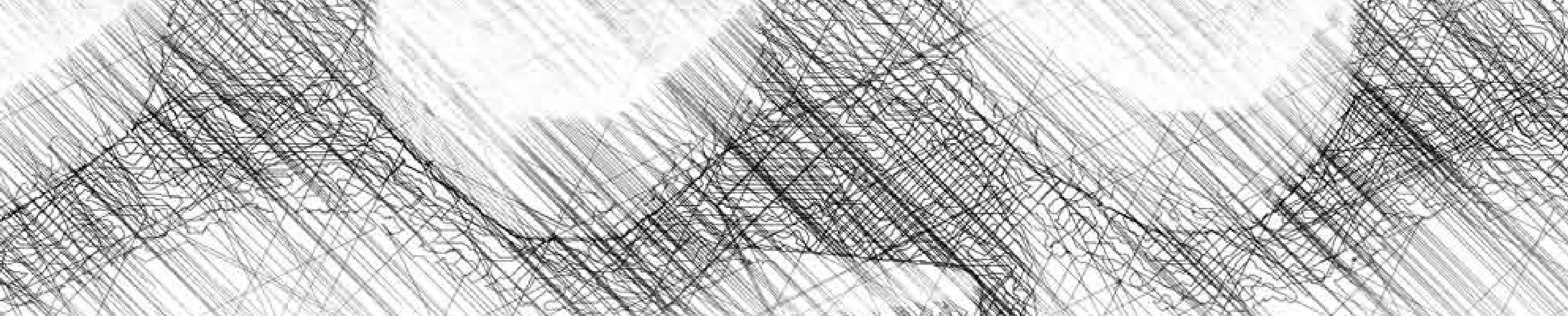


Archfarm

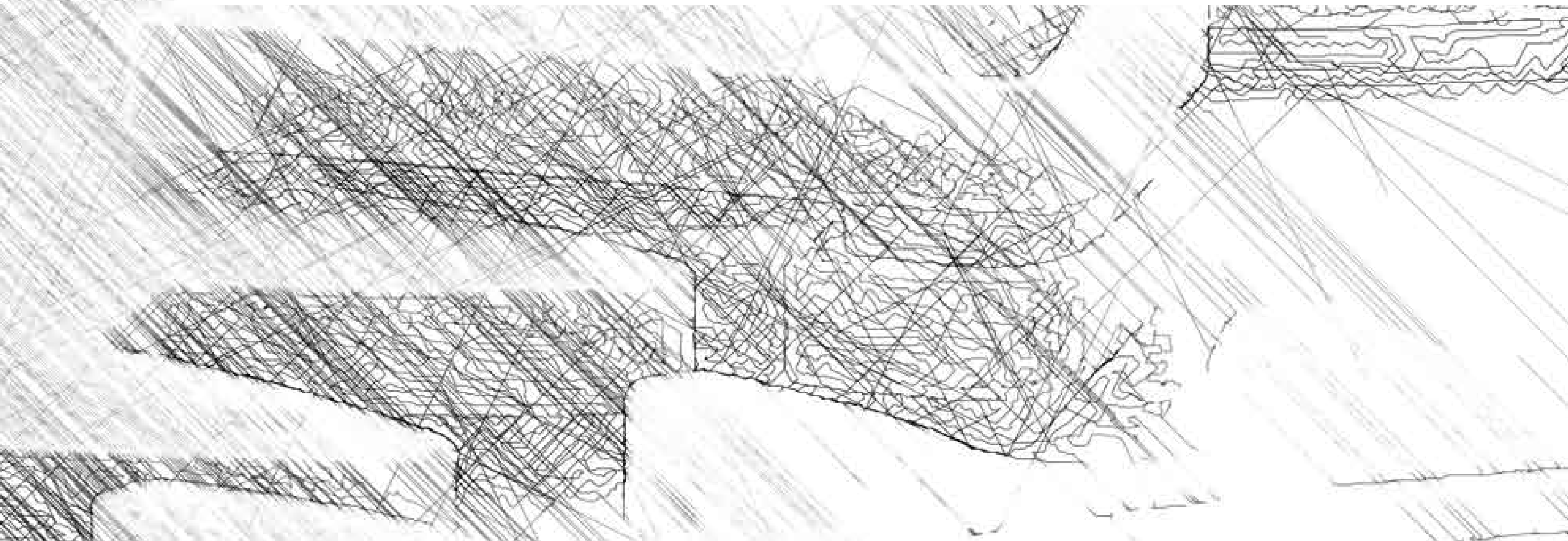
Non-periodical fascicles on architecture

ISSUE N°9 ‡ NOVEMBER 2006 ‡ ENGLISH EDITION

www.archfarm.org

SMALL IS BIG: THE DAWN OF A NEW EPOCH

PETER YEADON



www.Archfarm.org N°9 PAPER VERSION — ISSN: 1885-6527

One of the more significant technological advances of this century is being developed at a tiny scale, invisible to the human eye. Nanotechnology, though, can fundamentally change the ways we design, envision and build architecture.

Theorist and researcher Ralph Merkle wrote in the middle nineties: “Indeed, just as we named the Bronze Age, the Iron Age, and the Silicon Age after the most advanced materials that humans could make, we might call this new technological epoch we are entering the Diamond Age”

In September 2005, Dartmouth College in New Hampshire, USA, announced that their researchers had constructed the smallest robot on the planet. The tiny device was as wide as a single strand of human hair, and much shorter than the period at the end of this sentence. At that time, Bruce Donald, a Professor who led the research at Dartmouth, noted that the machine was significantly smaller than previous untethered robots that were controllable. “When we say ‘controllable,’ it means it’s like a car; you can steer it anywhere on a flat surface, and drive it wherever you want to go” Donald said. “It doesn't drive on wheels, but crawls like a silicon inchworm, making tens of thousands of 10 nanometer steps every second. It turns by putting a silicon 'foot' out and pivoting like a motorcyclist skidding around a tight turn."[1]

Measuring only 60 by 250 micrometers (one micrometer is one millionth of a meter), building the microbot was a truly astonishing feat. However five weeks later, scientists at Rice University in Texas announced that they had also developed a tiny robot that could drive upon a surface.[2] Their robotic device, which they called a *nanocar*, was made of a single molecule and was only a billionth of the dimensional area of the microbot that was built at Dartmouth. At three by four nanometers (one nanometer is one billionth of a meter), the Rice nanocar is about as wide as a single DNA molecule. And it looks like a car. It has a chassis with two axles and four wheels made of *buckyballs*, tiny spheres that consist of 60 carbon atoms each.

1
www.dartmouth.edu/~news/releases/2005/09/14.html

2
www.media.rice.edu/media/NewsBot.asp?MODE=VIEW&ID=8448&SnID=327288878

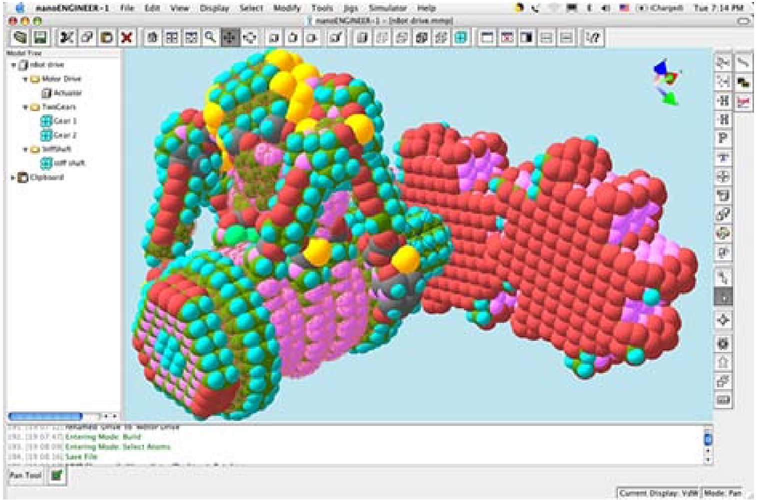
3
www.physorg.com/news64081416.html

4
www.nanotechweb.org/articles/news/4/10/3/1

External forces power both the Dartmouth microbot and the Rice nanocar, so the analogies to road vehicles are not useful for enabling us to envision how they work. Dartmouth's microbot was powered by a grid of tiny electrodes that are embedded in the surface that it walks upon. The Rice nanocar didn't have a motor, so it had to be pulled across the surface with the infinitesimal tip of a scanning tunneling microscope's probe. But by mid April of this year, Rice researchers announced that they we able to add a rotating molecular motor to their nanocar, so that the motor rotates 360° in one direction when light strikes it, driving the car forward.[3] The molecular engine wasn't entirely of their design; the researchers at Rice modified a molecular motor that was originally developed by Ben Feringa's group at the University of Groningen in the Netherlands.[4]

I live in an old, six-storey walkup in Manhattan. The fire escape that clings to the building is rusting and the brick walls shake when trucks roll down our street. The new buildings that are being constructed around me involve massive machines and a mass of workers. Unlike the microbot and nanocar, these are things that I can see and hear. What could such minuscule inventions possibly have to do with the making of architecture and cities? A nanometer is about a million times smaller than the diameter of a pinhead, and a thousand times smaller than the length of a typical bacterium. The researchers at Rice University are working on building a nanotruck that can ferry little molecules from one place to another. How could these tiny achievements possibly have any bearing on the work of an architect?

The advent of nanotechnology unleashes an entirely new age, our age, where we have achieved the domestication of atoms. Ours is an age of molecular manipulation, where common distinctions be-



Yeadon is using HyperChem and Nano Engineer-1 software to develop the *nBots* project. Image courtesy of Peter Yeadon

tween natural and artificial are no longer certain. We routinely design new forms of life and are fundamentally altering the properties of matter, and our relationship to it. Nanotechnology is concerned with the study and design of molecular and atomic phenomena. As Christine Peterson, President of the Foresight Institute, stated at a U.S. House of Representatives Committee on Science meeting in April 2003, "the ultimate goal of nanotechnology is the complete control of the physical structure of matter, all the way down to the atomic level."[1] Researchers, such as those at Rice University, have already shown how nanotechnology enables us to design and build matter from the bottom up, atom by atom, molecule by molecule. And, as in previous technological epochs, architects will soon find the new technology entirely unavoidable. It will significantly change the substance of architecture and it will revolutionize the way in which we make architecture.

1 www.house.gov/science/hearings/full03/apr09/peterson.htm

It is erroneous to think that nanotechnology is some sort of futuristic science that might arrive at our doorstep in 20 or 30 years, it is already here. During the past 15 years, more than a dozen Nobel prizes have been awarded for nanotechnology research. Most universities in the world are involved in nanotechnology research and engineering, and new nanotech products are already being incorporated into architecture. One of the challenges in understanding nanotechnology as an industry lies in the fact that it is not really a technology; it is technologies. It is a significant part of many industries. Like electricity, it is pervasive. Additionally, nanotechnology operates at the molecular scale, so it is an integral part of many disciplines (including physics, chemistry, biology, computer science, and materials science) and is not easily defined as a discipline in and of itself; rather, it is an area of research that is shared by many scientific fields. If you were to ask an assortment of scientists what nanotechnology is, you would receive an equally broad range of definitions. The word itself is derived from three Greek words: nano (dwarf or tiny), techne (craft or skill), and logos (reasoned thought). Hence, the word can be interpreted to mean applying science to the craft of making at a tiny scale.

Although physicist Richard P. Feynman is often attributed with having predicted the age of nanotechnology, during his famous 1959 lecture titled *There's Plenty of Room at the Bottom*, it was not until some decades later that nanotechnology appeared as a scientific pursuit. The word itself, nanotechnology, was nonexistent until it emerged within the scientific community during the 1980s. The word was popularized when physicist K. Eric Drexler used it repeatedly in his book, *Engines of Creation: The Coming Era of Nanotechnology*, in 1987. Drexler was looking for a word that would encapsulate future technological systems that would operate at the molecular level; that is to say, at many times smaller than the scale of the microtechnologies found in microprocessors. At that time, microtechnology was a common term applied to systems that manipulated matter at the scale of micrometers. Appropriately, Drexler coined the term nanotechnology to describe molecular systems that would be designed and built at the scale of nanometers.

Both Drexler's and Feynman's texts provide a marvelous introduction to the history and study of nanotechnology. Feynman's talk challenged physicists to think small, and Drexler's *Engines of Creation* excited the imagination in terms of the potential of nanoscale science and technology. Drexler's book outlined a future where we would be able to design and build atomically precise machines, tiny robotic systems that could sustain the human body and even assist in the creation of cities. Its implications were enormous, touching on materials science, medicine, engineering, economics, computers, travel, and new opportunities for designers.

Today, the term nanotechnology is often applied to the many products that have been created by researchers that have altered the molecular structure of matter. The emerging nanotech products that are applicable to architecture and related design disciplines, alone, are too numerous to detail in this short article. Websites like *nanoarchitecture.net* post at least a dozen fresh innovations every week, including materials like super insulates, pollutant-resistant coatings, shape-shifting polymers and alloys, and highly effective filtration membranes. Some material products are designed to perform a specific task and some materials, such as carbon nanotubes, can be engineered to perform multiple tasks. Nanotubes are stronger than steel and *kevlar*, can conduct or insulate electrical current, can harvest energy from light, can emit light, can filter pollutants, can disassemble a molecule and transport it to another location, and can bind with other molecular structures to form sophisticated composites with novel properties; nanotubes can even self-assemble, meaning they build themselves.[1]

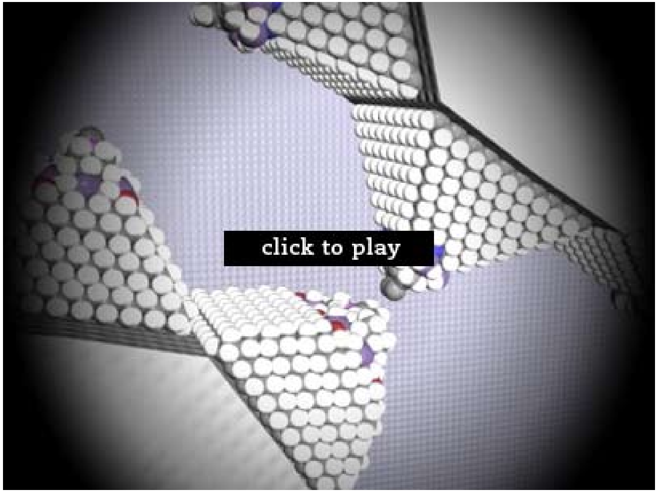
Being able to instruct a collection of molecules in a solution to self-assemble, building up molecule-by-molecule into a predictable material, is a remarkable achievement. At the same time, it is not an entirely surprising phenomenon given the fact that our own bodies are constantly creating and assembling molecules. But it has led to some dramatic thoughts on the possibility of creating architectures that self-assemble. Architect John Johansen, author of the book *Nanoarchitecture*, envisions a future where architecture is grown from a seed that has the support of a chemical vat. Here, there is an obvious analogy to the natural process of self-assembly and a peculiar pursuit of architecture as a planted organism. However fantastic Johansen's proposition, there is a more credible plan afoot which will enable nanotechnology to revolutionize the way in which we design and make architecture. It leads us back to Drexler's early thoughts on atomically precise machines, and back to the Rice nanocar I mentioned at the beginning of this article.

There are already a number of molecular devices that offer us the control and manipulation of matter at the molecular and atomic level. Scientists have developed molecular motors and switches, and are working on pumps, gears, and bearings. The California Nanosystems Institute has developed a molecular machine that works as a nanoscale elevator,[2] and the Dutch recently created a molecular machine that sorts molecules.[3] As I write this, researchers at New York University are announcing that they have been able to create DNA robots that self-assemble into an array of working machines, analogous to a factory assembly

1 www.nanoarchitecture.net

2 nanotechweb.org/articles/news/3/3/14

3 www.mb.tn.tudelft.nl/vandenheuvel-2006-science.pdf



Productive nanosystems, from molecules to superproducts
2006, 4'55"
Lizard Fire Studios
(www.workoutcompanion.com/nanofact/NanoFactory-Final_1.1_640.mov)

1
msnbc.msn.com/id/13463422/

2
cr.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&ARTICLE_ID=246107&VERSION_NUM=2&p=15

line.[1] The tiny devices grab various molecular chains and fuse them together, building materials one molecule at a time.

Those involved in this kind of research say that most of us that are currently in the workforce will see the early effects of molecular manufacturing in our lifetimes.[2] We will see the dawn of nanofactories, robust molecular machine shops that harvest atoms from a reservoir of molecules to make sophisticated materials, devices, and systems one atom at a time (see illustration at left). As an evolutionary progression from current desktop printing and rapid prototype 3D printing processes, nanofactories will offer us personal, desktop manufacturing capabilities. We will be able to make whatever we desire, including things that don't exist yet, from the bottom up; and if we can make anything, atom-by-atom, molecule-by-molecule, then we can also make exact copies of things that exist, including machines that replicate other machines, and nanofactories that make other, more sophisticated nanofactories. It is this exponential fabrication capability that makes molecular manufacturing attractive. It would be precise and cheap. The first few nanofactories will be expensive, but declining costs will rapidly emerge as the machines self-replicate; one machine builds a copy of itself, those two build two more, those four build four more, etc.

As I mentioned, nano-technology can be interpreted to mean applying science to the craft of making at a tiny scale. Naturally, the craft of making is central to the study and practice of architecture. It is an activity that has accelerated through the industrial revolution, the advent of electricity, the machine age, the space age, and the information age. Nanotechnology will leave its own mark on the architecture of our age by fundamentally altering our technologies and techniques; as nanoscale science and engineering advances toward its well-defined goal of complete control over all matter, it will utterly transform the means of architecture. It is impossible to predict how sweeping that transformation will be once molecular manufacturing becomes possible; however, I believe it will be swift, extensive, and irrevocable. I once met an academic that stressed, architects need to return to the source for inspiration: Greek Architecture! Mass is a manifestation of energy. That is the source.

About the author

Peter Yeadon is an architect that is known for his expertise in emerging, advanced technologies. Yeadon lives in New York City and teaches at the Rhode Island School of Design. A selection of his works can be viewed at www.yeadon.net

About the cover illustrator

Tim Redfern (eclectronics.org) creates video art, installations and music visuals using computer graphics, electronics and programming. The cover image uses a line-drawing algorithm to recreate the tones of a photography. The individual lines have very little idea of the 'big picture' and often randomly wander between areas of the picture, but the original image emerges, statistically, as huge numbers of lines are drawn.