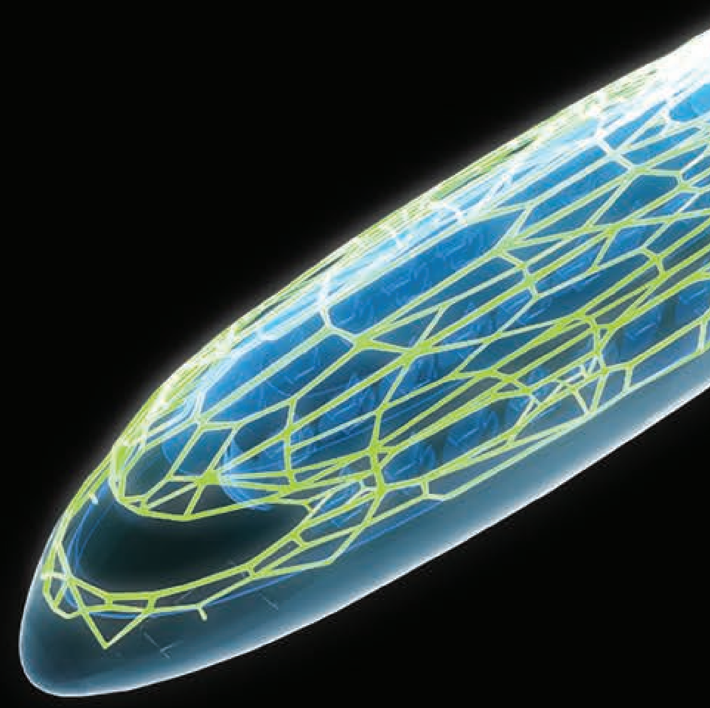
AI AND THE FUTURE OF MACHINE DESIGN

Artificially intelligent systems are learning how to develop new products and designs. What does that leave engineers to do?

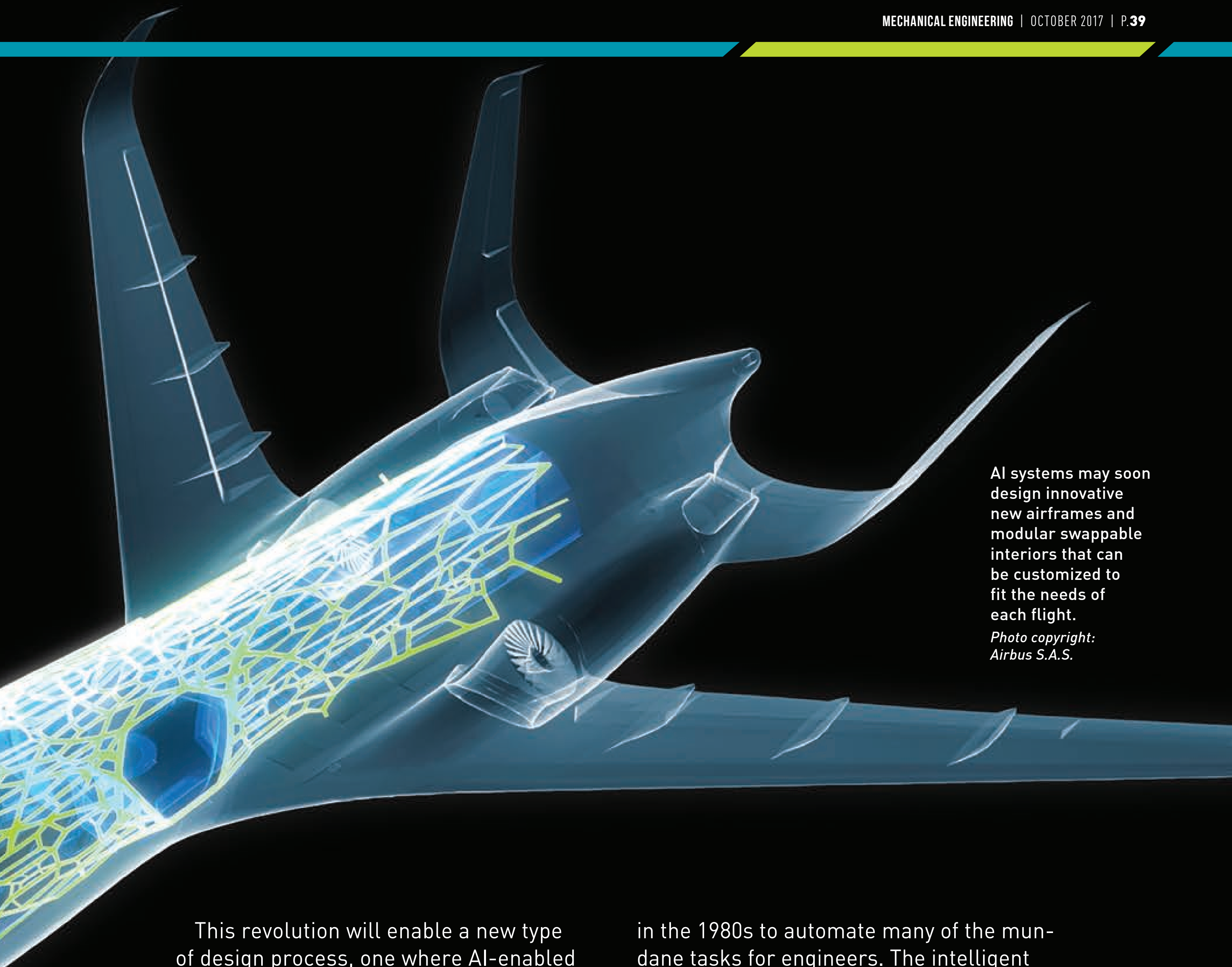
BY AHMED K. NOOR



Not all that long ago, engineering was a profession conducted with pencils and paper. Calculations were done by hand and designs were sketched out on large sheets. From actual blueprints, physical models would be made to work out how the final product should look and be made.

Today, of course, engineering is a discipline intensely involved with computational and software tools. Computer-assisted design, computational fluid dynamics, and finite-element analysis applications are some of the basic tools that engineers deploy when creating new product designs. When physical models must be tested, prototypes can be printed directly from the computer files.

Although these tools have enhanced the powers of engineers, the engineer is still clearly in control of the design process. But that control is now in question. There is increasing interest in using new artificial intelligence and other technologies to reach higher levels of product automation and accelerate innovation of new products. Advances in AI, combined synergistically with other technologies such as cognitive computing, Internet of Things, 3-D (or even 4-D) printing, advanced robotics, virtual and mixed reality, and human machine interfaces, are transforming what, where, and how products are designed, manufactured, assembled, distributed, serviced, and upgraded.



AI systems may soon design innovative new airframes and modular swappable interiors that can be customized to fit the needs of each flight.
Photo copyright: Airbus S.A.S.

This revolution will enable a new type of design process, one where AI-enabled programs iterate and optimize with little human intervention. The resulting designs seem impossibly complex, but thanks to advanced manufacturing technology, they are no more difficult to print than conventional designs. Already, parts that are the result of this generative design process are being readied for use in commercial aircraft and other critical systems.

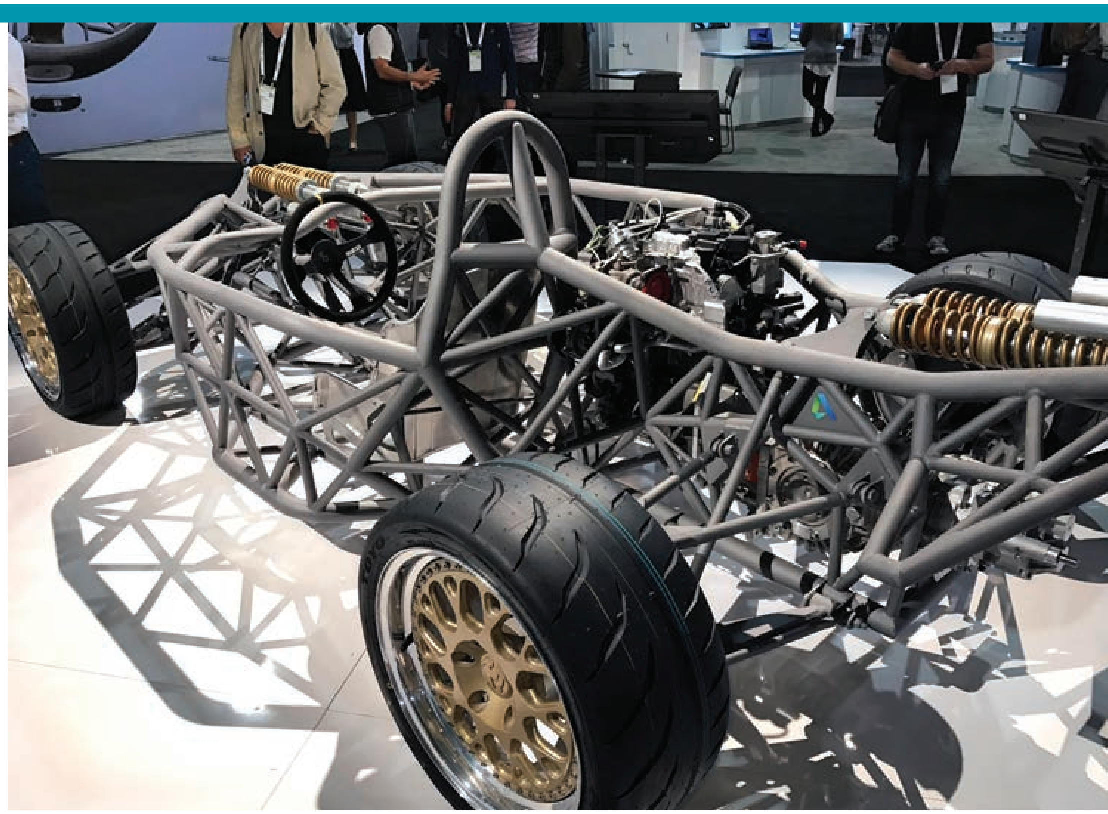
The transition from drafting boards to CAD was disruptive to engineering. The next transformation to generative design is expected to be more disruptive.

Artificial intelligence is a concept that encompasses a wide spectrum of technologies, and some types of AI have been applied to engineering systems for some time. Knowledge-based systems and AI rule-based expert systems were first used in the 1980s to automate many of the mundane tasks for engineers. The intelligent agent paradigm was introduced in 1990s and provided a common language to describe problems and share their solutions.

Those applications are considered to be "weak" AI.

In contrast, "strong" AI would behave more like general intelligence and be capable of sensing, perceiving, learning from, and responding to the environment and users. Strong AI, also known as artificial general intelligence (AGI), refers to machine intelligence and deep learning, systems that show complex behavior similar to living systems like swarms, ant colonies, and neural systems. These systems will have the ability to adapt to most situations.

Artificial intelligence is moving forward in leaps and bounds (indeed, some



The chassis of La Bandita Speedster was generatively designed to support a shape sculpted in virtual reality.
Photo: Hack Rod

researchers now speak of developing artificial superintelligence—ASI) and much of the excitement about AI is directed toward applications where computer systems will operate with great autonomy. The self-driving car is the poster child for AI, but there are a number of intriguing applications—from robotic clinicians who will be able to diagnose illnesses more accurately than any human doctor to AI-directed corporations that can orchestrate company activities without flesh-and-blood management.

The product-design process has already been affected by existing artificial intelligence, and AI will change the way we embed connected sensors and employ mixed or augmented reality headsets going forward. Based on the current trajectory, it is likely we will see AI impact product design and the creation of engineering systems in three distinct stages in the coming decade.

First, artificially intelligent systems will ease the laborious tasks that designers face, such as having to continually search for appropriate content, fix errors, determine optimal solutions, communicate changes, and monitor for design failure. Machine learning will be able to take on those jobs and do them much, much faster.

Next, AI will be able to assist in the creation of sophisticated designs. Intelligent systems will work at the designer's elbow, suggesting alternatives, incorporating sensor-based data, generating design precursors, optimizing supply-chain processes, and then delivering the designs to intelligent manufacturing facilities.

Acting on Intention

The final stage would have more profound implications. Engineering systems that incorporate stronger AI will be able to function more like human assistants during the design and creation process. Actual human designers will be able to "design" merely by expressing intent and curating results, while intelligent systems and machines will act on these intentions to create new design iterations for review.

The AI would not approach the project the way a human designer would, however. Instead, the computing power would be harnessed to mimic Nature's evolutionary approach—taking the best existing solution to a problem and iterating to optimize performance in a given environment. In this way, the AI would explore the variants of a design beyond what is currently possible using the traditional design process. This approach is called generative design.

Although much of the generative design process is conducted autonomously, the process starts with choices made by a human. That engineer or industrial designer sets high-level design goals, along with design parameters and constraints, including material type, manufacturing capability, and price points.

With the boundaries of the design problem established, the AI generative design system, such as Autodesk's Dreamcatcher, explores permutation of a design solution, quickly cycling through thousands—or even millions—of design choices and running performance analyses for each design. For the most intensive calculations, the system can tap available cloud computing processing power.

One key component of a generative design system is its machine-learning algorithm. That algorithm detects patterns inherent in millions of 3-D models and generates taxonomies without human direction or intervention. Using that capability, generative design software can learn what all of the components of a complex system are, identify how they relate to each other, and determine what they do. It can then serve up dozens of different design options for a specific dimension of a component and provide them as components for the next design.

Once new designs have been generated by the AI system, the human reenters the process. He will study different options based on the multiple choices of designs provided by the generative design system, and then modify the design goals and constraints to narrow down the options and refine the available ones. Using that input, the generative design system will then iterate another set of designs.

Over the course of several of these cycles, the most relevant solution will be selected through a combination of artificial intelligence and human intuition.

Generative design techniques are not especially new, but combining these deep reinforcement machine learning algorithms with cloud computing has produced new excitement.

PROJECT DREAMCATCHER

Dreamcatcher is an experimental platform being built by Autodesk to explore the potential of AI techniques and generative design tools in product creation from conceptual design all the way to fabrication.

THE AUTODESK DREAMCATCHER INCLUDES:

- Tools for designers to describe design problems. Through pattern-based description, solutions become modular and accretive, thereby expanding the quality and number of alternatives that are searched in each design session.
- Tools for shape synthesis, including several, purpose-built methods that algorithmically generate designs of different types from a broad set of input criteria.
- Tools for exploration, presenting designers with a set of possible solutions and their associated solution strategies. These tools help designers in building a mental model of which alternatives are high performing relative to all others in the set.

Once the design space has been explored to satisfaction, the designer is able to output the design to fabrication tools, or export the resulting geometry for use in other software tools.

Evolving an Answer

The generative design process may sound like something for the distant future, but recently it was applied to a real-world challenge involving a component for one of the most high-profile and expensive products in the world, the Airbus A320 aircraft.

The part was a partition that separates the passenger compartment from the galley of the plane and supports a flip-down seat for flight attendants during takeoff and landing. Airbus engineers were looking for ways to reduce the partition's weight and volume while retaining enough strength to bear the loads of flight attendants. It also had to hold up under the force of 16 g in the event of a crash landing.

A group of Airbus designers turned to Autodesk and other partners to see if they could come up with an improved partition through a combination of generative design, biomimicry concepts for material and structural design, and additive manufacturing.

The generative design process the team used employed two algorithms derived from biological models. The first drew from the adaptive networks of slime mold: a single-celled organism that can grow, stretch, and aggregate to form multicellular structures, with the minimum number of lines. These structures have a built-in redundancy to retain connectivity within the network, in case a line fails. This algorithm was used to inform the design of the bracing for the overall partition.

A second algorithm, derived from the microscale structure of mammal bones, was used to build the lattice that makes up each member. Several different load cases were considered, some requiring more than 66,000 micro-lattice bars in the partition.

Once the design parameters were set, the generative design software (in this case Autodesk Within) cycled through thousands of design variants. The human design team digitally mapped the different generated options against weight, stress, and strength parameters to decide which to prototype.

The resulting design is a latticed structure that looks random but is based on mammal bone growth. Like natural bone, the partition is dense at points of stress but lightweight everywhere else. The design, which Airbus and Autodesk call the bionic partition, is 45 percent lighter than the conventionally designed compartment divider found on existing aircraft. Fabricated using additive manufacturing, the finished product requires just one-twentieth the raw material compared with a partition built using traditional design processes.

More than 100 separate pieces, made of a high-strength metal alloy developed by Airbus, were 3-D printed and then assembled. The resulting partition is the world's largest 3-D printed aircraft cabin component, and it more than satisfies the Airbus team's requirements. It is thinner and stronger than the component it will replace, and because it is 30 kg lighter, each bionic partition will save approximately 3,180 kg of fuel per plane per year.

The partition is undergoing final testing and approval. Once complete, the final design could be used in A320 aircraft next year.

The lessons Airbus learned in designing the bionic partition pave the way for changing how an entire aircraft is conceived and manufactured. The next generation of Airbus planes will be made up of components based on generative design, built by 3-D printing, using innovative materials. Airbus plans to evolve its methods for producing larger structures inside a plane: for example, the cockpit wall, which is twice the size of the bionic partition and needs to be bulletproof to protect the pilots, or the structure that houses the galley for food and beverage service.

Autodesk has also applied its generative design and AI tools to other high-profile projects. Autodesk collaborated with the digital industrial engineering company Hack Rod to design the chassis of a race car. The company also is involved with the MX3D bridge project in Amsterdam—not only will the bridge be generatively designed but it will also be printed on-site by multi-axis industrial robots.

The generative design tools developed by Autodesk and other firms are only the beginning of a revolution in engineering, one that will change the way we think about it.

Considering the power of generative design tools—and the near-omniscient artificial general intelligence that will soon undergird it—some may wonder if the human designer and engineer will be made redundant. I think that is the wrong way to look at the contribution of artificial intelligence. Instead, through these technologies, designers' creativity will

THE AI CONTINUUM

Artificial intelligence is embedded in products ranging from smart gadgets and devices to drones, robots, and autonomous vehicles. Currently, the AI continuum can be divided into three general areas according to complexity:

- **ASSISTED INTELLIGENCE:** AI automates basic repetitive and standardized tasks, working from clearly defined rules. Humans are still making the key decisions. Examples include automated assembly-line robots as well as software-based agents that simulate the online activities of humans.
- **AUGMENTED INTELLIGENCE:** AI enhances the ability of humans to accomplish tasks, and humans and machines learn from each other. Examples include intelligent virtual assistants, some of generative design systems, and systems that can bring unusual or noteworthy events to human attention.
- **AUTONOMOUS INTELLIGENCE:** AI takes over some decision-making, but only after a human fully trusts the machine or becomes a liability to the prompt accomplishment of a task. Self-driving vehicles, currently in development by over 30 companies, are just one example of autonomous intelligence.

amplify and their productivity will dramatically increase.

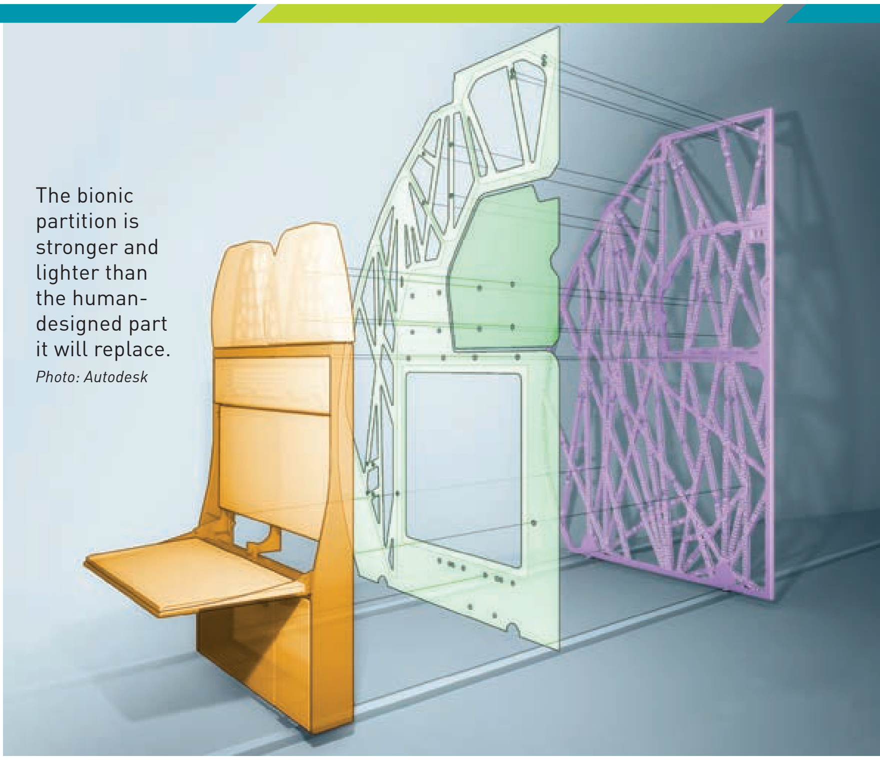
For instance, using a system tied to a powerful voice recognition system, a designer will be able to start a conversation with a cognitive design assistant. "Let's design an autonomous vehicle," he begins. A number of different categories of vehicles appear. The designer selects a category, identifies high-level design goals and constraints, and the design activities proceed with the cognitive assistant doing most of the work, and generating several options beyond what current generative design systems can do. The cognitive assistant will also help the designer in evaluating the different options and making the final decision. It will even use the new explainable AI (XAI) tools to clarify to the designer the rationale of the options selected. After finishing the design of a complex system, the cognitive assistant will automatically send the files to an automated additive manufacturing facility to have a prototype made for the system.

It won't only be the designs that undergo biologically inspired iterative processes. Future complex systems will become self-evolving, rebuilding or even redesigning themselves as needed.

An example is provided by the recent research by a team in the department of informatics at the University of Oslo in Norway. The research team, led by Kyrre Glette, discovered a way for robots to design, evolve, and manufacture themselves using generative design software. The robots are built in a virtual environment and their movements simulated. The researchers then introduce certain parameters, such as getting from one side of the room to the other, and the AI tests each generatively created design against those goals. The best results spawn new iterations, and then the final design is automatically printed.

The intent is to develop self-evolving robots. The only human intervention is in the assembly of the printed parts.

This research and related activities may ultimately result in the development of self-repairing, self-healing, self-adaptive, self-reconfiguring systems—and products that "operationally improve" themselves. Instead of depreciating in value and capability, such products could improve over time.



The bionic partition is stronger and lighter than the human-designed part it will replace.
Photo: Autodesk

In time, the role of the human engineer may be that of a director rather than of a producer. Humans may not be the ones executing the tasks, but we will be choosing the direction we want the machine to take and we will be providing the most critical feedback: whether we are satisfied with the results.

Much of the technical aspect of engineering will be moved to the machine-based design system, just as one need not be able to operate a slide rule or complete an isometric drawing to be a successful engineer today. To a certain extent, the engineer will become someone adept at translating the inchoate human desires—for products with a more elegant shape or which use less energy or which perform more efficiently—into a working relationship with an artificial intelligence that will find the solution as long as it knows what the problem is.

Once machines know how to design—even how to design themselves—engineering will be changed, but engineers will still be highly skilled. They will be augmented cognitively, physically, and perceptually by AI technologies. And therefore, they will simply need to build their capacity with a different set of skills, including teaching the AI systems how to innovate and become effective partners in future human-AI organizations. **ME**

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TO LEARN MORE

For more information on artificial intelligence and generative design, the author has created a website as a companion to this article:

http://www.aee.odu.edu/proddesign/.

The site contains links to online material related to a variety of aspects of artificial intelligence, generative design, and other AI engineering applications. The site also includes a daily news feed for up-to-date information on related subjects.