Organic Intersections
The Paths of Biomedicine and Engineering Grow Ever Closer
life, meet engineering

The line between the life sciences and engineering continues to blur; meanwhile, each discipline can take from the other.

Each week now, the national news seems to report a new discovery brought to us from the life sciences. In May, for example, Korean researchers announced that they had produced stem cells tailored for the first time to match the individual who would receive them.

Work in the life sciences, as in all technical fields, is becoming increasingly cross-disciplinary, as evidenced in new hybrid disciplines like bioengineering.

Because of its potential to combat disease and old age, life science is a well-funded research field. The U.S. government's 2006 budget, for instance, has earmarked almost $28 billion for research and development at the National Institutes of Health alone. That sum is greater than the R&D budget of any single branch of the armed services, including the Air Force, which is to receive $22.6 billion, according to the American Association for the Advancement of Science.

There are plenty of mechanical engineers already
engaged in developing devices and in other biomedical roles. And because it doesn't look like demand or funding is about to wane any time soon, there is a reasonable expectation that the field will be open to more of them.

At the same time, there may be opportunities for traditional mechanical engineering technologies to adapt ideas developed in the life sciences.

Advances in the life sciences require that mechanical engineers get on board to help solve complicated biological problems, according to Wei Sun, an associate professor of mechanical engineering and mechanics at Drexel University in Philadelphia, whose own research may one day lead to artificial replacement organs.

As the biosciences and engineering continue to blend and merge, the technologies and methods used by professionals in both fields have come to
overlap as well. As one advances, so does the other. Still, professionals must remember to borrow consciously from each other, Sun said.

He's on the forefront of research that aims to introduce proven mechanical engineering technologies to bioengineers who seek to grow new tissues and, perhaps one day, entire organs. For the past six years or so, Sun and his researchers have examined the role computer-aided design software might play in tissue engineering, an emerging field that aims to regenerate natural tissues and grow new tissue to replace damaged or wounded areas. The tissue sprouts from cells that grow on a scaffold, which is made from materials that can be implanted into the body and are easily absorbed by it.

Sun said tissue engineering has advanced beyond its origins in growing artificial skin on scaffolds. It's now used to regenerate bone.

"Say you have a bad bone," Sun said. "You design a scaffold on which you'll grow a new, functional tissue that can be implanted in your body."

Researchers hope to close in on the ability to create fully functioning organs for implant, although that day could be at least 30 years away, Sun said.

The technology that physicians and researchers rely on for tissue engineering hasn't kept up with the change, he said. Doctors can create 3-D images of a patient's damaged tissue, but can't really manipulate those images for analysis or create models of how the area can be healed.

Sun and his research team are working on
technology that can help, he said. He's brought his mechanical engineering background to the task.

"In modern engineering design, there's no question as to why you use CAD," Sun said. "It's a necessary tool that contains the model you can manipulate. In biology, there's no representational tool like that to do the work."

Sun expects to essentially turbocharge a mechanical engineer's CAD system so bioengineers can call upon it to perform the incredibly complex reconstructions and analysis that tissue engineering demands. He calls it BioCAD technology.

Bioengineers can't simply co-opt the CAD systems that mechanical engineers commonly use. Designing a part, no matter how complex the engineered assembly, and designing a human, living system are two different things, Sun said.

new field to blossom

Sun is a mechanical engineer by training. He never ventured much into the life sciences during his undergraduate and graduate days, but later, his thoughts turned to advancing CAD frontiers.

Problem was, within the traditional realm of engineering, he didn't see many places where the technology could blossom. But Sun, with his knowledge of composites, did make a discovery. At the beginning of its inception, CAD didn't work the smoothest on heterogeneous structures, those made up of diverse materials.
"CAD was mainly only used at that time to create products made from one material, traditional materials like wood, steel, or aluminum," Sun said.

His thoughts turned toward a CAD system that engineers could use to model composite structures. But he had difficulty getting funding. Vendors like Vistagy of Waltham, Mass., sell CAD products for work with composites. Sun's attention turned elsewhere.

"I thought about literally adding life to CAD," Sun said. "Tissue is a heterogeneous structure, but CAD doesn't currently represent tissue well."

Part of that reason lies in the way that engineers model in CAD.

"In conventional CAD, you use geometry and part material," Sun said. "What does it look like? Does it function? You show those things in conventional CAD.

"BioCAD doesn't do much about those concepts because we're dealing with human tissue," he added. "Human beings are each unique, so design needs to be unique to that patient to solve their problems."

The human anatomy, with its complex shapes made up by an array of biological materials, isn't easily reproduced in an engineering CAD program, Sun said. The geometry and the materials are obviously quite complex.

In other words, a mechanical engineer working on a
CAD system can't readily replicate the intricacies of the human body digitally. And, of course, everybody is different. A bone designed on a BioCAD system needs to have its basis in a patient scan. Each model will be unique.

Sun says his BioCAD system can represent molecules for biological applications, model the scaffolding that new tissue will grow on, and design complex tissue substitutes. Clearly, these applications don't use aluminum, plastic, or other commonly used engineered material, which means a BioCAD system must be powered by a complex system of algorithms.

**room to grow**

It's not as if doctors don't have access to images of a patient's structure they want to study. Physicians and tissue engineers can currently use computer-aided tomography and magnetic resonance imaging to make 3-D models of patients' internal structures. Those processes essentially make several 2-D images of the area of interest. Then those images are layered for a 3-D effect.

Still, the resulting models can't be readily used for applications like tissue engineering, Sun said. The CT and MRI techniques require large amounts of computational power and extreme sophistication in their data organizational and handling capabilities, and have no room for analysis applications.

The CT or MRI scan depicts an anatomical structure, but it is essentially a photograph, unlike a
CAD model, which has digital geometry that can be manipulated to change the structure.

Therefore, biomedical engineers can't manipulate the structures for tissue analysis and simulation. Those types of applications can be carried out only in a system like a CAD solid modeling system, Sun said.

He figures the boundary representation method behind many of the CAD systems can be used for tissue as well. Boundary representation means a
solid object is defined by the surfaces that surround it.

Those boundaries are mathematically described and the same mathematical functions can be used in BioCAD applications, Sun said. They make it possible to construct the computer model using fewer numbers of digitized points, which would significantly decrease the size of the files now used.

Unfortunately, the direct conversion of the CT data set of a human bone into a mathematical solid model isn't simple. Some programs on the market address the conversion problem, Sun said. However, none of the programs has been widely applied to bioengineering due to their complexity, cost, and their inability to generate sophisticated models, he said.

That's why Sun and his crew are working to further BioCAD, a system they say will be sophisticated enough to represent and analyze human structures.

works both ways

But it's not always life science fields like bioengineering that can stand to borrow from traditional engineering. Design engineering has much to learn about product innovation from the way genes and chromosomes evolve, says K.Z. Chen, an associate professor of mechanical engineering at the University of Hong Kong.

Chen and his team of researchers have isolated another frontier on which engineering and the life
sciences meet. Chen says that the same method by which genetic engineers isolate and change genes can be co-opted by engineers to design innovative products.

"We learned that genetic engineering is a set of techniques for isolating, modifying, multiplying, and recombining genes from different organisms," he said. "In a similar manner, the innovation of manufactured products can also be actively implemented using similar reforming methods, even though such products have no physical chromosomes."

An animal's genetic information is stored in genes on chromosomes within its cells. Evolution comes about when those chromosomes slowly vary over many, many generations. Genetic engineers, however, can now purposely vary an animal's chromosomes to speed evolution to the engineers' own ends. They may be seeking to accentuate good characteristics or to clone an animal.

If you think about it, product development also follows a type of natural evolution. A new product is usually based on an existing product. It's a slight variant—for the better, a company hopes—from the one that came before. The product is refined over time until the first model looks almost quaint to modern users. Compare the first horseless carriage to today's Lexus.

By that theory, manufactured products can be said to possess genetic information that can be manipulated to accentuate good characteristics, Chen maintains. To that end, engineers can advance product innovation in the same way gene
engineers artificially speed evolution. Engineers can start the innovation process by identifying defective genes on the product's chromosome.

A physical entity has neither genes nor chromosomes, you say? True, Chen says, but they have virtual ones.

To isolate them, engineers must find them by tracing their product back to its earliest inception. What has remained the same? What has changed? In this way, the fundamental building blocks—the wheels on a car, the steering mechanism, the axles—can be isolated. Those chromosomes may have mutated, but they serve as the car's base genetic makeup. How to isolate that genetic information?

"Some genetic and evolution information in a product's chromosome can be acquired from the design and manufacturing documentation of products, design handbooks, technical standards and specifications, technical documents, or even the designers' brains. Others have not been collected and sorted out, and need to be explored," Chen said. "The content and data structure of products' virtual chromosomes can be deduced, based on careful analyses of the evolution course of products' design and manufacturing."

In a similar manner, information in a product's virtual chromosome that affects performances is regarded as a virtual gene.

"For instance, the revolving accuracy of the spindle in a lathe is dependent on the type, structure, installation, and maintenance of its bearing system, which can be regarded as a virtual gene," Chen
said. "To improve a special aspect of performances, the related virtual genes and their locations in the virtual chromosome should be identified."

In isolating virtual chromosomes and genes, engineers can generally determine why a product isn't effective. That is, they can find out exactly where evolution took a wrong turn, a mutation for the worse. By going back to correct that mutation, the engineer improves the product.

Chen's technique relies upon technologies that help engineers find and isolate virtual chromosomes by analysis and deduction.

"Since the product's chromosome contains so much information and is very complicated in data structure, it has to be stored and edited by database management software," Chen said.

His innovation technique has benefits beyond straight trial and error and even other product innovation methods, he said.

According to Chen, many innovation methods get engineers to think about a problem from several different perspectives. And while those methods are more effective than straight trial and error, they don't always lead to innovative solutions because they don't provide a logically structured process and appropriate knowledge about product makeup.

As mechanical engineering creeps into bioengineering and other life sciences, and vice versa, trades like those described by Chen and Sun will become more common and ever more viable. CAD and other engineering technologies will mutate
and change, much as Chen describes, until students of tomorrow may have a hard time recognizing the tools of today.