CoLab(oratory)

A Biodesign Cookbook

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I would like to acknowledge and pay my respects to the traditional custodians of the lands, and elders past, present, and future, on which this research was conducted: the Gadigal people of Sydney, and the Canarsee people of Brooklyn.

Type
Windsor, designed by Eleisha Pechey, inspired by Stewart Brand's *Whole Earth Catalog*
Neue Haas Unica, designed by Toshi Omagari
Bodoni, designed by Giambattista Bodoni
Roboto Mono, designed by Christian Robertson

Images by Nina Szewczyk unless otherwise stated

The Stone Age did not end because humans ran out of stones. It ended because it was time for a re-think about how we live.

WILLIAM MCDONOUGH

A Manifesto for the Future

Evolve

We acknowledge the harmful consequences of the Oil Age, the irrefutable evidence of a climate crisis, and the desperate need for a new material system. Unlike other forms of life, humans have not (physically) evolved for some 10,000 years, instead relying on cultural evolution in order to grow and survive. We understand that our species needs to (culturally, socially, materially) evolve to meet our changing needs in a changing environment.

Redefine Materiality

We aim to redefine common and overused notions of 'sustainability'. We aim for wholly circular and regenerative (rather than linear or recycling) economies. We understand that in order to achieve more ecological futures, we have to look beyond mere 'green' materials; instead, we must create practices that minimize, eliminate, and even undo theirs and other's negative impacts on natural environments.

The Seventh Generation

We are motivated to design not just for ourselves but for future generations (both human and nonhuman). Our choices and practices have multi-generational effects that must be taken into consideration.

Collaborate with Life

We recognize both life and evolution as technologies in their own rights, and their potential to work alongside humans as design tools, collaborators, and co-designers.

Nature as a Designer

We continue to learn from and be inspired by human and nonhuman life, both individual and collective, and translate that into meaningful, ecological design that transcends biomimicry.

Growth Over Assemblage

We aim to create design methodologies, artefacts, and ways of thinking that are literally alive; ones defined by growth rather than assemblage. Design artefacts must be understood as singular, complex systems that adapt with functionality, rather than a collection of static, individual parts.

Decenter the Human

We want to erase the boundaries between the living and the built, thus decentering human intelligence and reconciling the fractured relationships between human and nonhuman life.

Embrace Decay

We embrace the inherent temporality of organic materials, systems, and life. We reconsider traditional theories of *firmitas* (in which decay is seen as destruction), and understand the advantages of decay.

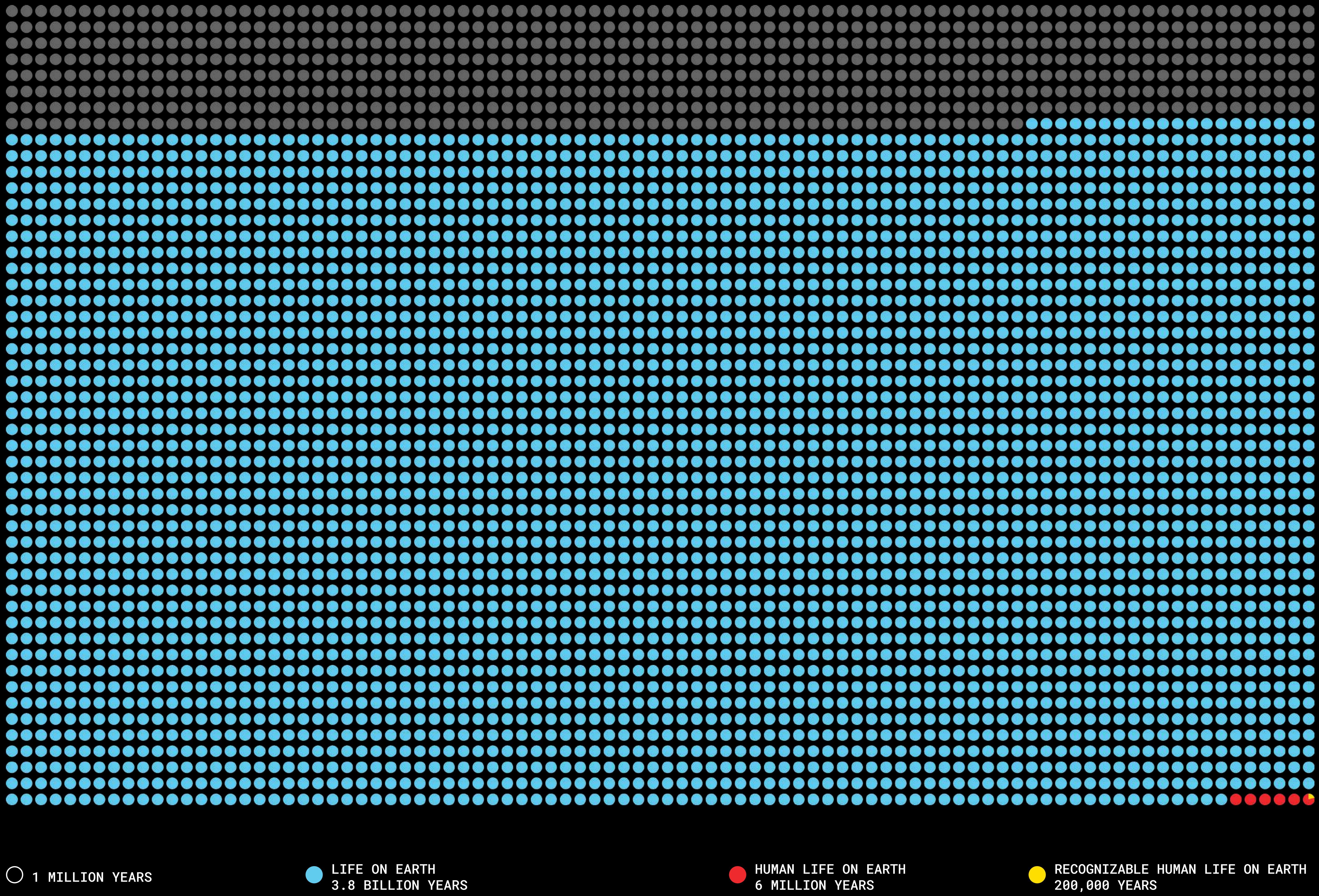
Biology with Design

We bring together science, engineering, art, and design in a functional, meaningful way that transcends just aesthetics. We challenge perceptions and common understandings of who science is for, how it is utilized, and why.

Designing for Life

We recognize that as humans, we are a part of a multitude of ecosystems much bigger than ourselves. In both coexisting and designing with nonhuman life, we have a moral responsibility towards them, ourselves, and all of our descendants.

CoLab(oratory)


1 MILLION YEARS
LIFE ON EARTH
3.8 BILLION YEARS
HUMAN LIFE ON EARTH
6 MILLION YEARS
RECOGNIZABLE HUMAN LIFE ON EARTH
200,000 YEARS

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Dicksonia antarctica

Kelp Leather

Ingredients

Fresh seaweed/kelp
Sodium carbonate
Fresh water

Tools

Large containers
Scissors
Stove
Large pot
Wooden spoon
Colander
Blender
Vat
Mold and Deckle
Sponge
Cotton cloths
Rolling pin
Thick cardboard
Bricks/Weights

Steps

Go to the coast. Feel the sand, the stuff of mountains, tickle between your toes. Watch the waves come and go, pulled by the moon, a rhythmic dance of eons. This is the sacred place from which life came. It keeps us alive today. Cyanobacteria created much of our Earth's oxygen-rich atmosphere.[1] Today, kelp forests produce 70 to 80 percent of the oxygen in the atmosphere. The ocean as a whole absorbs a quarter of human-produced carbon dioxide.[2] We, like the Earth itself, are 70 percent water. We can adapt, conform, and gather in force. We give life, and have the potential to take it away.

Cyanobacteria (formerly known as blue-green algae) has been the dominant life form for the greater part of the existence of life on Earth. The earliest fossil record is of cyanobacteria.

Collect fresh seaweed and/or kelp from the coast, avoiding any sand, sea creatures, rubbish, and other debris. Rinse with cold, fresh water and cut into 1-inch pieces.

Bring to a boil in a large pot of water. Add ½ cup of Sodium carbonate for every 4 cups of water. Simmer for approx. 3 hours, occasionally stirring.

Sodium carbonate (Na_3CO_2), commonly known as Soda Ash, is caustic and will separate the cellulose and non-cellulose matter from the plant.

Rinse the cooked fiber through the colander with fresh water and transfer to a blender. Blend to create a pulp slurry.

Transfer the slurry into a vat. Mix with fresh water to create a syrup-like consistency, being careful not to dilute it too much. Gently lower the mold and deckle into the slurry. Agitate it a little while submerged, then slowly remove to allow the slurry to form an even layer across the mesh. Carefully flip the seaweed sheet onto a flat cotton cloth and sponge it through the mesh to transfer. Gently remove the mold and deckle.

Sandwich the kelp sheet underneath another cotton cloth and a piece of plywood. Stack with a brick to compress and let dry for a few hours.

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bioMASON brick


Glass beads coated in bioMason bacteria and biocement

bioMASON

Materials Sand, Bacillus

Location Durham, NC, USA

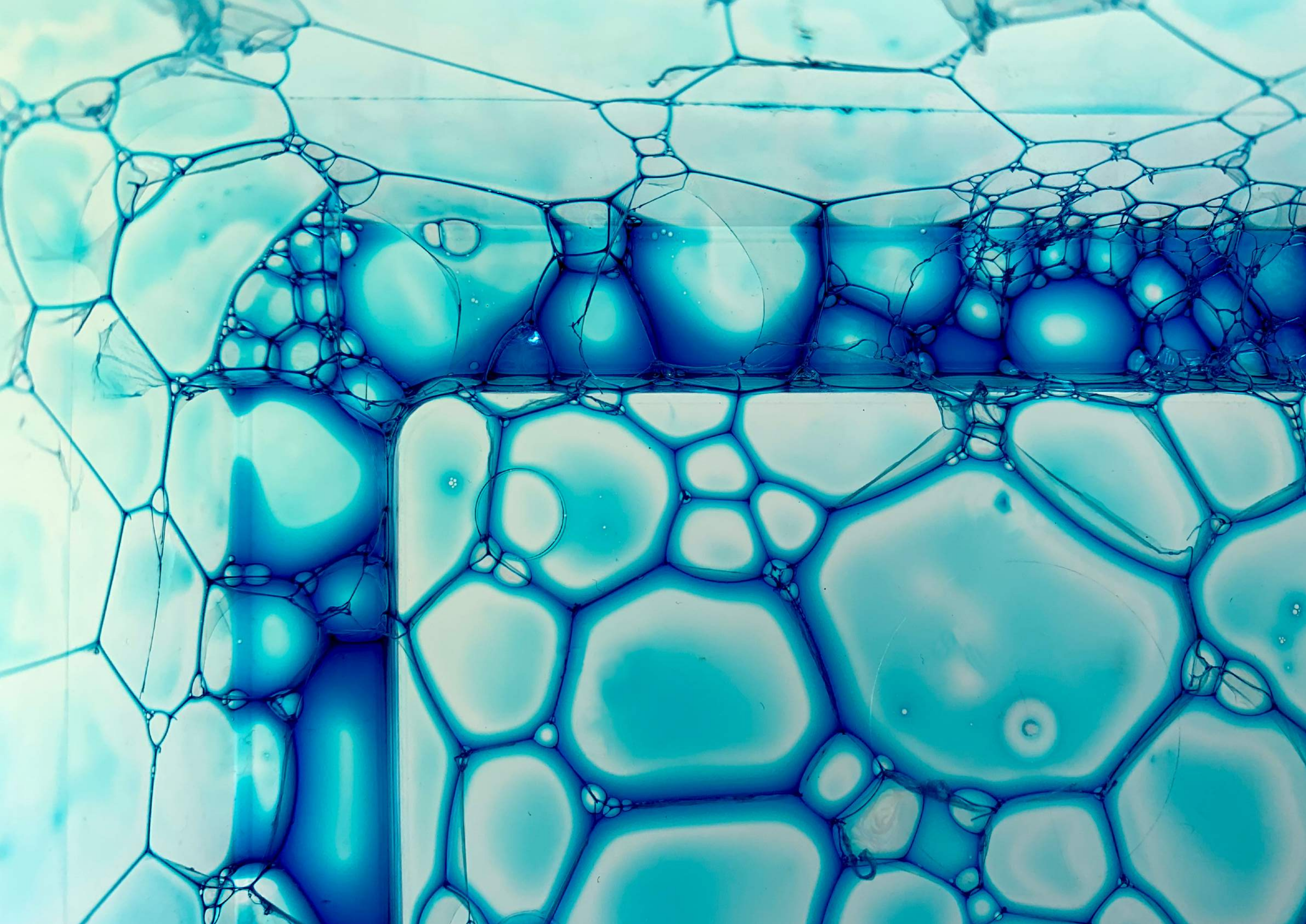
Year 2012 -

Return to the beach. Let the sand cling to your wet skin, wedging itself into every wrinkle and crevice. Somehow it finds itself everywhere – between toes and under nails, behind ears and tangled in hair. Sand is the most nomadic material we have. Formed far away from the sea as mountains, boulders, or precious stones, the elements break them down over time. As stones, they journey through rivers and streams, tumbling and leaving parts of themselves along the way like a trail of breadcrumbs. Finally, as if it were calling to them, they reach the shore. The waves break them down from rocks to pebbles to sand, each one containing "a story of the Earth."[3]

Concrete is the second-most consumed material on the planet, after water.[4] Cement production requires temperatures of up to 2,800°F, making the process responsible for 5 percent of annual greenhouse gas emissions.[5]

However, bioMASON uses bacteria and sand to grow bricks. The common, harmless bacteria Bacillus naturally produces a calcium carbonate crystal that, when combined with sand, mimics the processes of coral and shell formation. bioMASON bricks set at room temperature (eliminating carbon emissions), are 3 times stronger than concrete blocks, and even recaptures carbon dioxide. This biological process, informed by nature, forces us to reconsider traditional production methods and materiality, and to begin searching for more ecological alternatives.

Calcium carbonate ($CaCO_3$) is a common substance found in rocks, hard coral, and bones.



Bioplastics

Ingredients

¼ teaspoon corn starch, tapioca, or other starch
0.5 oz white vinegar
2.7 oz water
0-5 teaspoons glycerin
Beetroot juice, turmeric, or other natural dye

Tools

Pot
Silicone spatula
Flat plastic container or wooden frame

Steps

Oceans act as climate regulators, biodiversity havens, major sources of oxygen, food, and medicine, and a giver of life; however, our actions towards these essential ecosystems do not reflect how much we depend upon them. An estimated 8 million tons of plastic enter the planet's oceans every year,[6] and plastic are predicted to outweigh fish by 2050.[7] Half of all plastic that has ever existed was manufactured in the last 20 years.[8] Our oceans, our planet, and its species are choking on an entirely unnatural, human-made artifact of consumerism, convenience, and destruction. Solving the 'plastic problem' is one of the most urgent issues facing designers, scientists, and engineers alike.

One emerging solution is bioplastics. Unlike common plastics which are derived from petroleum and other fossil fuels, bioplastics are materials derived from natural, renewable sources or agricultural by-products. These include vegetable fats, food waste, straw, woodchips, starch, and cellulose.

Add starch, vinegar, water, glycerin, and any natural, liquid-based dye to pot and cook on medium heat for 10 minutes, stirring, until the solution becomes viscose and excess liquid evaporates.

Alternatively, substitute the starch and vinegar for 0.5 oz gelatin and halve the amount of glycerin, following the same steps

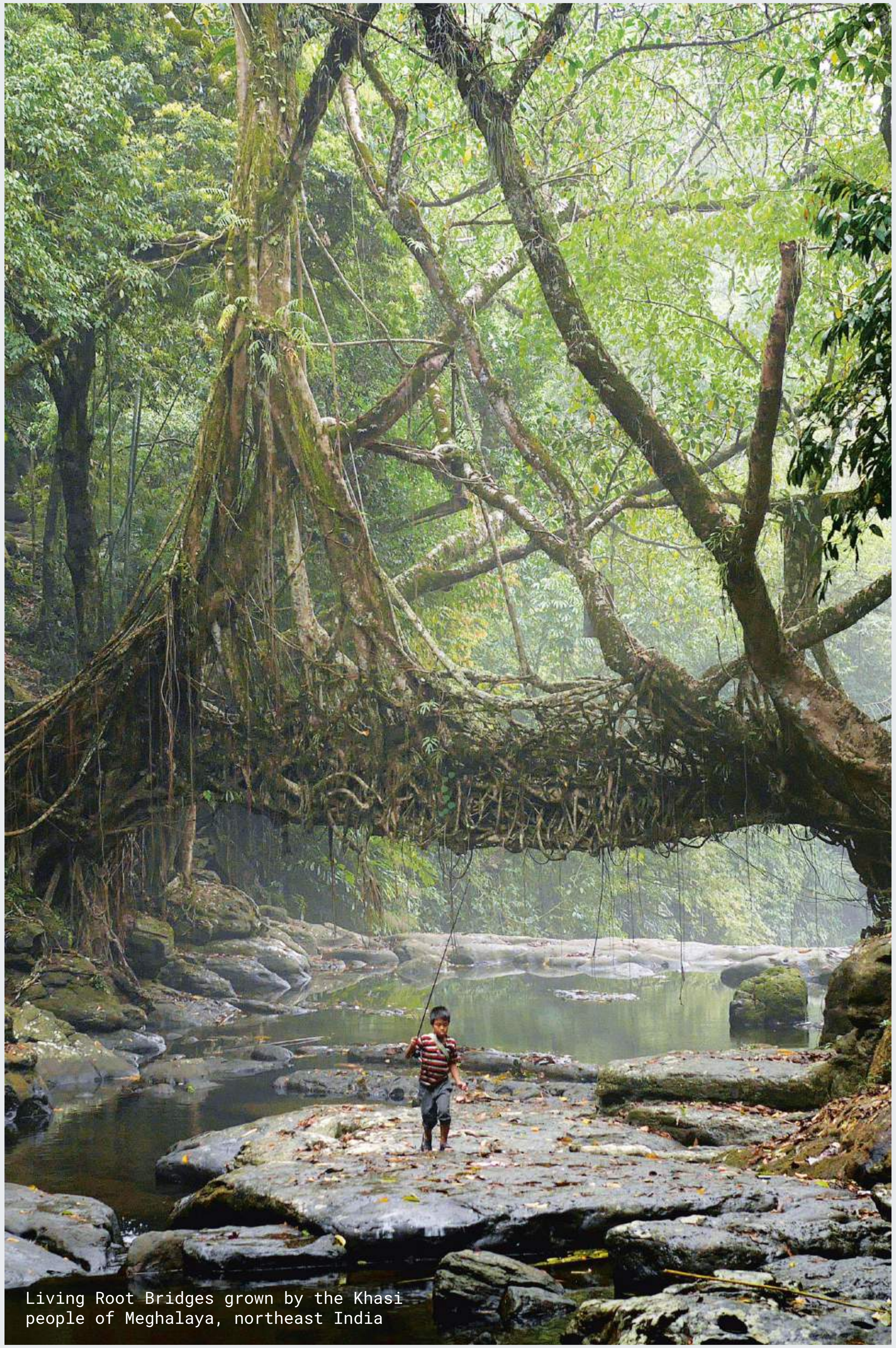
Tape down the frame to a non-stick surface. Pour a thin layer of the liquid into the container or wooden frame. If it is too thick, the bioplastic will crack as it dries. Once dry, remove from container or cut out of frame, and cut to shape.

Experiment with varying amounts of glycerin for different materiality. More glycerin (5 teaspoons) will yield a more flexible, malleable bioplastic, whereas less glycerin will produce a brittle bioplastic. When broken into smaller pieces and re-heated with water, these bioplastics can be recast into new forms.

The Seventh Generation

We are motivated to design not just for ourselves but for future generations (both human and nonhuman). Our choices and practices have multi-generational effects that must be taken into consideration.

“We do not inherit the Earth from our ancestors; we borrow it from our children.”



Living Root Bridges grown by the Khasi people of Meghalaya, northeast India

Living Root Bridges

Materials	Ficus elastica
Location	Meghalaya, India
Year	100 BCE -

Now we fly far away from the coast, ascending to the lush mountains "above the clouds" at an altitude of over 6,400 feet. The rest of the world dangles beneath your toes. The hills, fluffy with green canopies, are separated by gaping valleys. Fog floats from the trees like lace, transforming the view with every passing moment. Rivers meander across the landscape, while ever-present clouds roll in the sky.

The Khasi hills in Meghalaya, India, receive an average of 470 inches of rain every year, the wettest place of Earth. During the monsoon season, flood waters transform the mountainous terrain into isolated islands. The only structures strong enough to withstand the force of the rain and floods are the *jing kieng dieng jerry*: living root bridges and ladders.

Over decades, the roots of the common rubber fig tree – Ficus elastica – are molded and trained to grow across rivers to create intricate, living bridges. This native species not only holds significance within its ecosystem, but acts as a Cultural Keystone Species, bringing together ecology, mythology, technology, and spirituality. Hollowed trunks of betel nut trees are used as scaffolding, acting like a cast around a broken bone. The roots weave into an intricate lattice that is literally alive, capable of carrying 50 people after 35 years of growth. Some of these natural, knitted structures can be grown into double or triple-decker bridges, transforming the destructive rainfall into an opportunity for ingenuity. These breathing structures can live for several hundred years, self-repairing and growing stronger as the roots thicken, transforming individual materials into a single, integrated system. By working with nature's innate intelligence and fostering a symbiotic relationship, we can develop productive, resilient, and adaptable infrastructures that meet our needs and limit our impact on the planet.

Cultural Keystone Species: "An exceptionally salient species to a people, identified by its significance in their diets, materials, medicines, languages, traditions, histories, and spiritual practices."[9]

Designer Baby

Ingredients

A viable human embryo
Cas9 enzyme
Genetically amended DNA

Steps

CRISPR gene editing is a genetic engineering technique allowing for the modification of genomes in living organisms. This technology allows for gene editing with ease, extremely high precision, and minimal cost.

CRISPR stands for clustered regularly interspaced short palindromic repeats.

Humans are no strangers to genetic modification. With a centuries-long history of selective breeding, we have been picking and choosing qualities in both animal and plant life that best suits our own needs. There are many prospective uses for CRISPR-Cas9 in the human genome, such as curing genetic diseases and disorders, and creating an immunity to HIV/AIDS, smallpox, and cholera. The Berlin Patient was treated with a mutant CCR5 gene from a donor, curing his HIV/AIDS. However, this technology opens up the possibility of eugenic modifications simultaneously. This practice, known as *designer babies*, is heavily scrutinized as unethical, dangerous, and premature, raising confronting ethical questions.

This mutation is quite common amongst Northern Europeans, at a rate of 16 percent.[10]

To design your own baby, retrieve an egg from a female donor's mature follicles within an ovary. Inject it with a single sperm from a male donor, or mix the egg with sperm in a petri dish. This is a common fertilization process called in vitro fertilization (IVF).

Under the microscope, select what physical and/or biological traits you would like your baby to possess. Choose your child's infection immunity, disease resistance, susceptibility to chronic and mental illness, eye color, face shape, height, weight, and skin color. Challenge your own understandings of nature versus nurture by selecting your child's behavioral traits, sense of humor, empathy, and success potential.

Using the Cas9 enzyme, cut out a specific segment of the embryo's DNA. Replace it with the amended DNA strands. Allow the embryo to mature before transferring it to a host's uterus.

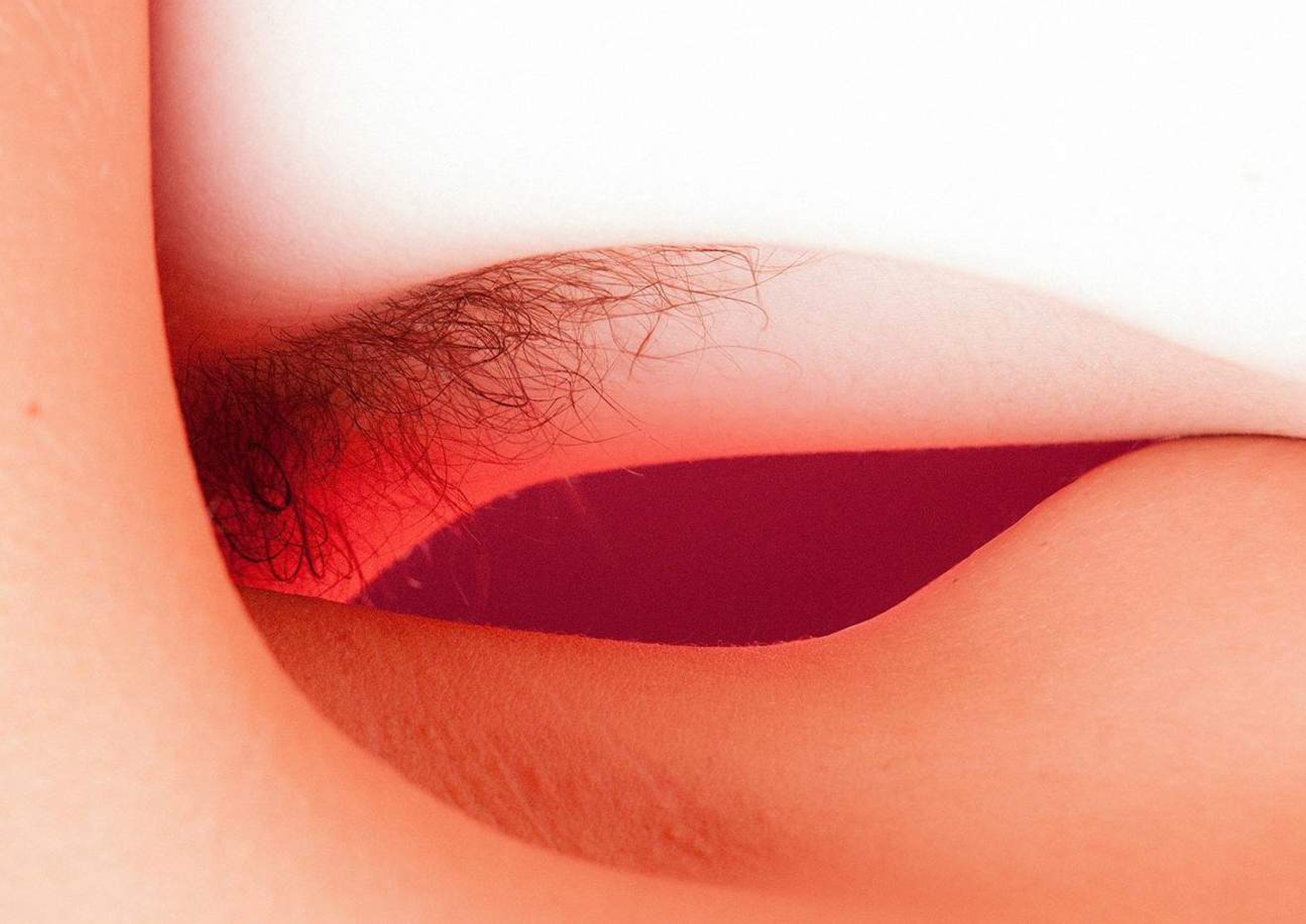
Wait for approximately 37-40 weeks for your perfect baby to be born.

Lennart Nilsson, 1965

Collaborate with Life

We recognize both life and evolution as technologies in their own rights, and their potential to work alongside humans as design tools, collaborators, and co-designers.

Grevillea sericea



Selfmade, Christina Agapakis and Sissel Tolaas, 2013

Selfmade

Materials The human microbiome, milk

Location California, USA; Edinburgh, Scotland

Year 2013

Now turn to look inwards at your own body. Feel your breath, your heartbeat, every tingle and sensation your skin picks up. Think of all of the incredible things this body can do, carrying you through life. Now think about the tiny creatures we share this body with – the bacteria in our nose, mouth, saliva, armpit, gut, between toes. It is estimated there are up to 100 trillion microbes in and on our bodies.[11] These microscopic roommates are essential to the development, immune function, and nutrition of the human ecosystem.

Some scientists believe we should see ourselves as a *holobiont*, a term that more accurately reflects the intimate, co-dependent relationship between humans and our microbes.

We live in a biological world, yet our cultural world is dominated by antiseptic practices. The fear of a few deadly germs has led to the normalization of complete sterilization and pasteurization, as opposed to "a more nuanced cohabitation with the many microorganisms that play a neutral or even positive role in human health."[12] Through exploring the human-bacterial collaboration that is the ancient cheese-making process, *Selfmade* challenges audiences' common understandings of bacteria, and pushes them to reconsider their relationship with their own bodies. Synthetic biologist Christina Agapakis and artist and smell researcher Sissel Tolaas swabbed microbes from different bodies and body parts, collecting a diversity of ecology. The swabs were left to incubate in fresh, pasteurized, organic whole milk overnight at 98°F (37°C). The milk curds were strained and pressed, producing unique-smelling cheeses that, while inedible, act as a microbial portrait of the donors. Through bringing together art and biology, and using non-human life as a design tool and collaborator, *Selfmade* poses timely questions concerning cultural understandings of life, safety, cleanliness, symbiosis, and interspecies collaboration.

In traditional cheese-making practices, rennet, an enzyme from cow stomach, is added to the milk, mimicking a calf's belly. This process allows a calf to absorb the nutrients of its mother's milk, as the milk turns into soft cheese, passing through the digestive system at a slower pace.

Bacterial Self-Portrait

Ingredients

Cheese starter culture
Organic whole milk
Your body

Tools

Small pot
Stove
Wooden spoon
Small glass jar
Cotton buds
Sieve
Cheesecloth (optional)
Your body

Steps

Warm up the milk (enough to fill a small jar) over medium heat, stirring gently. Be sure not to let the milk boil and curdle. Add the starter culture then transfer mixture to the jar.

Fresh, organic whole milk yields the best results.

Optional: sterilize your jar before starting. Wash in hot, soapy water then transfer to the oven (still wet) for 15 minutes at 320-355ºF (160-180ºC).

Swab a part of your body that has a high population of bacteria (hands, armpits, saliva, nose, feet, toes, genitalia, etc.) with a clean cotton bud. Use both ends of the bud to collect as much life as possible. Add the entire cotton bud to the milk mixture, and seal with lid.

Leave the jar in a dark, warm place for a few days to allow the bacteria to ripen.

For overnight results, keep warm at 98ºF (36ºC) to curdle.

Once large milk curds form, strain the cheese through a sieve and cheesecloth.

Warning: not for consumption. These cheeses are scientific and artistic objects, acting as bacterial portraits.

Selfmade, Christina Agapakis and Sissel Tolaas, 2013

Gwion Gwion paintings, Kimberley Region, Western Australia

Green lichen

Restoration and Preservation

Materials Lichen, *Chaetothyriales*

Location The Kimberley, Australia; Florence, Italy

Year 2010; 2016

This is a sacred place, the home of the world's oldest continuous culture. Wedged between sea and desert lies the Kimberley in north-western Australia. The ragged escarpments are a fiery red, with colossal blue waterfalls carving through the rocks. The sand is stuffed between your toes, behind your ears, buried in your nose. Magic and the Dreaming flutter through the leaves. The sky is wide and sun merciless. This sacred place, older than we'll ever know.

The Kimberley is part of Nyangumarda, Bardi, and Ungarinyin countries.

The Gwion Gwion paintings (formerly known as the Bradshaw rock paintings) in the Kimberly region of Western Australia, estimated to be up to 12,000 years old, are remarkably vivid despite their age and exposure to the elements. Research revealed that in the cases where paint was no longer present, a biofilm of cannibalistic, pigmented fungus has taken its place, contributing to the longevity of the artifacts. The researchers concluded that although biofilms were initially considered to be detrimental to rock art, "the tolerance of the biofilm organisms for extremes of temperature, radiation, and osmotic pressure ... would permit indefinite survival and replenishment of the paintings."[13]

Similarly, anthropologist Grace Kim investigated the use of "bacteria-masons"[14] in the restoration of Renaissance ruins and paintings in Italy. She writes: "The bacterium removes unattractive residue while preserving the marble that forms the artwork. This 'selectivity' ... makes biotechnology the superior alternative ... It relies on the microbe's natural ability to discriminate between materials – namely, between the materials that constitute art and those that devalue it."[15]

These two case studies, one occurring naturally and one with human intervention, provide useful insight into how designers can develop multispecies relationships with microorganisms.

Nature as a Designer

We continue to learn from and be inspired by human and nonhuman life, both individual and collective, and translate that into meaningful, ecological design that transcends biomimicry.

Bio-light, Philips, 2011

Bio-light

Materials Bioluminescent bacteria, methane

Location Eindhoven, the Netherlands

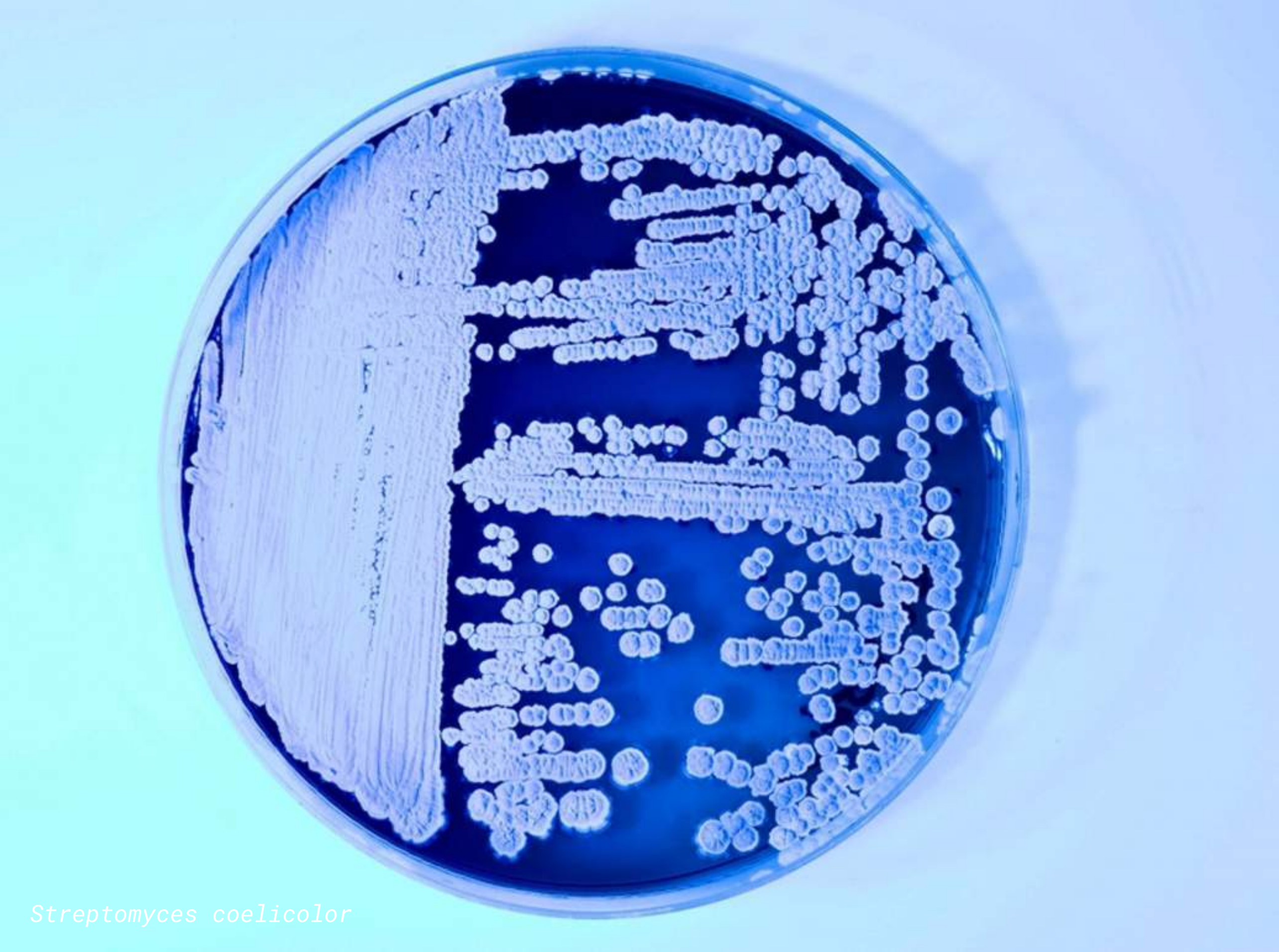
Year 2011

Light and water are the main sources of life and energy for all living organisms. The humming, zipping glow of creatures of the ocean bring these two sources together, making the sea sparkle. From squid, octopi, and jellyfish to algae, coral, and the infamous agape anglerfish, the world around us glows. Most bioluminescent creatures live in the twilight zone, relying on their own source of light for life. These living lightbulbs are powered by a chemical reaction and are used to attract prey or a mate, intimidate predators, as camouflage, or to simply observe their surroundings.

The twilight zone is a layer of ocean stretching around the planet. Most bioluminescent creatures live between 1600-3300 feet below sea level, some in perpetual darkness.

Inspired by the ingenuity of evolution, Philips developed a lighting installation in which the light is produced by living bacteria. Fed on a strict methane diet, courtesy of local kitchen and bathroom composting system, the bacteria can glow indefinitely. While bioluminescent light is not yet strong enough to replace our industrial LED or incandescent bulbs, *Bio-light* provides a hopeful glimpse into the future of everyday technology.

The chemical reaction that produces bioluminescence happens between a molecule called luciferin, one or two enzymes called luciferase and photoprotein, and oxygen.



Streptomyces coelicolor

Project Coelicolor, Faber Futures, 2019

Project Coelicolor

Materials *Streptomyces coelicolor*, silk

Location London, England

Year 2019

The moss is soft and damp beneath your feet, every step cushioned with layers of fallen twigs and leaves. Life grows in the cracks between their skeletons, slowly consuming the forest floor at a glacial pace. The earth will reclaim every leaf, branch, and tree that will fall here, a cyclical journey back to where they came from. A thimble of topsoil can contain over 20,000 individual organisms.[16] Forests are one of the most complex ecosystems in the world, playing crucial roles in the lives of millions, many of which live beyond its edges. Currently, forests make up around a quarter of Earth's land surface.[17] They play major roles in carbon sequestration, weather patterns, rain generation, water runoff redistribution, conservation and biodiversity, and traditional indigenous cultural beliefs and practices.

One particularly interesting yet invisible life form, commonly found in soil, is *Streptomyces coelicolor*. The bacterium is vital in the decomposition process, and also produces pink, purple, and blue pigments. Through understanding and harnessing this natural dye, London-based biodesign lab Faber Futures has developed much more ecological alternatives to industrial textile production. While the production process for a single pair of jeans requires 2,000 gallons of water, this natural, interspecies collaboration can produce a garment with just 6 ounces of water.[18] By twisting, tying, bunching, and balling silk garments in a dye bath populated with *S. coelicolor*, a unique dynamic between the human and non-human collaborators can be developed. Each unique stain marks a life that has lived, dyed, and died. Rather than dominating the design process, human designers can establish parameters for the non-human designers, relinquishing controlling and allowing for organic, collaborative growth.

Growth Over Assemblage

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Macrozamia communis

Fungi Mutarium, Livin Studio, 2014

Fungi Mutarium

Materials Fungi, plastic, water

Location Utrecht, the Netherlands

Year 2014

Forage at the base of the trees and up the rough bark for signs of life pushing through the leaf litter. You are looking for one of the most common and colorful forms of life: fungi. From the charming toadstools of fairytales, to the alien bio-luminescent species, to the mushrooms we eat for dinner, fungi make up a huge part of our lives. They live in the soil, air, waterways, and within other plants and animals, including humans. It is estimated that there are up to 3.8 million fungi species.[19] While some are poisonous, others play essential parts in the fermentation processes of our breads, wines, beers, and cheeses. Penicillin was first produced from a fungus mold that has the ability to kill bacteria. Fungi break down organic matter through decomposition, as well as act as communicators between some plant species, acting as a bedrock for essential ecosystems. Already deeply embedded into our everyday lives, fungi are perhaps one of the most useful yet misunderstood life forms.

Research suggests that fungi can detect and degrade toxic waste materials, including plastic, into an edible fungal biomass.[20] *Fungi Mutarium* is a speculative prototype system exploring the future of food production and waste. Developed by Livin Studio in collaboration with Utrecht University, this project is an exploration of mycelium as a novel food product. Plastic is sterilized with UV at the bottom of the mutarium, activating the degradation process. Next, in the Growth Sphere, fungi are fed their plastic-only diet to consume, grow, and populate their specially-designed individual agar spheres. When breaking down plastic, fungi do not store them or their byproducts as they do with metals, making them a safe consumable. The fungi are then harvested and prepared for consumption, creating a unique, ecological culinary and production experience.

Livin Studio worked with two types of fungi, *Schizophyllum Commune* and *Phleurotus Ostreatus*, commonly found throughout the world.

Agar, or agar-agar, is a gelatin substitute derived from algae that acts as a nutrient base for the fungi.

Mycelium

Ingredients

Mushroom stems and roots
Flour
Water
Organic waste (seed husks, corn stalks, etc.)

Tools

Glass/plastic container
Waterproof, non-porous mold (lamp, planter, etc.)
Gloves
Plastic bag
Wire backing rack

Steps

Mycelium is the vegetative part of a fungus and its primary role in an ecosystem is decomposition. Through a process called mycoremediation, fungi have the potential to consume and break down pollutants such as pesticides and petroleum, so long as they are not toxic to the species. Colonies and species vary in color, shape, size, and growth patterns. New York-based studio Ecovative Design have been developing mycelium-based design processes since 2007, creating unique material properties including water absorbent, flame retardant, and dielectric. Through greater understanding of and appreciation for fungi and its material potential, we could develop more ecological and biodegradable alternatives to the many harmful materials we rely on every day.

Mix all of the ingredients together to form a thick paste. Leave in a container for a few days until white fibers emerge.

The flour and organic waste act as a food source for the mycelium, and the water activates the growth process.

Wearing gloves, break up the biomaterial by hand. Poke holes into the mold to allow for air flow, then transfer the mixture into your preferred mold. Leave to grow for a few days.

Transfer into a sealed plastic bag to allow the biomaterial to set itself. Make sure the plastic doesn't touch the mycelium (except the bottom).

After one day, remove the material from the bag and the mold, and leave the mycelium structure to sit on a wire baking rack. It should feel like the rind around brie cheese.

Since mycelium is a living matter, so it has to be heated in order to lose its activity. Bake at 200°F (93°C) for 30 minutes. It will now feel like papier-mâché.

Myx, Jonas Edvard, 2013

Decenter the Human

We want to erase the boundaries between the living and the built, thus decentering human intelligence and reconciling the fractured relationships between human and nonhuman life.

Silk Pavilion I, MIT Media Lab
Mediated Matter Group, 2013

Silk Pavilion I

Materials	Silkworms, stainless steel, aluminium
Location	Cambridge, MA, USA
Year	2013

Humans have been developing a collaborative, yet exploitative, relationship with silkworms for over 5,000 years. Their cultivation began in China and the tiny weavers were brought to Europe in the 11th century. After centuries of domestication, silkworms no longer live in the wild, instead relying on human-made habitats, feeding exclusively on mulberry leaves. Each cocoon is made up of a single strand of silk measuring almost 3,000 feet long. While the fibers produced by silkworms are much weaker than those of spiders (hailed a "super fiber" at five times stronger than steel at the same weight[21]), it has been proved that under controlled conditions, their material capabilities and potentials can be strengthened.

MIT Media Lab's Mediated Matter Group explored the possibilities of silkworm silk on an architectural scale with their stunning project *Silk Pavilion I* (and a further iteration in 2020, *Silk Pavilion II*). Hovering over the audience, the work poses questions regarding the possibilities of future interspecies collaborative relationships. The stainless-steel and aluminium hemi-ellipsoidal dome was built upon by 5,600 silkworms, surrounding the audience in a thin, cotton-candy-like shelter. Through studying the silkworms' behavior, the team was able to influence the worms' spinning patterns using Earth magnets, allowing them to spin the silk as flat sheets rather than cocoons. This innovation allows for the ethical production of raw silk, replacing the traditional method of boiling the silkworms alive. The worms produced 1.5 million eggs, which carry the potential to construct another 250 pavilions. This self-sustainable experiment in interspecies collaboration and biological materials offers an exciting glimpse into the future of biodesign, construction, and production.

Embrace Decay

We embrace the inherent temporality of organic materials, systems, and life. We reconsider traditional theories of *firmitas* (in which decay is seen as destruction), and understand the advantages of decay.

Citrus sinensis

BioCouture

Ingredients

4 cups boiling water
2 bags black/green tea
7 oz apple cider vinegar
7 oz white sugar
1 piece of live kombucha culture
Fresh produce/food scraps

Tools

Heatproof jug
Large, shallow container (approx. 8 x 6.5 x 2.5 in.)
Metal/plastic spoon
Breathable cloth
Gloves
Wooden sheet

Steps

In a heatproof jug, brew the tea in boiling water for 15 minutes. Add the sugar, stirring to dissolve, and leave to cool to below 86°F (30°C).

Meanwhile, blend together fresh produce/scraps to create a slurry. Different produce will yield different colors (see chart below). More produce will result in a deeper color. Add some lemon juice to prevent colors from oxidizing.

Once the tea has cooled, remove the tea bags and pour in-to the growth container. Add the produce liquid, apple cider vinegar, and live kombucha culture, gently stirring together.

Cover with the breathable cloth and leave somewhere warm to grow (approx. 77°F/25°C). At first, the culture will sink. Fermentation will begin within 48-72 hours. Bubbles and a transparent skin will start to appear at the surface. Over time, the culture will rise, the layers thickening and forming bacterial cellulose. This can take a few weeks.

Once the biomaterial grows to approximately 1 inch (2cm) thick, remove from container, wearing gloves. Wash the biomaterial with cold, soapy water, rinsing thoroughly. Spread out flat on the wooden sheet to dry. Drying time will depend on temperature and ventilation. Once dry, cut and sew into clothing, accessories, face masks, reusable packaging wrap, or leather book covers.

Colors:

Red	Beetroot (no lemon)
Pink	Avocado skins and seeds*, strawberries
Orange	Carrot, paprika, sweet potato
Yellow	Onion skins*, turmeric, lemon peel*
Green	Chard, matcha, spinach, kiwi fruit
Deep blue	Beetroot and baking soda
Purple	Blueberries, red cabbage
Brown	Coffee*, cocoa powder
Black	Activated charcoal, squid ink

*Brew in boiling water instead of blending

Bacterial, or microbial, cellulose $(C_6H_{10}O_5)_n$ is an organic compound synthesized in collaboration with certain bacteria. Both bacterial and plant cellulose are naturally occurring and have the same molecular formula. However, the material properties of bacterial cellulose - high water-holding capacity, high moldability during formation, biodegradation, and high crystallinity[22] - make it an exciting ecological substitute to everyday plastic and leather.

(above) bacterial cellulose, Elena Amato, 2019
(below) *Xylinum mask*, Sun Studio, 2020

De-Extinct a Mammoth

Ingredients

A well-preserved mammoth
An Asian elephant

Steps

The vast tundra of Siberia covers almost all of northeast Asia, covering 77 percent of Russia. The landscape of Central Siberian Plateau is made up of taig and permafrost, with temperatures dropping to as low as -80ºF (-62ºC). This climate made Siberia perfect for one of the most famous animals to have ever existed: the woolly mammoth. Russia has been dubbed “a motherland of mammoths”, with 75 percent of the world’s known mammoths (and related graves) found in Yakutia, Russia.[23] It is estimated that during the Pleistocene, the steppe was a rich wildlife ecosystem made up of mammoths, bison, horses, reindeer, muskox, elk, woolly rhinos, snow sheep, moose, and saiga antelope. After centuries of accumulation of organic matter, faeces, bones, and dead plants, and millennia of development under the permafrost, enormous *yedoma* have formed in the soil. These *yedomas* trap 1,700-1,850 billion tons of carbon, more carbon than what is present in the atmosphere and all vegetation combined.[24] However, climate change threatens the stability of these carbon stores, and rapidly thawing permafrost will release these gases into the atmosphere, exacerbating a climate catastrophe.

Taiga (also known as a boreal or snow forest): the world’s largest land biome, made up of pines, spruces, and larches.

The Pleistocene epoch began around 2.6 million years ago, and ended some 11,700 years ago.

Yedoma: a Pleistocene-era permafrost that stores carbon. In some areas, this permafrost dips 4,900 feet deep into the earth.

On top of this, decomposition produces methane, and the combination of these two gases would rapidly increase the affects of global warming.

Some scientists are looking into the possibility of de-extinction as a solution. Through bringing the legendary woolly mammoth back to life, the Pleistocene ecosystem could be somewhat restored, allowing for the preservation of the permafrost.

To bring the species back to life, first locate a well-preserved woolly mammoth. Extract as much DNA as possible. Based on this preserved DNA sequence, locate a specimen of a close living relative – in this case, an Asian elephant.

The best-preserved specimen known is 40,000-year-old ‘Lyuba’, discovered in 2007 in Russia.

It is important to note that it is impossible to bring a “real” mammoth back to life; instead, a mammoth-elephant hybrid based on their shared genetic makeup could be possible one day.

Fill in the gaps in the mammoth’s DNA sequence with that of the elephant’s, bringing the two cousins together. Transplant this patchwork DNA into the egg cell of a female elephant, and from there, a live mammoth-elephant hybrid will grow.

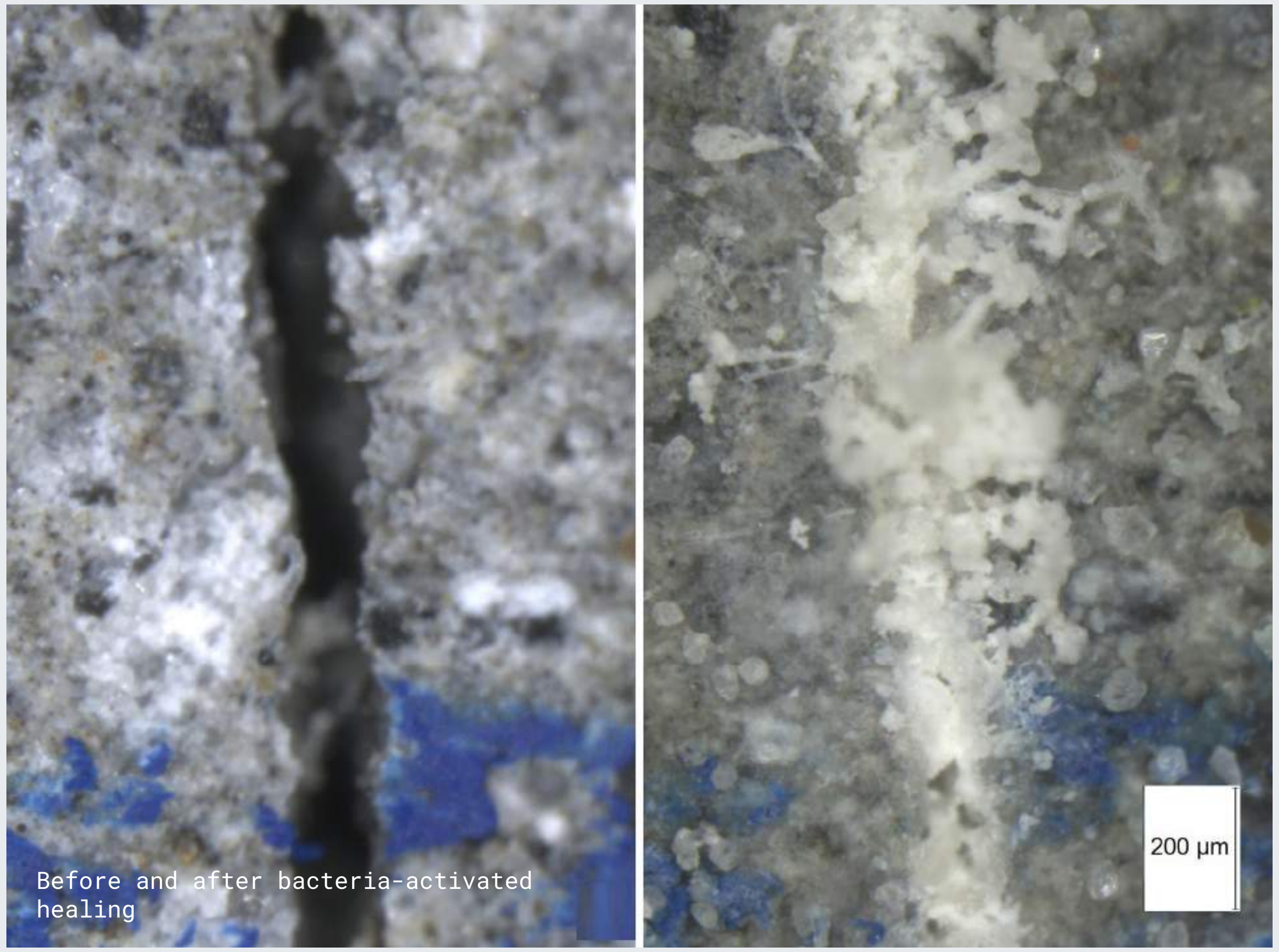
Museum worker with replica woolly mammoth (*Mammuthus primigenius*)

Design with Biology

We bring together science, engineering, art, and design in a functional, meaningful way that transcends just aesthetics.
We challenge perceptions and common understandings of who science is for, how it is utilized, and why.

Eucalyptus melliodora

BioConcrete, Henk Jonkers, 2015-



Before and after bacteria-activated healing

Bio-concrete

Materials: Concrete, *Bacillus Pseudofirmus*

Location: Delft, the Netherlands

Year: 2015 -

Concrete is the most widely used construction material in the world, and while it is one of the strongest and most reliable, it is prone to cracking. Cracking, and in particular, micro cracks, are common, difficult and costly to repair, and catastrophic if left unattended. Cracks expose concrete, and any material it reenforces, to water, carbon dioxide, and oxygen.

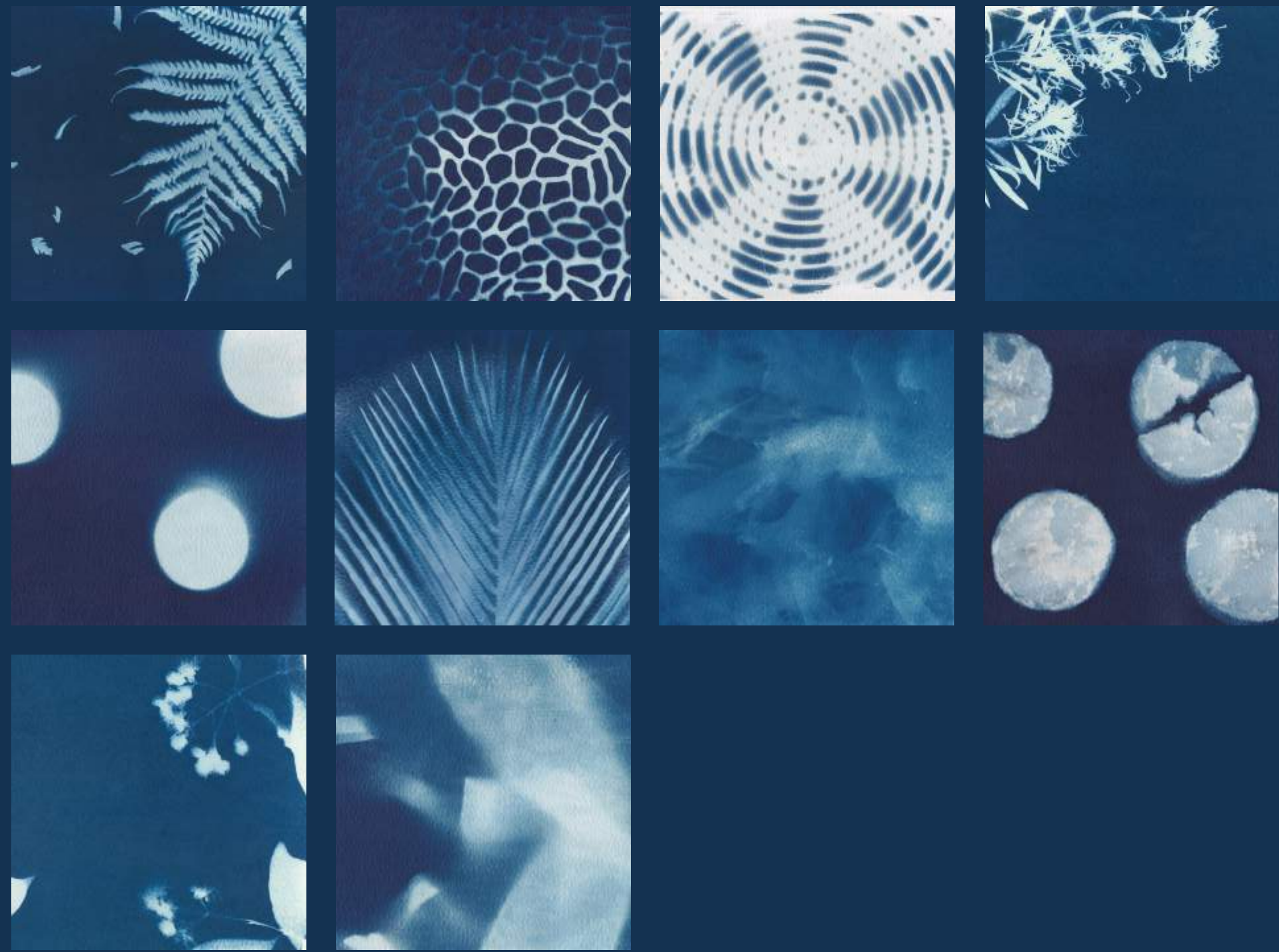
Researcher and self-healing bio-concrete expert Hendrik Jonkers has developed a biologically-based solution to cracks in concrete. During the mixing process, the bacteria *Bacillus Pseudofirmus* (or *Sporosarcina Pasteurii*) and calcium lactate are added to the liquid form. The bacteria lie dormant in the concrete, and can survive for up to 200 years after construction. Once cracks emerge, typically from exposure to extreme weather conditions, natural concrete shrinkage, and heavy load bearing, water seeps in. However, instead of damaging the structure, the water activates the bacteria, triggering a chemical reaction. The bacteria begin to produce limestone, naturally filling in the cracks from the inside out in less than a month. A liquid-based solution of the same makeup is also being developed to be applied onto existing concrete structures.

Calcium lactate ($C_8H_{10}CaO_6$) increases the strength and reduces water permeability of bio-concrete by encouraging the bacteria to produce more calcite, a common constituent of limestone.

Designing for Life

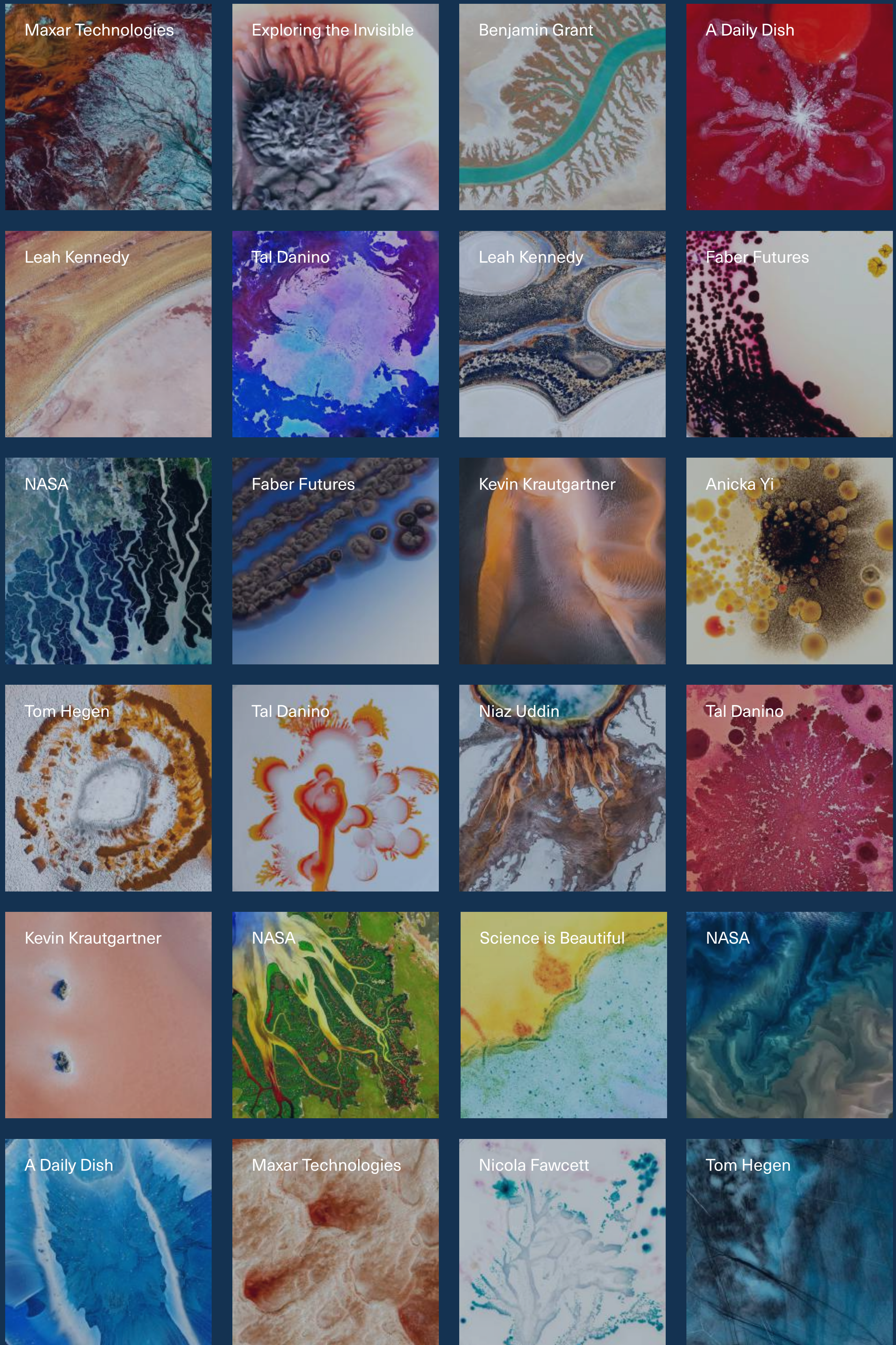
We recognize that as humans, we are a part of a multitude of ecosystems much bigger than ourselves. In both coexisting and designing with nonhuman life, we have a moral responsibility towards them, ourselves, and all of our descendants.

Image Credits



Cyanotypes were developed in the 20th century as a low-cost photographic printing process used to produce copies of drawings (blueprints) and document plant life. The two chemical ingredients (ferric ammonium citrate and potassium ferricyanide) are activated by water and sunlight - the sources of all life - to produce vivid cyan-blue prints.

Images by Nina Szewczyk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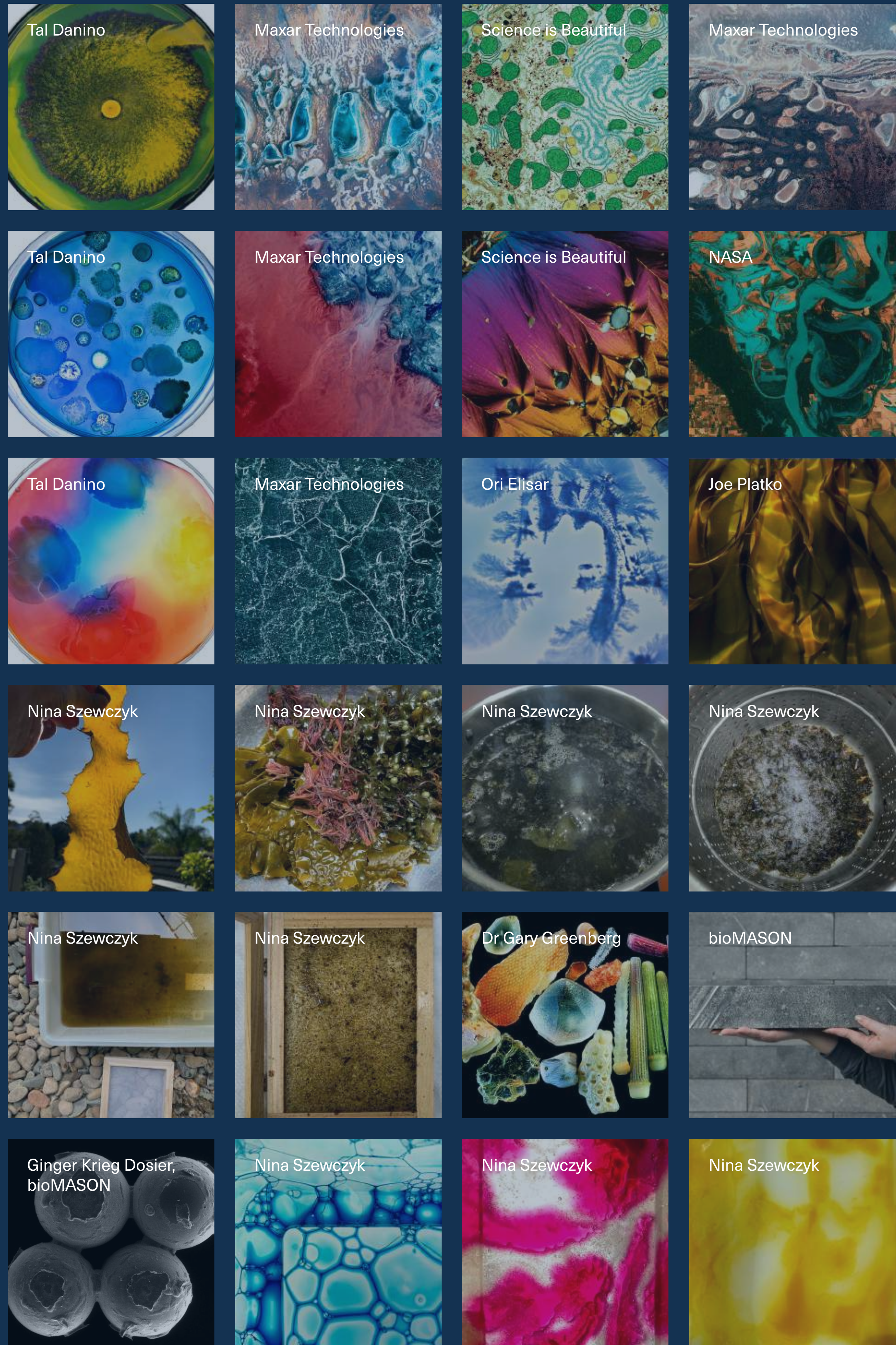
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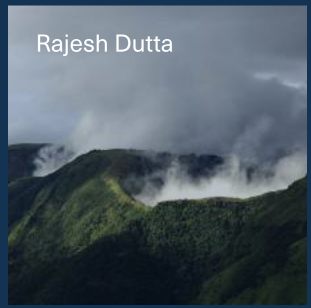
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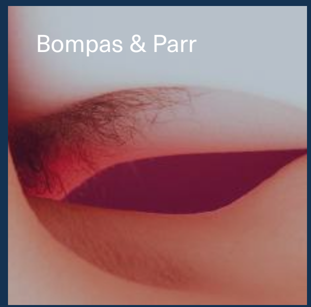
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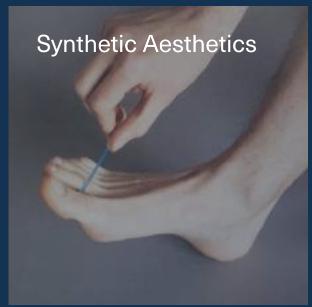
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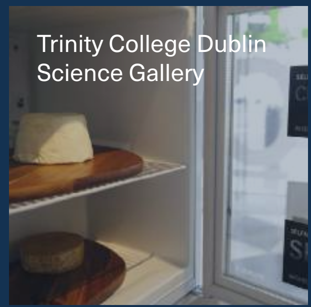
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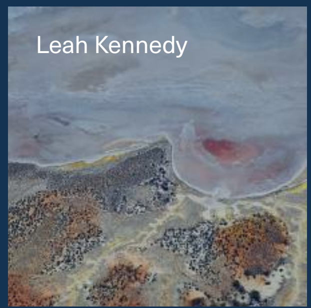
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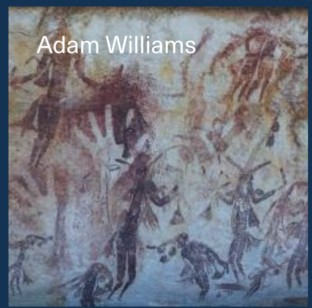
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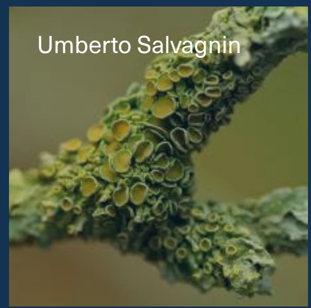
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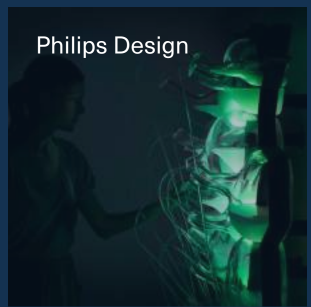
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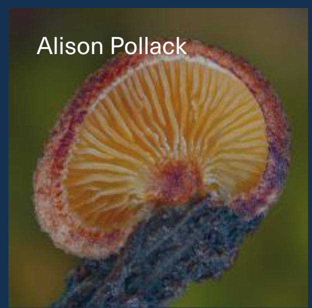
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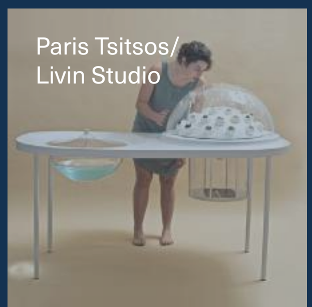
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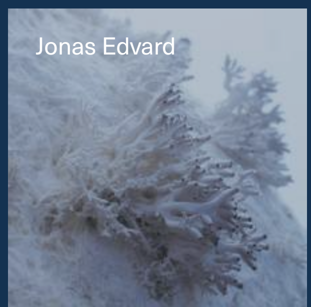
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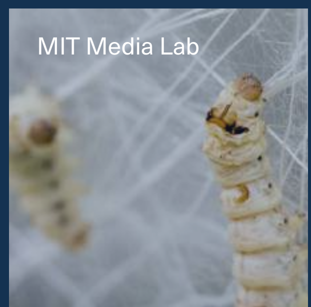
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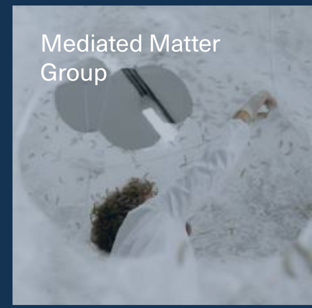
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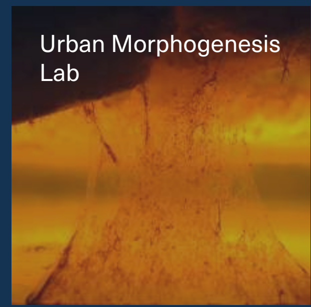
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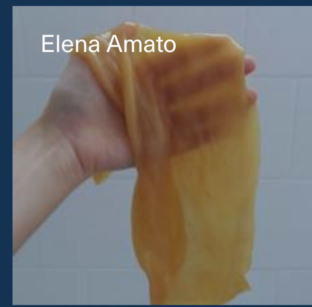
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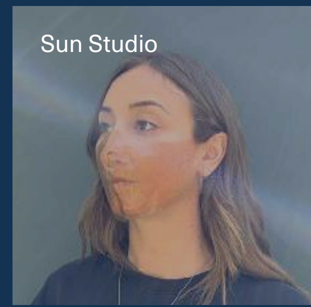
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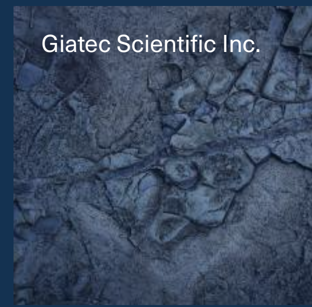
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HENK

Kim van Tittelboom
and Didier Snoeck

Nina Szewczyk

Tom Hegen

Notes

01 Jack Hall, "The Most Important Organism?" *Ecology Prime* (November 8, 2019), http://ecologyprime.com/2019/11/08/the-most-important-organism/.

02 "Ocean-Atmosphere CO2 Exchange." National Oceanic and Atmospheric Administration, accessed February 23, 2021. https://sos.noaa.gov/datasets/ocean-atmosphere-co2-exchange/.

03 Rachel Carson, "Our Ever-Changing Shore," *Holiday* Vol. 24 (July 1958): 70.

04 Colin R. Gagg, "Cement and concrete as an engineering material: An historic appraisal and case study analysis," *Engineering Failure Analysis* Vol. 40 (May 2014): 114

05 Lucy Rodgers, "Climate change: The massive CO2 emitter you may not know about," *BBC*, December 17, 2018, www.bbc.com/news/science-environment-46455844.

06 Jenna R. Rambeck, et al. "Plastic waste inputs from land into the ocean," *Science* Vol. 347, Issue 6223 (February 2015): 768-771.

07 Ellen MacArthur Foundation, *The New Plastics Economy: Rethinking the future of plastics & catalyzing action*, 2017, www.ellenmacarthurfoundation.org/assets/downloads/publications/NPEC-Hybrid_English_22-11-17_Digital.pdf.

08 Roland Geyer, et al. "Production, use, and fate of all plastics ever made," *Science Advances* Vol. 3, No. 7 (July 19, 2017): https://advances.sciencemag.org/content/3/7/e1700782.

09 Julia Watson, *Lo-TEK: Design by Radical Indigenism* (Cologne: Taschen, 2019).

10 John Novembre, et al. "The Geographic Spread of the CCR5 32 HIV-Resistance Allele," *PLoS Biology* Vol. 3, No. 11 (October 18, 2005), https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.0030339.

11 Peter J. Turnbaugh, et al. "The Human Microbiome Project," *Nature* Vol. 449 (October 18, 2007): 804

12 Christina Agapakis and Sissel Tolaas, "The Inside-Out Body," in *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature*, ed. Alexandra Daisy Ginsberg et al. (Cambridge: MIT Press, 2017), 274.

13 Jack Pettigrew et al., "Living pigments in Australian Bradshaw rock art," *Antiquity* Vol. 84, Issue 326 (December 2010), http://antiquity.ac.uk/projgall/pettigrew326/.

14 Grace Kim, "Putting Microbes to Work: Using Biotechnology to Restore Architecture & Art in Italy," *Thresholds 44: Workspace, Journal of the MIT Department of Architecture* (2016): 177.

15 Ibid., 180.

16 "Forest Ecosystems," Extension: Climate, Forests and Woodlands, May 16, 2019, https://climate-woodlands.extension.org/forest-ecosystems/.

17 James E. M. Watson, et al. "The exceptional value of intact forest ecosystems," *Nature Ecology & Evolution* Vol. 2 (2018): 599-610.

18 Natsai Audrey Chieza. 2015. "Fashion Has a Pollution Problem - Can Biology Fix It?" filmed October 2017 at TED&BCG Milan, video, 13:06, www.ted.com/talks/natsai_audrey_chieza_fashion_has_a_pollution_problem_can_biology_fix_it?language=en.

19 "Importance of Fungi," Britannica, accessed March 2, 2021, www.britannica.com/science/fungus/Form-and-function-of-fungi.

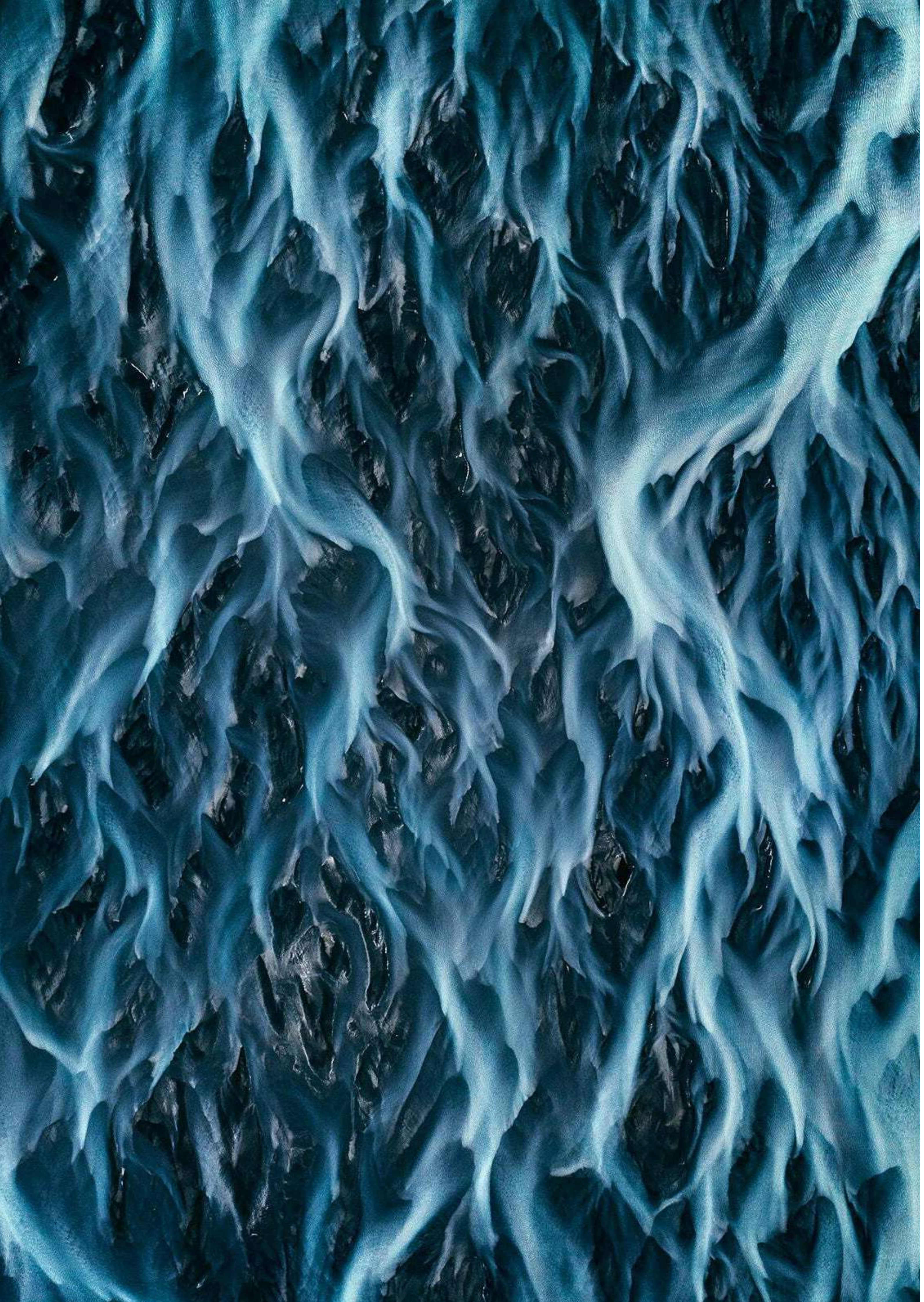
20 Royal Botanic Gardens Kew, *State of the World's Fungi*, ed. Katherine J. Willis, 2018, https://stateoftheworldsfungi.org/2018/reports/SOTWFungi_2018_Full_Report.pdf

21 Zhengzhong Shao and Fritz Vollrath, "Surprising strength of silkworm silk," *Nature* Vol. 418 (2002): 741.

22 S. S. Silva, et al. "Polymers of Biological Origin," in *Comprehensive Biomaterials II*, ed. Paul Ducheyne et al. (Amsterdam: Elsevier Ltd., 2017), 228-252.

23 Ksenia Zubacheva, "'The Motherland of Mammoths': Can the woolly beasts still be found alive in Siberia?" *Russia Beyond* (May 12, 2020), www.rbth.com/science-and-tech/332160-mammoths-siberia-russia.

24 Britt Wray, *Rise of the Necrofauna: The Science, Ethics, and Risks of De-Extinction* (Vancouver: Greystone Books, 2017).



Nothing (hu)man-made can ever match the imagination of nature.

JASON DECLAIES TAYLOR