the three pillars of Sustainability goals. From an environmental point of view, we have seen how we should gradually stop mining and deploying resources focusing instead on improving existing methods of raw materials extraction from the huge streams of waste we produce worldwide. This will create a dual value, breaking down the uncontrollable amount of pollution that waste creates at the end of its life, burdening the environment. Furthermore, it is possible to say that a new way to envision waste is rising from the projects developed by designers able to create new materials starting from a DIY approach until reaching the market. Among them, there are food waste made disposable packaging, new sustainable textiles from waste fibres, organic waste made objects, and a whole new generation of products for the new bioeconomy. Moreover, projects are tackling different aspects aiming to spread

[33] Available at: https://eur-lex.europa.eu/summary/glossary/sustainable_development.html#:~:text=Sustainable%20development%20was%20defined%20in,to%20meet%20their%20own%20needs

awareness as a form of new egalitarianism, treating people and waste as valuable resources reframing the paradigm of manufacturing goods, replacing it with growing new ones.

In an attempt to frame biofabrication within the three sustainability pillars, is it possible to confirm the potential that these materials have in meeting the aims of all three pillars. From an environmental point of view, the potentiality of biofabricated materials is evident, whose performances can equal (if not exceed) those of different materials in use today, but with a strong environmental advantage in terms of consumption and management resources. The environmental potential of these materials is also found at the base of the economic pillar framing biofabrication in the context of a circular and regenerative economy. On a social level, it is essential to highlight the effect of the DIY-bio movement on science democratisation, opening new possibilities for innovation on a local scale and in remote contexts. However, the transition toward the Anthropocene requires also a posthuman perspective. Human activities need to act in a shared environment, including non-human agents as stakeholders; here, the need for a multi-species design approach to expand the reference system to an even wider one must include the well-being of the ecological system as a whole.

For summarizing, the materials that we imagine as the most useful and promising for a transition towards the post-Anthropocene are firstly those that will increasingly be employed using waste and scraps as raw materials, overcoming the traditional dichotomy between natural and artificial to support the changes taking place and those to come. Secondly, the bio-manufactured materials look ahead by including co-design processes with living organisms, putting apart humans and pushing them out of the centre of the action.

Both of these new families of materials respond to the circular bioeconomy principles. We hope that studies will be undertaken focused on their analysis concerning the three pillars of sustainability.

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The environmental emergency of the last century, highlighted by the pandemic, has led to an urgent need to reformulate the predominant role of human beings on the planet by undertaking a less anthropocentric design approach. This urgency has been especially outlined by a re-evaluation of the concept of the Anthropocene, which can be defined as a geological era characterized by the significant human impact on the geology and ecosystems of the Earth. Within this theoretical framework, the book explores the role of Design as a multifaceted discipline capable of exploring the complexity of a changing world, and reconsiders the human being's position in a pervasive relationship with the contemporary environments (physical and abstract) through a More-than-Human approach.

This volume illustrates reflections, analyses, and interventions guided by or intersected with the concept of the post-Anthropocene, and traces two different scales of observation. The first, explored in the two starting chapters, highlights how the complexity of the topic requires a large-scale analysis perspective in order to be fully understood. The concept of the post-Anthropocene does not exclude the human being as a fundamental component but takes the latter as a departing point to frame wider contemporary needs and issues and to support a call for action to envision and shape the future. The second part of the book instead explores the possibility to include, within this broad discussion, the theme of More-than-Human applied to specific disciplines – linked to the culture of Design – analyzing different aspects that move from taxonomy, application, and creativity.

FrancoAngeli
La passione per le conoscenze

(edizione fuori commercio)