‘The biggest innovations of the twenty-first century will be the intersection of biology and technology. A new era is beginning.’ Steve Jobs

Featuring lab-grown leather, self-healing concrete, leaves that glow in the dark, and DNA that stores data, *Bio Design* explores a future that may be closer than we think.
To my teachers, especially Celeste Topazio, Lisa Farber, Michael Rosenfeld, and Alice Twemlow

William Myers is a curator, writer, and teacher based in Amsterdam. He has organized several international exhibitions highlighting how scientific advances and emerging technologies influence culture. His work has been profiled in The New York Times, The Wall Street Journal, Smithsonian Magazine, the journal Science, de Volkskrant, and Voska de S Piave, among others. William has worked in a variety of roles for the Museum of Modern Art, the Solomon R. Guggenheim Museum, the Cooper Hewitt Smithsonian Design Museum, Science Gallery Dublin, and Het Nieuwe Institute in Rotterdam. He is a graduate of the Design Criticism program at the School of Visual Arts (SVA) in New York.

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First published in the United Kingdom in 2012 by Thames & Hudson Ltd, 181A High Holborn, London WC1V 7SJ

This revised and expanded edition 2018

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Foreword text © 2012, 2014 & 2018 Paola Antonelli

Design concept by The Studio of William Curran

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British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

ISBN 978-0-500-29449-0

Printed in China by RR Donnelley

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On the back cover:

(top left to top right)

Carnivorous Domestic Entertainment Robots. © Marcus Grubb Studio

Blood Lamp. Image courtesy of Mike Thompson

(ding-a-ling order)

Image courtesy of the Wyss Institute for Biologically Inspired Engineering at Harvard University

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Dune. Image courtesy of the architect

Carnivorous Domestic Entertainment Robots. Image courtesy of the designers

Future Venice. Image courtesy of Rachel Armstrong

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Algernon. Image courtesy of Mari Savi

VITAL DESIGN
Paola Antonelli

THE HYBRID FRONTIER

BEYOND BIOMIMICRY

ECOLOGICAL OBJECT ENGINEERING

REPLACING INDUSTRIAL AND MECHANICAL PROCESSES

SPECULATIVE OBJECTS, TEACHING TOOLS, AND PROVOCATIONS

PROFILING PROGRAMS AND COLLABORATIONS

CONSILENCE IN THE 21ST CENTURY

CHAPTER 1
THE ARCHITECTURAL HYBRID

Living Structures and New Ecological Integrations

CHAPTER 2
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VITAL DESIGN

Paola Antonelli

Design is not what it used to be. In schools and in studios, in corporations and in political institutions, designers are using their skills to tackle issues that were previously out of their bounds, from scientific visualization to interfaces, from sociological theories to possible applications and consequences of nanotechnology. They do so by teaming up for every case study with the right experts, who often seek designers’ help in order to connect their theories with real people and the real world. In the late 1960s, Ettore Sottsass famously declared that design ‘is a way of discussing society, politics, eroticism, food and even design. At the end, it is a way of building up a possible figurative utopia or metaphor about life.’ Design is indeed about life and, at a time of accelerated technological evolution and dramatic political, environmental, demographic, and economical concerns, designers’ presence guarantees that human beings are always kept at the center of the discussion.

Designers’ fascination with science is today reciprocated by a generation of scientists who are eager to get their brains dirty with reality. As explored first in the 2008 exhibition ‘Design and the Elastic Mind’ at the Museum of Modern Art, New York (full disclosure: yours truly was the curator), these novel collaborations are often joyous contaminations in which scientists feel, even if just for a moment, liberated from the rigor of peer review and free to attempt intuitive leaps. Indeed, physicists, mathematicians, computer scientists, engineers, chemists, and bioethicists have leaped at the opportunity, their contribution encouraged and celebrated in a few centers of ‘irradiation,’ such as London’s Royal College of Art Design Interactions program or Le Laboratoire, an idea incubator previously in Paris and now in Cambridge, Massachusetts.

The results (based on current research) have the lyrical and demonstrative power of art and the realistic possibilities of design. It is, however, the experiments with biologists that have garnered the strongest momentum, and a new form of organic design is rapidly evolving—the biodesign that William Myers explores in detail in this volume. Biodesign harnesses living materials, whether they are cultured tissues or plants, and embodies the dream of organic design: watching objects grow and, after the first impulse, letting nature, the best among all engineers and architects, run its course. It goes without saying that when the materials of design are not plastics, wood, ceramics, or glass, but rather living beings or living tissues, the implications of every project reach far beyond the form/function equation and any idea of comfort, modernity, or progress. Design transcends its traditional boundaries and aims straight at the core of the moral sphere, toying with our most deep-seated beliefs. In designers’ ability to build scenarios and prototypes of behavior lies a power that they should protect and cherish, and that will become even more important in the future.

Since the first publication of this book, new technologies (CRISPR/Cas9, to name just one) have provided powerful tools bridging the natural and the manufactured world, and ideas that were once confined to speculation are increasingly becoming reality. This shift has been on full display at the annual Biofabricate event in New York, which in its fourth edition in 2017 celebrated two important launches—Modern Meadow’s animal-free, liquid leather, Zoa, and Bolt Threads’ silken fibres ‘spun’ from yeast—along with many promising new prototypes and concepts.

William Myers has collected an impressive variety and number of case studies that involve organisms at all scales, from plants and animals to bacteria and cells, to be used as architectural, graphic, or interior elements. Architects working on wet buildings that adapt to changing environmental conditions and levels of occupancy, almost as if they were living organisms; designers concocting new diagnostic and therapeutic tools that rely on animals and plants; engineers devising new, self-healing construction materials; creatures themselves becoming the infrastructure of entire architectural systems. Despite the multitude of conversations and investigations happening in this space, biodesign remains a burgeoning industry that would benefit from increased public support and financial resources if it is to become truly viable at a global scale. If our relationship with nature is broken, this book makes us hope that perhaps we will be able to fix it from within.
This book presents an emerging and often radical approach to design that draws on research from the life sciences and even incorporates the use of living materials into structures, objects, and processes for the first time. Each chapter introduces a different theme, from designing for ecological enhancement to the use of speculative design and art as teaching tools. Taken together, the projects profiled here reflect an overdue shift in societal priorities toward sustainable approaches to building and manufacturing. This unifying purpose is driving increased collaboration between designers and biologists—an essential ingredient in many of the projects—and offers thrilling new forms and functions.

This new edition brings together the most inspiring recent examples of biodesign from around the world. Since the first edition was published, the practice of designing with biology has proliferated rapidly and become the focus of several competitions, school programs, museum exhibitions, conferences, and books. In addition, biodesign is the approach underlying the launch of numerous products and organizations, entering markets with solutions such as lab-grown leather, algae-based tableware, or self-healing concrete filler.

Biodesign goes further than the many biology-inspired approaches to design and fabrication. Unlike biomimicry, cradle-to-cradle, and the popular but frustratingly vague ‘green design,’ biodesign refers specifically to the incorporation of living organisms or ecosystems as essential components, enhancing the function of the finished work. It goes beyond mimicry to integration, dissolving boundaries between the natural and built environments and synthesizing new hybrid typologies.

The label is also used to highlight experiments that replace industrial or mechanical systems with biological processes that tend to be more renewable while making fewer material and energy demands. Chapter 4 ventures beyond functional or speculative design into the realm of art practices, which can often illuminate the way forward for design.

The structures, prototypes, and concepts chronicled here, including proposals that employ new biotechnologies, prompt several questions. What are the implications and likely outcomes of these speculations? Can we avoid thinking of life as simply another material or tool without extending it due respect? Can we unlearn our fear of aspects of biology, such as invisible microbes, and embrace design that utilizes them? Can designers learn to empathize with other forms of life and surrender a small amount of control of their work to them? Finally, does this new practice, including an embrace of natural systems and collaboration with the life sciences, amount to a paradigm shift in design practice? If so, how does it compare with other field-changing shifts in the trajectory of technological developments, from industrialization to the invention of computers?

As answers to these questions unfold over time, the space for cross-disciplinary collaboration and creativity prompted by scientific research will only expand, propelled by global imperatives such as the urgency to develop and implement cleaner technologies and the rise of do-it-yourself biology. This convergence of fields, as well as the expert with the amateur, is ultimately necessary to support the ongoing effort to alleviate the negative impacts of the legacies of the Industrial Revolution. And it will lead to the reconception of the primary design principles of value generation, growth, and sustainability. This book sets out to accelerate this effort by highlighting achievements in, and new approaches to, biodesign, as well as encouraging collaborations and providing historical context for this growing field.

William Myers
BEYOND BIOMIMICRY

A NEW URGENCY

‘It will be soft and hairy.’  
Salvador Dali on the future of architecture,  
in response to Le Corbusier

Designers face an unprecedented urgency to alter their methods and reprioritize their goals to address the accelerating degradation of the environment. This new pressure—interconnected, ethical, and regulatory—demands recognition of the fragility of nature and our responsibility to preserve it for future generations. Under such shifting and intensifying constraints, designers are beginning to go beyond emulation to harness processes observed in the living world, where systems achieve near perfect economies of energy and materials. Within this pursuit, working to achieve enhanced ecological performance through integration with natural systems, designers are turning to biologists for their expertise and guidance. This contrasts markedly with the design approach that characterized the 20th century: the mechanization of functions in order to overpower, isolate, and central forces of nature, usually by utilizing advances in chemistry and physics. The examples explored here illustrate how this new approach—designing with biology—lands itself to collaborations with life scientists and foreshadows what kind of consilience, or integration with natural systems, designers are able to achieve enhanced ecological performance through the use of algae bioreactors, biodesign includes the use of and they are included in this book.

The imitation of nature in the design of objects and structures is an old phenomenon, recalling stylistic developments such as iron-enabled Art Nouveau in the 19th century through to the more recent titanium-clad fish shapes in the computer-aided designs of architect Frank Gehry. Yet this design approach is form-driven and offers only a superficial likeness to the natural world for decorative, symbolic, or metaphorical effect. Design that sets out to deliberately achieve the qualities that actually generate these forms—adaptability, efficiency, and interdependence—is infinitely more complex, demanding the observational tools and experimental methods of the life sciences. The effort to master this complexity is well under way; ‘it’s been more than 40 years since scientists first altered a bacterium’s DNA so that it could serve as a tiny factory producing an inexpensive and reliable source of human insulin. ’ In the early 21st century, the DNA-modifying techniques to reproduce such a feat and reconfigure the activity of a cell have become widely accessible. We have even reached the milestone of synthesizing an entirely artificial DNA molecule that has successfully replicated and formed new cells. This affordability of the basic tools of biotechnology has put them within reach of engineers and designers who may now consider basic life forms as potential fabrication and form-giving mechanisms. Indeed, that is precisely the intention of architects such as David Benjamin, who is teaching and practicing how to wield life as a design tool.

A number of early and effective examples of biodesign profiled here set out to deliberately achieve the qualities that actually generate these forms—adaptability, efficiency, and interdependence—is infinitely more complex, demanding the observational tools and experimental methods of the life sciences. The effort to master this complexity is well under way; it’s been more than 40 years since scientists first altered a bacterium’s DNA so that it could serve as a tiny factory producing an inexpensive and reliable source of human insulin. In the early 21st century, the DNA-modifying techniques to reproduce such a feat and reconfigure the activity of a cell have become widely accessible. We have even reached the milestone of synthesizing an entirely artificial DNA molecule that has successfully replicated and formed new cells. This affordability of the basic tools of biotechnology has put them within reach of engineers and designers who may now consider basic life forms as potential fabrication and form-giving mechanisms. Indeed, that is precisely the intention of architects such as David Benjamin, who is teaching and practicing how to wield life as a design tool and insists that ‘this is the century of biology.’ In the 19th century the combination of standardization of measurements, the Bessemer steel-making process, and the steam engine converged to enable the Industrial Revolution, answering the call of democratic, capitalistic nation-states seeking market growth. Facilitating this development was the increasing quality and plummeting price of steel, which rapidly fell from $170 per ton in 1875 to $14 per ton before the end of the century. Similarly, and following what has become known as Moore’s Law, the computing power of microchips roughly doubled every two years in the period 1975–2012. This phenomenon, amplified by the rise of the internet and the worldwide adoption of

ABOVE In contrast with traditional architecture that is in conflict with the environment, Fab Tree Lab is a housing concept that integrates and enhances the surrounding ecology. Living trees are integrated into the structures.

ABOVE Researchers at Delft University of Technology have developed BioConcrete, which is embolded with limestone-making microorganisms that allow the material to repair itself.

ABOVE A modular system of algae-fabricated absorbs solar energy for electricity generation and shaded interior spaces in Process Zero, a proposed retrofit for a General Services Administration building in Los Angeles (page 19).

ABOVE A feat and reconfigure the activity of a cell have become widely accessible. We have even reached the milestone of synthesizing an entirely artificial DNA molecule that has successfully replicated and formed new cells. This affordability of the basic tools of biotechnology has put them within reach of engineers and designers who may now consider basic life forms as potential fabrication and form-giving mechanisms. Indeed, that is precisely the intention of architects such as David Benjamin, who is teaching and practicing how to wield life as a design tool and insists that ‘this is the century of biology.’ In the 19th century the combination of standardization of measurements, the Bessemer steel-making process, and the steam engine converged to enable the Industrial Revolution, answering the call of democratic, capitalistic nation-states seeking market growth. Facilitating this development was the increasing quality and plummeting price of steel, which rapidly fell from $170 per ton in 1875 to $14 per ton before the end of the century. Similarly, and following what has become known as Moore’s Law, the computing power of microchips roughly doubled every two years in the period 1975–2012. This phenomenon, amplified by the rise of the internet and the worldwide adoption of
computing power became inexpensive commodities of investment and growth is significant: more than easily be applied to complex organisms, the pace demands of a rapidly globalizing economy. Industrialized countries will surely multiply, particularly given the sound practices in design that guide scarce resource allocation, also follow in the footsteps of tech entrepreneurs working out of garages in the 1970s and 1980s, and they bring an ethos of independence that is unlinked from the agendas of a new revolution—the requirement for ecologically sustainable practices. This reality, when coupled with the effects of the rapid rise of mechanized industry as a dominant feature of economic, aesthetic, and political life in Europe and the United States. Interest in nature as a model or tool for design remained a consistent, if minor, current in architecture of the early 20th century. This partiality of the era foreshadowed the now burgeoning do-it-yourself biology (DIYbio) movement. Facilitated by the availability of inexpensive equipment and embodied by like-minded enthusiasts through instant communication over the internet, amateur biologists are now creating transgenic organisms and even inventing novel equipment on their own. These new arrivals, some of them with design experience, also follow in the footsteps of tech entrepreneurs working out of garages in California in the 1970s and 1980s, and they bring an ethos of independence that is unlinked from the agendas or conventions of universities and corporations.

**PHYSICAL SCIENCE TO LIFE SCIENCE: A HISTORY OF NATURE IN DESIGN**

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. **Architect William McDonough**

The desire to follow nature, to adhere to its underlying forms in the pursuit of harmony and beauty, can be traced back to antiquity, to the writings of Vitruvius, as well as to Goethe’s work on morphology and ‘form’. This Romantic notion that certain truths were observable in nature and unknowable to reason. The close examination and formalization of nature by designers reached a height in the late 19th century, in the Art Nouveau style in France and in its iterations across Europe, coinciding with the work of naturalists and pioneers of biology, like Ernst Haeckel, who meticulously described, named, and illustrated thousands of new species. Shortly thereafter, in On Growth and Form (1917), D’Arcy Thompson described numerous links among biological form, physics, and mechanics, and highlighted how optimization was frequently achieved in nature. This also coincided with the First World War and the rapid mechanized industry as a dominant feature of economic, aesthetic, and political life in Europe and the United States. In 1956, the developmental biologist Ernst Haeckel, after a visit to the United States, wrote: ‘If we start a new age of art, we may call it “biological art.” This art will have as its goal the perfection of living forms and the creation of new life forms, which will develop through the same evolutionary processes as natural life forms.’

**MIMICRY**

Symbolists is a pioneering research laboratory at the University of Oregon in Eugene working to map the microbial (microbiome-related) population of the built environment, collecting samples from a variety of spaces and analyzing how these different microorganisms impact human health. **BiOrb Lab**

RIGHT

The Human Microbiome Project is a five-year research program undertaken by the US National Institutes of Health to identify and characterize the many microorganisms that live but are not alive in our bodies. Since 2007, researchers have sequenced more than 15 trillion human and foreign cells make up the human.

**ABOVE**

Art Nouveau attempted to bring natural forms into industry. The movement emerged in France then spread rapidly throughout Europe with artists and designers advocating its use in mainstream home environments. The most famous symbol of the movement was the wisteria flower, which was controlled by the engineer Victor Horta, and was completed in 1893 for the Société Beaux-Arts.

**ABOVE**

Illustrations of shells from a variety of gastropods (mollusks, reproduced from Ernst Haeckel’s influential book Kunstformen der Natur (‘Forms of Nature’), which was published in 1904).

**ABOVE**

A microbiologist at the University of Oregon in Eugene is working to map the microbial (microbiome-related) population of the built environment, collecting samples from a variety of spaces and analyzing how these different microorganisms impact human health.
depend on all this microscopic life—trillions of cells—for essential functions, like digestion and resistance to infection, making us all ecosystems in miniature. The built environment is no different, as research by the BioBE Center (page 258) suggests, a better understanding of microbial life in indoor spaces—a vast and undiscovered realm we interface with all the time—may inform a probiotic design approach that reduces reliance on mechanical ventilation. These realizations arise in part from new access to the nanoscale, the ability to manipulate matter on the cellular and molecular levels. Just as standardization and manufacturing tolerances to the millimeter scale were crucial to the move from craft to the Industrial Revolution, as well as to the practices and goals of the Bauhaus school, the ability to change the inner functioning of a cell exponentially increases designers’ reach, and in enabling a move from the industrial to the biotechnological. This in turn is becoming the medium of choice for a new Bauhaus school to emerge, perhaps in the form of the DKE lab (page 257).

This new access in scale offers new vocabulary to the language of form, and may satisfy a larger need to bring the living world closer to our everyday lives. Perhaps in the recent past the mere mimicry of forms displayed by industrialization and globalization was sufficient as a symbol, but that time has passed. In Complexity and Contradiction in Architecture (1966), which laid the intellectual foundation for postmodernism in architecture, Robert Venturi argued that the labored rectilinear style of the modernists was in fact a dishonest representation of functionalism and that both greater visual harmony and expression of function were achieved through formal conflict: shapes, lines, and textures that disrupt one another. Echoing that critique, one can see nature-inspired design and its iterations, often posturing under the banner of biodesign, as a laborer style for its own sake that does not represent biodesign, for its intention strays from the priority of delivering enhanced ecological performance. It is primarily by cooperation, communication, and debate that effective approaches to biodesign will be developed and implemented, and a legible formal language will emerge. As progress is made, however, and as designers and scientists work together more frequently, it’s essential to recognize the challenges and opportunities that will arise in part from new access to the nanoscale, the ability to manipulate matter on the cellular and molecular levels.

Concrete is 2,400-year-old history offers an insightful example of the shift over time to biodesign from some of civilization’s earliest structures to new methods of using bacteria as an ecological means of reinforcement. Concrete has served designers and engineers as the spine of infrastructure and the foundational material of structures since antiquity. First widely used in the 4th century BC, it was integral to the Roman Archetypical Revolution, which spanned several hundred years and generated structures—including domes, arches, and aqueducts—that still stand today.11 Soon after the fall of Rome, the formula for concrete, calling for particular proportions of calcium oxide, pulverized rock, clay, ash, and water, was lost for thirteen centuries. It is useful to pause for a moment to ponder how builders for so long looked at ancient monuments that bastardized their own engineering ability. This aporia without concrete ended with its rediscovery in 1766 in England, the precise time and place of the dawn of the Industrial Revolution. Approximately a century later, reinforced concrete was developed in France by François Coignet, and was deployed to create several structural typologies that are common today.12 The utility and historical significance of the material are well illustrated by many of his projects, from the sea wall in Saint-Jean-de-Luz, to the lighthouse in Port Said, Egypt, and the Aqueduc de la Vanne in Paris. All of these projects met infrastructure needs arising from the forces brought to bear by widespread industrialization and the rise of global capitalism in the form of colonialism: constructing ports to facilitate the movement of freight to support commerce, and infrastructure to facilitate rapid growth in urbanizations. Similarly, the first structures in Britain to feature a reinforced concrete frame was a factory: a four story built in Swansea in 1897.13, 14

With the benefit of centuries of hindsight, it is possible to see concrete’s evolution—from its discovery, loss, and rediscovery to its current widespread use in construction—has been closely intertwined with the evolving needs and priorities of the societies that used it. In the centuries during which its formula was unknown, much building occurred, but the forces driving it apparently did not create a siting-temporarily imperative for the material's rediscovery to occur. The needs of an empire—roads, bridges, ports, barracks, and aqueducts—demanded such a material from the Roman builders who, through experimentation and discovery, founded a new way to deliver it. With the dissolution of the empire, the need for a material like concrete was likewise diminished, although many builders, mocked by the splendid monuments in their midst, would be in want of its formula.15 Similarly, one can see the needs of the industrial age to maximize land use—by means of factories, bridges, ports, and ever-taller buildings—as driving the deliberate search for a leap in material technology, one that was answered by iron, and, eventually, steel-reinforced concrete.

Concrete, a new and powerful need is emerging to reduce the environmental impact of human activities, including buildings, to use fewer materials and less energy, and consider the entire design life cycle, from conception through manufacture to disposal. Understanding as part of the continuum of developments in material technology, this need introduces a new dimension to how performance is evaluated: the degree of sustainability of design. The design of the 21st century is expected to perform in new ways, that take into account its impact on water, energy, and material cycles. The effects of the rapid development of the global economy and the rising prosperity of hundreds of millions of people, particularly in India and China—are exacerbating scarcity of natural resources and demanding that systems of design, manufacture, and consumption evolve. The scarcity problem set by the United States and Western Europe, in terms of environmental degradation, and waste of material resources throughout the 19th and 20th centuries, simply cannot be followed by the world’s citizens, now numbering more than seven billion—the environment cannot endure.17

The urgency of this demand for material sustainability and ecological preservation continues to grow; at current rates of production and consumption, carbon emissions would lead to an uninhabitable climate for much of the planet within 300 years.18 Developing strategies to respond to this bleak outlook results in exercises such as considering how to build...
in a desert with precious few resources, as shown by the architect Magnus Larsson in his proposis in 'Dune', which would harness bacteria to build walls that halt the spread of the Sahara. Ultimately, the constraints of extreme environments force designers to examine and replicate life: the only resource available is that which is known to function within conditions as harsh as those of a desert. If we were incapable of handling this new type of concrete being developed at Delft University of Technology in the Netherlands. There, Henk Jonkers has adopted the use of bacterial cultures to create a long, soft-healing concrete that might outlast, and be cheaper to maintain than, the conventional variety (page 82).19 The bacteria offer a means of reinforcing, infusing the material and lasting for many years or decades until a crack appears, overwriting the crack at a rate similar to a road or structural support. By admitting oxygen and moisture, the crack propagates, and calcium carbonate is secreted to silence the environment for a sense of human connectivity, enable new behaviors. Larsson’s proposal both addresses and harnesses elements of nature in an struggle more consequential than those that a la quantitatively pondered, his declarations of ‘architecture or revolution notwithstanding.’20 The 20th century did not demand as drastic a transformation as that which the 21st century appears to require. Building with bacteria and other organisms is simultaneously becoming a technological possibility and a necessity. An analysis of the history of technology and design rights prompts skepticism about the advent of new design that uses living matter, regardless of whether in a road or structural support. A new outlook must result in a more nuanced view of the world’s biologically managed landscape, whether in a road or structural support. A new outlook must result in a more nuanced view of the world’s biologically managed landscape, whether in a road or structural support. A new outlook must result in a more nuanced view of the world’s biologically managed landscape. 

**Abbreviations**

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**Notes**

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The northeastern Indian state of Meghalaya includes some of the wettest places on the planet, with up to 1,200 cm (470 in.) of rain annually. In the Khasi and Jaintia hills, the water creates numerous swift-flowing rivers that are dangerous to cross and require bridges to afford basic mobility to the local people. In a predominantly agrarian economy made up of tribes that have lived in the area for centuries, a natural and effective solution has been developed: bridges grown from the roots of rubber trees.

Without the need for specialized training and equipment that other types of bioengineering require, the Root Bridges of Meghalaya are coaxed from the natural, albeit slow, growth of Ficus elastica—a rubber tree within the banyan group of figs. These trees thrive on the slopes of hills and have strong rooting systems. The growth of their many secondary roots, which would normally fan out in all directions, can be guided using a betel nut trunk that has been sliced down the middle and then hollowed out into a half-cylinder. Placed across a river, these trunks ensure that the thin, tender roots grow straight and eventually reach the opposite bank, where locals encourage them to take hold in the soil. Given enough time and repeated with several trees in each part of the river, this process ensures that sturdy, ever-evolving living structures are created, the form of which adjusts over time and is never fully complete.

Some of these root bridges, which take approximately fifteen years to become functional, are more than 30 m (100 ft) long. The stresses of use and weather can strengthen them over time, allowing them to last for hundreds of years. Although precise dating is difficult, it is widely accepted that many are in excess of 500 years old (the practice is thought to have begun in the 1500s). One example, partly named after the river that it spans, is known as the Umshiang Double-Decker Root Bridge and is a remarkable testament to the engineering possibilities of living structures.

Sadly, many of the region’s rivers have in recent years been poisoned by the runoff from nearby illegal mines. If the disruption to local ecosystems continues unabated, these ingenious works of design that are engineered to live indefinitely will shrivel and die.
The Doubl-Decker Root Bridge: a dramatic two-story structure that spans the Umshiang River.

As with all living structures, the bridges rely on a healthy environment for their maintenance. Abundant clean air, water, and soil are essential.
The art of designing constructions that are made using living trees has been dubbed *Baubotanik* (‘building botany’) by a group of architects at the University of Stuttgart, Germany. This demonstration project explores engineering with living plants to integrate a small tower into its immediate environment. It also blends research and application by uniting architects, engineers, and natural scientists in an endeavor to create a structure and test new possibilities, offering insight from the perspectives of their individual disciplines.

The main feature of *Baubotanik* Tower is its utilization of plants as load-bearing systems, taking advantage of what the architects call the ‘constructive intelligence’ of trees: like human muscles, tree branches naturally strengthen in response to stress or increased loads. At the same time, this practice exposes researchers to the biodynamics and uncontrollability of natural growth. The conflicts that this lack of control creates in building inspires a form of architecture that is characterized by accidental processes, hope, and risk. The architects also take a critical stance by embracing an ‘aesthetic of uncertainty’ in the use of living materials. Building botany undermines the implicit claims of traditional architecture as stable, permanent, and self-sufficient.

The tower has a footprint of 8 sq. m (86 sq. ft) and a height of 9 m (29 ft), and it incorporates three walkable levels. It is the first Baubotanik project using the plant-addition method, which involves grafting trees together. These create a timber-framed support structure that is bolstered by scaffolding. As soon as the living structure is stable enough to support the ingrown levels and take over the loading capacity, the scaffold is removed. As it is dependent over time on natural factors, such as rain and temperature, the duration of the process is hard to predict, but a period of 5–10 years is expected for the design to become fully functional.
Bio Milano is a six-part plan aimed at reforesting and rehabilitating sections of Milan, forming symbiotic relationships between natural and built environments. The goal of the architect is to create a biodiverse metropolis emphasizing an increase in biologically active spaces, including new types of agriculture. The project also aims to facilitate the germination of new businesses and jobs for thousands of people in sustainable industries, such as renewable-energy generation.

One component, Bosco Verticale (vertical forest), completed in 2014, is a residential project in the center of Milan. Its dual towers are a bold experiment to combine housing and dense forest in a single, compact footprint. Reaching 110 m (360 ft) and 76 m (249 ft) high, the towers’ external walls host more than 800 trees of a variety of species, as well as several thousand shrubs. Achieving a similarly verdant tract of land would likely require 20,000 sq. m (215,000 sq. ft) of uninterrupted forest or 50,000 sq. m (538,000 sq. ft) in a conventional residential setting. The potential benefits of the towers are many: in addition to the aesthetic appeal of so much dense foliage, the plants offer footholds for a multitude of species, including birds and insects.

Boxes, integrated into terraces that cover the structures, have been planted with trees of varying size and root strength, taking into consideration the greater wind force with increasing height. For the building’s residents, the trees dampen noise and generate newly cleaned air. As their dense vertical arrangement deprives them of sufficient rain, the trees rely on the building’s graywater circulation system for water.

Wood House is a proposed social housing project that taps into the cycle of tree-growth and clearance taking place along the Ticino River. The low-density structures would rely on prefabricated forms of construction to control costs, but also allow for a high degree of customization to suit individuals’ needs.

Courtyard Farms calls for the restoration of 60 publicly owned and abandoned courtyard farms around Milan to provide a new source of locally grown food. The renovated structures would serve as a base for biomass growth for clean energy and, potentially, a testing area for research and development in biotechnology.

Orto Botanico Planetario, designed for Expo Milano 2015, visualized a vast ‘global kitchen’ in the northwest of the city. Instead of the traditional natural pavilions, each country taking part would have a section of land to cultivate in order to display forms of biodiversity protection and remediation, new technologies, and possible solutions to food-production problems. After the event, the proposal envisioned the area being used as a scientific park for agricultural research.
Metrobosco aims to develop a circle of forests around the city to support several species of animals that live in or pass through the Milanese plain. The project combines existing parks and farmland, and is only partially accessible to people. It includes the planting of three million trees.

Alongside these efforts, the Bio Milano plan seeks to cultivate remedial plants and microorganisms on polluted land in order to eventually reintegrate these spaces into the wider ecosystem. This effort is part of a research project by Chiara Geroldi that uses biological cleanup methods around Porta Romana. A long, unfortunate history of industrial pollution and eventual abandonment in the area is giving way to decontamination and slow healing.
CHAPTER 1

OYSTER-TECTURE

Can New York—former oyster capital of the world—remodel part of its harbor by resurrecting the humble mollusk?

Marine piles, fuzzy rope, wooden platforms, artificial reefs, oysters (Crassostrea virginica).

Kate Orff (American)—SCAPE/Landscape Architecture PLLC, New York, USA

With oyster reefs as the building blocks of a reincarnated ecosystem, largely intended to protect against storm surges and the rising tides expected in New York Harbor in the coming decades, this project demonstrates the potential of biology to enhance the urban environment beyond conventional, aesthetic effects. The project envisions a return to the thriving oyster habitat that existed there until the early 20th century but was destroyed by over-harvesting and pollution. If realized, it would significantly improve water quality through the biofiltration of the oyster beds, and support economic growth and community development in stubbornly depressed portions of Brooklyn by creating a new regional park.

Oyster-itecture includes spaces dedicated to spawning and farming the oyster—a cornerstone species that enables other marine life to thrive—in the shallow waters of the Bay Ridge Flats, south of Red Hook, Brooklyn. The architects have designed an armature of marine piles connected by a mesh of fuzzy rope that provides a support structure for young oysters, raising them above the harbor floor to prevent them from being silted up. Over time, a new reef will develop, with agglomerations of oysters and other sea life creating a watery urban landscape that will include navigational channels, diving platforms, and recreational boardwalks. While it would take decades for the mollusks to be safe for human consumption, this project could prepare the way for the eventual return of oyster carts to the streets of Manhattan, as well as reconnect New Yorkers with their harbor.

The scheme was part of a special exhibition organized by MoMA PS1—a contemporary art center—in 2009 to address one of the most urgent challenges facing the United States’ largest city: sea-level rise resulting from global climate change. The exhibition was the culmination of an architects-in-residence program that brought together five interdisciplinary teams to re-envision the coastlines of New York and New Jersey, and to imagine new ways of occupying the harbor with adaptive “soft” infrastructures that are sympathetic to the needs of a vibrant ecology. The resulting proposals were intended to help change residents’ relationships with the city’s vast but underutilized waterfront.

The design research by SCAPE for Oyster-itecture has expanded to inform multiple ongoing projects, including the large-scale ecological infrastructure proposal Living Breakwaters on Staten Island and the waterfront esplanade of Red Hook Point in Brooklyn. The work of Kate Orff through SCAPE studio has been recognized for its original approach to design that prioritizes habitat remediation and support: in 2017 Orff was awarded a MacArthur Fellowships Grant.
Every year MoMA PS1 in New York selects a proposal from an emerging architectural talent to develop a temporary outdoor installation in the museum’s courtyard. The winners of the Young Architects Program (YAP) are challenged to demonstrate new approaches to all phases of the work, from conception and design to construction, operation, and disposal or repurposing. The winning entry for the 15th annual award, from studio The Living, proposed a novel cluster of structures made from mycelium bricks, which were grown, constructed, and eventually composted using a fraction of the energy required of typical architecture.

The Living’s approach considers the built environment as it truly is but as few see it: as one phase in a system, or a single step in a long process of production, construction, and disposal. By using virtually valueless agricultural waste, in a process developed in collaboration with Ecovative, the firm grew 10,000 bricks in reusable molds, each taking just a few days to solidify due to the growth of the natural mushroom root system that digests the nutrients within. The bricks were cemented together with an organic mortar and supported with wooden rods to create a branching structure for the public setting. The design meets the demands of the MoMA PS1 brief, which includes providing shade, seating, and a water feature, to complement the annual ‘Warm Up’ program of live music in the summer months. Its appearance is enhanced by both natural dyes to give it color and newly developed reflective plastic sheathing, which covers some of the structure’s upper reaches, bouncing light through the hollowed interiors. Simultaneously, the arrangement of bricks in a more porous pattern near the bottom of the structure allows for passive cooling, inverting the typical brick-structure logic of increased density near a building’s base. As planned, the structure was decommissioned and its components composted, returned to the earth in a completely safe manner. The materials used in the construction came almost entirely from within a 240 km (150 mile) radius of the site, which—like the local food movement—both saves energy and works to support workers and businesses nearby. The project signals new priorities for our age, in which the urgency to reform building practices has never been greater.
LUNG-ON-A-CHIP

By replicating organs outside of the human body, could we reduce the substantial time and costs involved in clinical trials?

Microfluidic channels etched into transparent polymer, human alveolus, and endothelial cells.

Donald E. Ingber (American) / Dongeun Huh (South Korean)—Wyss Institute for Biologically Inspired Engineering, Harvard Medical School, Harvard School of Engineering and Applied Sciences, Boston, USA / Children’s Hospital Boston, USA

This biomedical application incorporates live human cells in a tiny testing device that mimics the functioning of the human lung. It allows researchers to monitor the behavior of cells at the margin between the air sacs and the capillaries, a critically important area in which the body interacts with the environment. It is at this boundary that inhaled particles and pathogens are passed into the bloodstream. The advantage in recreating this interface outside the body is its potential to replace human and animal subjects for numerous types of drug testing and toxicity screening.

Lung-on-a-Chip consists of a series of microfluidic channels etched into a flexible, transparent polymer casing. A central conduit houses two layers of human cells with a porous membrane in between. The upper layer comprises cells from the alveoli (the air sacs deep within the lungs that resemble miniature bunches of grapes, where gases pass between the lungs and the blood). The lower layer is made up of endothelial cells from the capillaries, which convey blood that is rich in oxygen to the rest of the body.

The flexible channels expand and contract as the controlled air pressure fluctuates. This stretches the cells and very closely replicates the conditions of breathing. The unit’s transparency facilitates real-time observations of inflammation or other responses to foreign bodies being introduced into the airflow chamber.

So far the behavior of the cells replicates that in live subjects, suggesting that in the near future this coin-sized device might help to dramatically reduce the cost of certain medical testing procedures while addressing ethical concerns.

The team has also developed other organs-on-chips, such as a beating heart and a gut undergoing peristalsis, as well as bone marrow and cancer models. In 2015 the Museum of Modern Art in New York acquired ‘Human Organ-on-Chips’ for the permanent collection of its Department of Architecture and Design.

This chip contains live human cells, in a system of channels in a way that replicates the region of the lung where inhaled particles, organisms, and gases pass into the bloodstream. Air pressure, temperature, and moisture levels are air-tightly controlled so as to mimic human breathing.

Observations have shown that the cells in the device respond in the same way as those in live subjects. The technology helps to accelerate medical research while also cutting costs and tackling ethical concerns about animal testing.
The proliferation of inexpensive drones creates new security risks in a variety of settings, including wherever large equipment is operating or fragile or toxic materials are handled. Perhaps at the top of the list of environments sensitive to such risks are airports, where interference by or collisions with drones have the potential to cause a catastrophic failure during a take-off or landing of a commercial aircraft.

As with other security considerations that are prompted by new technologies, experts have grappled with the question of what can be done in terms of protection. Solutions such as lasers, electromagnetic pulses, defensive guard drones, or nets cast at high speed have been considered. But a more elegant and low-tech approach seems to be most viable: training birds of prey such as eagles to hunt and take down the airborne vehicles.

The firm that has taken the lead in training and deploying birds for this purpose is Guard From Above, based in The Hague. Their team of experts train the eagles to consider the drones as a new type of prey, rewarding them with food after a successful interception. The process takes about one year of daily training to reinforce behavior through care and conditioning. Bald and White-tailed eagles have proven to be the most suitable bird species due to their combination of hunting ability and amenability to handling by humans.

To obtain the birds, Guard From Above partners with animal parks and zoos across Europe, following a rigorous vetting process. As the founder Sjoerd Hoogendoorn has said, “Not every bird has the right skills and capacities to become a true drone hunter.” To see the birds at work is akin to witnessing the use of bomb- and drug-sniffing dogs, serving as a potent reminder that some of our best technologies are hard-pressed to compete with the capabilities forged by millions of years of evolution.
COACHING YOU TO MAKE COLLAGEN, AND MASTERING HOW IT CAN BE PROCESSED TO EXHIBIT THE MATERIAL PROPERTIES OF SKIN OR MUSCLE, WITHOUT THE NEED FOR ANIMALS OR THE LIMITATIONS OF THEIR FORMS.

Knitted cotton, polyester spacer, biofabricated leather.

Suzanne Lee (British) / Amy Congdon (British)—Modern Meadow (USA)

This project is a material prototype that may mark the beginning of the end of the vast waste resulting from the production of leather. The core component of leather that bestows its desirable texture, flexibility, and durability is collagen, the main structural protein found in connective tissues in animal bodies. Skin, tendons, and ligaments are held together with it, as a kind of biological glue. This is why we use the hides of large animals such as cows to make leather products, as they are abundant if inefficient sources of the material.

It has long proven difficult to find a substitute material that shares the material properties of animal collagen while reducing its environmental footprint. Synthetics often fall short, requiring significant quantities of petrochemicals or degrading much more quickly. Biological substitutes such as microbial cellulose show promise yet face obstacles—how best to make them durable, for example. Other lab-grown substitutes using mammalian cells have shown to be energy-intensive and prone to infection by opportunistic microorganisms. Additionally, mammalian tissue in the lab requires the use of fetal bovine serum to thrive, and this is extracted from the blood of unborn calves. Thus, most of what is called lab-grown ‘meat’ is not really as innocent as it may sound.

The scientists and designers at Modern Meadow have turned to the plant kingdom, and use genetically modified yeasts fed with sugar to produce collagen, which is then purified, pressed, and processed using the firm’s own unique methods. As Zoa is free from the bounds of the animal form, it can assume shapes, thicknesses, and visual effects that have never before been possible. The prototype shown in these pages was commissioned by the Museum of Modern Art, New York, on the occasion of the 2017 exhibition ‘Items: Is Fashion Modern?’ curated by Paola Antonelli. Here Zoa is used in liquid form, which allows it to morph into shape, and combined with other materials without stitching. The tagline Modern Meadow attaches to the prototype is ‘A new animal is born’ to underline the flexibility of leather grain patterns in this process, allowing them to create forms unseen in the natural world.
Zoa bioleather can morph into any shape and be combined with other materials without stitching, as shown in this T-shirt.

Collagen produced by yeast instead of animals results in a leather product that is free from scarring, insect bites, or imperfections that might result from removing hair.

CHAPTER 2

**G**ene**G**en**e**ral **G**i**o**cal **B**iolog**e**cal **G**i**e**ne**e**ering

**G**en**e**ral **G**e**o**cal **B**iolog**e**rogen

CHAPTER 2

A textile spacer joined with a sample biofabricated leather; (right) A sample of biofabricated leather on mohair.
The studio of Eric Klarenbeek and Maartje Dros takes on a variety of projects that reveal a range of interests and expertise, from designing outdoor public spaces and private interiors, to glassworks, perfumes, and DIY kits for making simple LED lamps. They also exemplify the ‘polydextrous’ studio in their sustained interest in working with biology, and in finding new ways to integrate it into their production processes in an ecologically sound way.

With their algae, they have made progress using locally sourced algae to produce a 3D-printable, degradable bioplastic. Research on harvesting and processing the organisms has advanced with the help of several partners, including members of Arles-based project LUMA, as well as Dutch scientists. The prototypes that have been produced are inspired by Roman tableware in design but, unlike the ancient pottery that has been passed down to us, these algae-based objects will degrade and return to the earth much faster, and without the toxic legacy of contemporary plastics.

Another long-term effort of the studio is the Mycelium Project, which is focused on printing pieces of furniture, such as chairs, in a most unusual way. They use a substrate inoculated with fungal spores and nutrients in a mold. Given several days to grow, the mycelium—the threadlike root structure of the fungi—expands in the mold, increasing the substrate’s density and rigidity. The results are prototypes that visually reference their origins, as small but visible fungal bodies that sprout from the chair at different points. The works made in this way, such as ‘Veiled Lady,’ are a potent if delicate symbol of the potential of using materials like mycelium in design.

A related initiative of the studio is distributing the product ‘Krown,’ which is a kit that includes scaffolding for a lampshade, along with substrate and spores to fill its shape with mycelium. It relies on methods developed earlier by the firm Ecovative, and results in design forms that are refreshingly simple, yet ingrained with variety and complexity such that no two units would ever be exactly identical.
CHAPTER 2

The 'Veiled Lady 1.0' stool demonstrates an integration of a 3D-printed casing within which rigid volumes contain mycelium. The hardening following extrusion of an inoculated medium.

Detail view of the 'Mycelium Chair', utilizing an interior structure of mushroom roots or mycelium. Here bundles of spore-bearing fruiting bodies of the fungal burst through the small seams of the chair's shell.

Process studies for the 'Mycelium Chair', in search of a working combination of growth media, forms, printing processes, and materials.

The 'Veiled Lady 1.0' from above, with an organic, interwoven pattern that echoes the tiny fungal structures grown within.
In works that blend botany and photography with the history of design and architecture, Diana Scherer manipulates the growth of plant roots to achieve new, yet familiar forms. The production process can take up to a year, beginning with material research into biology: the testing of several plant species, such as grasses including grains, to see how well they respond to an environment carefully shaped and layered to produce patterned root growth. Scherer directs the roots to grow in a particular pattern underground using a specially designed template; once growth has progressed enough, the roots are cut, separated from the rest of the plants, and treated to keep them stable. The results of this process are compositions that make clear references to the history of decorative design, yet depart from them in important ways. Here, the maker wields only limited control, opening the door to the unpredictability of biology, and welcoming the serendipitous irregularities and asymmetries that make each work unique. The artist cites the work of the German photographer Karl Blossfeldt as an important influence—best known for his extreme close-ups of plants from the late 19th century onwards, which he used mainly as a visual teaching aid. Like Blossfeldt, Scherer treats biological forms with reverence, as a potent inspirational guide. Scherer is interested in scaling up the process to make ever larger and perhaps more functional works. For example, one area of new research is in growing patterned fabric to be integrated into garments such as dresses, as well as exploring ways to treat the roots so that they could be hung for long periods as tapestries. Exhibitions of Scherer’s works have been held at the Salone del Mobile in Milan, the Nederlands Fotomuseum in Rotterdam, and the Victoria and Albert Museum in London.
The work ‘Rootbound, 2’ explores the potential of growing a wearable garment, prepared for the 2018 exhibition ‘Fashioned from Nature’ at the Victoria and Albert Museum, London.

Details of root systems grown in ‘Interwoven, 11’ (left) and ‘Interwoven, 15’ (right). These studies include design research involving a variety of plant species and growing conditions over several months.
CONCRETE HONEY

Pondering a future graced by winged, 3D bio-printers that could be used to repair or build structures, and the unpredictable outcomes as they become a man-made invasive species.

Digital renderings.

John Becker (American) / Geoff Manaugh (American)

This work explores a possible future scenario in which bees have been modified to secrete concrete and are used to slowly build structures, embellish them with ornaments, or make repairs. The author-designer team behind the project is quick to point out that this is not an earnest proposal to alter bees genetically to have such abilities, but is designed to illustrate the spatial or architectural possibilities that would emerge. The scientific element is actually not so far-fetched, as certain bees (Colletes inaequalis, a common species of plasterer bee) can naturally produce a material that is comparable to plastic in terms of performance, yet derived from renewable resources.

One inspiration for this illustrated thought experiment was the discovery of a 600-year-old beehive found built into the masonry of Rosslyn Chapel in Scotland. This brought to mind references such as the cranes in Archigram’s ‘Plug-In City,’ mechanisms by which an aesthetic of incompleteness is coupled with the achievement of a rapidly adapting urban form. Recent projects that point to this approach being a possibility include the genetic modification of goats to produce quantities of spider silk for military applications, the ‘Silk Pavilion’ project at MIT that utilizes silkworms for form and material creation, and the vases and other objects by designer Tomáš Libertíny (page 216). In essence, the bees are thought of as printheads, which is logically equivalent to how, in fields such as synthetic biology, living matter can be programmed to produce useful substances.

One of the appealing outcomes of such a project, imagining a new species called Apis caementicium, or cement bees, is to contemplate the results when they inevitably go out to flourish on their own, or outlive us. Perhaps we will see the rise of a planet-wide series of bee-printed structures, a Memphis-like agglomeration of forms, colors, and textures that becomes humanity’s architectural legacy—like the pyramids, outlining civilization and leaving puzzles for those who come after. As ever, from computer viruses to invasive plants, it is a fair prediction that our creations will reap unintended consequences.

CHAPTER 3

Experimental functions

While traditional urban nuisances such as pigeons have long bespeckled public infrastructure, genetically modified printer bees might misprint ornamentation in ways that enliven it, injecting variation and surprise. Here, feral concrete-printing bees are imagined taking creative license to add ornamentation to temples in Rajasthan, India.

Digital renderings.

In envisioning bees as architectural printheads, we can imagine their eventual escape, errant scribbling on various structures, and then death, marking the environment with their altered bodies and fragments of concrete.

LEFT

Imagining bees as concrete printers put to work repairing or augmenting architectural ornamentation may inspire lesions scattered with a particular style, such as layer upon layer of concrete until it forms a decorative reef of concrete and honeycomb.

BELOW

While traditional urban nuisances such as pigeons have long bespeckled public infrastructure, genetically modified printer bees might release the potential that nature has, injecting variation and surprise.

ABOVE

In envisioning bees as architectural printheads, we can imagine their eventual escape, errant scribbling on various structures, and then death, marking the environment with their altered bodies and fragments of concrete.
LIFE SUPPORT

Close relationships between humans and animals have a long history, but how might that symbiosis evolve in a biotechnological future?

Humans have domesticated animals for thousands of years, using them for food, companionship, security, and assistance for physical disabilities, such as blindness. Life Support proposes a scenario in which domestic animals function as ‘external organs’ in a surprising extension of the service animal tradition.

People love their pets, but could they love their respirators? The Life Support Respiratory Dog is a pedigree greyhound raised for track racing. Around five years of age, when most racing dogs are retired (and thousands euthanized each year), the dog would be acquired for training as a respiratory assistant. Someone suffering from lung disease would then adopt the animal as a replacement for mechanical ventilation. The dog would be fitted with a harness that would use its chest movements to pump air through a trachea tube and into its owner’s lungs. This extended symbiotic relationship between patient and pet would then transform man’s best friend into man’s best augmented breathing apparatus.

The Life Support Dialysis Sheep is a transgenic lamb capable of filtering its owner’s blood. Scientists would extract the regions responsible for producing blood and immune responses from the patient’s DNA, substituting this for the equivalent genetic material in a sheep. The resulting recombinant DNA would then be inserted into a sheep egg, which would in turn be implanted into a ewe. When born, the genetically modified lamb would be given to the patient, who would care for it during the day and use it as a substitute for a dialysis machine at night. Prior to sleep, the sheep’s kidneys would be connected to the patient’s vein and peristaltic pumps would push the patient’s blood into the sheep’s kidneys, which would clean it before it was pumped back into the patient.

Leather, foam, acrylic, aluminum, rubber, solid maple, powder-coated steel, stuffed rabbit, peristaltic pumps, vinyl tubes, needles, hay.

Reprint by New York Times

Revital Cohen (British, born Israel) & Tuur Van Balen (Belgian), London, UK—Design Interactions, Royal College of Art, London, UK

CONCEPT
Bred for speed, a greyhound becomes a service animal following its brief racing career.

In a similar symbiotic relationship, a sheep's DNA is augmented with that of the patient, preparing a transgenic offspring that can filter human blood.

During the night—in the role of a living dialysis machine—the sheep's kidneys filter the human blood before returning it to the patient.
Transgenic art is a nascent discipline in which portions of genetic code are added to and expressed by a host organism. Natural History of the Enigma involves a range of items that include a new life form—a genetically engineered flower that is a hybrid of the artist and a petunia. The result, ‘Edunia,’ was developed through the application of molecular biology and so is not found in nature. The alien, human gene that the plant contains was isolated and sequenced from a sample of blood. It produces an immunoglobulin, a protein that functions as an antibody and is used by the immune system to identify and neutralize foreign antigens (antibody generators that trigger an immune response). The gene produces a protein that makes the veins of the flower’s petals red, creating a living image of human blood within a flower. The creation of this novel organism, which entailed using a virus promoter to insert the gene precisely, was overseen by Professor Olszewski in the Department of Plant Biology at the University of Minnesota.

In anticipation that Edunia would be distributed and planted outside of galleries and museums, the artist created limited edition seed packs. Embedded magnets keep them closed while visitors are invited to open and examine them like books. The project includes several watercolors, photographs, and lithographs. All of the blooms featured are genetically identical clones, yet they look quite different, supporting the view that all life, no matter how similar genetically, is fundamentally unique.
Diagram showing how the artist’s DNA becomes part of the plant and is expressed in its flowers.

1 - Cut leaf.
2 - Expose leaf to bacteria carrying the new gene and an antibiotic-resistance gene. Allow bacteria to deliver the genes into new leaf cells.
3 - Expose leaf to antibiotic to kill the cells that lack the new gene. Allow surviving (gene-altered) cells to multiply and form a clump (callus).
4 - Allow callus to sprout shoots and roots.
5 - Plant in soil. Within three months, the plants grow, bearing new flowers with the artist’s gene. The gene is expressed only in the red veins.

‘Edunia Seed Pack Studies I–VI’ on display in the Fethería art gallery, Santiago de Compostela.
Here the artist takes a living system and gives it the form of a manufactured pattern, which is then allowed to develop and change shape naturally. Tobacco leaves are die-cut into a bilaterally symmetrical pattern and suspended in tiling square petri dishes containing the nutrients and hormones necessary to promote new leaf growth. The plant cells, like spores, are totipotent, which means that they are able to multiply and eventually differentiate into all of the different cell types of the whole organism. In Growth Pattern the newly growing leaves undergo morphological changes and thereby extend the form of the traditionally inspired botanical motif over time. Alternatively, although the tiles are sealed ecosystems, accidental pre-contamination can result in the decay of plant tissue or infestation by a parasite, again allowing the design to change in unpredictable ways.

Light box, petri dishes, agar, nutrients, hormones, die-cut tobacco leaves.

Allison Kudia (American)—Center for Digital Arts and Experimental Media, University of Washington, USA
Tiling squares together on exhibition at the Luminária Centro de Arte y Creatividad Industrial in Gijón, Spain.

The tiles are self-contained ecosystems that usually exhibit only slight variation, but if a parasite enters the vessel during preparation it can alter the intended pattern of leaf growth.

The tobacco leaves are cut into specific shapes and prepared beneath a sterile hood to minimize the likelihood of contamination of the dishes.