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GENERATIVE DESIGN: REDEFINING WHAT'S POSSIBLE IN THE FUTURE OF MANUFACTURING

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Introduction

Technology has played a key role in the design and manufacturing of products for years. Having said that, I think it's fair to say that technology has been used primarily as a productivity tool. But imagine if technology could be our partner in the process instead. That's the idea behind generative design, an artificial intelligence–based design exploration process that lets humans and machines create together.

With generative design, designers and engineers shift their focus from drawing things and storing them in a computer to spending more time framing the real problem they want to solve. The user inputs goals, constraints, and priorities (such as weight, safety factors, material preferences, manufacturing methods, and cost constraints) and then the partnership with technology begins. The software goes to work, using a combination of artificial intelligence (AI) and cloud computing, to explore thousands of options in pursuit of the best outcome. Solving complex problems more quickly—and delivering more potential solutions than a human ever could—is what makes generative design so powerful.

Sounds pretty futuristic, right? When I first became familiar with generative design, I was blown away but admittedly skeptical. But just a few years later, generative-design software is being used in surprising and inspiring ways. In these pages, meet some of the early adopters of generative design. Read about how General Motors is transforming the future of the automotive industry with generatively designed parts that create lighter, more fuel-efficient cars. Learn how French creator and visionary Philippe Starck designed the world's first production chair created by AI in collaboration with humans. And find out how heavy-equipment manufacturer Claudius Peters is using generative-design technology for traditional fabrication methods.

But not only well-known brands are embracing generative design. Start-ups, makers, and universities are also using it to create everything from affordable prosthetic devices to search-and-rescue drones to a humanoid robot that may allow us to better understand the human brain. Together, these pioneers share a desire to redefine the way things are made—and in the process, they're helping people live better lives. This is the next generation of engineers and companies.

When I began working in the manufacturing industry more than 20 years ago, I couldn't have imagined something like generative design being possible. We were so focused on the way that things had been done that we weren't able to see how things could and should be done.

I'm excited about the possibilities of what humans and machines can create together when we go beyond what we once imagined. And I think we have only seen the beginning of what's possible.

SCOTT REESE
Senior VP Manufacturing, Cloud and Production Products
Autodesk, Inc.

A standard General Motors auto part gets a nonstandard redesign with the help of generative design—and becomes lighter and stronger in the process.

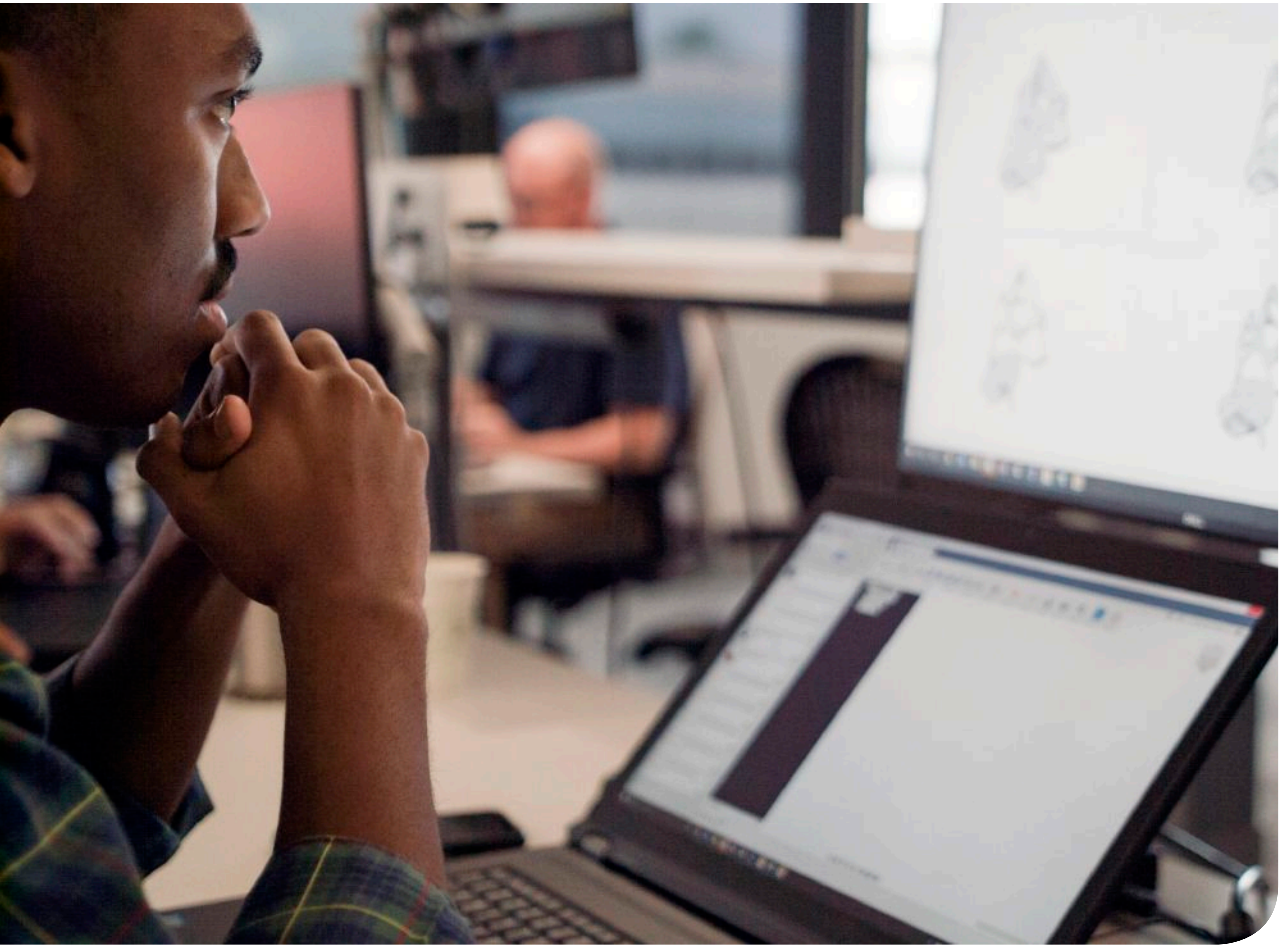
DRIVING A LIGHTER, MORE EFFICIENT FUTURE OF AUTOMOTIVE-PART DESIGN AT GM

BY MATT ALDERTON

Additive manufacturing has already assisted with 3D-printed musical instruments, including a drum set, electric guitar, bass, and keyboard; 3D-printed food, including meals for astronauts and the military; 3D-printed clothing, prosthetic limbs, and human organs for transplants; and even 3D-printed two-story concrete homes. What's next, 3D-printed cars?

Actually, yes. For example, in 2015, Local Motors introduced the Strati roadster, an electric two-seater made in just 44 hours and featuring 75% 3D-printed parts. In 2016, Divergent 3D followed suit with the Blade, a 700-horsepower "supercar" with a 3D-printed body and chassis. And in 2018, Italian start-up XEV announced plans to produce the LSEV, a small electric car that, according to the company, is the world's first mass-producible 3D-printed vehicle.

GM consolidated an eight-part seat bracket into a single part using generative design and additive manufacturing. Courtesy of General Motors.



With generative-design technology, engineers and computers can collaborate in new ways to create new designs never possible before. Courtesy of General Motors.

But it's not just upstarts and experimentalists working with 3D-printed automotive design. Instead of pumping out headline-grabbing proofs of concept, traditional automakers are investing in incremental upgrades and tangible improvements. General Motors embodies this approach, designing 3D-printed components that offer increased performance, customization, and personalization.

"On average, there are 30,000 parts in every vehicle," says GM Director of Additive Design and Manufacturing Kevin Quinn. "We're not looking to print all 30,000 pieces. Instead, we're being very realistic. We're focused on production opportunities where we can provide a business value for GM and for the customer. For us, it's not about what you can do; it's about what you should do."

Disruptive Design

If additive manufacturing were a door to the automotive future, generative design would be the key to unlock it. "Generative design is a way for us to explore different design solutions for parts and components of our vehicles by using the cloud and artificial intelligence to combine the engineer and the computer," Quinn says. "By getting them to work together, we can come up with part-design solutions that would be impossible to generate with either the computer or the engineer working on their own."

With this model, engineers establish component design goals and constraints—including parameters such as materials, manufacturing methods, and budget—and then input them into generative-design software. The software then uses an algorithm to analyze and evaluate all possible design permutations and recommends an optimal solution based on its calculations.

"Generative design paired with additive manufacturing can be completely disruptive to our industry," says Quinn, who adds that the auto industry historically has been handicapped by the limitations of traditional manufacturing tools such as mills and injection molds. For one, such tools can only fabricate very simple geometries.

Also, traditional tools are as expensive as they are inflexible, which makes experimentation cost-prohibitive. Generative design and additive manufacturing can support infinite design solutions with minimal capital investment. A single piece of software paired with a single 3D printer can produce myriad parts and unlimited forms—including organic shapes and internal lattices, which can be executed only using additive manufacturing.

A Better Bracket?

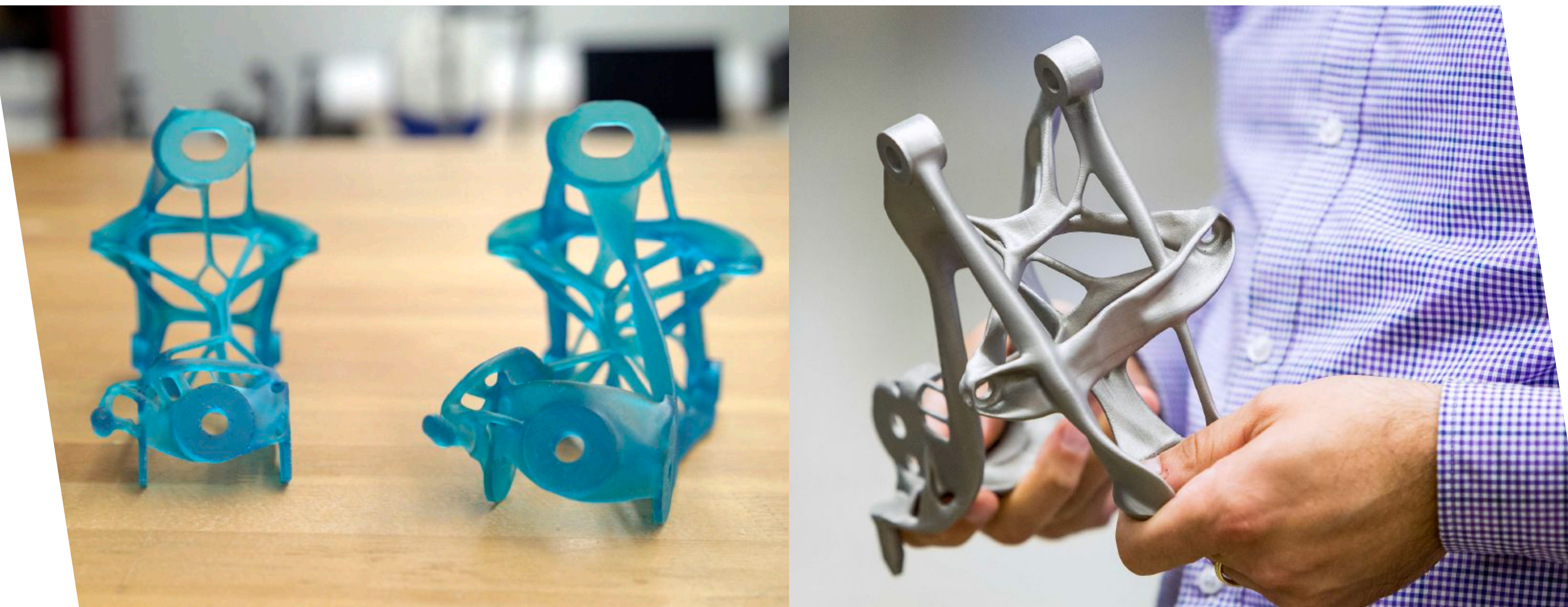
To understand the business case for generative design, consider the challenges posed by electric vehicles (EVs). Although automakers are extremely bullish on them—GM alone plans to have at least 20 electric or fuel-cell vehicles on the market by 2023—such vehicles are more expensive to produce. For GM, generative design might help solve those challenges by facilitating lighter vehicles and a shorter supply chain.

“Electrification and autonomous vehicles are going to be game-changers for our industry,” Quinn says. “Having a leadership position in those highly technical areas is critical going forward. We believe additive manufacturing and generative design can help us gain that first-to-market advantage.”

In a recent collaboration with Autodesk using the generative technology in Autodesk Fusion 360, GM engineers designed a new, functionally optimized seat bracket, a standard auto part that secures seat-belt fasteners to seats and seats to floors. While the typical seat bracket is a boxy part consisting of eight pieces, the software came up with more than 150 alternative designs that look more like a metallic object from outer space. Made of one stainless-steel piece instead of eight, the design GM chose is 40% lighter and 20% stronger than its previous seat bracket.

“The motivation to consolidate eight parts into one is twofold,” Quinn says. “One, we can optimize for mass. But another ancillary benefit is that you’re reducing all the supply-chain costs associated with having many different parts that may be made by many different suppliers, which then have to all be joined together.”

Automotive-part designs like these are possible today only through additive manufacturing. Courtesy of General Motors.



Applied across hundreds or even thousands of parts, it's easy to see how such improvements could make vehicles cheaper, lighter, and more fuel-efficient.

"The challenge for us now will be to find those other unique applications where generative design and additive manufacturing make sense," Quinn says. GM already is working to optimize many other parts on its vehicles.

"If we can use generative design and additive manufacturing to give another mile per gallon of fuel economy or to extend by 10 miles the range of our electric vehicles, that can be a huge competitive advantage for General Motors going forward," he says.

Benefits, Not Buzz

Increased performance is only the beginning. In the future, GM envisions using additive manufacturing to affordably and efficiently make service parts at dealerships and to customize its vehicles.

"Right now, to customize something on a vehicle requires a huge capital outlay for GM because you've got to build a new tool every time you want to make something custom," Quinn says. "Since there's no return on investment, often in our industry, we make the decision that we just won't do those things."

Quinn adds that additive manufacturing could allow customers to order custom trim packages or personalize their vehicles with their names or the logos of their favorite sports teams. "If we can offer something that our competitors don't, that will set our vehicles apart," he says.

At its best, that's what technology is all about, according to Quinn: It's not about building buzz; it's about delivering benefits. "Generative design and additive manufacturing really excite me [because they're going to allow us] to deliver performance to our customers that they couldn't get any other way."

Learn how Airbus has continued to use generative design on the latest version of its bionic aircraft cabin partition—with even better results.

Courtesy of Airbus.

Indian company Social Hardware used generative design to create a prosthetic device that combines the best features of two very different types of prosthetic limbs.

MEET THE PROSTHETICS START-UP THAT'S AIDING AMPUTEES IN RURAL INDIA WITH HELPING HANDS

BY RINA DIANE CABALLAR

"There is a gaping hole in the prosthetic market," says Abhit Kumar, cofounder of Indian prosthetics start-up Social Hardware. "Our aim is to fill that hole with prosthetic devices designed specifically for low-income rural amputees from the agricultural or construction industry, as this is where most of the casualties occur."

According to a report from India's Ministry of Statistics and Programme Implementation, 2.21% of the country's population lives with a disability. Of that population, 20% have a disability of movement, and most live in rural areas. The highest rate of amputation occurs in these rural settings, where the main employment is in agriculture and construction. Prosthetics are typically imported from overseas and can cost more than six times the average monthly income of a rural Indian family.

After researching existing solutions, Social Hardware cofounders Kumar and Cameron Norris saw a need for a new approach to upper-limb prosthesis design. The pair met through the online community Reddit, where they contributed to an open-source prosthesis project to help a fellow user with a disability. Kumar came from a biomedical and robotics background; Norris worked in the UK start-up world.

Social Hardware's prosthetics are purpose-built using generative design to be affordable for agricultural and construction workers in rural India. Courtesy of Social Hardware.

Finding a Path Forward

As a recognized start-up under the Startup India initiative and a technical partner of Bengaluru-based nonprofit Association of People with Disability (APD), Social Hardware works toward outfitting amputees in rural India with prosthetic devices and providing rehab opportunities—at no cost to the recipients.

Through partnerships with APD and other disability rehab centers, Social Hardware will provide rural amputees access to a rehab program that includes physiotherapy and training to effectively use an assistive device in their daily lives. The start-up wants to keep the retail price under ₹20,000 (about $280) for each prosthetic hand; those who successfully complete the program will be fitted with Social Hardware's prosthetics for free.

"By speaking directly with amputees and those working within the prosthetics and orthotics industries, we learned that most devices are unsuitable for end users in rural India," Norris says. "In particular, durability and hygiene are two major issues not being addressed appropriately."

It's All in the Wrist

Once Social Hardware developed a suitable electric prosthetic arm, the team created the Avocado Wrist Connector, an assistive device used to securely attach agricultural and construction tools to their prosthetics. "We took inspiration from the ruggedness of military hardware design," Norris says. "We looked through old patents to help us understand how different attachments were mounted in military settings."

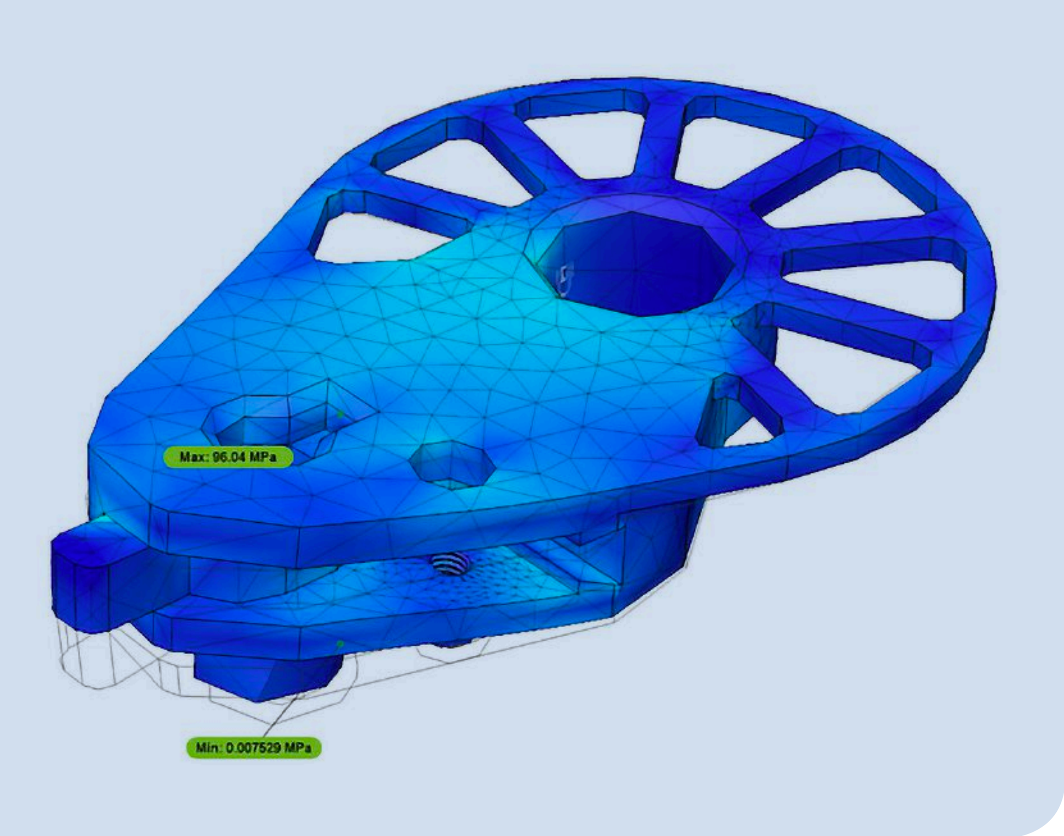
The latest Social Hardware prosthetic arm with a farming tool attached (top), with a prosthetic hand attached (middle), and with both the hand and farming tool attached to the wrist connector (bottom). Courtesy of Social Hardware.

3D renders of Social Hardware's latest wrist connectors and farming tool. Courtesy of Social Hardware.

They also wanted it to be compatible with the existing anchor system of connectors and sockets made by ALIMCO, one of India's largest manufacturers of prosthetic and orthotic devices. "Instead of replacing what was already available in the prosthetics market, we wanted to support and supplement it," Norris says. "We wanted to create an add-on device that fits between the bionic hand and the socket, which can be used to attach different tools such as a small hammer or a trowel or whatever tool the individual may need."

But first, the team had to address the issues with existing prosthetic devices. Externally powered prosthetic limbs don't rely on a user's strength but, instead, have limited battery life and typically aren't sturdy enough for high-intensity work. Body-powered prosthetic limbs are generally much more durable and do not require batteries, but they are heavy and have limited functionality. Kumar and Norris wanted to combine the two: the lightweight, feature-rich approach of an externally powered prosthetic limb with the durability and reliability of a body-powered device. "The end goal is to provide the best of both worlds," Norris says.

To achieve this balance, Social Hardware turned to generative design. With measurements from traditionally fabricated sockets, the team used Fusion 360 and a five-stage generative-design process to bring down the weight of its Avocado Wrist Connector and speed up the development process. "Generative design enabled us to reduce the weight from 300 grams to 96 grams while maintaining the durability we needed," Kumar says. "These results would have taken months of trial and error to achieve through traditional means."



Social Hardware used generative design to bring down the Avocado Wrist Connector's weight while maintaining its strength. Courtesy of Social Hardware.

Generative design also helped Social Hardware tackle the challenges amputees experience with their prosthetic sockets and to improve their appearance. "There are issues with sweat and heat, especially in humid environments or if you're working at a high intensity," Norris says. "We used generative design to create a lightweight, breathable socket with a unique aesthetic. Although we're targeting low-income communities, we want them to feel like they have the latest cutting-edge technology."

Prosthetics for the Masses

As part of their future plan, Kumar and Norris want to transition from a working prototype to an end product ready for mass production. Preparing for clinical trials before releasing their product as a medically certified prosthesis, they plan to work with international aid agencies and humanitarian organizations to bring their devices to other APEC countries that need them.

Moreover, Social Hardware's founders want to provide the first commercial version of their device for preorder as a prosthesis development kit for STEM (science, technology, engineering, and math) education. The kit will include everything that hobbyists, researchers, and students need to build their own prosthetic hands.

"We're providing the kit to raise awareness of India's rural amputee population, encourage others to participate in the development of assistive technologies, and for young graduates to understand the concept of design engineering and fabrication," Kumar says. "It also builds on our foundation: frugal innovation and participatory design."

Watch how Stanley Black & Decker used generative design to cut the weight of its hydraulic crimping tool in half.

Both of these parts, produced by generative design, feature traditional CNC milling techniques: 3-axis (left) and 2.5-axis.

Generative design: It's not all weird-looking geometries produced by additive manufacturing, says Autodesk's vice president and general manager of Fusion 360.

THE PROMISE OF MANUFACTURING AUTOMATION FOR ALL STARTS WITH GENERATIVE DESIGN

BY STEPHEN HOOPER

As a manufacturer, you're certainly familiar with the concept of generative design by now—but there's still some confusion over its real definition.

Many in the manufacturing community would have you believe that generative design is merely a branch of topology optimization or procedural modeling. But in reality, generative design is a more profound change in approach than that. It's an artificial intelligence–powered process that leverages the cloud to drive innovation by exploring thousands of possibilities, rather than simply removing excess material from an idea you've already had. (That's topology optimization.)

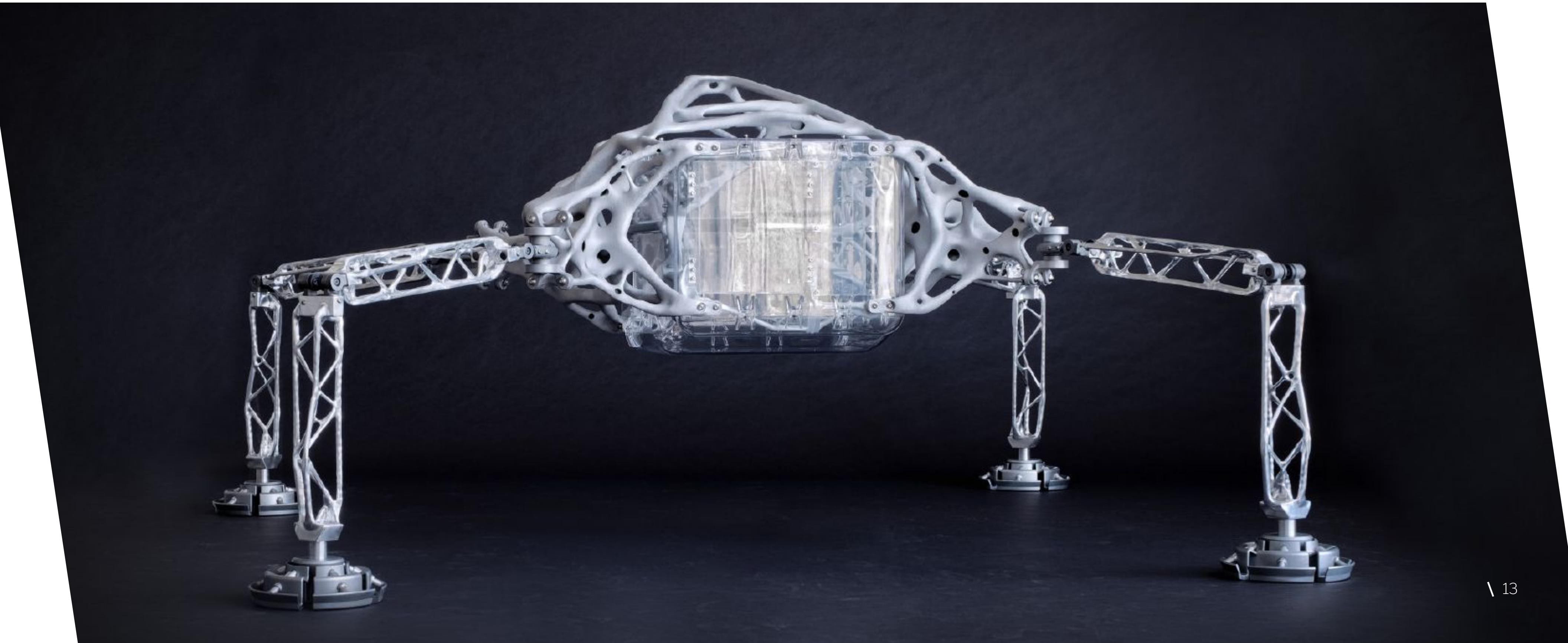
If you know that, you're hopefully already convinced of generative design's revolutionary possibilities for the future of manufacturing automation. But you might also think the technology is useful solely for complex geometries that can be produced only with additive-manufacturing techniques.

To be fair, many of the generative-design examples you've seen to date have been intricate, often otherworldly looking pieces printed in metal. One reason for that is because the output of generative design hasn't been connected to the traditional means of manufacturing. And if your manufacturing business can't afford a $2 million 3D metal printer, the technology hardly seems accessible or relevant.

Generative Design for All

Many forms of manufacturing automation are initially too expensive or too complicated to fully adopt. In the 1960s, when **industrial robots** first became available, only the likes of GM could afford them. Generative design—the automated process of creating a design geometry based on simulation outcomes that are generated with an understanding of the manufacturing process—is just the latest seemingly out-of-reach tech. But the good news for manufacturers is that the scope of generative-design automation is expanding to include new manufacturing processes that support traditional manufacturing.

This interplanetary lander, the result of a research collaboration between NASA's Jet Propulsion Laboratory and Autodesk, is an example of a cool generative-design project fabricated through a combination of additive metal printing, casting, and milling.

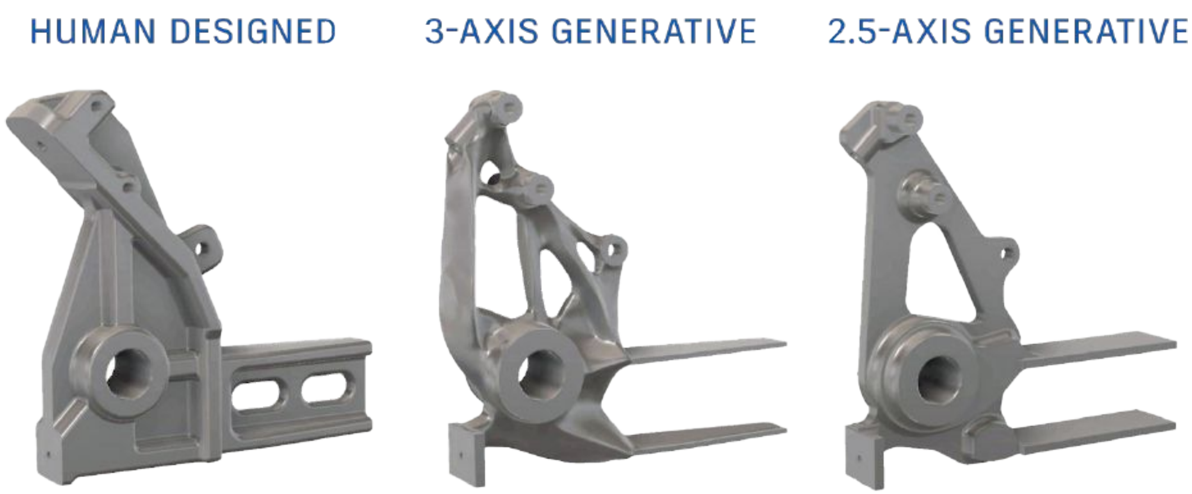


With a manufacturing constraint such as casting or machining, generative-design software can produce results that you can fabricate using tools and equipment you likely already have in your shop. These outcomes aren't just possible; they're affordable.

Take, for example, three versions of a metal support part for a wheelchair, derived from the same generative-design output. Each part is essentially the same: same functional and performance requirements, same material, same rough form. The only difference is the manufacturing process, but as you'll see, not all processes are created equal.

The original part is die-cast out of metal, at a cost of about $15 when tooling costs are fully amortized. The 3-axis-milled iteration can be made on a more common machining center, but it costs closer to $100 to make, due to the length of time it takes to machine the organic form. The third option—2.5-axis milled—is utopia because it gives you a part that does everything that the die-cast part does, but for $25. For roughly the same price, you get the absolute best solution for your design problem, without the need for custom tooling, and you can make it with your existing machine-shop hardware.

Clearly, the manufacturing process is a big influence on the type of geometry you produce, and it's finally possible for anyone to apply generative-design technology to accessible means of manufacturing. But the promise of manufacturing automation doesn't stop with generative design.



A human-designed part alongside two generative-design versions milled on 2.5-axis and 3-axis CNC machines.

A Digital Pipeline for Continuous Workflow

To realize the next significant advance in automation, a digital pipeline is necessary to enable a continuous workflow from concept to physical product. Consider today's basic product-development workflow: An engineer completes some design geometry and then hands it over to someone else to do simulations. That person has to finish the simulations and validate them before handing off to yet another person who creates the machining instructions in the form of g-code. In many cases, that g-code file is then copied onto a memory stick and walked down to the shop floor, where the machinist can load it onto the machine controller and actually start to cut metal.

That waterfall workflow is linear and highly inefficient. A better way forward is an automated, agile product-development process, one that allows for some form of concurrency so that one person can start working on simulation studies before the design is even finished. With feedback from the simulations, someone else can start the manufacturing instructions also before the whole design is complete.

This enables your business to work less like a 19th-century factory and more like a highly competitive sports team. Having process elements happen in parallel shortens the total amount of time it takes to produce a product, and it leads to greater product innovation, better product performance, lower costs, and faster time to market—all key attributes of a killer business.

To really make that work, you need to create that digital pipeline: a direct connection between the manufacturing instructions produced in the software and the machine tool. In that scenario, the g-code is created in the background and sent straight to the machine tool without the designer ever being conscious of it. Think of it like this: If you want to print something on paper, you send it over the network, directly from the word processor; you don't copy files across the network or insert a thumb drive to make the printer understand what you typed into your word processor. The same should be true in manufacturing, with a network of machines and CAD/CAM applications.

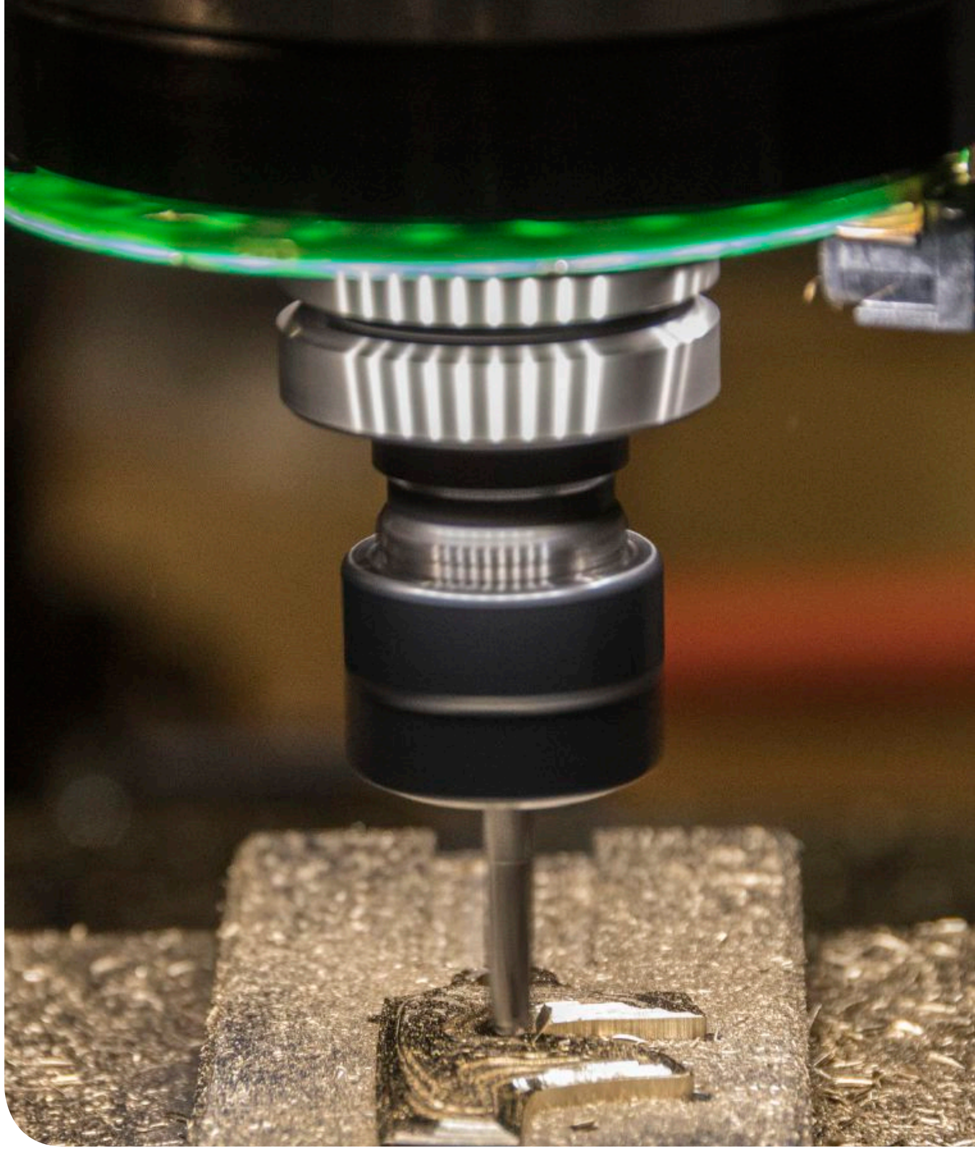
Closing the Loop on Feedback

As valuable as that type of manufacturing automation is, it's still linear and thus incomplete—the information goes to the machine tool, but no feedback returns. Things would be more inspiring if those controllers on the machine tool could also capture information about the tool's performance. That kind of automation would provide closed-loop feedback, allowing you to take information from the machine tool and update the machining instructions in real time.

When a CNC machine cuts metal, the spindle turns and drives the cutter into the metal. The controller knows how much pressure is on the spindle and its maximum capacity. It knows, for instance, if the spindle's under 50% of its maximum loading condition in the middle of an operation—which means it has 50% capacity that you're not leveraging.

With a direct networked connection to the machine controller, you can "listen" to the controller and, in real time, update the machining strategy that you've automatically generated in your design software. If you're aware that the spindle load capacity is at 50%, you can either increase the feed rate so that the cutter goes through the material faster or cut deeper to remove more material. Either choice increases the spindle force, pushing the machine further toward its limit. And that means you can manufacture faster and get better operational efficiency at the factory.

Taken all together, these three forms of manufacturing automation—generative design, digital pipeline, and closed-loop feedback—present a powerful case for a new way of working. Today, you can input traditional manufacturing constraints into Fusion 360 and use its generative-design functionality to produce optimal design solutions. Soon, the digital pipeline and ability to reclaim information through connectivity to the shop floor will no doubt change your business outcomes for the better. For manufacturers, the best really is yet to come.



A Tormach CNC machine cutting metal. Courtesy of Getty Images.

A welder fabricates the prototype for the new transport part, reverse-engineered using ideas from generative design, traditional design, and input from the foundry. Courtesy of Claudius Peters.

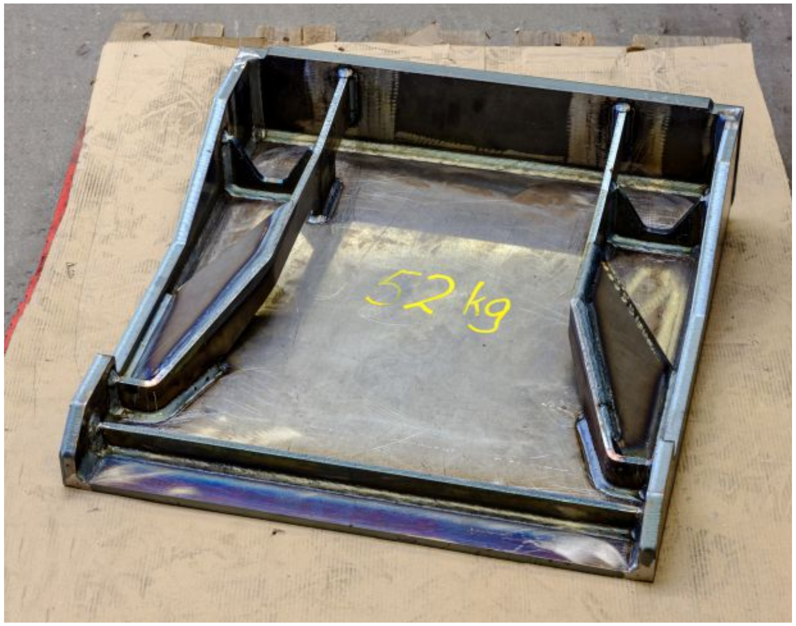
You won't find any 3D-printed parts at Claudius Peters: This century-old firm has adapted generative-design technology for traditional fabrication methods.

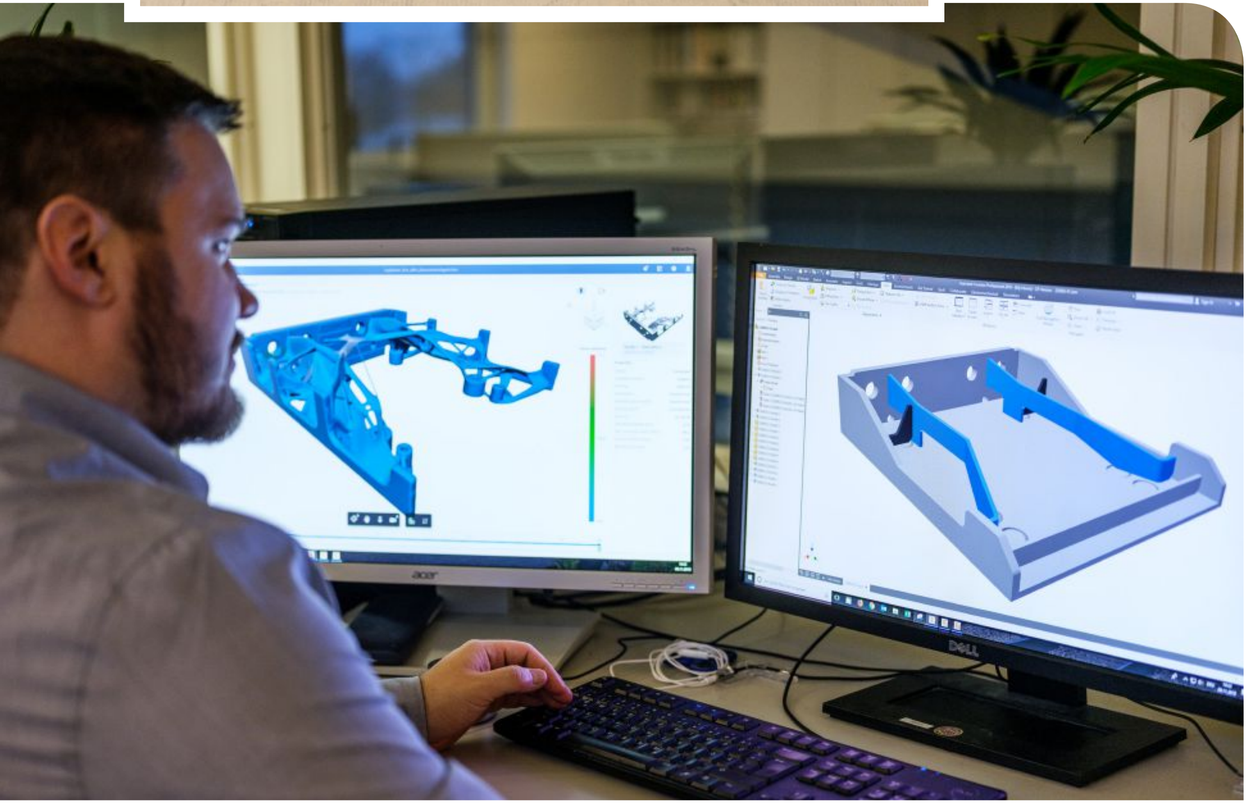
HEAVY-EQUIPMENT MANUFACTURER BRINGS GENERATIVE DESIGN DOWN TO EARTH

BY LAURA NEWTON

Claudius Peters, a 113-year-old manufacturer of bulk-materials processing equipment, is undergoing a transformation to become a digital company for the 21st century. Generative design is a game changer for the firm, offering a radical new way to approach product design and optimization.

By adapting this technology—which is usually associated with 3D printing—for traditional fabrication methods, the company is making more cost-effective products for a price-sensitive industrial market. Generative design in heavy manufacturing helps cut material, energy costs, and lead times to make Claudius Peters more competitive in changing times.





The new part design, based on generative design, is more than 50% lighter than the original. (left)

Design engineer Maximilian Lerch works on a reverse-engineered version of the generatively designed part that can be fabricated with traditional manufacturing methods. (below)

Courtesy of Claudius Peters.

An Old-School Company Embraces Change

German manufacturer Claudius Peters exemplifies the term "heavy industry": The company produces big industrial machinery and processing plants for the cement, steel, gypsum, and aluminum industries. "We're the specialists in handling bulk materials," says Thomas Nagel, operations director at Claudius Peters (CP). In addition to its headquarters near Hamburg, Germany, the company has 12 regional offices in the Americas, Europe, and Asia.

Founded in 1906, CP has manufactured huge, capital-intensive industrial products—conveyors, silos, grinding mills—for more than 100 years. But instead of clinging to its venerable history, Nagel, acting as chief digital officer, is helping the company establish a reputation as a global leader in digital innovation. Claudius Peters initiated an innovation journey in 2014 with the goal of improving business outcomes related to cost, quality, speed of delivery, and customer satisfaction. But the company realized that staying competitive in the 21st century requires more than just new software. In 2018, CP began a further transformation into an agile company, which would require new digital skills and a culture focused on design thinking, experimentation, and iteration.

The Innovation Journey Begins

Working with technology partners such as Autodesk has been key to Claudius Peters' innovation journey. CP has adopted new tools, including **Autodesk BIM 360**, to connect processes across sales, engineering, design, manufacturing, and assembly. The company also found new ways to streamline manufacturing processes using **Autodesk Inventor** and finite element method (FEM) analysis. To install its machines, CP began using 3D reality-capture scans with **Autodesk ReCap** and **Autodesk Navisworks** to capture data at customer facilities, then quickly hand off the files to the engineering and design teams in Germany. "This means we do our job faster, with higher quality at lower cost, leading to higher customer satisfaction," Nagel says.

"But our innovation didn't stop there," he adds. Inspired by a demonstration of generative design in Fusion 360, Nagel set up a four-hour workshop for the CP team to learn about this emerging technology.

Autodesk generative-design software takes design goals and constraints and explores the possible permutations of a design solution, quickly generating dozens of options to choose from. After experimenting with a few generic parts, the team decided to try using generative design to optimize a part from one of CP's core products for the cement industry—a clinker cooler.

The ETA Cooler at the Holcim Untervaz Cement Plant in Switzerland is a huge machine that's almost half a football field in size. Courtesy of Claudius Peters.

What's a Clinker Cooler?

The cement industry has been a mainstay for Claudius Peters from its earliest days. Cement manufacturers mix crushed rock and heat it in a kiln to 1,450°C (2,640°F), fusing it into marble-size lumps called "clinker." The red-hot clinker is discharged to a clinker cooler, a massive machine 50 by 25 meters (164 by 82 feet). Air cools the clinker to around 100°C (212°F) as it's moved through the cooler. It's then ground and mixed with other ingredients to form cement.

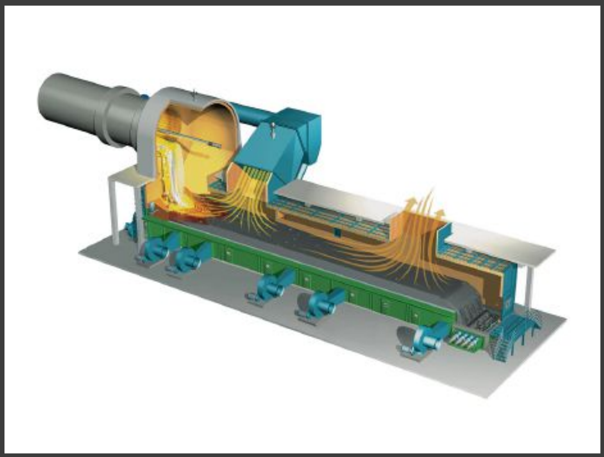
CP began supplying clinker coolers to the industry in the early 1950s, producing more than 700 coolers over the next 60 years. But clinker production consumes a lot of energy, making the cement industry one of the world's biggest CO2 emitters.

In the early 2000s, CP began developing a next-generation clinker cooler designed to save energy: the ETA Cooler, named after the Greek symbol "η" ("eta"), which denotes energy efficiency. "One of the greatest benefits of our ETA Cooler is outstanding thermal efficiency," Nagel says. "These energy savings can help reduce the negative environmental impact of cement production." Today, CP's main business is replacing existing clinker coolers with ETA Coolers to increase efficiency at cement plants.

WHAT'S A CLINKER COOLER?

Images courtesy of Claudius Peters.

In the cement-production process, red-hot clinker is transferred from the kiln to the ETA Cooler, which can handle up to 13,000 metric tons of clinker per day.

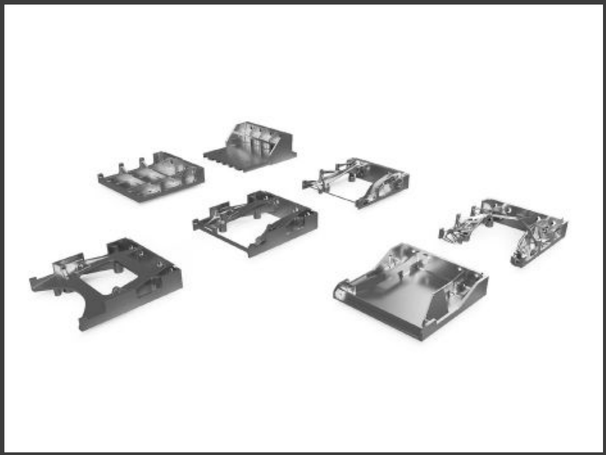


Conveyor lanes move the clinker through the ETA Cooler, where air cools the molten rock to around 100°C (212°F).

Each ETA Cooler has around 60 transport parts that are placed on conveyor lanes to move hot clinker through the cooler.

The original transport part (left) was redesigned in 2016 and has been installed and proven in 14 clinker coolers.

The new part design (right), based on generative design, is more than 50% lighter than the original—providing significant savings on material cost and energy.



Renderings show the clinker-cooler part's evolution from the original heavy geometric design (top row, far left) through generatively designed and reverse-engineered iterations.

Generative Design Yields Surprising Results

CP decided to use generative design to optimize a part for the ETA Cooler—a heavy-metal piece that had been recently redesigned to remove excess material using traditional design methods. Each cooler has 50 to 60 of these parts, which are bolted together on a series of conveyor lanes that move the molten clinker through the ETA Cooler. “This cast piece has been optimized over and over again,” says Maximilian Lerch, design engineer at CP. “The target was to lower weight and the linked cost of the metal. Even a little weight optimization would have a big effect.

“It was really cool to watch all the engineers gathered around the computer screen, watching generative design create an optimized, strong part out of almost nothing, just the constraints,” Lerch continues. “All the iterations that are needed to come to the best solution are done by the software.”

After that first four-hour session with generative design, the team had its first result: “We called it ‘the alien part,’” Nagel says. “The result surprised us—how could it be so different from our optimized part? And 30% to 40% lighter?”

Adapting a Generatively Designed Part for Traditional Manufacturing

Claudius Peters’ skeptical engineers ran calculations and FEM analysis on the “alien part” and were astonished to find it was more effective than their traditionally optimized version of the part. The team began to analyze the design to figure out how to manufacture it. “Generative design normally uses 3D printing or other additive-manufacturing methods to make the product,” Nagel says. “Our industry will not use 3D-printed parts—it’s too expensive.”

But using ideas from generative design and traditional optimization, “it took us only a week to reverse-engineer the part so we can make it using traditional manufacturing methods.”

With Inventor and FEM analysis, the team tested different fabrication solutions with Claudius Peters’ foundry. “We decided to move from a cast part to a solution with laser-cut plates and welding,” Nagel says. “We’ve made the part an additional 25% lighter, faster to make, and more cost efficient.” The team continues to study design options for the transport part, finding additional opportunities for improvement and even more cost savings. “It should be rolled out into production very soon,” Nagel says.

Reaping the Benefits of Generative Design

CP’s generatively designed part can ultimately save the company a significant amount of money on each clinker cooler it installs. With the weight of the transport part reduced by about 20 kilograms (44 pounds), the company anticipates saving about €100 (USD $113) per part—multiplied by 60 or more parts in each cooler. In addition, less weight means lower shipping cost. “From the first prototype we developed, we believed that generative design will help us achieve better costs for our products and make us more competitive,” Nagel says.

Generative design also delivers greater sustainability. “We can move from a heavier part cast in a foundry in India or Turkey to a lighter part—a welded design that we can even do in our workshop here,” Nagel says. “We save material, energy, transportation time, and other negative effects on the environment.”

Claudius Peters is now at the point where generative design is becoming a standard process for optimizing existing parts or designing new ones. “We will figure out more parts on which to apply optimizations and material reductions in the future,” Nagel says. “Part by part, we’ll try to see if generative design will have the same positive benefits.”

Courtesy of Claudius Peters.

What do you get when you combine a French visionary, an Italian contemporary furniture maker, Autodesk Research, and AI? The A.I chair, which is available now.

FROM ANALOG IDEAS TO DIGITAL DREAMS, PHILIPPE STARCK DESIGNS THE FUTURE WITH AI

BY ERIN HANSON

The opportunity to work on a truly unique project is every designer's dream, and new technologies can certainly provide the occasion to do just that—as one world-famous French creator and visionary can attest.

Philippe Starck—the mastermind behind designs for everything from furniture and household objects to hotels and even space travel—can add one more accolade to his impressive CV: designer of the world's first production chair created by AI in collaboration with humans.

That chair, A.I, is the result of Starck's collaboration with Italian contemporary furniture maker Kartell and Autodesk Research. Starck provided the overarching vision for the chair, and advanced generative-design algorithms output myriad design options to meet Kartell's injection-molding manufacturing requirements. The A.I chair, representing a leap forward in human-machine collaboration, is now available in Kartell's showrooms.

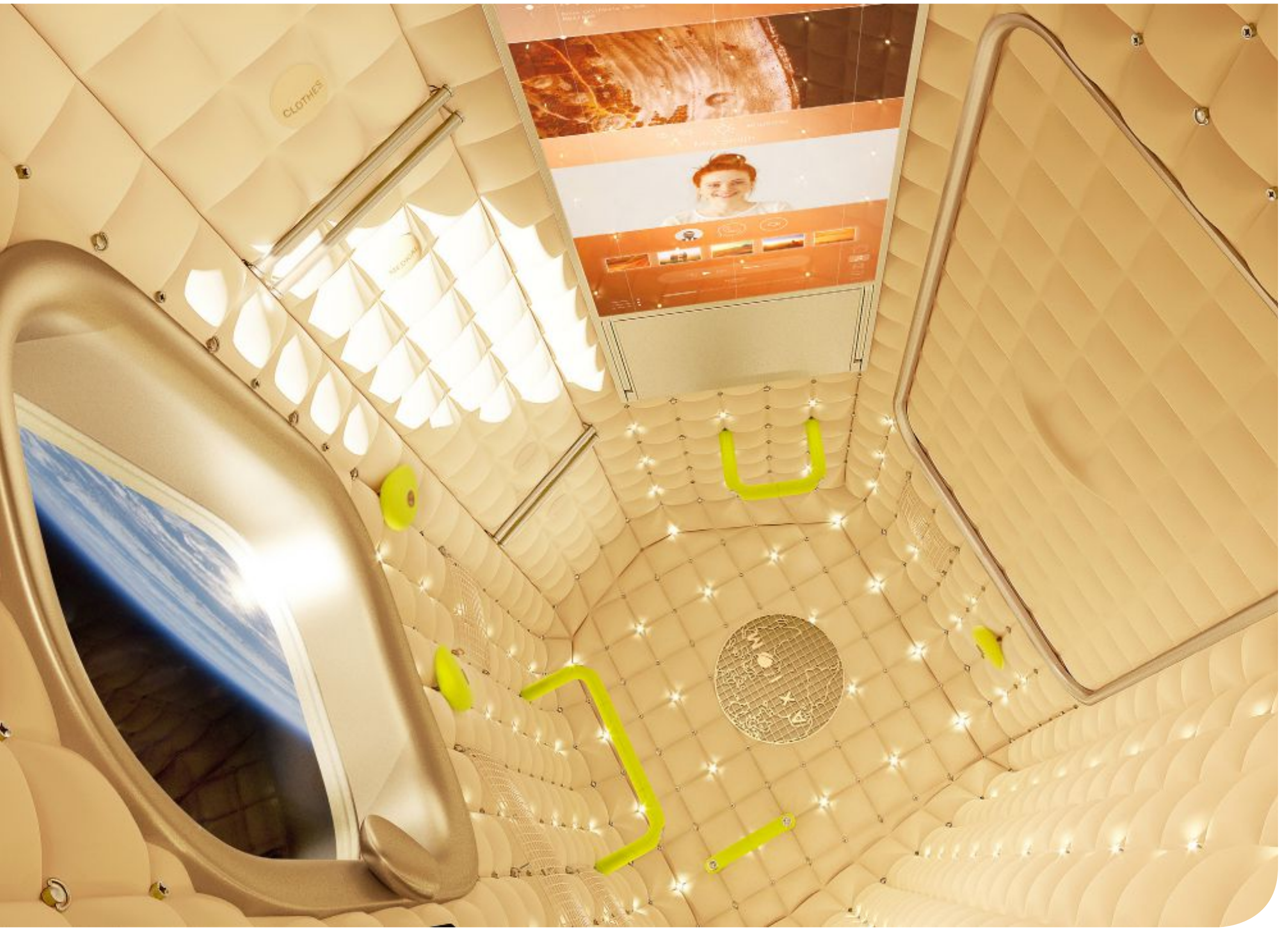
Here, Starck shares some of his thoughts on the present and future of design, including what it's like to work with generative design and when technology will be able to achieve its own true brilliance.

Philippe Starck. Courtesy of Starck Network/JB Mondino.

The A.I Chair. Courtesy of Kartell.

As someone who doesn’t own a computer, how do you feel about using generative-design technology, where the computer becomes a design partner?

I do not have a computer because for my job—being a creative—I am faster than any computer on the market. And above all, my field of creativity is unlimited. The best creative person with the best program can exercise his creativity, his idea, only within the imagination, talent, and intelligence of the programmer. It is like an incredibly intelligent and talented fly flying inside an invisible glass cube. All these dreams are limited. Obviously, with the upcoming arrival of a talented AI, the situation will change. In a few years, it might be possible that I would be able to increase my creative potential with this tool.



Well-known for traditional hotel designs, Philippe Starck goes extraterrestrial with designs for the Axiom commercial space station, its habitation module pictured here. Courtesy of Starck Network.

How would you describe the A.I chair that you created with the use of generative design?

I have designed dozens of chairs that are fairly well made, intelligent, and diverse. But after all these years, I realize that they come from the same brain—a brain that belongs to the same animal species, therefore to the same intelligence and logic. In other words, even if I twist my brain in all directions—if everyone twists their brain in all directions—if we are all geniuses, all great designers, we will always come out with pretty much the same thing because our DNA, our "background," our structure does not allow us to do it differently. I was getting bored, but I have great hope with AI to get out of this creative ghetto.

When I saw the great chess grandmaster Garry Kasparov beaten by a computer, I dreamed of being Kasparov beaten by a computer. Today, we are at exactly the same place: Kasparov was beaten under certain conditions; I fought under certain conditions. The A.I chair is the beginning of a great freedom—a great revolution—that human revolutions can no longer offer.

How does the A.I chair fit in with your personal ethos of "democratic design"?

Democratic design is not a style. It is a humanism that aims to increase quality in every respect—cultural, qualitative, technological—to lower the price and to share it with as many people as possible. AI should optimize all parameters of democratic design. And no longer coming from my brain, it will no longer please only people who have the same brain as me, but also a kind of universal brain.

What's the most unique design challenge you've been asked to solve?

The programmers' cultural memory [behind advanced generative-design algorithms]. It took me several years to try to chase away any human trace in AI's reasoning. Finally, human reasoning gave way slightly to a vegetal reasoning that does not satisfy me much more but which, despite everything, is a vital beginning.

Given your work with architecture and interiors, would you apply generative-design technology to, say, a hotel project?

It is an interesting idea but incredibly complicated. In a hotel, the function is an obligatory one but quite easy to understand. The importance is the human and sentimental function, which is difficult for a human being to evaluate and which still seems difficult today to get evaluated by a generative intelligence. But this question is a challenge—why not try it?

What's the funniest design mishap you've ever encountered?

One day, I received a very poor-quality phone call from a person I love very much, but whose mother tongue is not English. He ordered a 50-meter sailboat. I developed it for six months. I was extremely proud until the day I introduced it to this friend. He had difficulty understanding and, for the first time, showed a rather appalling lack of enthusiasm. I then understood that it was not a 45-meter boat, but a 145-meter boat that he wanted. I'm still humiliated by it.

How do you know when a project or a design is done?

Designers understand that a project is well done in two ways: First, we feel it in our guts. There is something magical in it. Second, after some analysis, success is the perfect balance of all parameters that make a proposed design fair, good, and deserving to exist.

What makes you most excited or hopeful about the future of design?

The most exciting thing about design is to understand that it was a temporary activity that dates back, as we know it, to the middle of the 20th century and will disappear in the middle of the 21st century. The intelligent part of human production follows the strategy of dematerialization: We will have much more with much less. Today, the task of design, with great naivete, is to try to make daily obligations bearable so that we can love them. But that is not true; we will never love a coffeepot, well designed as it is. This announced failure will end when the coffee maker disappears, and so will we.

Do you think technology is capable of genius?

Today it's not, because it relies on limited memory that is castrating. However, we only have to give AI a little time to grow in its heart, to make it capable of even more sophisticated feelings. The day when it will be in love, when it will be afraid, when it will have desires and dreams, it will have become a genius.

Under Armour's giant step forward: Learn how the company created the next-generation athletic shoe using generative design.

Courtesy of Under Armour

Downhill mountain-bike test rider Dominik Doppelhofer catches wicked air while wearing the Rotational Spine Protection System. Courtesy of Edera Safety.

Austrian design studio stands up to spinal-cord injuries with a generatively designed "skin" that's got your back.

THIS SPINE PROTECTOR THAT'S WORN AS A SECOND SKIN MAKES EXTREME SPORTS EXTREMELY SAFER

BY DREW TURNEY

In the first episode of Friday Night Lights, a high school quarterback suffers a paralyzing spinal-cord injury (SCI) on the football field. As his community struggles to absorb this devastating blow, the show's oracle, Coach Taylor, intones: "Life is so very fragile. We are all vulnerable, and we will all at some point in our lives fall—we will all fall."

According to a 2016 article in the Journal of Spinal Cord Medicine, researchers have identified countries with the highest incidence of SCIs that are sports-related (Russia, Fiji, New Zealand, Iceland, France, and Canada) and sports with the highest risk (diving, skiing, rugby, and horseback riding). Although there are many mandatory helmet laws worldwide for bikes and motorcycles, almost no standards are in place for spine protectors—or recommendations for their use in sports.

Most spine protectors are made for motorcyclists and are variations of belts or armor that restrict movement or absorb blows. But a new project out of Graz, Austria—the Rotational Spine Protection (RSP) System—acts as a "second skin" with straps and buckles that fit onto the body and "lock" movement inside a certain range, keeping the wearer in a green zone of safe motion. If spinal rotation enters a critical range, the tightening straps capture and absorb the excess rotational energy.

Cofounder and CEO Thomas Saier of Edera Safety, the design studio behind the RSP System, studied medical surveys of spinal injuries, determining how and where they occurred, as well as the type. Under the in-house brand name adamsfour, the team concentrated on rotational injuries, which are five times more common than direct spinal impacts.

"It's a biomechanical injury," Saier says. "The natural range of motion is overaccentuated. Injuries happen when the rotational force to your spinal cord, which is centered in the middle of your spine, is getting torn or sheared apart."

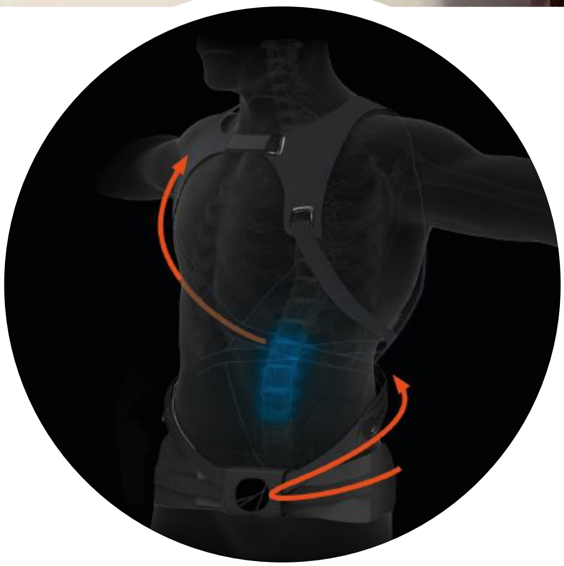
The Body Electric

Step one was discerning where potentially damaging forces exert themselves on the spine when the body moves in extreme or sudden ways. The team had to develop its own crash-test dummy with sensors and a spine that rotated properly, apply rotational forces in every direction, and gather the resulting data.

The team concentrated on the vertebrae joining the thoracic-lumbar and lumbar-cervical regions, where most rotation—and injury—occurs. It also referenced human spines from cadavers with the University of Graz Institute for Anatomy, applying rotation and taking 3D scans to collect more data on the spine's biomechanical range.

A critical discovery was the spine's natural limits with two types of movement: one managed by the body's musculature and one where connections between bones

Edera Safety CEO Thomas Saier works on the RPS System design. (above)



A rendering of the Rotational Spine Protector. (right)

Courtesy of Edera Safety.

(including vertebrae) start to take on the load. The human body can reach only about 60% of its range of motion using active muscular force—the rest is done passively through bone movements such as spine rotation.

So the trick was not to restrict the active movement made by directing muscles, but to put the brakes on when the passive bone movement is too much. When the spine enters that critical phase, the RSP System absorbs the resulting force.

A New Generation

Step two was putting all the data about spinal movement into practice, designing a system that restricts simulated force and energy but doesn't feel like a suit of armor.

Saier began considering generative design and its potential applications for RSP. "If you just work on the test pad, you can only simulate one kind of movement," he says. "Sports are such a complex thing with so many variations of movement—you don't know how much force, rotation, or disruption really occurs in your system until it's out there taking impacts."

Using Fusion 360 to fill the simulation with the real-time data, adamsfour developed a prototype. The team put it to work, integrating more sensors and an app to accurately measure and record all relevant forces, and then feeding it into the generative-design algorithm.

For René Stiegler, adamsfour's resident sportsman and designer, the next step was working with the geometries from the generative-design process to find the best solution. "The results we got were a bit too extreme to be sold as a product," he says. "For usability issues, you have to reduce it into something people actually want to wear."

Various iterations of adamfour's design for the Rotational Spine Protector. Courtesy of Edera Safety.

Daniel Krobath gets ready to test the RSP System in Schladming, Austria. Courtesy of Edera Safety.

The RSP System is a business-to-business technology—adamsfour will sell it as a kit to other manufacturers to be incorporated into their own products. Even though adamsfour is in the preproduction stage, it is already finalizing contracts with three large sportswear brands.

"Depending on the constraints, you get a lot of structural proposals out of it," Saier says. "Generative design produced the key image, and the final product we're using right now was driven by that geometry. You need to combine it with your intuitive know-how and the development skills of the design team to transfer it into a commercial product."

One advantage of this process was reducing the amount of material needed, based on the system's calculations for where the lines of force and energy apply to the body. "Without it, we might have had more material, or it might have been heavier," Stiegler says. "It basically gives us the answers about the amount of load we have to carry or how thick the material needs to be. It's your decision how you implement it in the final product. It's actually based on a skeleton to build the entire system around."

The next phase is to equip a larger number of test riders with more sensors, which will generate even finer detail, and then regenerate the current design to refine the topology further.

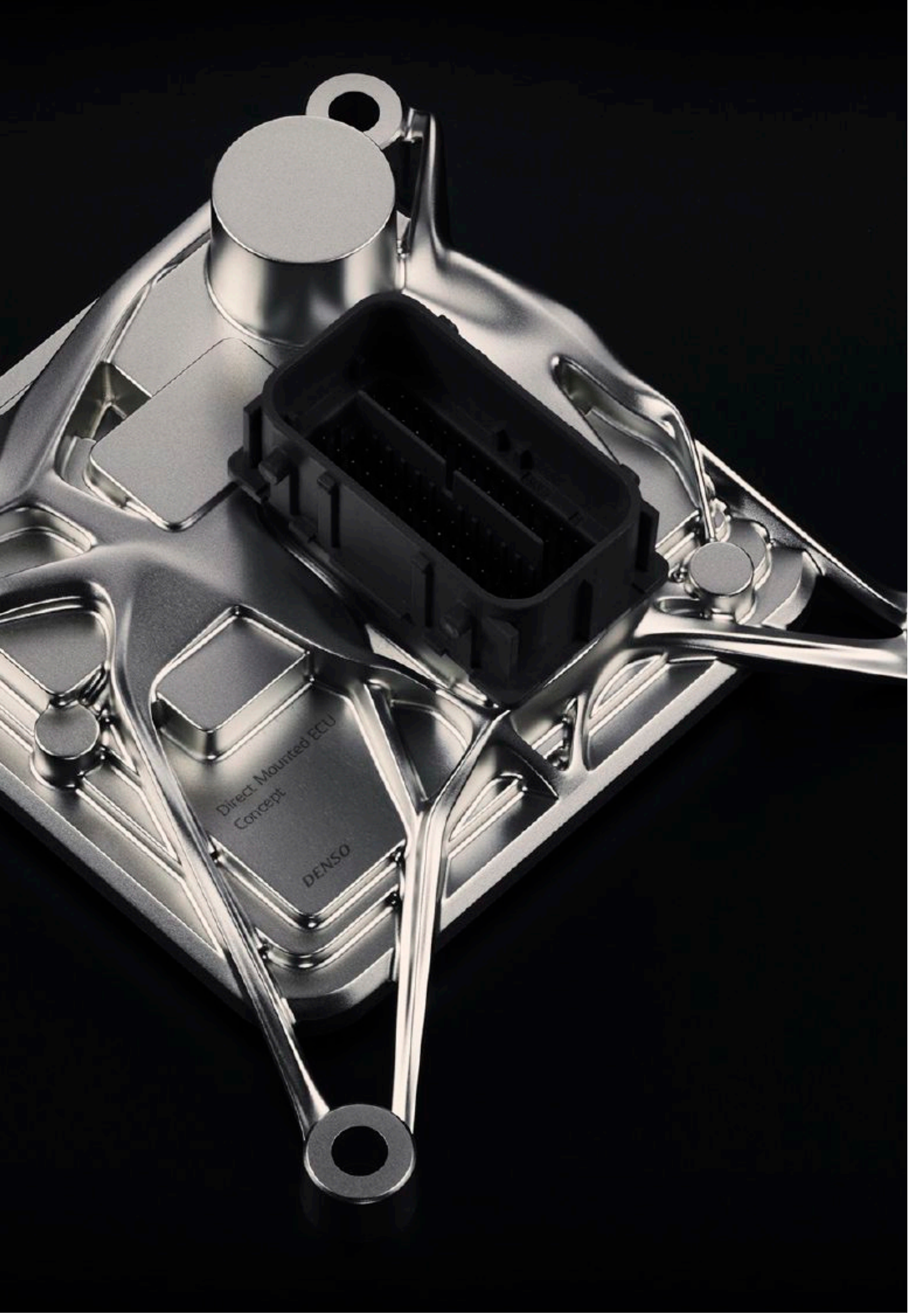
In the Real World

After all that simulating, data crunching, and finessing, does the user experience stack up? Is the device easy to put on, comfortable, and effective?

The right material was crucial. It needed to be cuttable and shapable without losing its intrinsic strength and required appropriate friction with the surface of the skin or clothing. If the device slides around on a sheer fabric or sweaty body, it won't restrict sufficiently. The answer was a substance called "chlorosulfonated polyethylene synthetic rubber," similar to the material used for rubber dinghies.

"It's comfortable to wear," says Dominik Doppelhofer, adamsfour's downhill mountain-bike test rider. "Compared to other back protectors, it's a little bit different to put on. You have to adjust it properly because it has to sit on your body like a skin, but it works really well."

This all means that if you play sports and soon find your spine better protected from overzealous twisting, you might have anatomical research, generative design, and a small company in Austria to thank.



A concept model of an ECU fabricated using metal cutting. Courtesy of DENSO Corporation.

A leading auto-parts manufacturer used generative design to optimize a critical component, making it lighter and increasing its thermal performance.

JAPAN'S DENSO TAKES ON THE ENGINE CONTROL UNIT, A SMALL BUT MIGHTY AUTO PART

BY YASUO MATSUNAKA

The global auto industry is scrambling to adapt to a number of major changes: increased regulations mandated by governments and the Paris Climate Change agreement, dizzying technological breakthroughs (some of which put the industry in direct competition with tech giants such as Google), and consumer demand for greater efficiency and lower carbon emissions.

To this end, automakers are looking for ways to improve engine performance and reduce vehicle weight, reexamining the 30,000-plus parts that make up a car, such as the steering wheel, pedals, seats, engine, brakes, and one key component tiny enough to rest in the palm of your hand: the engine control unit (ECU).

Another view of the metal-cut ECU concept model. (above)

Akira Okamoto, head of the second product development unit of DENSO's product design office. (left)

Courtesy of DENSO Corporation.

The ECU is an electronic fuel-injection control system that determines the proper fuel supply required by the engine: Think of it as the "brain" of the engine. This system plays a critical role by optimizing the amount and timing of fuel injected, which can improve driving performance and reduce the amount of harmful emissions.

In 2019, the iF Design Award for Professional Concept went to Japan's DENSO Corporation, a leading auto-parts manufacturer, for a redesigned ECU. Founded 70 years ago, DENSO today develops technologies for autonomous and electric vehicles, AI, mobility as a service (MaaS), and even quantum computing. To optimize the ECU, Akira Okamoto, DENSO's project assistant manager of product design, used generative design to meet two critical goals: making the part lighter and increasing its thermal performance.

Okamoto is developing ECUs for mounting on small diesel engines used in construction and agricultural machinery, incorporating generative design into his workflow to create advanced conceptual models. "From the outset, I designed the components with lightness in mind," he says. "I realized I could then use generative design for even greater weight reductions."

An engine's "room temperature" can reach 120°C (248°F). To operate without problems, the ECU hardware's temperature needs to be lower than that by dispersing heat from where it contacts the engine block, where temperatures are about 105°C (221°F).

"I can draw on my experience to visualize a shape that disperses heat well," Okamoto says. "However, in a lightweight design, there are fewer pathways for drawing off heat, which reduces the heat-transfer efficiency. I thought

I could use generative design to create parts using new shapes that are lighter but still retain heat-dispersing properties."

Solving the Heat-Transfer Dilemma

In his research, Okamoto used the generative-design features of Fusion 360, even though it does not offer heat-related parameters. "To calculate for heat, I hypothesized I would need to treat the heat as load, so by adding load to areas that need to disperse heat, the optimal shape could be found," he says. DENSO collaborated with partners at the Nichinan Group and with designers Satoshi Yanagisawa and Yujiro Kaida during this process.

In generative design, AI creates copious design variations based on the designer's provided parameters. By sifting through the choices—discarding unsuitable designs and accepting others—a person arrives at the optimal design. "Our work designing this ECU was a process of trial and error, and many unusable designs were generated," Okamoto says. "However, variations that could be used began to have similar shapes.

"What I liked about this process was that I could make a 3D print of a model and get a better sense of how the heat would flow around that part," he continues. "Lots of the models were ugly at first look, but you began to see the beauty in these designs. The final design had a beautiful shape that we modified to allow for manufacture using conventional methods."

Designing for Production

Objects created with generative design can be difficult to produce without 3D printing—which is unsuitable for mass production. "When you need tens of thousands of parts, cost and production time become challenges," Okamoto says. For this project, the team incorporated elements from the generative-design process into a part that conventional die-cast molding could produce.

To do this, a geometrically shaped circuit-board cover was made and integrated with a frame created through generative design. Autodesk Alias SpeedForm and Fusion 360 were employed to taper the overall body and give it a smooth shape, and adjustments were made for production via conventional manufacturing methods. "We combined the essentials of each component to create the shape of the overall unit," Okamoto says.

A metal-cut mockup of the result is called the Direct Mounted ECU Concept. "We realized a 12% overall weight reduction," Okamoto says, "but we could maintain the heat-dispersing capacity of the original.

The conceptual model shown in the middle combines the circuit-board cover with the generative-design frame to the left. The model to the right is the original general-purpose design. Courtesy of DENSO Corporation.

While the reduced weight meant there are fewer paths for heat to escape, since the performance is identical, we can say the exothermic capacity of the part has improved over the original.”

Although Okamoto had experimented with other approaches to weight reduction, such as topology optimization, this was the first time he tried generative design. The project took about three months to finish. “While it took us a little time to get up to speed, we achieved results in a relatively quick time frame,” Okamoto says. “We think we will realize even greater gains with larger ECUs, and we have found areas we can further refine in the next round of design work.

“If we can lighten each part one by one, even slightly, the overall result will be a much lighter automobile,” Okamoto continues. “We can apply these results toward other parts beyond ECUs. It would be ideal if we can apply these methods regularly to lighten automobiles overall. While this model is just for proposal to our clients, our next step is to put in the electronics and test its performance to see the actual results of our work.”

A frame for direct mounting on an ECU unit to an engine block, created using generative design. Courtesy of DENSO Corporation.

Another view of the initial ECU frame, made using generative design. Courtesy of DENSO Corporation.

Courtesy of X-Vein.

Learn how a massive natural disaster in Japan inspired this student maker duo to develop a lightweight, highly customizable drone for search-and-rescue missions.

TAKEAWAYS

Generative design lets humans and machines collaborate to create better, stronger, and more efficient things. Whether the goal is to minimize weight, consolidate parts, improve performance, or meet sustainability objectives, generative-design software can help achieve it.

Generative design helps:

Save time

In the time that a human can create a few designs, a computer can generate multiple iterations, along with data to prove which designs are performance-based frontrunners.

Boost creativity

Generative design automates routine tasks and opens new doors for designers and engineers to explore more innovative and imaginative outcomes.

Save money

Simulation and testing are built into the initial design process, preventing expensive changes later in the manufacturing process.

Fuel innovation

Generative-design software makes formulating this complex geometry possible, and hybrid manufacturing helps accelerate the entire design-to-make process.

From the past to the future: Generative design upgrades a vintage van and aids research on the human brain.

VOLKSWAGEN

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