REVOLUTIONS – IN – MAKING

Now that scientists are developing mindboggling new materials every year, what does it mean to be a designer and maker in the 21st century?

IN NOVEMBER 1989 DON EIGLER, A PONYTAILED SCIENTIST at IBM's Almaden Research Lab in California, became the first person to design using atoms. Working for over 20 hours, he moved 35 xenon atoms at a temperature of minus 452 degrees Fahrenheit to create the iconic IBM logo—designing at a size of 660 billionths of an inch. This was not a parlor trick. As most designers grappled with controlling matter in the macro world, Eigler was the first to break the nanoscale barrier in design by making letterforms about 75,000 times thinner than the average human hair—at a nanometer (one billionth of a meter).

About the time that Eigler was designing with atoms, something else happened in a parallel nanoscale universe. In August 1990 the US government formally announced its intention to sequence the entire human genome—our 23 pairs of chromosomes, involving a total of 3 billion base pairs. It was the biological equivalent of shooting for the moon. In April 2003 the results were published at a total project cost of around $3 billion, opening new worlds of possibility for ongoing research into the nature and function of genes. Today, the cost of sequencing the entire human genome is approaching $1,000.

In 1990 we also passed another milestone. Working at CERN, the European Organization for Nuclear Research in Switzerland, computer scientist Tim Berners-Lee proposed the hypertext system that was the beginning of the Internet as we know it. In other words, within the period of just one year, three transformative currents in technology—nano-, bio- and info—began to move. Within the decade, they increasingly began to converge, changing the possibilities for innovation and design. As this convergence plays out over the next two to three decades, old distinctions between science and engineering, design and production, the studio and the lab, and the organic and inorganic will become increasingly irrelevant. The world of bits (code) and atoms (things) will merge.

text by ***David Rejeski*** *73 ID*
illustrations by ***Amanda McCorkle*** *98 GD*

When I arrived at RISD in 1970 to study industrial design, I entered an analogue world complete with vinyl records, vacuum tubes and fax machines. It would be another year before the first email was sent and 12 years before compact disks were introduced. I spent weeks trying to master hand-cut dovetail joints, painstakingly render concept drawings or draw invertebrates in the Nature Lab, never imagining that nature itself would become a design medium. Four decades later, we are moving into a world where we can design atom-by-atom and gene-by-gene and quickly share production code via a rapidly expanding global network. The design space that I inhabited existed at a scale of one millionth of a meter and up, not *one billionth of a meter and down*. This shift in direction of three decimal points will change the way we make things forever.

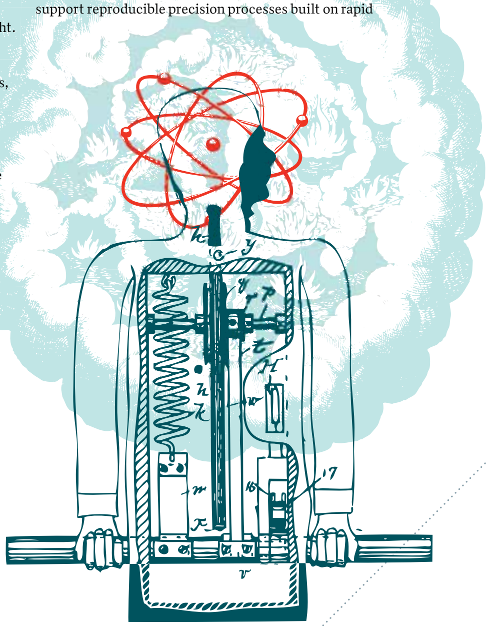
As Stan Williams at Hewlett Packard Labs observed, "Every industry that involves manufactured items will be impacted.... Everything can be made in some way better—stronger, lighter, cheaper, easier to recycle—if it's engineered and manufactured at the nanometer scale."

For instance, we were taught to think about carbon in two basic forms: diamonds and graphite. But in the new nano world, scientists are producing many more forms of carbon, including single- and multi-walled nanotubes, nanocones, fullerenes and graphene—materials with amazing properties from a design standpoint. The width of a strand of DNA, carbon nanotubes are about 100 times stronger than steel at one-sixth the weight. Changing shape and size at a nanoscale allows us to take common materials and create variants with completely new properties—designing new optical and surface characteristics, changing conductivity or reactivity, or dramatically boosting strength-to-weight ratios.

Imagine entering a world of programmable matter governed by another set of laws: quantum mechanics instead of the Newtonian physics we all learned in high school. At the turn of this century, nanoscientists started down this path by building so-called 'passive' materials designed to produce certain macroscale properties. Since 2005 they have moved into 'active' materials designed to respond and adapt to their environments. The next step—started around 2010—is to assemble these active parts into more complex systems capable of self-assembly and with highly programmable functions—matter modeled *on* biology and integrated *with* biology. The National Science Foundation predicts that next year we will enter the fourth phase of the nanotechnology revolution: the ability to create molecular nanosystems 'by design,' building from the bottom up using nanoscale parts with specific structures and roles.

For centuries designers have manipulated materials by hand, first adding tools to their repertoire, and then machines. As Bauhaus director Walter Gropius once said, "[we] accept the machine as the most modern means of design." As designers we worked with what we were given and exploited new materials that appeared on the scene, from lightweight metals like aluminum to thermoplastics. Changing the properties of matter was not in the cards, let alone changing the properties of nature (normal evolution was simply too slow and our control of biology too unpredictable and costly).

Today, as Neri Oxman at MIT's Media Lab has observed, "the biological world is replacing the machine as the general model of design." The emerging field of synthetic biology promises to make biology easier and faster to engineer. Many of the capabilities that enabled the last industrial revolution are finding their way into biology: the standardization of parts, interchangeability and modularity. These changes support reproducible precision processes built on rapid



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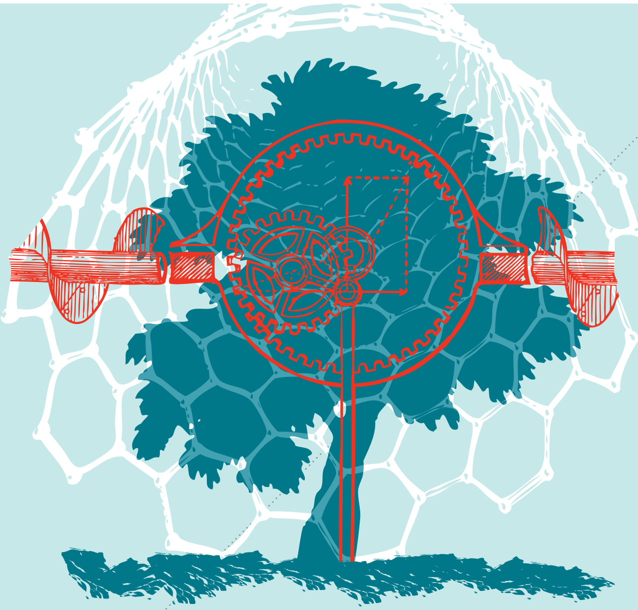

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prototyping, compressed design-build-test cycles and controlled variability. As the hallmarks of flexible industrial production systems, these replicate the processes that have enabled the design profession to flourish for decades.

An open-source biological parts catalogue is already online (partsregistry.org), offering more than 20,000 components with a broad range of functions—from biosynthesis to odor production and sensing. The catalogue is creating a plug-and-play infrastructure for biological design and construction and is growing at 1,500 parts annually. Using these parts as a starting point, hundreds of college students per year now participate in iGEM, an international competition to create genetically engineered machines (igem.org).

Cells, the basic building blocks of life, just happen to be very good chemists. We can already use 3D printers to make parts for a chair, but how about growing a chair by improving the characteristics of cellulose secreted by the gram-negative bacterium *Acetobacter xylinum*? Angela Belcher at MIT has built highly efficient rechargeable batteries by using viruses that have been engineered to coat themselves with iron and then attach to ultrathin carbon wires to form a conductive network. Scientists at Columbia University recently created miniature biobots from hydrogels (similar to contact lens material) that are powered by cardiac cells, not batteries or motors.

These transformational and converging technologies raise a fundamental question: What does it mean to be a designer in the 21st century? As culture historian C. P. Snow once put it, "Technology . . . is a queer thing. It brings you great gifts with one hand, and it stabs you in the back with the other." If we design at the level of life itself—and design *with* life—things can go wrong and continued vigilance will be required to mitigate unintended consequences.

Nanotechnology has already raised concerns around product recyclability, human toxicity and environmental impacts. The introduction of synthetically engineered organisms into the environment raises valid questions concerning the stability of synthetic DNA, its persistence in the environment, the fate and transport of synthetic organisms, horizontal gene transfer and a lack of adequate methods to even assess risks, much less deal with new, unexpected problems.

Historically, changes in the means of production have had profound effects on settlement patterns, labor, education, transportation systems, public health and the environment. At a more fundamental level, these techniques raise ethical issues and questions about our relationship to technologies that can simplify, accelerate and abstract production—separating our head and our hearts from our hands.

The science fiction writer Arthur Clarke once noted that, "Any sufficiently advanced technology is indistinguishable from magic." We are entering a magical world. But we arrive on this new frontier burdened with old tools and maps, meaning we need to sort out which skills will work and which will not, and where we're most likely to be fooled by the magic or the magicians. We need to reexamine our intentions, our ethics and ultimately, our role as designers —and the biggest challenge we face today is where and how to start. ■