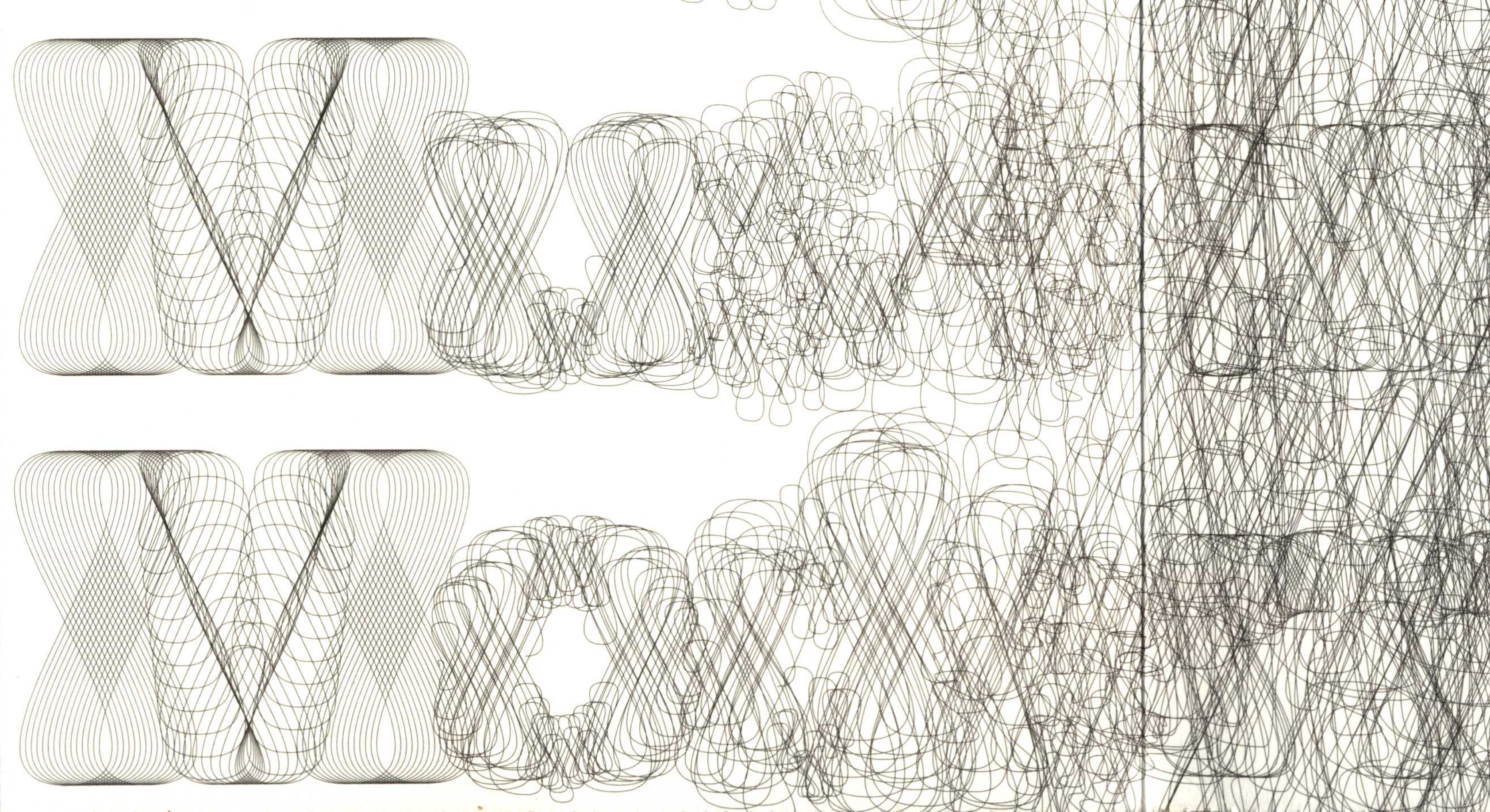
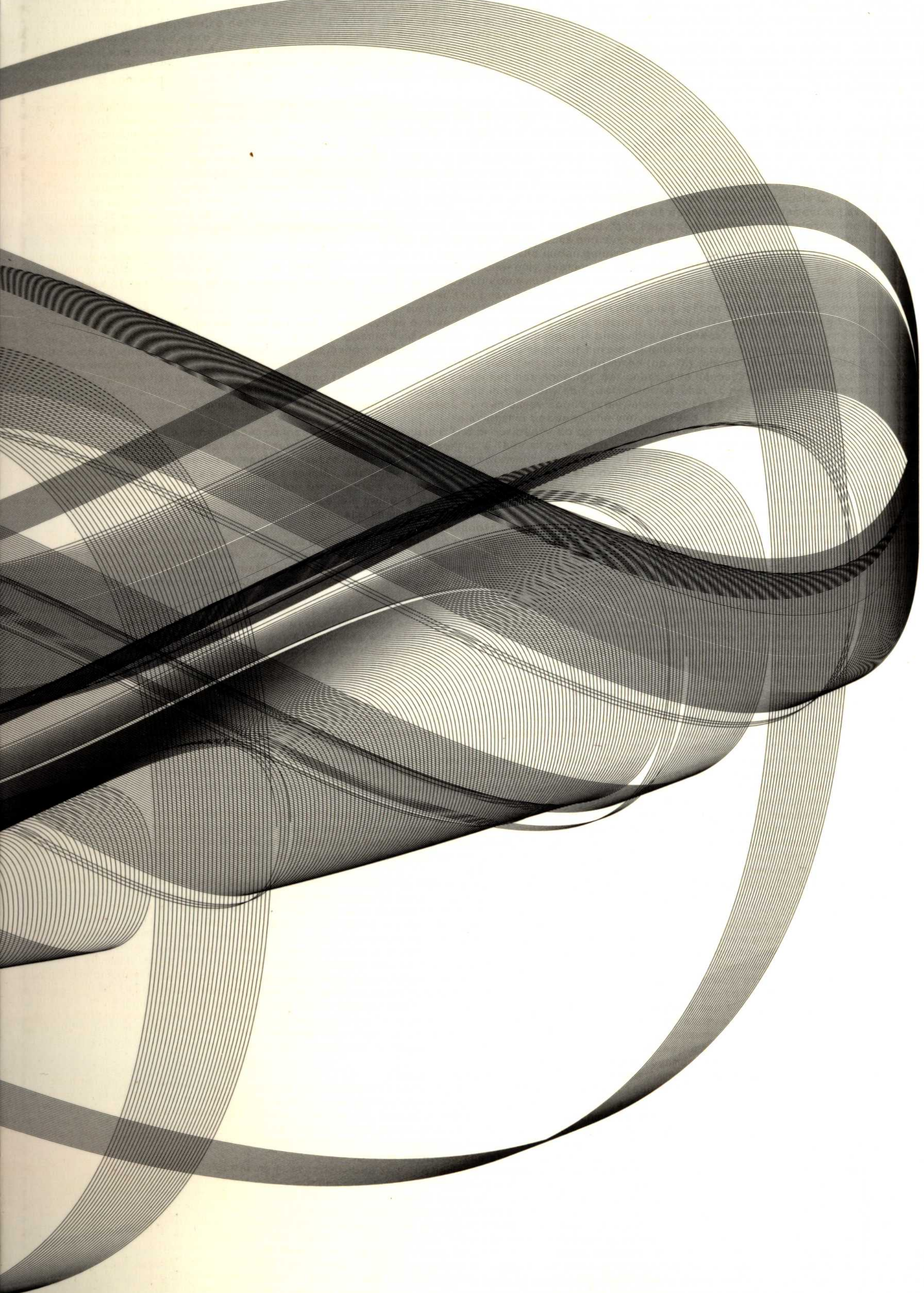
Design and the Elastic Mind





Design and the Elastic Mind

The Museum of Modern Art, New York

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Nanotechnology: Design in the Quantum Vernacular
Ted Sargent

The values of design and the aspirations of nanotechnology are one: Each strives to mold matter with an eye to function. Nanotechnologists fashion materials and construct edifices from the smallest of building blocks—atoms and molecules. We build designer molecular beacons that help visualize cancers before they run amok within us; create lightweight, wearable "power suits" to store and deliver electrical energy; and build new camera chips that sense colors to which we ourselves are blind.

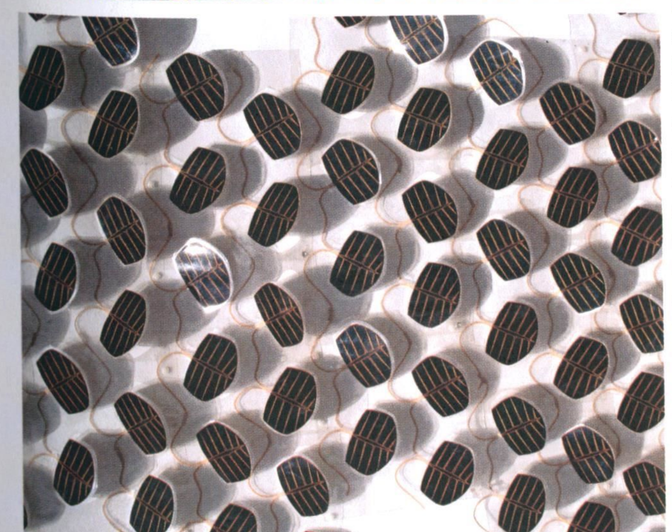
In many respects, little changes when one enters into the realm of the small. When we jump down the rabbit hole into Alice's Wonderland, things often behave much as they did in the macroscopic universe. If teacups and teapots are scaled down to the same degree, and if tea pours as it did aboveground, then—were we ourselves proportionately shrunken—we would be hard-pressed to say whether length had been rescaled or not. We call this idea—the indistinguishability of small from big if all is commensurately shrunken—scale invariance. It is a powerful idea. It means that all of our ideas and imaginings from the daily world serve us well, even when we craft materials smaller than we can see.

What makes nanotechnology more powerful is that while our visual imagination remains useful, scale invariance does not, in fact, apply. The world of the nanometer is not simply the same card game with smaller cards and smaller players. This world is instead governed by a different set of rules—ones recorded not by Newton but by Einstein. The rules that emerge in the realm of the nanometer brighten the spectrum of aesthetic and functional possibilities.

The Nanoscale Alphabet

Nanotechnologists endeavor to showcase the best of human-centered design, but at the scale of the nanometer—one billionth of a meter. This is the size of the cloud of electrons that orbits an atom's inner core, its nucleus. A typical molecule, such as a protein, is only a few nanometers in size. Before we explore design at the nanoscale, however, we must first ask two sets of questions. Is the discreteness of atoms too limiting? In other words, with only about one hundred building blocks in our atomic palette, will our range of expression be too confined? And is nanoscale architecture too sensitive to flaws? Would minor molecular mistakes—analogous to defects in a building material—make a nanoscale edifice crumble where its human-scale counterpart would stand?

We can answer the first two questions empirically, observing the world around us. Nature builds all matter—including all life—from the nanoscale; it is restricted to the same atomic building blocks as are we, yet



Samuel Cabot Cochran. SMIT Sustainably Minded Interactive Technology, LLC. **GROW.** Prototype. 2005–ongoing. Aluminum, flexible photovoltaic, piezoelectric device, steel wire rope, and copper wire, 8' x 4' x 7" (243.8 x 121.9 x 17.8 cm)

creates infinitely variegated materials and motifs. Nature's nanometer-narrow DNA molecules program the composition of proteins, and the laws of physics and chemistry determine how these linear chains fold into complex three-dimensional forms. As for the latter questions, even with such a well-perfected set of design principles, nature is tolerant: Countless methods of molecular error-checking and correction ensure that stochastic processes yield robust structures and functions.

Nature builds masterpieces, beginning at the nanometer and finishing with us. Nanotechnologists seek to learn and then to begin to emulate her craft. As aspiring nanoscale designers, scientist need to ask one more question about the realism of our own aspirations. Does our inability to see nanometer-sized structures with our own eyes prevent us from designing creatively and compellingly? No: It is through the exploration, and exploitation, of both the analogies and disanalogies between the macroscale and the nanoscale worlds of design that nanotechnologists find their groove.

Engineering Form for Function

One of the greatest threats to our way of life is our dependence on a frighteningly finite legacy of fossil fuels. Our addiction to oil has negative ramifications across the environmental, economic, and geopolitical landscape. Nanotechnologists can play an important role in the quest to find alternative sources of energy, one of the most promising being striving to capture the sun's clean energy efficiently and to turn it into electrical power for direct use or storage.

For decades, conventional solar panels have made this conversion between two forms of energy—optical and electrical—quite effectively. However, solar cells are far from ubiquitous. Our electrical energy is largely delivered in a centralized fashion today, originating from hydroelectric, nuclear, and fossil fuel sources and then distributed to its many destinations. Solar energy, in contrast, is already a distributed resource. Why are we not harvesting pristine photons when they land on our roofs, our tents, our hats, and our roadways? Is the problem that the sun is too weak? Bright enough to illuminate but not powerful enough to heat our homes or energize our laptops? No. It is well documented that solar energy reaching the earth's surface in one hour is sufficient to power the whole of the world's energy needs for one year; solar energy striking the earth over one month corresponds to the total energy stored in all known fossil fuel reserves on the planet.

The lack of solar adoption at present is circumstantial, not fundamental. Existing solar cells are made from pure, perfect crystals of the semiconductor silicon. These wafers of crystal have to be fashioned under highly controlled conditions. The requirements of purity and perfection make today's solar cells expensive, and the cells' rigidity mandates large, inflexible panels. To create low-cost, light-weight, flexible solar cells ranks high among nano-technologists' ambitions. Our approach has been to work not with rigid semiconductors but with nanometer-sized clusters of atoms designed specifically to have light-harvesting ability, and to consider fresh applications for gathering solar energy. Could we weave flexible light-harvesting materials into fabrics? Make plastic sheets that could be rolled out? Or even produce a paint that absorbs light, extracting the energetic electrons generated when photons strike its surface?

So far we have made such solar cells about one-quarter as efficient as conventional silicon. We do not know of a fundamental—nor even of a practical—reason why we cannot engineer nanoparticle-based solar cells to be as efficient as silicon, or even more so. In fact, recently, by capturing the sun's invisible infrared wavelengths as well as its visible colors, we have started to catch within our nanoscale solar net those photons to which silicon is permeable.

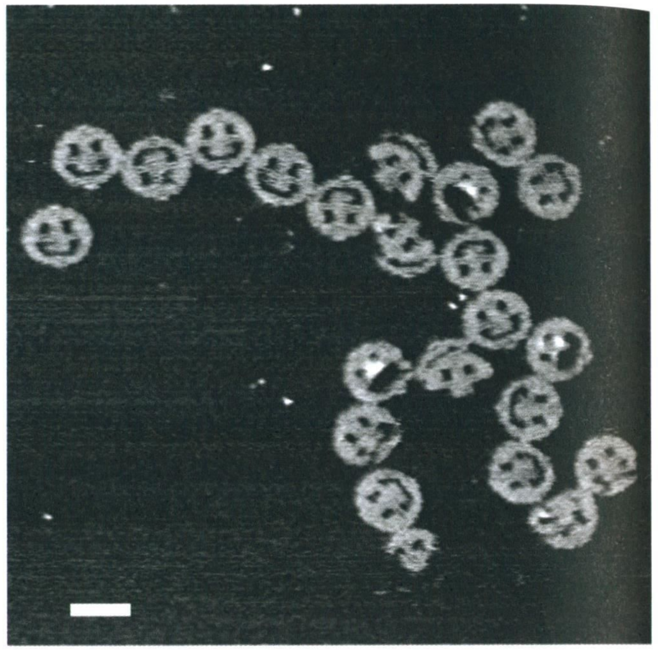
What would solar capture as a guiding principle mean for design? It might mean buildings aligned to maximize incidence of the sun's rays, or the use of parabolic reflective surfaces that could concentrate the sun's power. At the other extreme, choosing the right solar material could become simply mundane: a functional item, commoditized like window caulking, necessary but given little thought.

Fundamentals Are Our Beacon

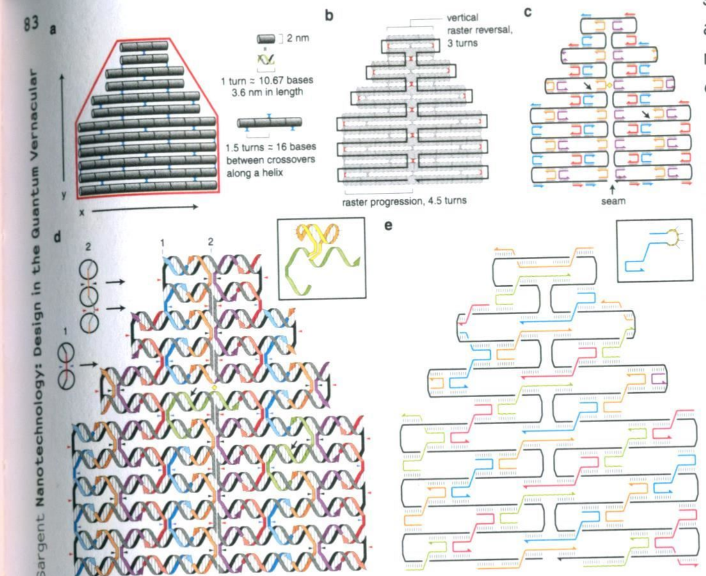
Just as design is built on a foundation of understanding—both of function and aesthetics—nanotechnology, too, relies on a deep appreciation of underlying principles. Nanoscientists seek to systematize the grammar that atoms, molecules, and supramolecular structures obey.

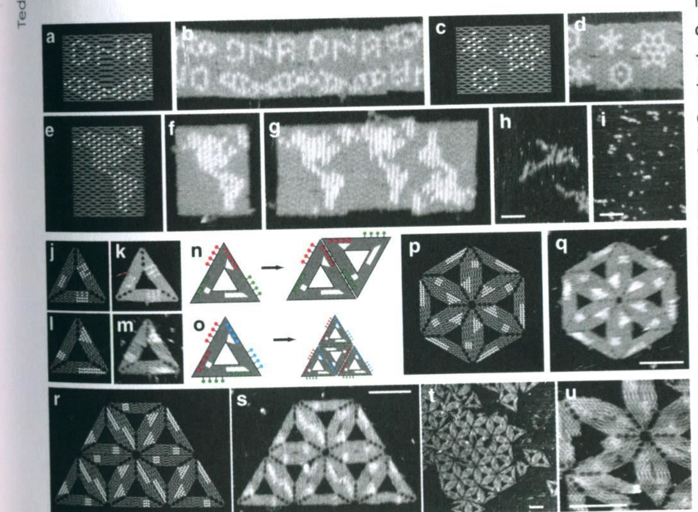
The foundations of the nanoworld are well understood. Physics gives us a detailed knowledge of the atom, and even of its constituents—from the quantum theory of particles and their interactions via forces. Chemistry explores and exploits the behavior of the known cast of characters, raising to the next level of abstraction the propensities of each atomic element: sulfur and metals adore one another; chlorine and its cousins are highly reactive; atoms orbited by four outer electrons love forming beautiful, perfect crystals—diamond and silicon chips are the most famous—in which each atom has four nearest neighbors.

Such tropes are well known—some have been for centuries; others are more recently learned. Nanotechnologists, on the other hand, seek to exploit interactions at the next step in the hierarchy of length scales: to investigate, for example, how small or long molecules assemble into larger shapes. One striking example is the work of Paul Rothemund. The Caltech scientist sought to understand the



Paul W. K. Rothemund. California Institute of Technology.
DNA origami. Prototype. 2004–05. Natural and synthetic DNA molecules, 100 nanometers diam. Synthetic DNA manufactured by Integrated DNA Technologies, USA (2004–05)





self-organization of a particular class of engineerable molecules so well as to be able to redesign the molecules and thereby determine how they fold. He calls his beautiful work DNA origami.

Scale Bar = 100 nm.

DNA is an appealing molecule to work with for a number of reasons. It is famous; it is the basis of life; and it is sufficiently important that chemical biologists have developed an entire class of technologies that have rendered the programming of DNA sequence routine. This itself is remarkable: that we understand the chemistry of DNA's bases' pairings and affinities so well that we can build millions of identical custom molecules to order. The instrument of choice is the DNA synthesizer; as with its musical counterpart, the artist programs in her choice of notes, and the resulting tune is entirely deterministic and replayable at will.

Rothemund's molecular vocabulary—of "scaffolds" and "staple strands"—emphasizes our reliance on analogy. It is by forging such connections that we empower our imaginations. Rothemund's genius is in rendering this analogy robust through a deep understanding of the true nature of his scaffolds and staples, and then exploiting it in the extreme—building original shapes, and even a map of the world, using DNA.

The power of Rothemund's findings lies in the potential for molecules' controlled self-assembly. Imagine—instead at the macroscale now—a factory, fully automated, that does nothing but produce two-by-fours of a specific length and then attach one of a few different varieties of Velcro at various points along the wood beams. The various Velcro patches are sticky only to their complementary mates: red sticks only to orange, blue sticks only to green, and so on. The beams would then be delivered to the construction site. No need to hire a crew and take years to assemble the complex mass, though. Instead just add water, shake, and stir, and the building assembles itself, programmed through beam lengths and Velcro pairings.

At the length scale of a skyscraper, the idea seems unlikely. At the nanometer length scale, however, working with water-soluble molecules that at room temperature bounce off one another very frequently—red Velcro gets to sample orange millions of times every second, checking for a compatible match—Rothemund made the idea work.

Of course, we already knew that such self-assembly was possible—we are its greatest triumph. DNA programs proteins to self-assemble into cell walls, differentiated cells form communities that produce functional organs, and organs work together to constitute people. All this is programmed by a string of 3.2 billion base pairs on our DNA and more than thirty thousand genes. Rothemund's triumph is to show that nature—our inspiration, the ultimate in sophisticated molecular design—is not the only agent capable of design for self-assembly.

The Quantum Vernacular

In the examples above, design at the nanometer length scale benefits from quantitative rather than qualitative differences compared to what happens at macroscopic dimensions. More striking, however, is when rules break down and new ones emerge—when we enter a new length scale. It is then that new possibilities emerge. This is indeed the case when we design on the scale of the nanometer—the quantum length scale.

Though the world we experience every day is built of atoms, we rarely see direct evidence of the discreteness of matter's constituents. And we observe interactions between objects—their statics and dynamics—that Sir Isaac Newton, in his famous Principia Mathematica, described succinctly in 1687. Science has since discovered—with the aid of Max Planck, Albert Einstein, Erwin Schrödinger, and Werner Heisenberg in the early decades of the twentieth century—that, at the length scale of a few nanometers, there is another layer of logic lying beneath what we see in the world around us. The elucidation of the grammar of quantum physics led to a powerful new understanding of electrons, too, and photons and other quantum particles. Einstein won his Nobel Prize by explaining, for the first time, why it was that the electric current emitted from a metal depended not only on the brightness but also on the color of light impinging on it. This photoelectric effect was explainable only if we posited that light was made not only of waves, but also of discrete bundles—quanta—of energy.

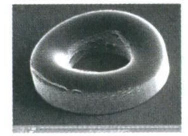
Quantum mechanics also tells us that electrons, too, are simultaneously particles and waves. An electron's characteristic wavelength is short enough—a few nanometers—that, in our daily lives, we rarely experience directly the "softness" of an electron. In fact, we know that even the hardest rock is made up of fuzzy clouds of constituent particles—particles that are soft, but only at the scale of a nanometer.

When nanotechnologists build nanometer-sized particles, though, we trap electrons into cages sized on the order of their wavelengths. From the world of classical physics we know the implications of confining waves: changing the length of a guitar string, for example, changes the selection of waves that can be suspended across it; changing the tension in a tympani drum changes its resonances.

Phenomena wherein electrons' dual nature as both wave and particle is manifest are constantly at play within the materials that surround us—including those from which we ourselves are built. We seldom see their effects directly, though, because they are apparent only when we look for them with an acuity corresponding to electrons' characteristic wavelength of a few nanometers.

Through structure, waves can be readily tuned. One way, observable by human eyes, in which quantum structures' tunabilities are manifest is through the colors of light these materials absorb and emit.

Microscope images showing scientists' and engineers' ability to form matter on the scale of the micrometer, one thousandth of a meter.

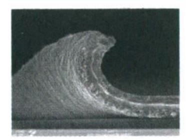


Philips Research Laboratories. FEI Company. **Micro-molded part from a deep-etched silicon mold.** 2007. Polymer, 1,250x magnification on a FEI NovaNanoSEM600 microscope. Horizontal field width: 250 microns

The donut shape shows an incomplete replication due to premature vitrification of the thermoplastic polymer.

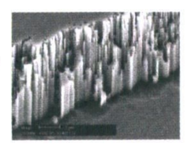
Philips Research Laboratories. FEI Company. **Titanium oxide crystallite during the deposition of a wet-chemical layer.** 2002. 2,500x magnification on a FEI scanning electron microscope. Horizontal field width: 125 microns

The amount of TiO2-procursor was too high and these tagliatelle-like crystallites were formed on the surface.



Philips Research Laboratories. FEI Company. **Bad adhesion of metalization.** 2007. Metal thin film on silicon, 40.000x magnification on a FEI NovaNanoSEM600 microscope. Horizontal field width: 7.5 microns

Metal thin film deposition is commonly used in the manufacturing of semiconductor devices. In this example, internal stress makes the film curve upward to outline a metal wave.



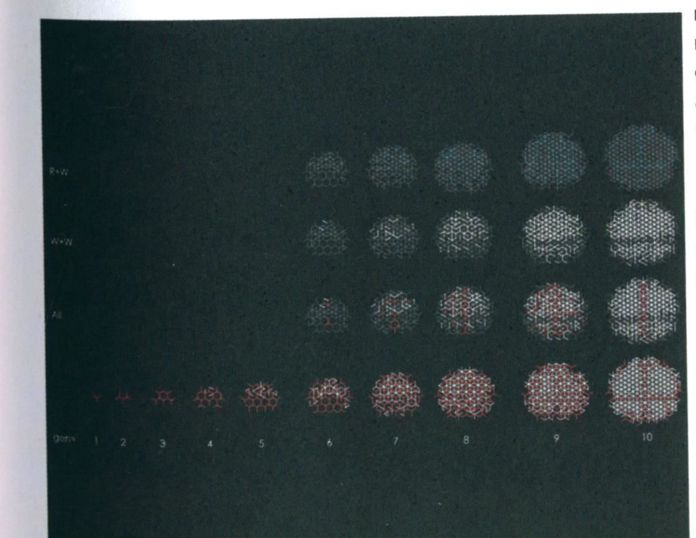
Philips Research Laboratories. FEI Company. **Plasma etching done by SF6 plasma in the so-called Bosch process.** 2006. Silicon, 20.000x magnification on a Philips XL40FEG microscope Horizontal field width: 24 microns

The so-called Bosch process is generally used for making Microelectromechanical Systems (MEMS), 3-D high-density storage capacitors, and other devices. Successive etching of silicon using the Bosch process resulted in this skyline pattern.

Quantitatively, while foot-long guitar strings tune harmonics in the hundreds and the thousands of Hertz—the oscillation frequencies of acoustic waves—nanometer-long quantum dots tune harmonics in the trillions of Hertz, corresponding to light waves.

Such tunability opens new avenues of freedom in expression. For a given material—say silicon or another semiconductor—the degree of chromatic expression is no longer circumscribed by the medium's god-given color. Instead, we can build bespoke matter simply by controlling particle size. It is as if we have discovered that each letter of the alphabet has an infinite variety of tones, and that new poetry, new songs, and new puns have become possible as a result of this expanded palette. The solar cells discussed above benefit from this tunability. The sun's rays are intensely polychromatic—they span not only the visible colors but also stretch into the ultraviolet and the infrared. Indeed, over half of the sun's light lies in these chromatic regimes invisible to our eyes.

Solar cells are most efficient if they collect photons of different colors—different energies—into neatly sorted piles, and harvest the maximum energy of each slice of the spectrum. In the past this has meant searching for new materials—a different semiconductor for each pile. But with the capacity to tune materials' colors using the quantum size-effect, collecting a particular slice of spectrum is as simple as making a bunch of nanoparticles of a particular size and thereby tuned to a particular frequency. Is building same-sized nanoparticles to order a simple matter? No, but it is now a known art. Self-organization—materials chemistry—has been the key. Nanotechnologists can now build particles—spheres, cubes, rods, and even tetrapods and ribbons—that are identical in their key quantized direction to within a few percent.



Cecil Balmond, Jenny E. Sabin, **Seonhee Yoon**, David B. LeFevre, **Firas Hnoosh**, and Huayou Li. University of Pennsylvania School of Design. **Abstract Branching Model for new Nanotechnology Facility.** Concept. 2007

Three-dimensional digital model generated by a branching algorithm.

To Visualize the Invisible

While what we have built so far at the nanoscale is remarkable, it barely scratches the surface of possibility. Even the simplest living organisms are richer and more complex than what nanotechnologists have so far sought to grow from the bottom up. A virus uses a highly compact genetic code to build a set of proteins that form a protective capsid, a delivery system into its host, and a strategy for self-replication. And this is one of the simplest living entities we can imagine.

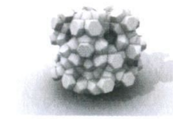
We debate whether a brain can ever understand itself. We need not resolve this debate to believe that we can understand so much more about designing custom structures and properties from the smallest constituents. And thus we should imagine the limits of possibility: Will we program the growth of living solar cells that build themselves, trained to expand only across otherwise unused land, and connect inductively into an electrical grid? Will regenerative medicine, a fast-moving field, succeed in generating banks of healthy organs available for transplantation so that we each have a spare? Will we succeed in measuring expression levels of genes in our bodies so sensitively and so cost-effectively that we can perceive, warn of, and act against cancers as soon as they first strike?

To get there we will depend, as we always have, on the human imagination. Breakthroughs will continue to come from a union of two distinct human capacities. The first is to imagine a world identical in its underlying rules of behavior but simply scaled down in spatial dimensions to the world we touch and see each day. The second is to picture potentiality within a world that is more than scaled—it is altered, built from quantized clouds of probability. Much hope lies in finding new possibility in strangeness.

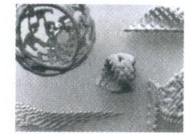
approach a problem from
a human-centric macroscale → different rules applicable → same product
quantum nano-scale → different rules applicable → same product

PERHAPS A BIT LIKE THINKING IN AN ALTERNATE LANGUAGE TO FOSTER IDEAS OUTSIDE OF THE FORMER'S LEXICON?

Benjamin Aranda and Chris Lasch of Aranda/Lasch.



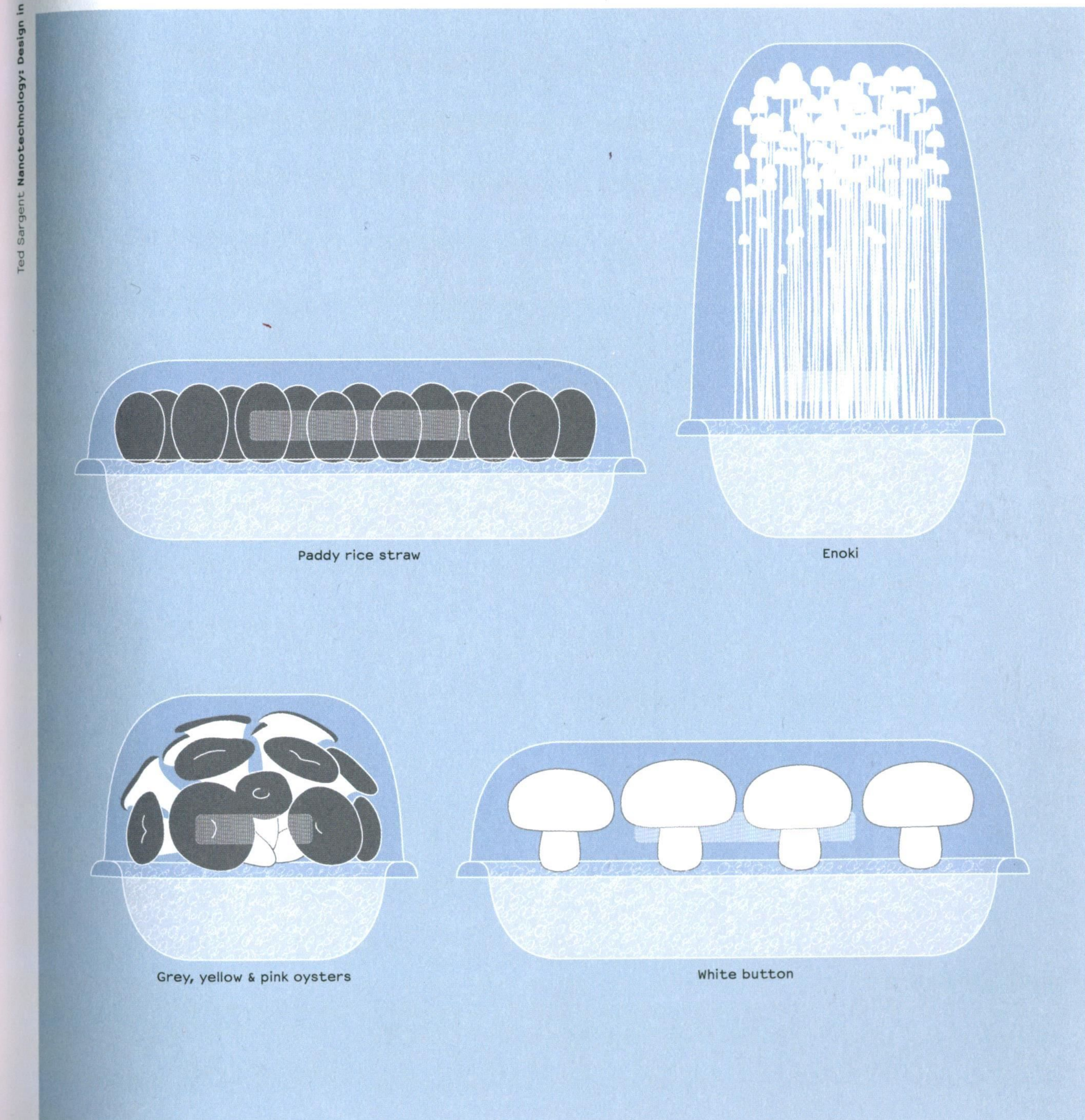
QuasiCrystal packing study. 2006.
Rhino 3-D software

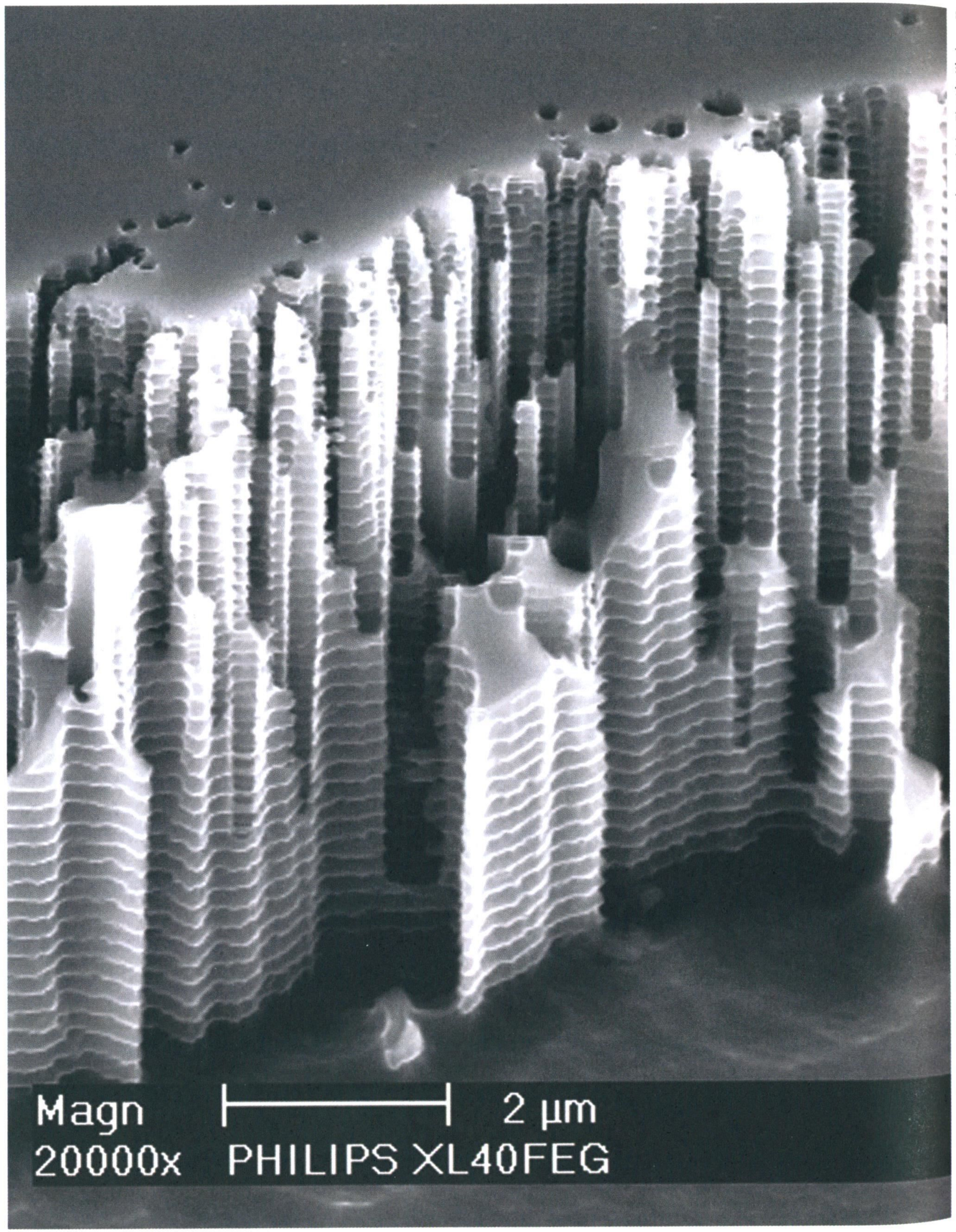


Woven Rope. 2005.
Rhino 3-D software

Weaving study collection. 2005.
Generative Components software

Agata Jaworska. Design Academy Eindhoven. **Mushroom Growth Packaging** from **Made in Transit, a concept for sustained growth within the supply chain.** Concept. 2007

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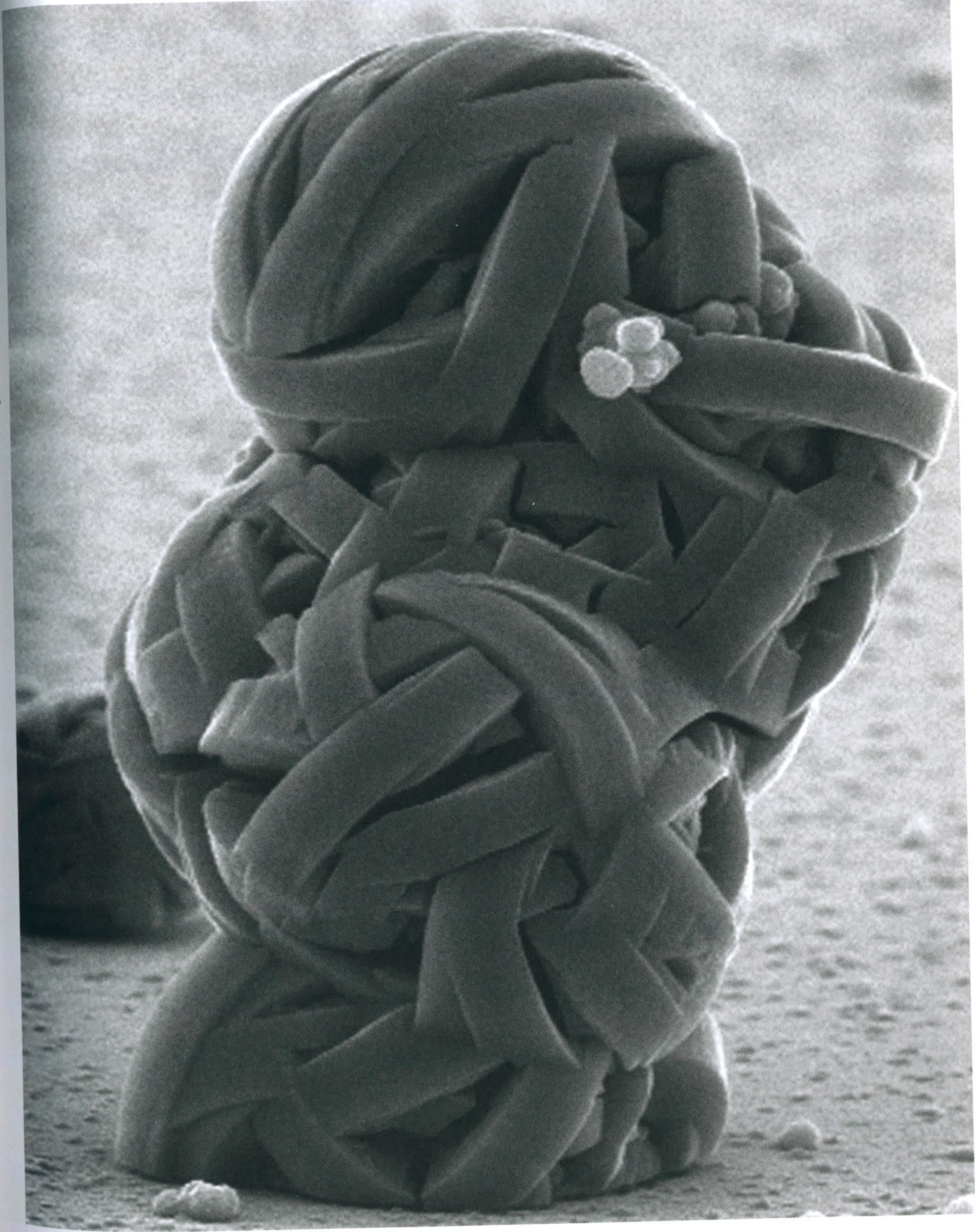
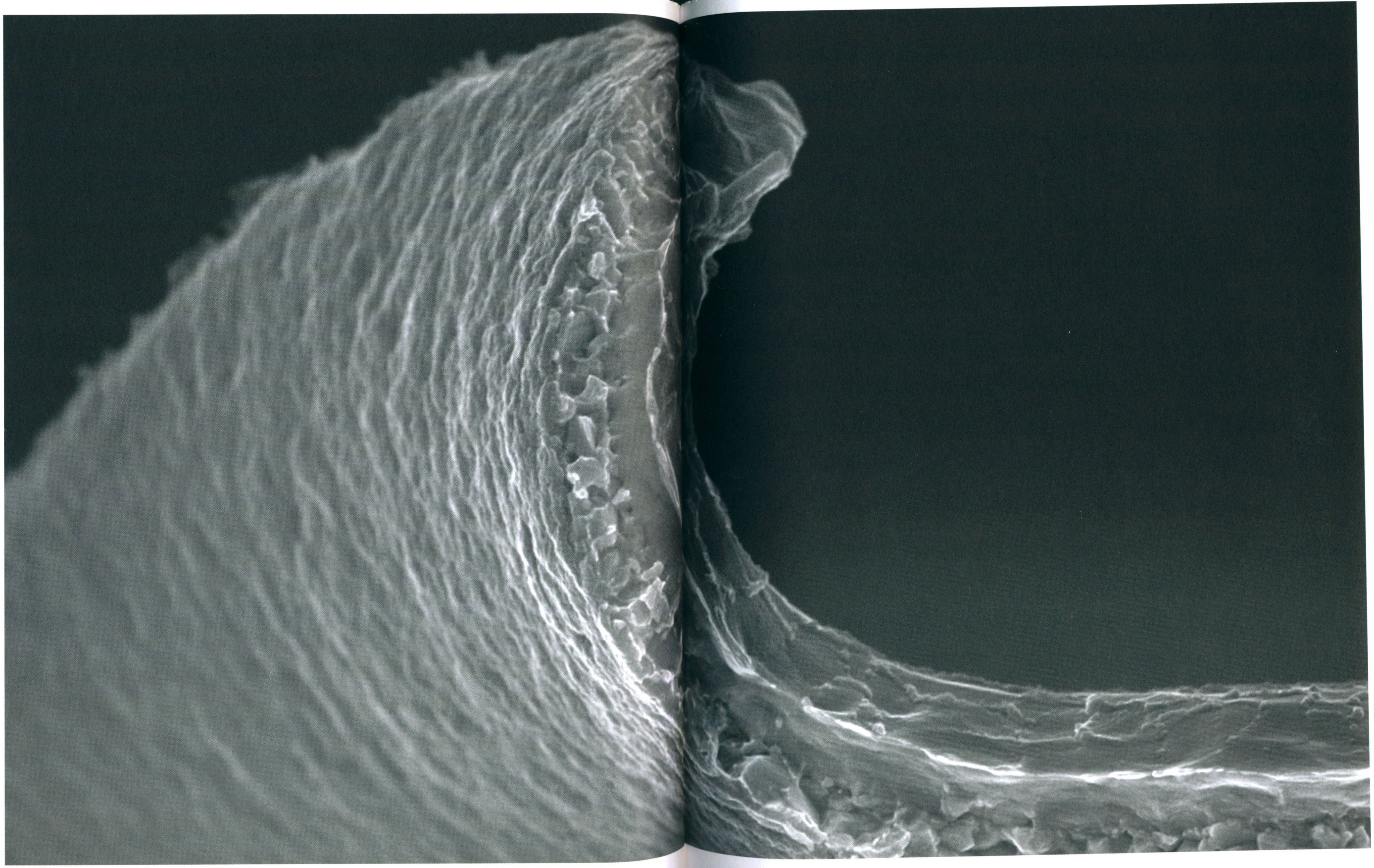
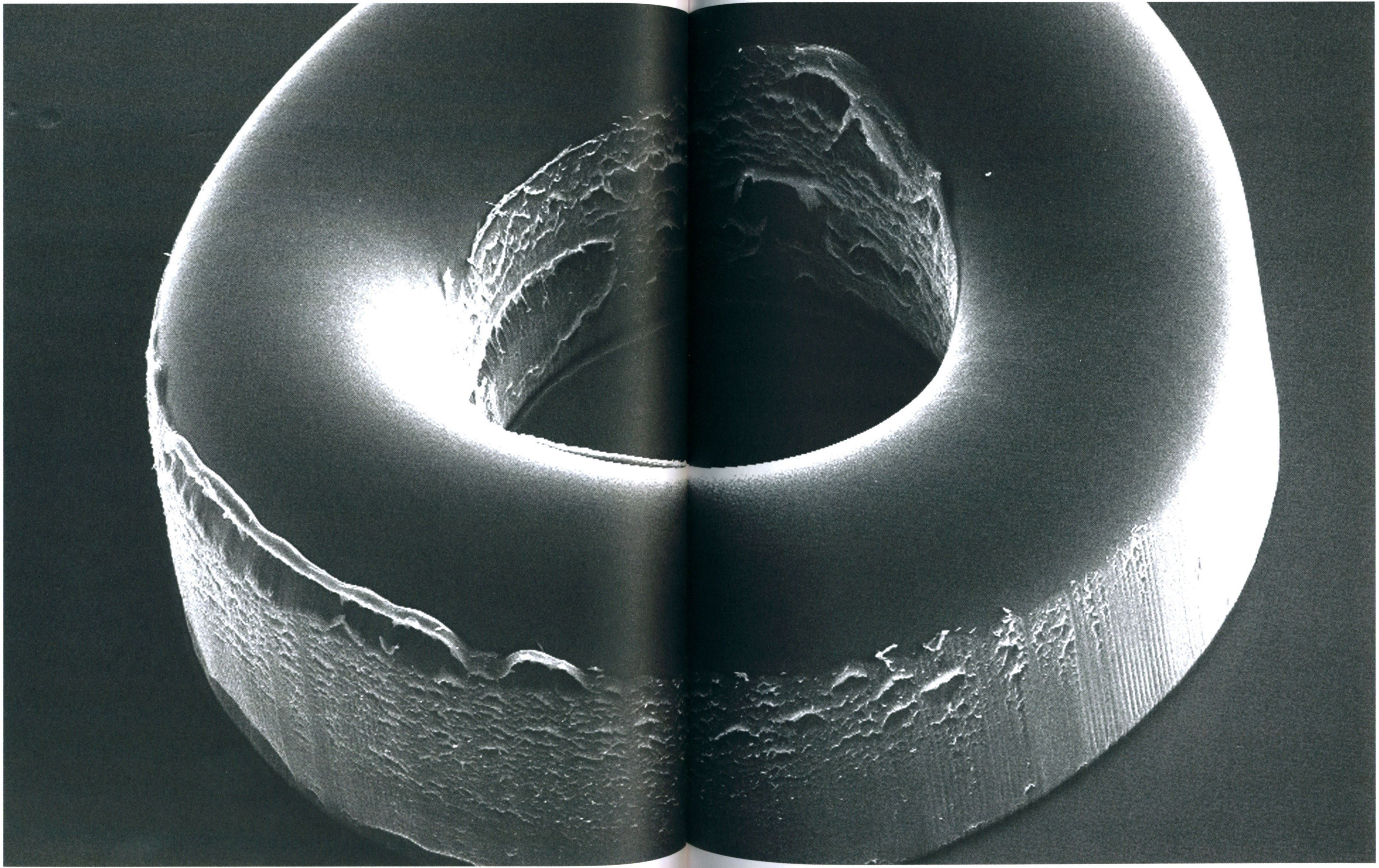
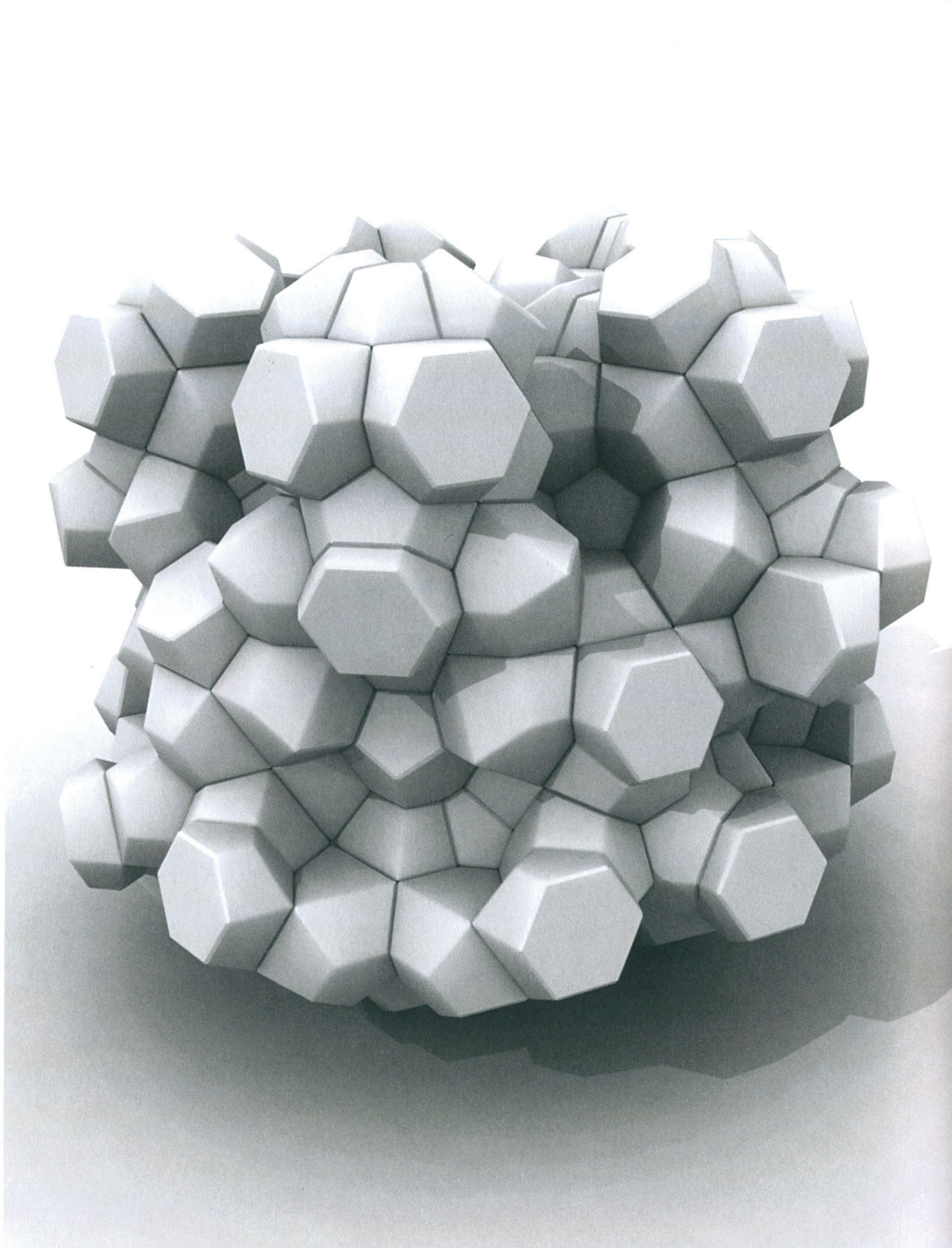
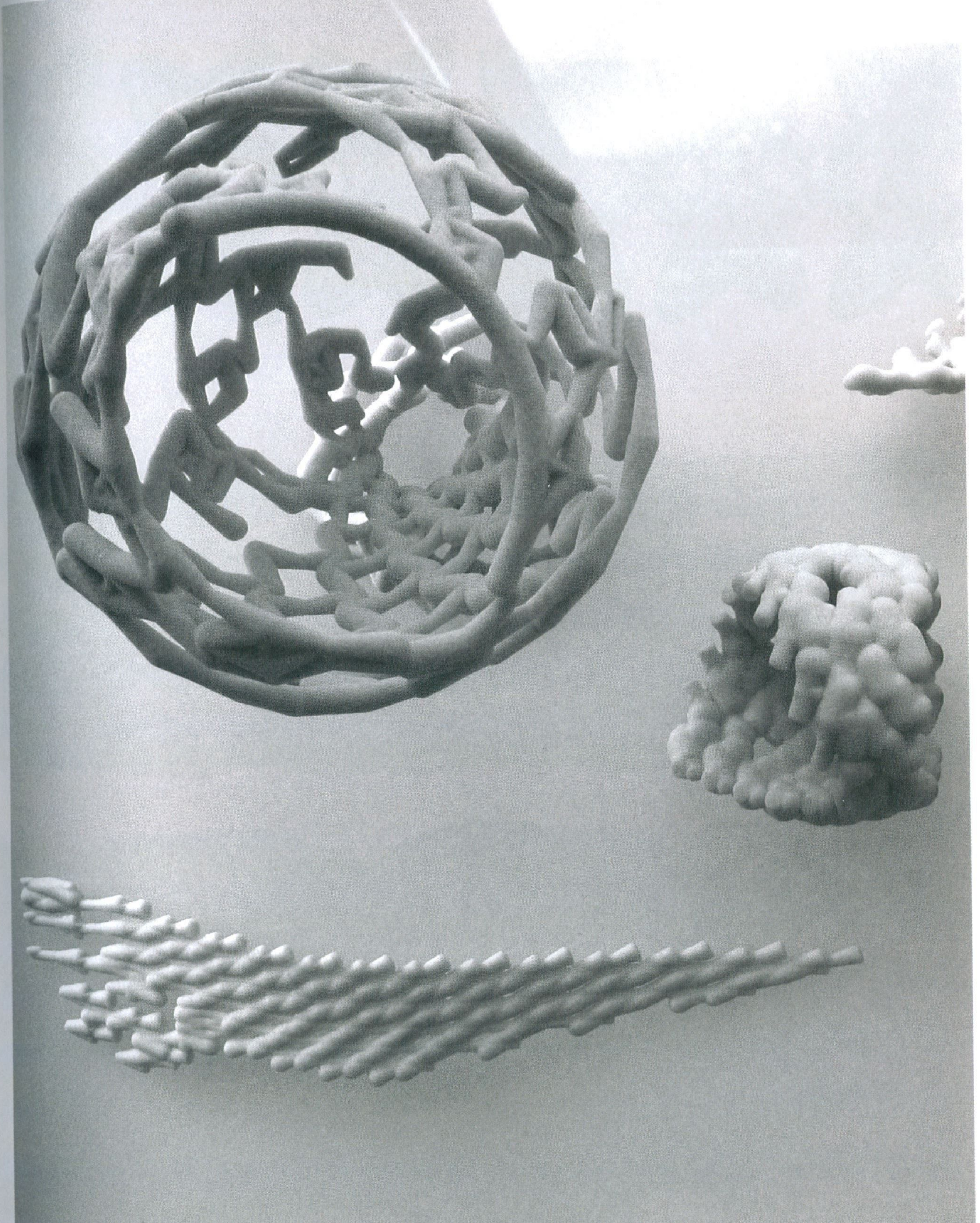
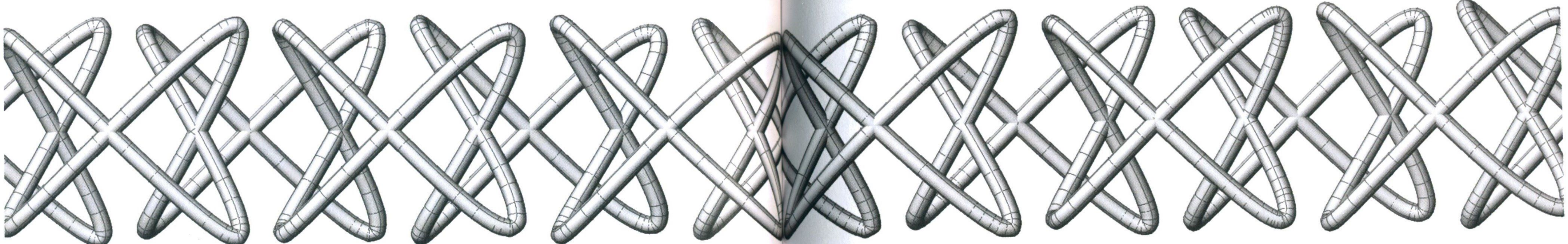


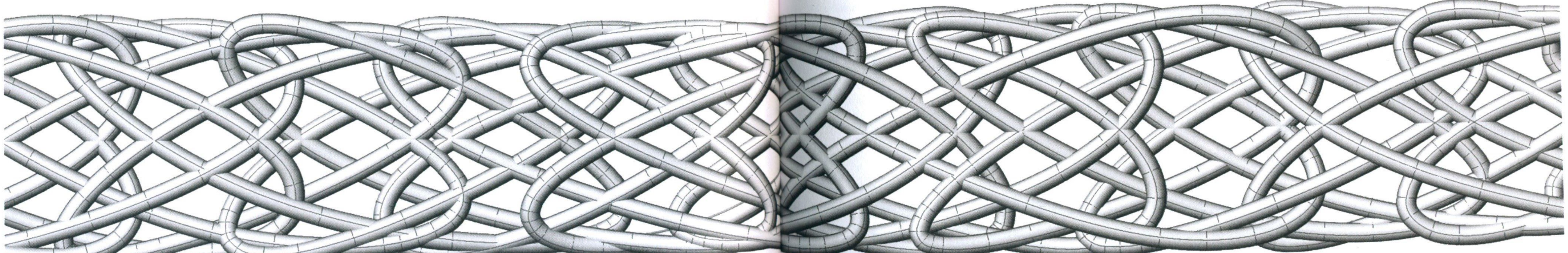








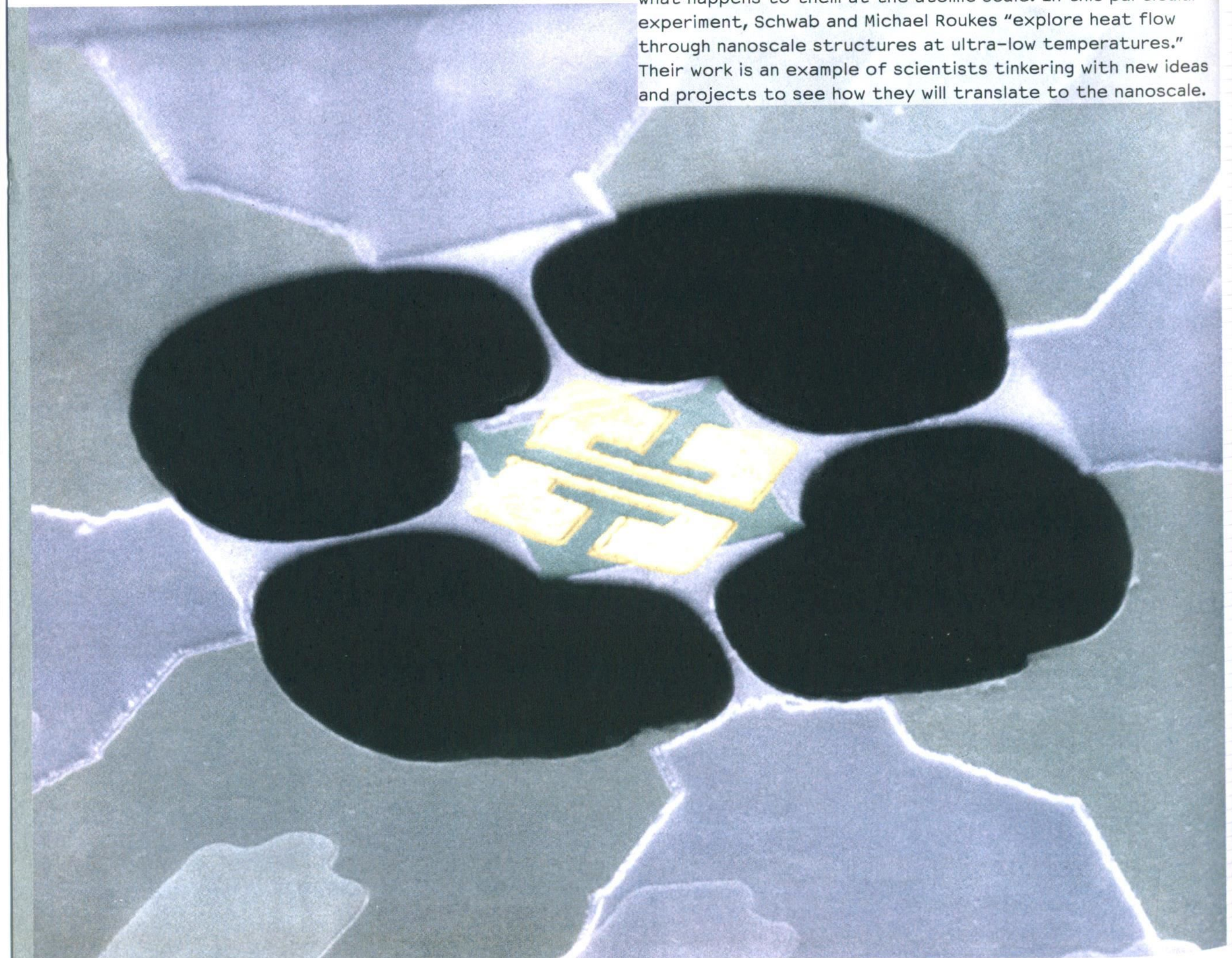




Designers and scientists unite in the exploration of the possibilities of nanotechnology. At the nanoscale (one nanometer is one billionth of a meter) molecules can be used to construct larger entities either by allowing them to come together chemically according to the laws of molecular recognition or by assembling them in a top-down process more like traditional engineering. Scientists are acting as designers and tinkering with nano objects with abandonment, while designers are irresistibly attracted to the possibility of building new objects that will respond to their circumstances in an autonomous and novel fashion, almost having lives of their own.

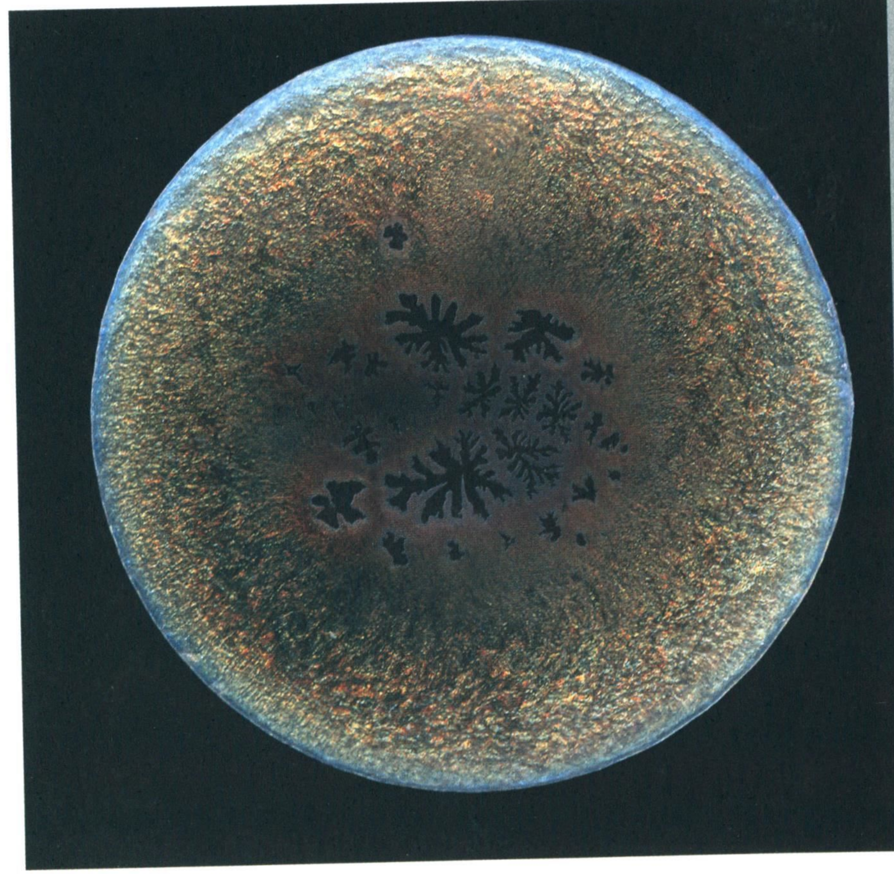
Keith Schwab (American, born 1968) of the Department of Physics, Cornell University (USA, est. 1865)
Michael Roukes (American, born 1952) of the Department of Physics, California Institute of Technology (USA, est. 1891)
Measurement of the Quantum of Thermal Conductance 1996–2000
Nanofabricated from submicron-thin films of silicon nitride, gold, niobium, and silicon oxide, field of view: 20 microns; central square: 4 microns

Keith Schwab's focus is "the study of fundamental quantum behavior of small mechanical structures" and to understand what happens to them at the atomic scale. In this particular experiment, Schwab and Michael Roukes "explore heat flow through nanoscale structures at ultra-low temperatures." Their work is an example of scientists tinkering with new ideas and projects to see how they will translate to the nanoscale.



Felice Frankel (American, born 1945) of Harvard University (USA, est. 1636)
Microphotography 2007
Nanotubes: 1 nanometer
Block copolymers (48 hours): 3/8" (1 cm) diam.

Felice Frankel is a science photographer whose rigorous manipulation of images is akin to a design gesture. By tweaking colors and backgrounds in order to exalt the scientific focus of her images, she achieves a level of clarity and beauty that highlights the sublime design that can be found in science in general, and more specifically at the nanoscale. These two images serve as a visual introduction to the world of nanophysics. The first is an optical rendition of nanotubes—among the most promising structures in nanotechnology. Because no camera exists that is able to photograph at the nanoscale, Frankel had to construct her own image: "I imprinted a pattern on acetate, made the latter into a cylinder, scanned the material on a flatbed scanner, played with the image in Photoshop through a series of steps." The second image shows the magnified detail of a gel-like structure made of polymers over forty-eight hours. Because her images are frequently accompanied by statements that detail her process and explain exactly what she has done to manipulate them, Frankel sees her work as an example of designing to communicate information.



Institute of Bioengineering and Nanotechnology (Singapore, est. 2003)
Blue Beetle Design (Singapore, est. 2003)
Nano-Bio Kits 2003–06

Biological Fuel Cell Kit
Acrylic fuel cell cartridge, proprietary nanostructured catalyst-immobilized electrodes, polymer membrane, resistors, wires, and steel, 9 1/2 × 7 × 2 3/8" (24.1 × 17.8 × 6.1 cm)

Thermo-responsive Hydrogel Kit
Thermo-responsive hydrogel polymer in powder form, reagents, and polystyrene plastic, 9 1/2 × 7 × 2 3/8" (24.1 × 17.8 × 6.1 cm)

Dielectrophoresis Chip Kit
Glass slides etched with microchannels, glass slides coated with electrode metal layer and photoresist film, yeast cells, acrylic plastic, and aluminum, 9 1/2 × 7 × 2 3/8" (24.1 × 17.8 × 6.1 cm)
Manufactured by the Institute of Bioengineering and Nanotechnology, Singapore (2006)

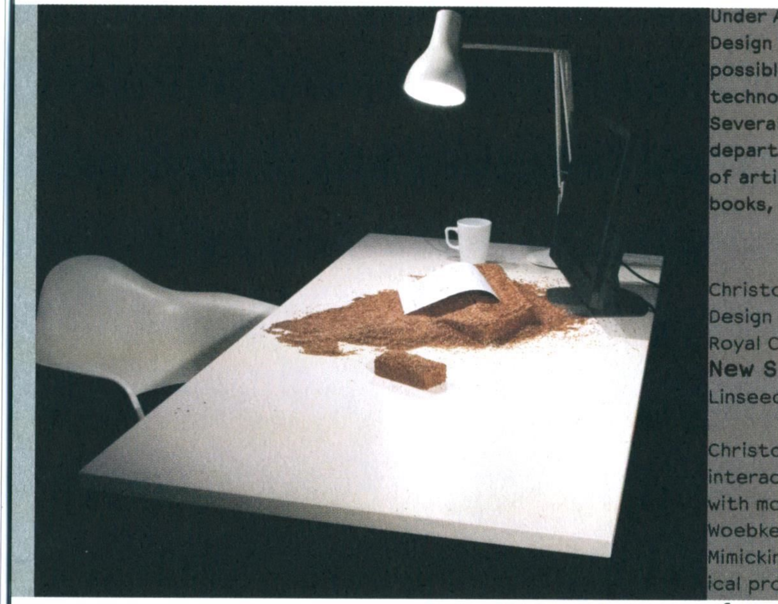
These three Nano-Bio Kits, individualized science curricula offering hands-on learning tools for students between the ages of fifteen and nineteen, are the first in a planned series designed to introduce students to professional lab experiences in the field of biomedical technologies. Highlighting the science behind alternative "green" energy, the Biological Fuel Cell Kit explores how electricity can be generated from such a mundane household item as sugar with the help of enzymes fixed on nanoparticles. The Thermo-responsive Hydrogel Kit shows how a temperature-sensitive material is made and how the rate of diffusion of particles within that material is affected by different temperatures; this experiment helps students understand how medical drugs can be delivered at different body temperatures from a hydrogel drug carrier embedded into a patient. The Dielectrophoresis Chip Kit shows how individual cells behave during a phenomenon called dielectrophoresis (DEP), the movement of an object in a non-uniform electrical field. Making their own DEP chips and then observing the movement of yeast cells, which are included in the kit, students gain hands-on experience with a cutting-edge technique, which may be used to diagnose diseases at the cellular level and invent new drugs in the near future.

Thomas G. Mason (American, born 1968) and Carlos J. Hernandez (American, born 1979)
Department of Chemistry and Biochemistry and the California NanoSystems Institute (est. 2000), University of California, Los Angeles (USA, est. 1919)
LithoParticle Dispersions: Colloidal Alphabet Soup 2006
Polymer microparticles containing fluorescent dyes and dispersed in water, 4 × 4 3/4" (10 × 12 cm)
Manufactured by UCLA in conjunction with Colloidia LLC, USA (2006)

Scientists at UCLA have designed and mass-produced billions of fluorescent lithographic particles in the shapes of all twenty-six letters in the English alphabet. Dispersed in a liquid solution, each particle has a custom-designed shape achieved with the same lithographic technology used in computer electronics. They can customize the font style of these particles and, according to Thomas G. Mason and Carlos J. Hernandez, even "pick up the letters and reposition them in a microscale version of the game Scrabble." Mason and Hernandez anticipate that their LithoParticles will have significant technological and scientific uses, such as marking individual cells with particular letters in order to identify them. The two have also designed different shapes, including triangles, crosses, and donuts, as well as complex three-dimensional forms. "The research could lead to the creation of tiny pumps, engines, or containers for medical applications," the two explain. As scientists continue to hone their skills in working with these tiny forms, which in the future will become the bricks from which functional micro-devices will be produced, they will be able to assemble them into more complex structures.

Oded Ezer (Israeli, born 1972)
Typosperma Concept. 2007
Macromedia FreeHand and Rhino software

Typosperma, the second experimental project in Oded Ezer's Biotypography series, are cloned sperm with typographic information implanted into their DNA. These fantastical creatures literally embody the dream of design and science coming together. Ezer, a typographer trained at the Bezalel Academy in Jerusalem, appears on his Web site wearing a white lab coat and contemplating a vial, surrounded by tools not found in a typical design office. As he explains it, "The term Biotypography refers to any application that uses biological systems, living organisms, or derivatives thereof to create or modify typographical phenomena. The main purpose of the Typosperma project was to create some sort of new transgenic creatures, half (human) sperm, half letter."



Under Anthony Dunne's direction, the Royal College of Art's Design Interactions Department has been focusing on design's possible implementation of the most cutting-edge scientific and technological innovations, from bioengineering to nanophysics. Several of the projects presented in this book come from that department's students and professors, most often in the form of artifacts accompanied by scenarios described by videos, books, and other narratives.

Christopher Woebken (German, born 1980)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
New Sensual Interfaces Concept. 2007
Linseeds, 1 1/2 × 4 1/2 × 20" (3.8 × 11.4 × 50.8 cm)

Christopher Woebken's project explores innovative ways of interacting with information. By using nanotechnology—starting with molecules and counting on their self-assembly tendencies—Woebken proposes a way to build devices from the bottom up. Mimicking organic behaviors, natural systems, and microbiological processes, these devices will behave like body cells, made of a network of micro- or nano-sized elements. Since each element of these new modular and moldable products contains the same basic information, similar to DNA in living organisms, it will be possible to break these devices apart in order to change their functions or share them with friends, redefining the very essence of a product.

James King (British, born 1982)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
Fossils from a Nanotech Future Models. 2006

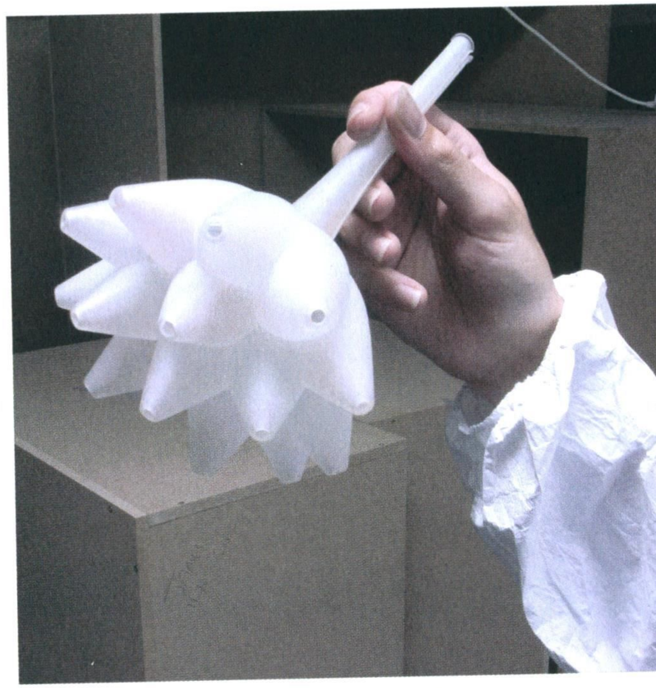
The Flower
Polyamide resin, 8 × 11 3/4" (20 × 30 cm)

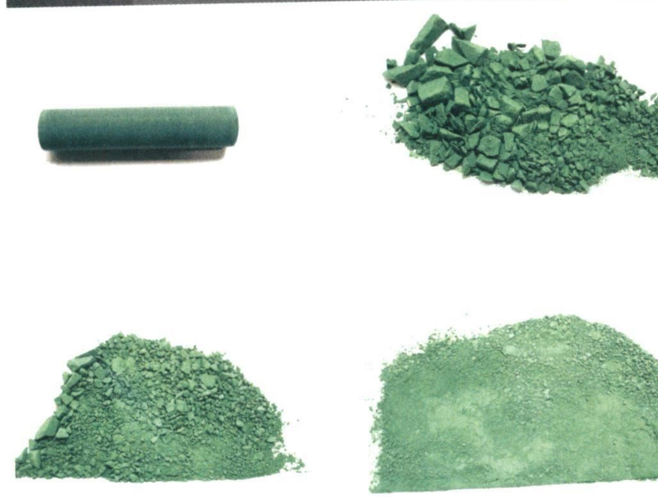
The Chalk
Chalk, 3/8 × 1 3/4" (1 × 4.5 cm)

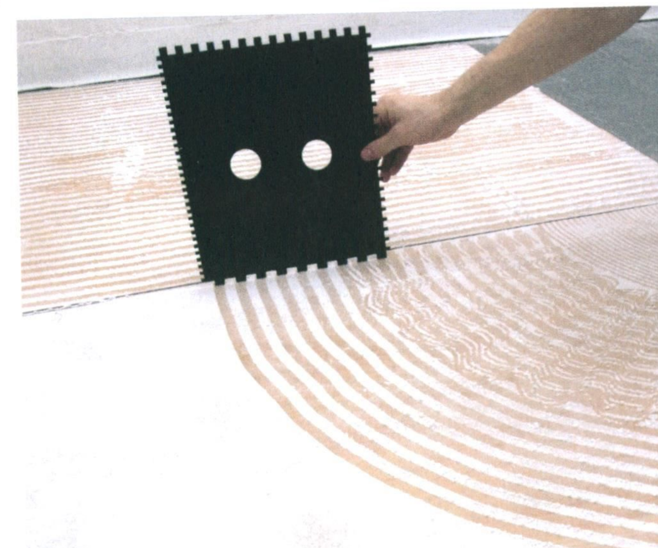
The Comb
Cardboard, 11 3/4 × 9 7/8" (30 × 25 cm)

James King's project Fossils from a Nanotech Future documents the findings of a team of future anthropologists as they examine a collection of fossils believed to originate from the year 2025. One of the artifacts, which the team calls The Flower, seems to be a breathing apparatus, almost certainly man-made, with a slender stem forming a mouthpiece. It comes apart in two halves to reveal something resembling a seedpod. They think this might be either a filter to clean the air or, alternatively, some sort of medical device that adds particles to the inhaled air. Another artifact is a small stick of what looks like chalk; observation under an electron microscope shows an amalgam of loosely packed particles, each measuring a few hundred nanometers. To get a better idea of its properties, the stick is broken up into fine powder, thereby freeing the particles and increasing their active surface area. The futurologists also find a small container of what they call "smart dust"—dust is commonly associated with nanomaterials—and discover that if they sprinkle it onto a flat surface, an intricate pattern appears. Another found object, The Comb, is a tool for manipulating the dust.

In trying to decipher the objects, the team discusses nanotechnology as it may be experienced in daily life in a world transformed by the advances in the field. The possibility of a nanotech future seems very real, and imagining the kinds of objects that might appear can help us envision the actual impact of such advances. As King states: "Some technologists believe that this science will one day allow us to cure all diseases, reverse ecological damage, and even halt the aging process. Skeptics argue that nanotechnology will do nothing of the sort, though it might provide us with faster computers, self-cleaning windows, and wrinkle-free trousers."

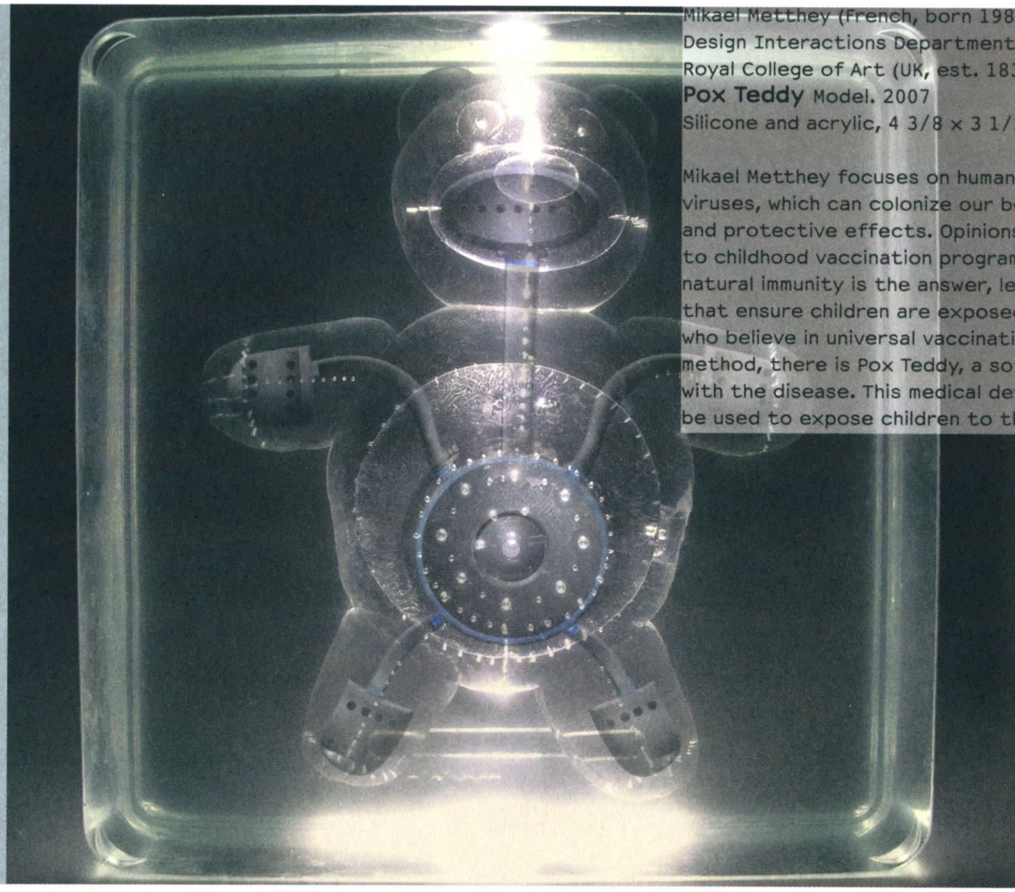






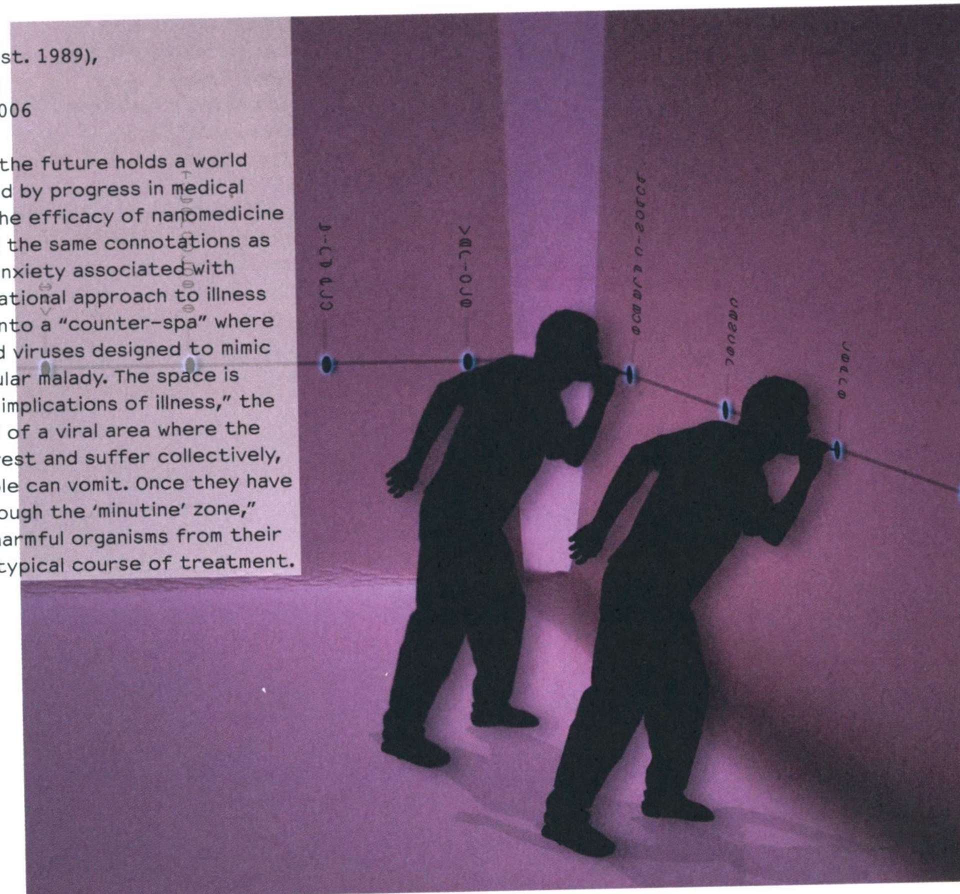
Mikael Metthey (French, born 1983)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
Pox Teddy Model. 2007
Silicone and acrylic, 4 3/8 × 3 1/2 × 1 1/8" (11 × 9 × 3 cm)

Mikael Metthey focuses on humans' ambiguous relationship with viruses, which can colonize our bodies with both destructive and protective effects. Opinions vary greatly when it comes to childhood vaccination programs. Some parents feel that natural immunity is the answer, leading to "chicken pox parties" that ensure children are exposed to the disease. For those who believe in universal vaccination but prefer a more exact method, there is Pox Teddy, a soft teddy bear impregnated with the disease. This medical device in the guise of a toy can be used to expose children to the virus instead of a needle.



Mikael Metthey (French, 1983)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
The Minutine Space Concept. 2006

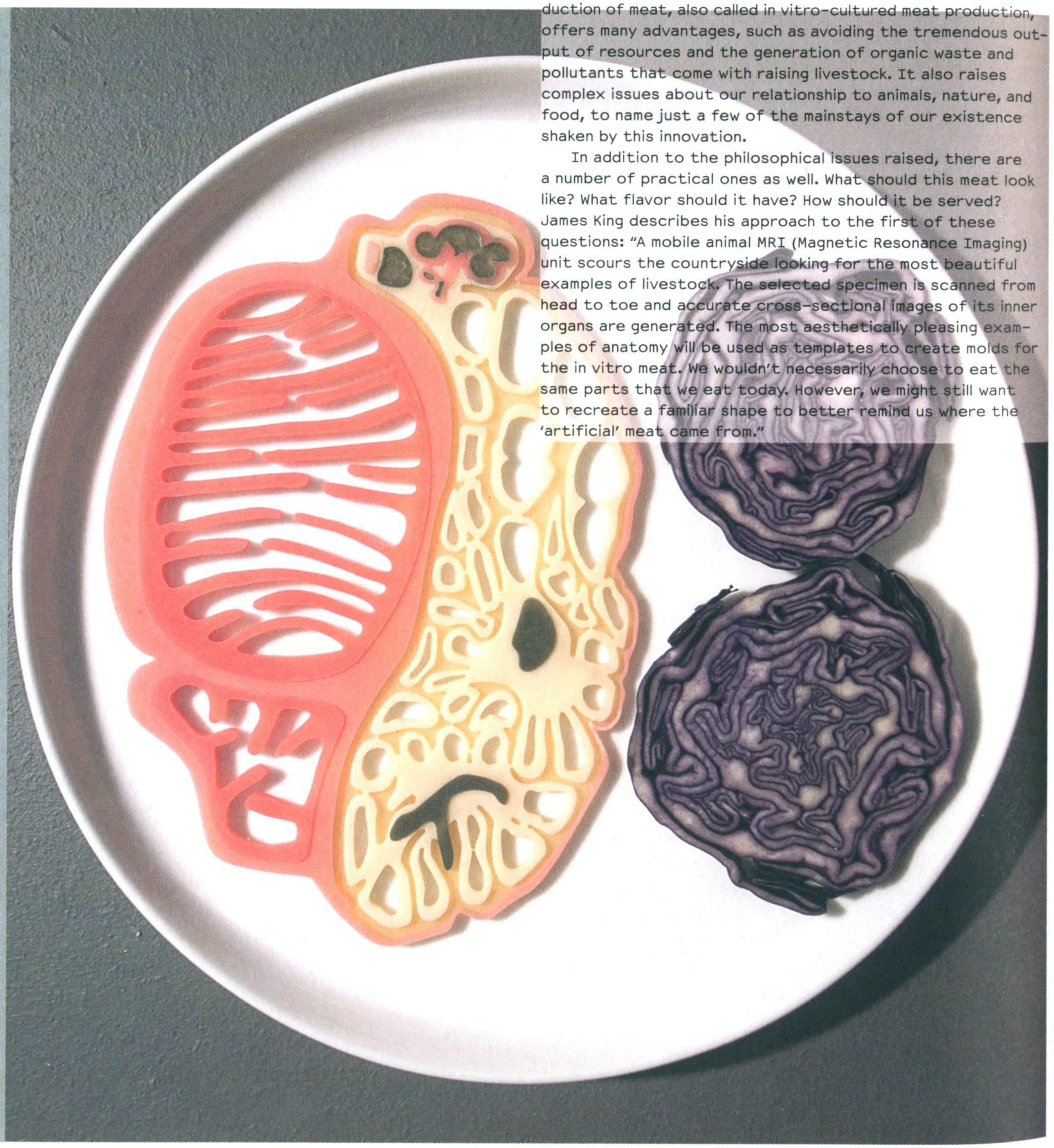
In Mikael Metthey's utopian vision, the future holds a world where all illness has been eradicated by progress in medical diagnostics and treatment. When the efficacy of nanomedicine is perfected, sickness will not hold the same connotations as in our present world. Rather, the anxiety associated with disease will be replaced by a recreational approach to illness in which potential patients check into a "counter-spa" where they will be infected by engineered viruses designed to mimic the experience of having a particular malady. The space is "designed to emphasize the social implications of illness," the designer explains. "It is composed of a viral area where the virus can be chosen, facilities to rest and suffer collectively, and a 'central sick pit' where people can vomit. Once they have had enough, visitors can leave through the 'minutine' zone," where nano-antidotes remove all harmful organisms from their bodies in one minute instead of a typical course of treatment.



James King (British, born 1982)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
Dressing the Meat of Tomorrow Model. 2006
Plastisol (fiberglass-reinforced polyester), 5 1/2 × 7 1/2" (14 × 19 cm)

Scientists at the University of Western Australia have coined the term "disembodied cuisine" to refer to a new tissue-engineering technique that makes it possible to grow edible meat in a laboratory from sample cells. The artificial production of meat, also called in vitro-cultured meat production, offers many advantages, such as avoiding the tremendous output of resources and the generation of organic waste and pollutants that come with raising livestock. It also raises complex issues about our relationship to animals, nature, and food, to name just a few of the mainstays of our existence shaken by this innovation.

In addition to the philosophical issues raised, there are a number of practical ones as well. What should this meat look like? What flavor should it have? How should it be served? James King describes his approach to the first of these questions: "A mobile animal MRI (Magnetic Resonance Imaging) unit scours the countryside looking for the most beautiful examples of livestock. The selected specimen is scanned from head to toe and accurate cross-sectional images of its inner organs are generated. The most aesthetically pleasing examples of anatomy will be used as templates to create molds for the in vitro meat. We wouldn't necessarily choose to eat the same parts that we eat today. However, we might still want to recreate a familiar shape to better remind us where the 'artificial' meat came from."



Michael Burton (British, 1977)
Design Interactions Department (est. 1989), Royal College of Art (UK, est. 1837)
Nanotopia from the **Future Farm project**
Concept. 2006–07
Human hair and prosthetics, 1 1/4 × 6 1/2" (3.2 × 16.5 cm)

The promise of nanotechnology invites utopian imaginings, but it could have a darker, dystopian side as well. Many believe that nanotechnology will reach its true imaginative and creative potential when applied to organisms, where it can stimulate and control cellular self-replication. One of the possible unintended consequences of this might be a widening of the gap between rich and poor, and Michael Burton illustrates the impact of this future scenario on people at the opposite ends of the social scale. Whereas today it is possible to profit, whether legally or illegally, from your blood, sperm, or kidneys, in the future the poorest will be able to go to even further extremes. In the imaginary world of Nanotopia, Burton explains, poor people will be able to "utilize the body as a farm to cultivate desirable clinical and pharmaceutical products," including stem cells developed from adipose tissue. All the while the upper classes will make the most of the advances in bodily aesthetics, and new cosmetic rituals, such as beguilingly long eyelashes, might arise. Burton's project Future Farm explores the future relationships between "producers" and the medical industry, foreseeing changes in body morphology and accepted notions of beauty.

Michael Burton (British, 1977)
Design Interactions Department (est. 1989), Royal College of Art (UK, est. 1837)

The Race Concept. 2006–07
Resin, lamb, prosthetics, and wool

"We are alarmingly near the end of the antibiotic era," writes Michael Burton. "Bacteria and viruses are evolving faster than our scientific innovation. Trivial infections we had forgotten about will once again become fatal." Burton's project incites us to literally join the race to evolve with—or faster than—germs, bacteria, and viruses. It implicates our excessively hygienic habitats and lifestyles as having wiped out the symbiotic microflora that perform vital roles in our body, thereby weakening our immune systems. The Race, whose fundamental realization is that we are "a part of nature and not outside or above it," aims to reconstitute some of this heritage. By reengineering the growth of our nails, for example, we can create a more rugged surface for microbes to grow and hopefully infect us. By designing new hybrid animals with the right coiffure, we can optimize our exposure to their dander, hair, and parasites. With these and other suggestions, The Race "responds to a growing societal angst and obsession with the evolution of our species, and recognizes our evolutionary past as our symbiotic future."

Michiko Nitta (Japanese, born 1978)
Design Interactions Department (est. 1989), Royal College of Art (UK, est. 1837)

Body Modification for Love project Concept. 2005
Latex and acrylic paint, 1/8 x 3/8" (0.3 x 0.9 cm) diam.

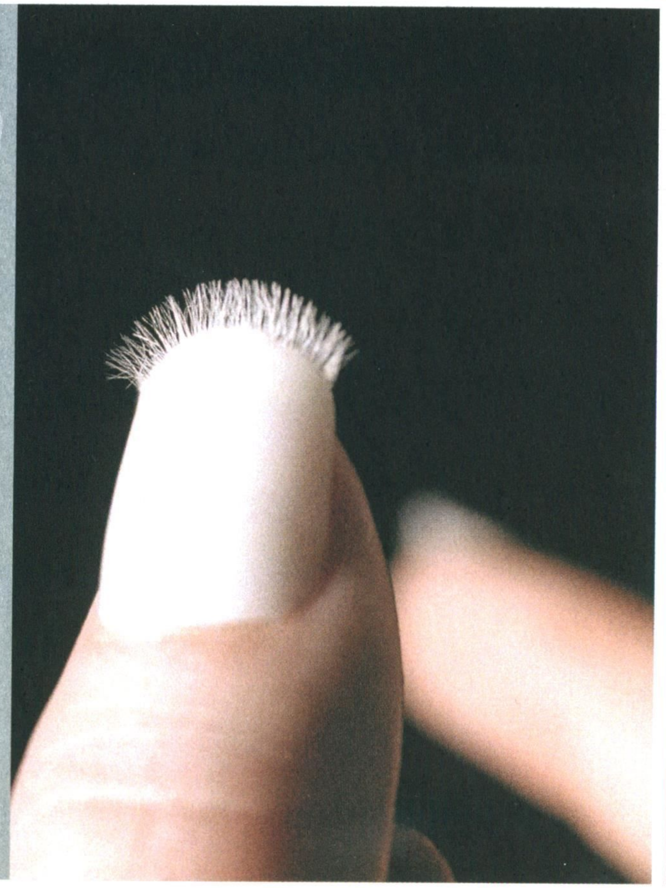
Body Modification for Love takes previous research on in vitro–cultured meat production technologies into the realm of memories and emotions. Michiko Nitta's project envisions a technique for genetically growing selected body parts on your skin, allowing you to sport your partner's favorite mole on your shoulder, your ex-girlfriend's nipple close to your pelvic bone, or a patch of living hair on your arm to remind you of your mother. This is a long-term commitment, of course, as the mole and nipple will grow and demand care and the hair patch will need to be cut and groomed. By embedding our emotional background into our own bodies, we would create a "growing memory" to keep our recollections alive.

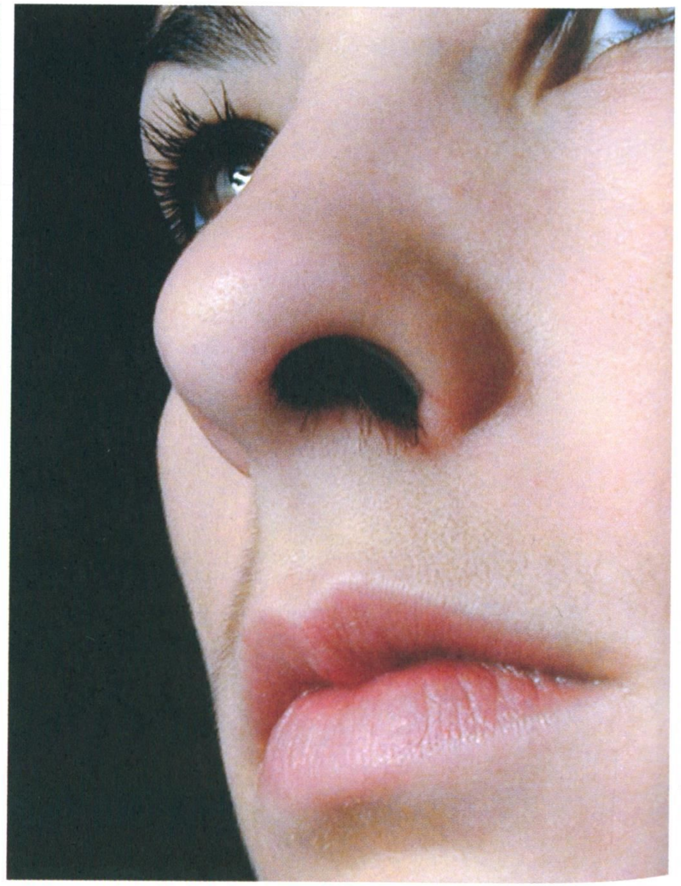
Susana Soares (Portuguese, born 1977)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)

Genetic Trace: New Organs of Perception
Concept. 2006
Acrylic nails and feathers

Genetic Trace, Part Two: Sniffing Others
Concept. 2007

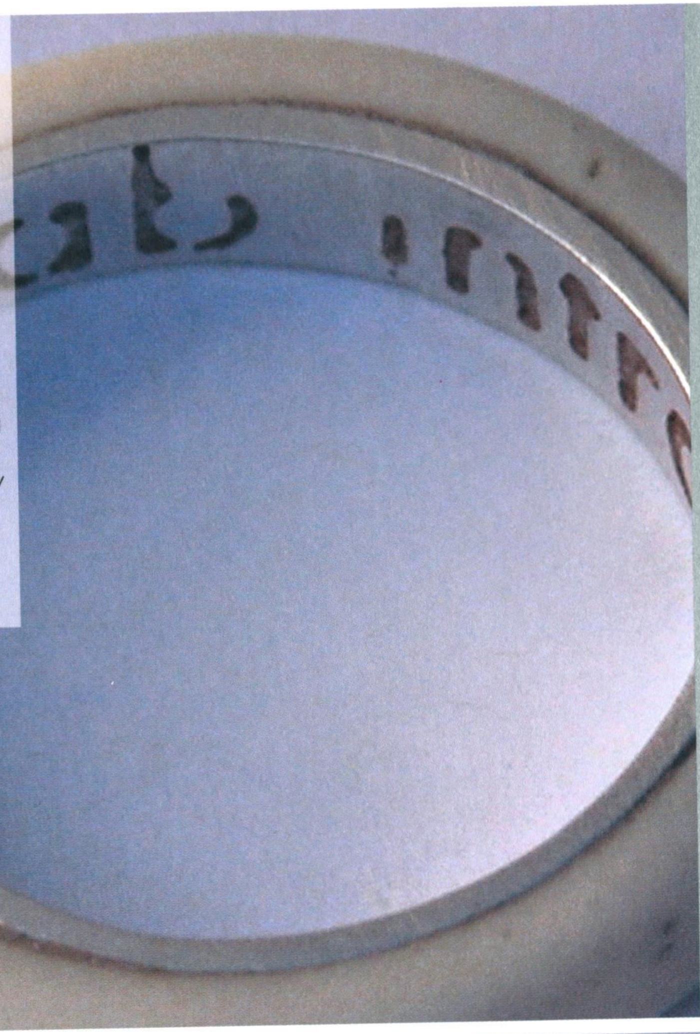
Genetic Trace imagines a future in which people are equipped with specially designed organs that act as perception enhancers, allowing them to collect genetic material from those they encounter. The need for such "complementary sensors," according to Susana Soares, stems from the belief that "advances in genetics, biotechnology, and nanotechnology are changing our very nature and that our evolution now relies on genetic technology rather than natural selection." Cilia in the nails could scrape dead cells from others when shaking hands, while whiskers grown in eyebrows will increase the signals we pick up from the environment. These innovations could allow genetic siblings who may not have met identify each other, for example, and help people collect information to be used as a tool for selective mating. Sniffing Others explores the development of new tools that will allow us to "sniff" other people's genetic codes.

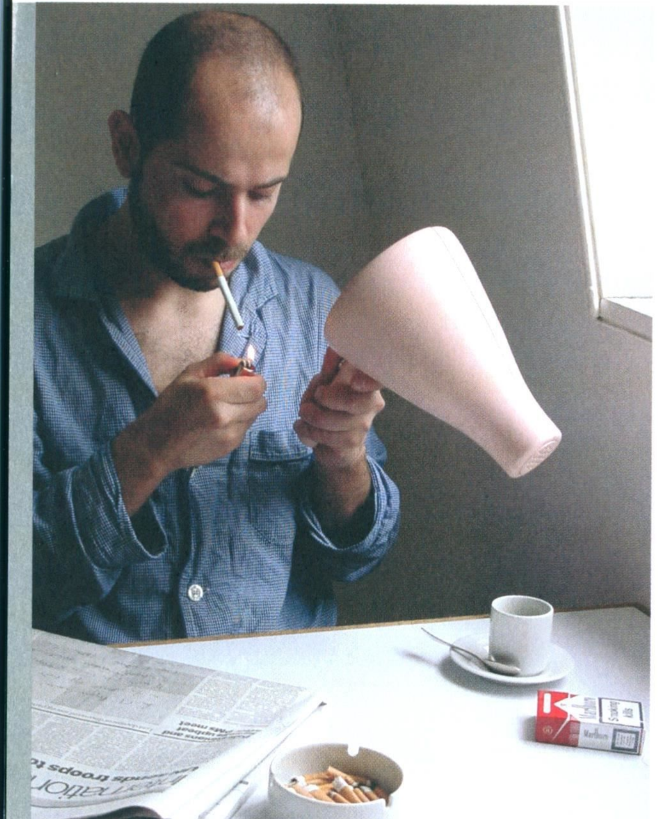


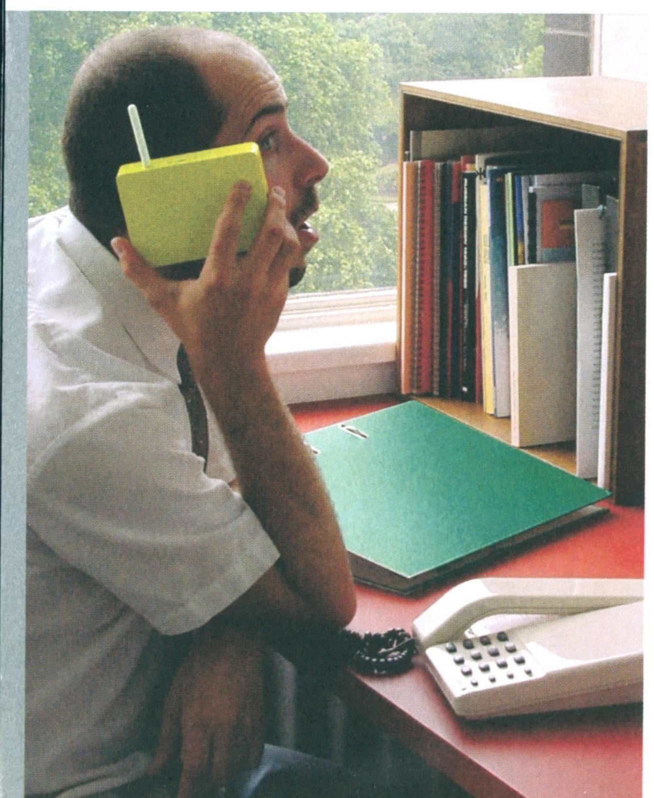


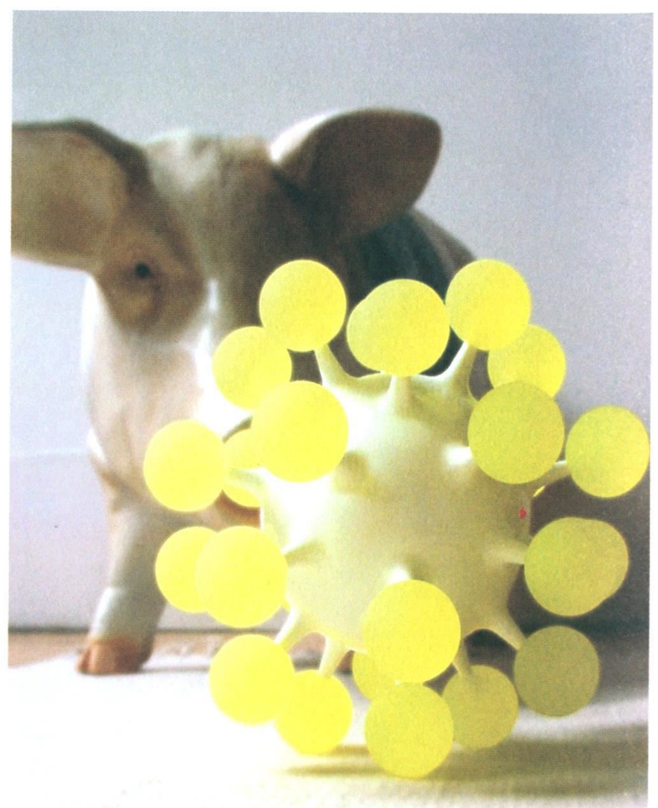
Tobie Kerridge (British, born 1975), Nikki Stott (British, born 1977), and Ian Thompson (British, born 1975)
Design Interactions Department (est. 1989),
Royal College of Art (UK, est. 1837)
Biojewellery Prototype. 2003–07
Cow bone and silver, 1/8 x 1" (0.4 x 2.4 cm)
Prototype by Nikki Stott, UK (2003)

Biojewellery uses design to engage the general public with the processes and technologies of tissue engineering. It redirects this emerging medical technique to provide couples with what its designers call "a unique symbol of their love for one another." A team from the Royal College of Art and scientific researchers at King's College London worked together to create rings for several couples that donated bone cells. The bone tissue was cultured in a laboratory and then seeded onto a bioactive ceramic that acted as a scaffold for the growing cells. When cells began to divide and grow rapidly, they took on the form of the scaffold. The final bone tissue was taken to the designers' studio and combined with precious metals to finish the rings. Each participant received a ring made with the tissue of his or her partner, making it possible for them to literally wear their loved ones on their hands.









Elio Caccavale (Italian, born 1975)
Utility Pets Prototypes. 2003

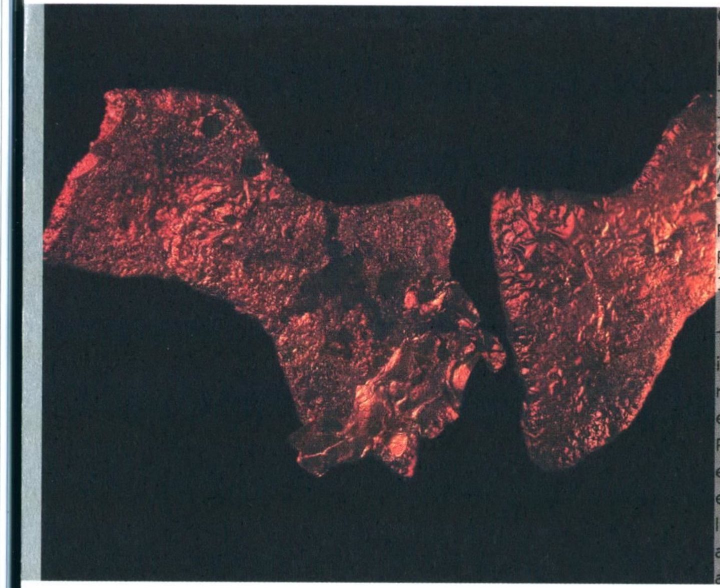
Smoke Eater
Polypropylene, 8 5/8 × 6 1/4 × 11" (22 × 16 × 28 cm)

Toy Communicator
Polypropylene and rubber, radio receiver: 1 × 7 1/8 × 3 3/8" (2.5 × 18 × 8.5 cm); communicator: 8" (20 cm) diam.

Memento Service
Polyurethane and pig snout, 3 1/2 × 4 × 2 3/8" (9 × 10 × 6 cm)

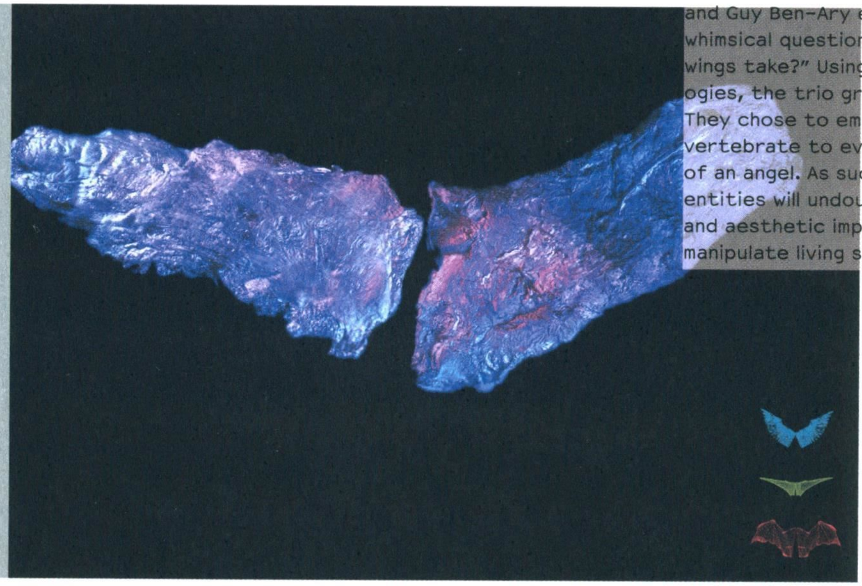
Comforting Device
Polypropylene and pig snout, 1 5/8 × 3 3/8 × 10 5/8" (4 × 8.5 × 27 cm)

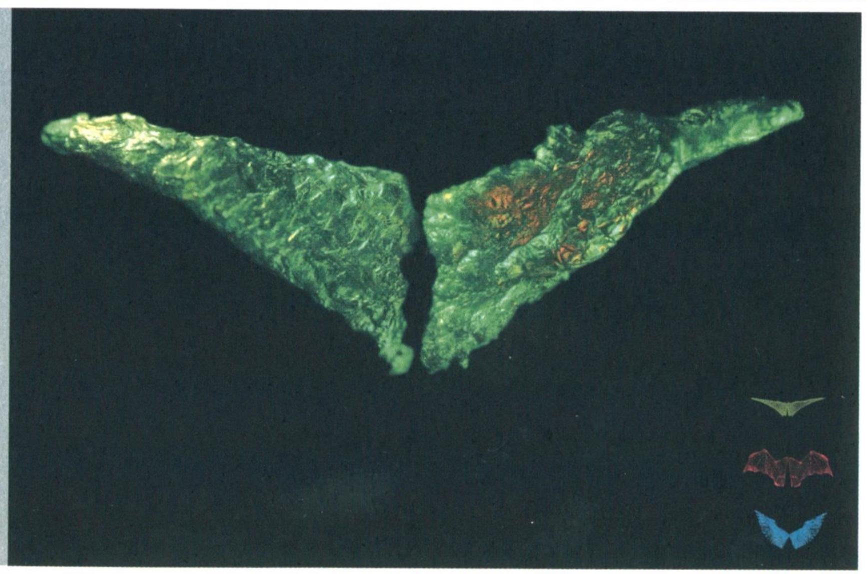
Elio Caccavale's project Utility Pets addresses the various effects that xenotransplantation (interspecies organ transplantation) might have on our lives in the not-so-distant future. Caccavale has imagined a scenario in which the organ recipient maintains a close relationship with the organ donor. Instead of suffering the cruelty of factory farming, the donor, in this case a pig, is taken home and given an enjoyable existence while waiting for the day of the organ replacement. From the unique relationship between an owner and his or her utility pet, a new typology of objects emerges. The Smoke Eater, for example, is a smoke-filtering device that allows the user to smoke at home while protecting the pig from secondhand smoke that could damage its health. The Toy Communicator, a pig toy with a microphone and a radio handset, creates an open channel between animal and human when they are not in the same room. The Memento Service preserves the snout of the utility pet in a clear cast box to be kept as a remembrance, while the Comforting Device, made from the snout of the sacrificed pig, helps people come to terms with the psychological apprehension and contradictory feelings of having a foreign body inside them.



Oron Catts (Australian, born Finland 1967), Ionat Zurr (Australian, born UK 1970), and Guy Ben-Ary (Australian, born USA 1967)
The Tissue Culture & Art Project hosted by SymbioticA, The Art and Science Collaborative Research Laboratory, School of Anatomy and Human Biology, University of Western Australia (Australia, est. 1996)
The Pig Wings Project Prototypes 2000–01
Pig mesenchymal cells (bone marrow stem cells) and PGA and P4HB biodegradable, bioabsorbable polymers, 1/4 x 3/4 x 1 5/8" (0.5 x 2 x 4 cm)

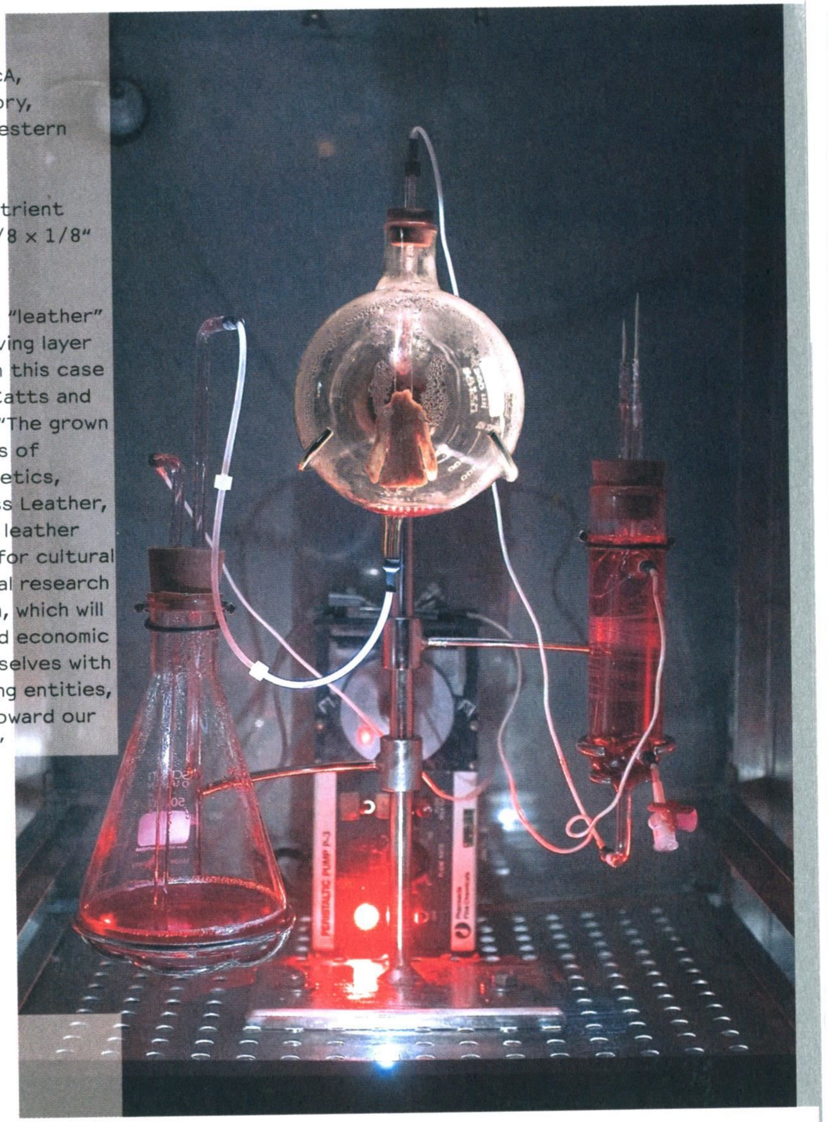
Thanks to their genetic closeness to humans and to advances in biomedical technologies, pigs could one day become precious repositories whose body parts can be easily grown and exchanged with our own. Since 1996, The Tissue Culture & Art Project has used tissue engineering as a medium for artistic expression. The artists create what they call semi-living entities, a new type of object/being artificially designed using living and nonliving biological materials—cells or tissues from a complex organism grown onto synthetic scaffolds and kept alive with technological intervention. Oron Catts, Ionat Zurr, and Guy Ben-Ary employed this technology to answer the whimsical question, "If pigs could fly, what shape would their wings take?" Using tissue engineering and stem cell technologies, the trio grew pig bone tissue in the shapes of wings. They chose to emulate the wings of the Plerosaur, the first vertebrate to evolve for flight, those of a bat, and those of an angel. As such technologies progress, these and other entities will undoubtedly raise questions about the cultural and aesthetic implications of biotechnology's ability to manipulate living systems for human-centered purposes.





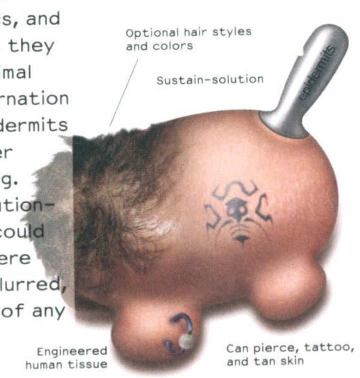
Oron Catts (Australian, born Finland 1967) and Ionat Zurr (Australian, born UK 1970)
The Tissue Culture & Art Project hosted by SymbioticA, The Art and Science Collaborative Research Laboratory, School of Anatomy and Human Biology, University of Western Australia (Australia, est. 1996)
Victimless Leather Prototype. 2004
Biodegradable polymer, connective and bone cells, nutrient media, glassware, and peristaltic pump, coat: 2 x 1 1/8 x 1/8" (5 x 3 x 0.4 cm)

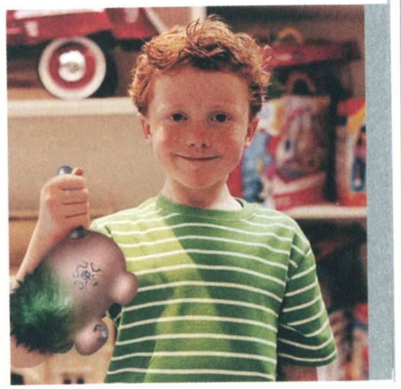
Victimless Leather is the small-scale prototype of a "leather" jacket grown in vitro. Like all in vitro tissue, it is a living layer supported by a biodegradable polymer matrix, only in this case that matrix is shaped like a miniature coat. As Oron Catts and Ionat Zurr, the artists behind the project, explain, "The grown garment confronts people with the moral implications of wearing parts of dead animals for protection, aesthetics, or expression of identity and social class." Victimless Leather, on the other hand, offers the possibility of wearing leather without directly killing an animal as "a starting point for cultural debate." Catts and Zurr believe that "biotechnological research occurs within a particular social and political system, which will inevitably focus on manipulating nature for profit and economic gain." They argue that if the things we surround ourselves with every day can be both manufactured and living, growing entities, "we will begin to take a more responsible attitude toward our environment and curb our destructive consumerism."



Stuart Karten (American, born 1957), Steve Piorek (American, born 1974), and Simon Sollberger (Swiss, born 1973)
Stuart Karten Design (USA, est. 1984)
Epidermits Interactive Pet from the **Cautionary Visions project** Concept. 2006
Living engineered human tissue, 3 x 3 x 4" (7.6 x 7.6 x 10.2 cm)

Following the popularity of Tamagotchis, digital devices endowed with biological and emotional needs that enslaved children all over the world when they were released about ten years ago, come Epidermits. Still only a provocative concept, they are, according to their designers, "fully functioning organisms resulting from advances in tissue engineering, electronics, and fuel cell research. They don't feel pain, they don't think, they just follow a complex set of algorithms. They require minimal maintenance and can be stored in a state of forced hibernation in a standard refrigerator." Users can customize their Epidermits with different body, skin, and hair selections, and further personalize them through tanning, tattooing, and piercing. Epidermits are part of Stuart Karten Design's project Cautionary Visions, which considers humorous aberrations that could stem from future technological advances. "In a world where boundaries between real and artificial are increasingly blurred, comes the toy that will truly confuse kids and rob them of any remaining sense of what is natural," the designers say.



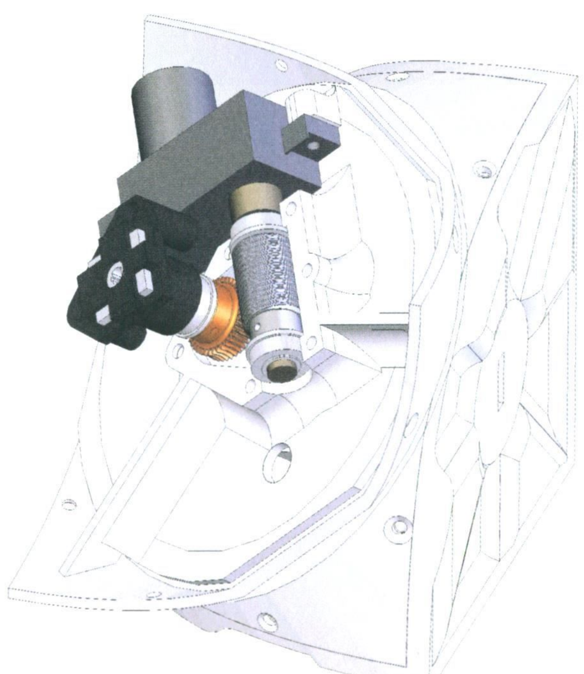


Viktor Zykov (Russian, born 1979), Stathis Mytilinaios (Greek, born 1980), and Hod Lipson (Israeli, born 1967)
Computational Synthesis Lab (est. 2001), Cornell University (USA, est. 1865)

Molecubes functional robots 2003–04
Somos 9120 epoxy photopolymer, 4 × 4 × 4" (10 × 10 × 10 cm)
Manufactured by ProtoCall, LCC, USA (2004)

The creators of Molecubes aim to use advances in nanotechnology to transpose the very basic biological process of self-reproduction to inorganic objects. "Self-reproduction," they explain, "is a process whereby a physical system is capable of producing an autonomous, functional copy of itself. The copy, by definition, should also be capable of self-reproduction." This principle is central to biological life but had yet to be exploited in machine design. "Long-term physical survivability in robotics is achieved through durable hardware," continue the Cornell scientists. "In contrast, most biological systems are not made of robust materials; sustainability and adaptation are provided through processes of self-repair and, ultimately, self-reproduction."

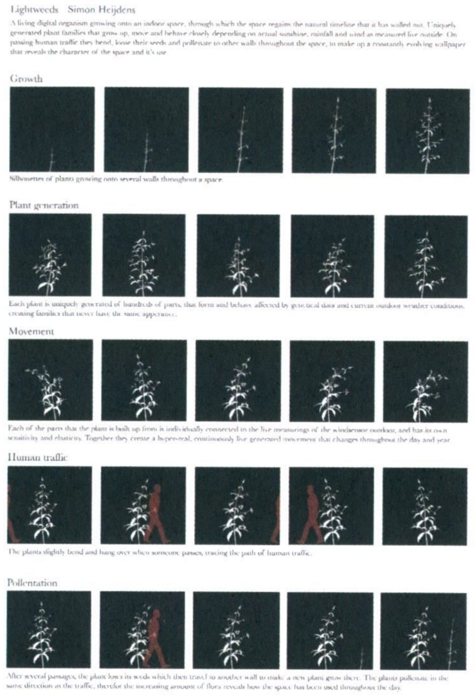
The Computational Synthesis Lab has built a set of eight functional modular robots called Molecubes, "composed of actuated modules equipped with electromagnets to selectively control the morphology of the robotic assembly," in order to demonstrate artificial self-reproduction. The stop-motion sequence seen here shows autonomous self-reproduction of a four-module robot: the top three rows show the first generation of self-reproduction, while the bottom three rows show the second generation. This feat could have an application in self-sustaining robotic systems used in space exploration and other hazardous environments, where conventional approaches to long-term maintenance are not feasible.



Tomáš Gabzdil Libertíny (Slovak, born 1979)
Studio Libertiny (The Netherlands, est. 2006)

The Honeycomb Vase "Made by Bees" Prototype. 2006
Beeswax, 9 × 5 1/2 × 5 1/2" (23 × 14 × 14 cm)

For his Honeycomb Vase project, Tomáš Gabzdil Libertíny constructed vase-shaped beehive scaffolds (to be removed at the end of the process) and then let nature take its course: a group of bees goes to work building a hive, layer by layer, in the same shape as the scaffold. The work may take from two to ten days, depending on the weather, the season, the size of the colony, and the colony's need to expand. Because bees are driven to impress the mother-queen with increased building activity, the most productive were hives with a new queen. It took one week and approximately forty thousand bees to complete this particular honeycomb vase. The process, which the designer calls "slow prototyping" in an ironic counterpoint to today's rapid manufacturing technologies, poetically brings this natural phenomenon full circle, starting with the flowers that enabled the bees to produce it and ending with a vessel that is meant to contain those flowers.



Simon Heijdens (Dutch, born 1978)
Lightweeds wall installation 2006
Self-developed software, dimensions variable

As we spend most of the day in fixed spaces with regulated climates and artificial lighting, nature is becoming more and more scarce in our daily lives. Simon Heijdens's Lightweeds is a "living digital organism" that "grows" onto the walls and floors of an indoor space, restoring a natural cycle. The projected silhouettes of uniquely generated plant families grow, move, and behave according to current weather conditions and the way the space is used. Each plant is made of hundreds of parts, each with its own sensitivity and elasticity and individually connected to a live sensor outdoors that measures variables such as rainfall and sunshine. All parts together create a continuously evolving wallpaper that changes throughout the day and the seasons. The plants also trace the path of human traffic; they slightly bend and lose their seeds when someone passes, pollinating nearby walls in the direction of the movement and the breeze it generates. Over time, the proliferation of flora reveals how the space has been used, keeping track of our everyday activities and biorhythms.

Rachel Wingfield (British, born 1978) and
Mathias Gmachl (Austrian, born 1974)
Loop.pH (UK, est. 2003)
Biowall Prototype. 2006
Fiberglass and plants, dimensions variable

Biowall is a woven scaffold that can become a partition wall when colonized by living plants. In their attempt to create a modular building system based on structures found in nature, designers Rachel Wingfield and Mathias Gmachl looked at several geometries, such as Penrose tiles (pairs of shapes that tile the plane only aperiodically) and Synetic structures (an airy and lacelike basketry of thin arcs patterned in curvilinear triangulation). They finally opted for a dodecahedron weave of twelve small circles made of one-millimeter fiberglass rods, around which plants grow and creep. The designers explain that the curved elements "are tangentially joined, so that forces are distributed in a near continuous manner. The construction is based on the principle of self-similarity, translating a biological construction from the nanoscale to the macroscale. It can be seen in our natural environment in the formation of bubbles, living cells, and water molecules." Loop.pH uses technology to create objects "inspired by botanical life that reflect and communicate environmental changes. As it becomes increasingly difficult to read the signs of our natural environment in urban, built landscapes," the designers resort to plants "as the most sophisticated of sensors."

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The installation was indeed a challenge even for our heroic Department of Exhibition Design and Production. Jerry Neuner, Director, and Lana Hum, Production Manager, designed the installation, and their incomparable crew built it, as usual, to perfection. My gratitude goes to them and to Charlie Kalinowski, Media Services Manager, A/V, and to K Mita, Director, Technology Services, and his whole team, who performed miracles in order to ensure that the technology worked smoothly and effectively. The exhibition also lives on the Web, thanks to the magic touch of Allegra Burnette, Creative Director, Digital Media, and Shannon Darrough, Senior Media Developer, Digital Media.

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Lastly, I would like to thank the person with whom I shared this adventure, Patricia Juncosa Vecchierini. Yet another adventure, I should say, and once more she has proved to be the most valuable partner. I am very lucky to have had so many chances to work with her.

Design and the Elastic Mind celebrates the endless and restless curiosity of human beings and praises design as an expression of creativity and an affirmation of life. For this reason, I would like to dedicate this book and this show to the late Herbert Muschamp, who certainly knew what I am talking about.

Paola Antonelli
Senior Curator, Department of Architecture and Design

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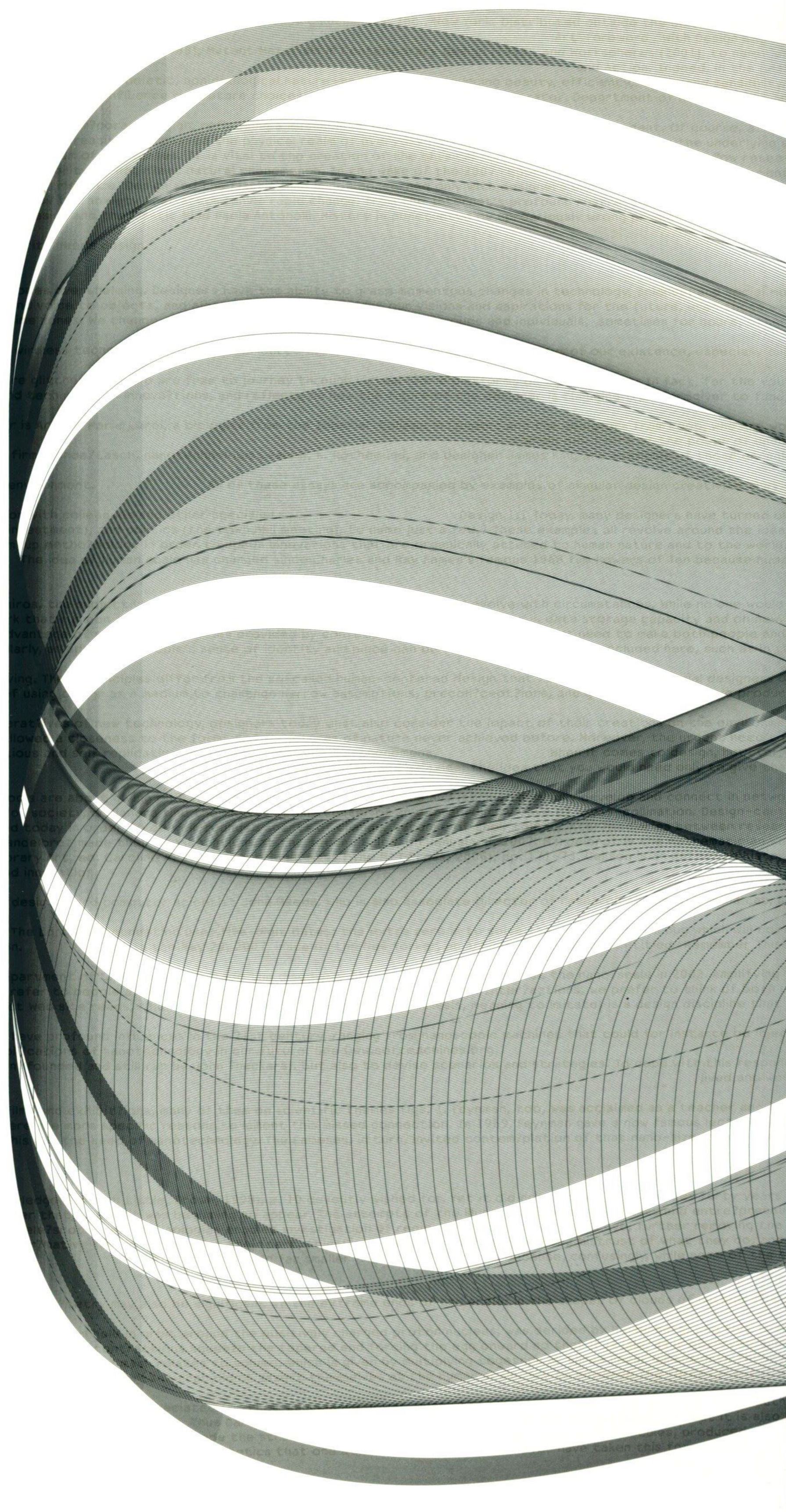
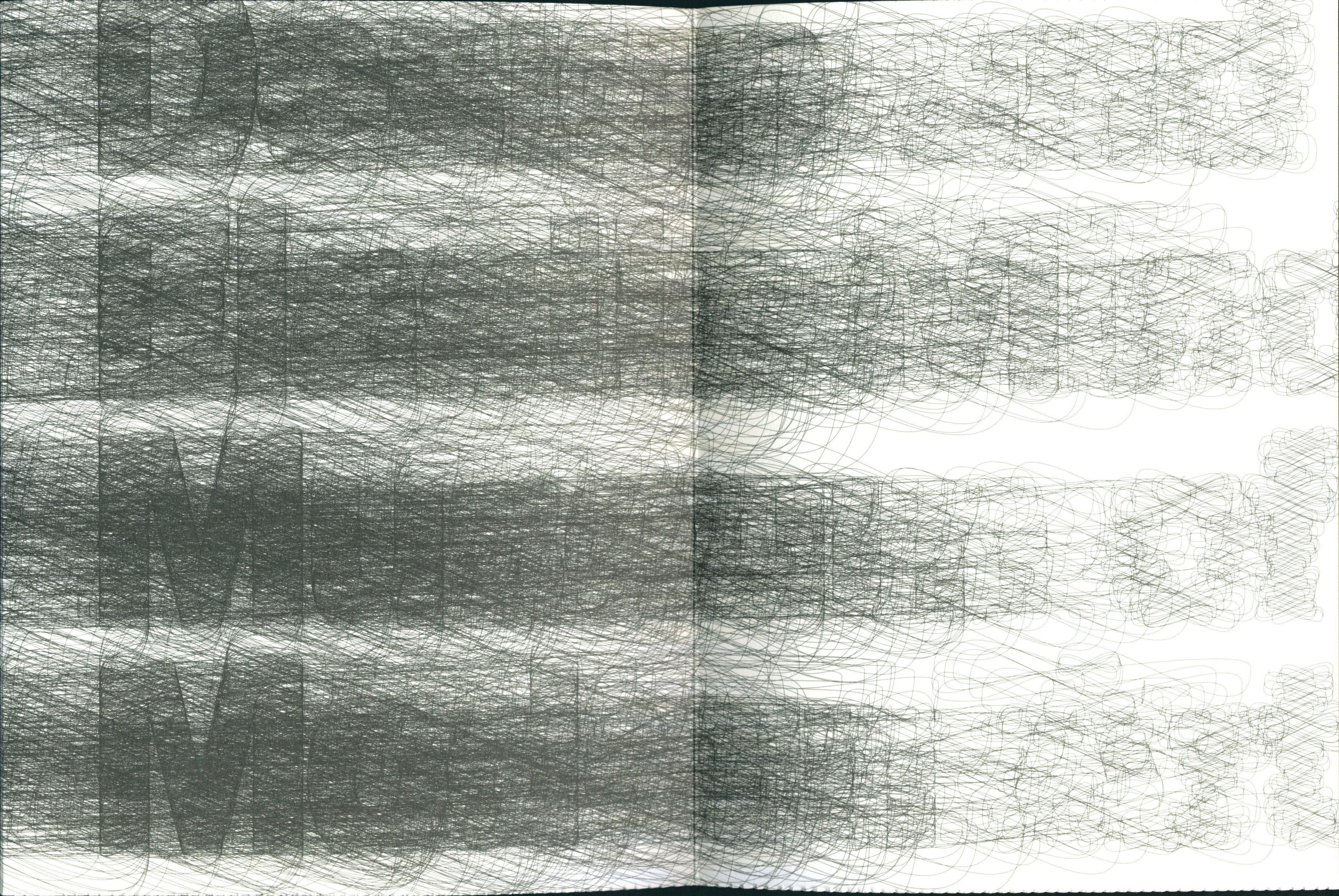
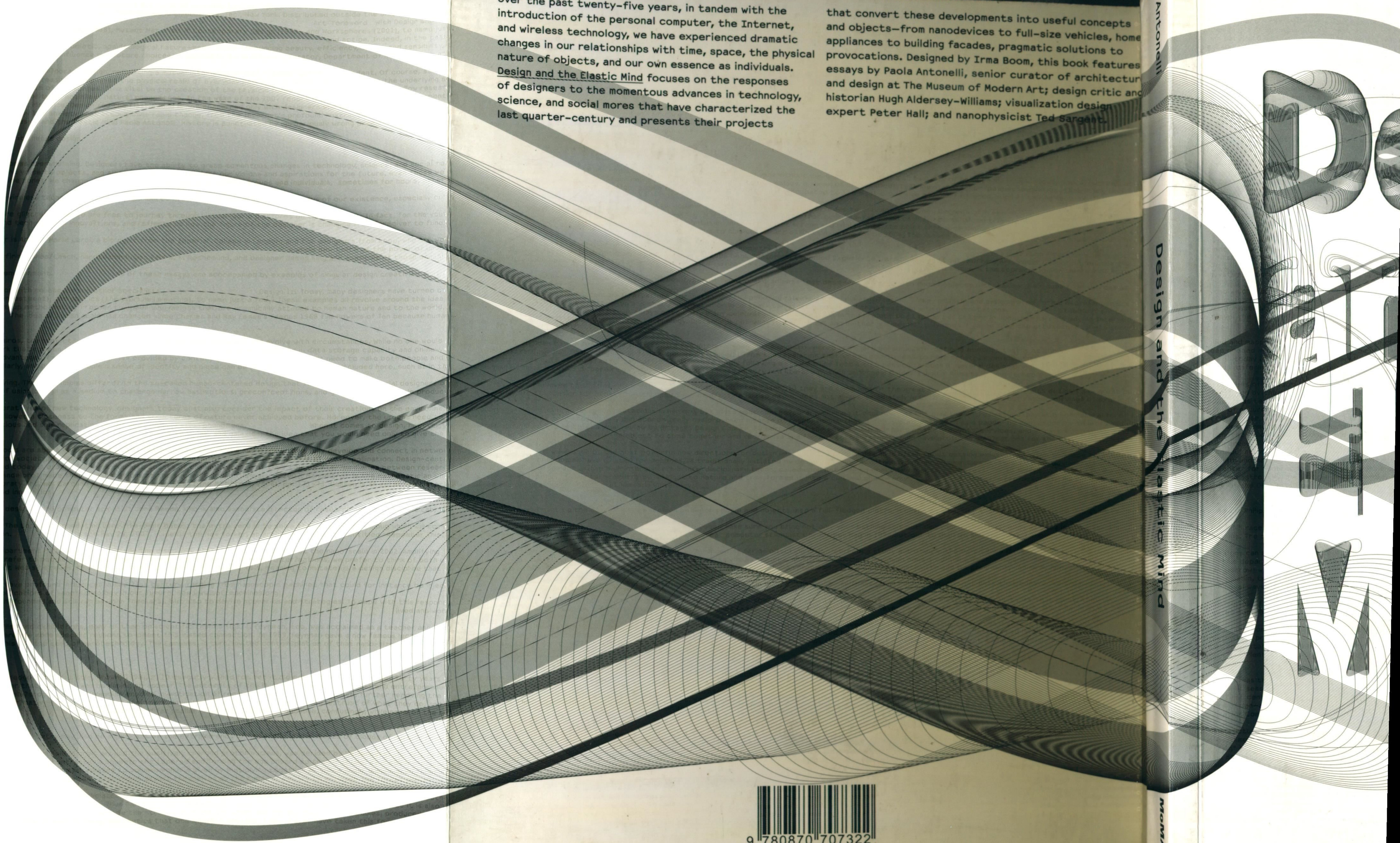
Design and the Elastic Mind





Over the past twenty-five years, in tandem with the introduction of the personal computer, the Internet, and wireless technology, we have experienced dramatic changes in our relationships with time, space, the physical nature of objects, and our own essence as individuals. Design and the Elastic Mind focuses on the responses of designers to the momentous advances in technology, science, and social mores that have characterized the last quarter-century and presents their projects that convert these developments into useful concepts and objects—from nanodevices to full-size vehicles, home appliances to building facades, pragmatic solutions to provocations. Designed by Irma Boom, this book features essays by Paola Antonelli, senior curator of architecture and design at The Museum of Modern Art; design critic and historian Hugh Aldersey-Williams; visualization design expert Peter Hall; and nanophysicist Ted Sargent.



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