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Briefing Paper

THE NEXT WAVE OF INTELLIGENT DESIGN AUTOMATION

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Autodesk generative design technology: Shaping the future of intelligent design automation and empowering teams to deliver innovation and productivity.

The way things are designed, made, and used is changing at lightning speed, and the pressure to get to market with groundbreaking products in less time is very real. At Autodesk, a company that makes software for people who make things, we see generative design technology delivering the ideal combination of innovation and productivity required to help companies address the challenges of this disruption.

Powered by artificial intelligence (AI) and the computing power of the cloud, Autodesk generative design technology gives us the ability to simultaneously generate multiple CAD-ready solutions based on real-world manufacturing constraints and product performance requirements. From there, the designers or engineers can filter and select the outcomes to best meet their needs.

With its ability to explore thousands of valid design solutions, built-in simulation, awareness of manufacturability, and part consolidation, generative design impacts far more than just the traditional notion of design. It's really about the entirety of the manufacturing process providing companies with new insight to bridge the gap from design to manufacturing, enabling major advantages from reductions in cost, development time, and material consumption to improvements in product performance.

All of a sudden, we are no longer limited by our own imaginations or past experience; we have the ability to design with engineering and manufacturing expertise in a way that is almost superhuman.

What originated at Autodesk as design software inspired by nature's evolutionary approach, has evolved with further development and additional customer insight. And after several months in a closed beta, Autodesk generative design is being released within Autodesk's Fusion 360 platform. Now, companies everywhere have access to intelligent design automation software, giving them the power to shape the future of making things.

As you will read here, a few of the most forward-looking companies in the world, including Airbus, Under Armour, and Stanley Black & Decker, are already using generative design to solve engineering challenges, demonstrating immense opportunity for design and manufacturing across industries. As AI becomes part of all work processes and generative design becomes the norm for product design, it will be exciting to see what we can achieve.

THE NEXT WAVE OF INTELLIGENT DESIGN AUTOMATION

For decades, the process of product development has been painfully iterative and rigid. Designers and engineers would take customer requirements, create a few design concepts, experiment with possible forms and materials, test designs virtually and physically to determine how they held up in various conditions, and tweak them until they got one that met specifications—before they ran out of time and money. There simply were not enough hours in the day to come up with the ideal design. And little thought was given to the manufacturability of the resulting design.

With the democratization of a new wave intelligent design automation technology, we are on the cusp of a paradigm shift in how products are designed—a world in which engineers might dedicate their creative focus to what they are building rather than how.

Product designers long ago swapped their drawing boards for computer-aided-design (CAD) programs, which made modifications and revisions easier and, over time, increased in functionality and decreased in price. Despite the name, however, CAD software did little to aid in the design process; even with later bells and whistles, it was fundamentally a tool for documenting what an engineer had come up with in his or her head.

Thanks to low-cost, high-performance computing power available via the cloud, and intelligent design algorithms powered by machine learning capabilities, a new breed of generative design software has emerged that will offer a step change in computer-aided engineering (CAE). "The nexus of software capabilities, fast computers, thoughts about manufacturing capabilities and ability to engineer new materials will totally revolutionize engineering and product innovation in the future," says Keith Meintjes, practice manager for simulation and analysis with product life cycle management consulting and research firm CIMData.

Manufacturers of all sizes can use advanced generative design tools, which employ algorithms to transform a designer's requirements into product geometry, optimizing the product design based on the conditions and constraints provided. The tools can provide a plethora of design options in the amount of time it would take engineers to set up a meeting to discuss just one.

HIGHLIGHTS

- With the democratization of a new wave of intelligent design automation technology, we are on the cusp of a paradigm shift in how products are designed
- A new breed of generative design software has emerged that will offer a step change in computer-aided engineering

With **generative design**, the options are pre-validated to work within the manufacturing and business constraints provided.

The primary benefits are twofold: generative design tools decrease the amount of time it takes to design a product, and open the door to design options that might never have been dreamed up by human engineers on their own. Engineers, with only their own experience and skills to guide them, are naturally limited by "what they've seen in the past and what they believe to be true," says Frank DeSantis, vice president of breakthrough innovation at Stanley Black & Decker, an early adopter of generative design technology.

In addition to enabling the exploration of multiple design alternatives for each product, such software considers the manufacturing, cost, and schedule impacts of the design as part of the process. In the past, designers and engineers would pass a design back and forth in seemingly "endless manual iteration loops," says Bastian Schäfer, innovation manager with Airbus. With generative design, the options are pre-validated to work within the manufacturing and business constraints provided, reducing long-standing friction between engineering and manufacturing, providing increased business value to enterprises and their customers.

With the potential to continuously feed learning data into the software, generative design systems will be able to produce more effective designs over time. Some early adopters are already extending the use case for generative design technology beyond product and parts development to designs for the components and tools used to manufacture those parts. Down the line, manufacturers could utilize the same technology to design better factories or supply chains.

What Is Generative Design?

The phrase "generative design" has been used in architecture and civil engineering to describe the use of advanced computer programs to synthesize designs for structures or circuit diagrams, for example, based upon input requirements.

In recent years, some manufacturers have worked with advanced topology optimization tools to make existing parts or components perform better or make the finished products lighter or stronger. General Motors, for example, used topology optimization to remove 400 pounds of weight from the design of its latest Chevrolet Equinox, while retaining interior space and vehicle performance characteristics.

Generative design, however, goes much further than topology optimization. Generative technology can take the many specific goals input by a designer or engineer—size, weight, strength, style, materials, cost, schedule, manufacturability—and employ algorithms running in the cloud to produce a plethora of possible design solutions. Incorporating machine learning and advanced simulation, the intelligent design software can rapidly cycle through thousands or millions of design choices, and test configurations to produce options that would be difficult for designers and engineers to discover and model efficiently. FIGURES 1 AND 2

Generative design is just beginning to be applied to the development of parts and products in a holistic way, with early adopters using such tools to design everything from aircraft components to athletic shoes. It takes the way companies have designed for the past 30 to 40 years with CAD software—taking something in our heads and pushing the geometry around on the screen with a mouse—and flips it. The software works at the service of humans instead of the other way around.

An engineer seeking to design a frame for a quadcopter drone, for example, might specify needed space for a battery, electronics, and cameras; the weight of those electronics; the

thrust required for propellers; and the forces that will act upon the aircraft. The software would then resolve those requirements into a number of optimized physical forms that the engineer can review and further refine. "The ability to generate feasible designs that a CAD engineer would never be able to generate on his or her own and then give a human the ability to choose from them can revolutionize product engineering," says Meintjes.

"We can actually feed our requirements into the algorithms and let them go—and over time it will be able to create more complex and better results," says Schäfer at Airbus, which has been experimenting with generative design tools for five years. "This is the direction in which we are headed."

An Entirely New Way to Develop Products: The Early Adopters

"We are only at the beginning of the frontier of innovation that these tools will generate," Meintjes says. "But some companies are seeing the fruits of generative design right now."

Airbus began using generative design tools to come up with a new design for the partition that separates the passenger compartment from the galley in the Airbus A320 cabin. The partition had to be significantly lighter than the current versions yet strong enough to anchor flight attendant jump seats, have a cutout to move wide items in and out, attach to the airframe in just four places, and be no more than an inch thick. It also had to meet strict parameters for weight, stress, and displacement in the event of a crash.

The ultimate design—dubbed the "bionic partition"—is an unusual-looking, latticed structure unlike any cabin partition in existence, but optimized to be strong and light, requiring the least material to be built. Airbus 3-D printed the partition's 100-plus pieces, made of a new high-strength metal alloy, and assembled the component. It fits exactly the same way as the old one, but saves airlines 3,180 kilograms of fuel per plane per year.

While Airbus started with a single part, Schäfer envisions a time when generative design could be used to conceive an entire aircraft.

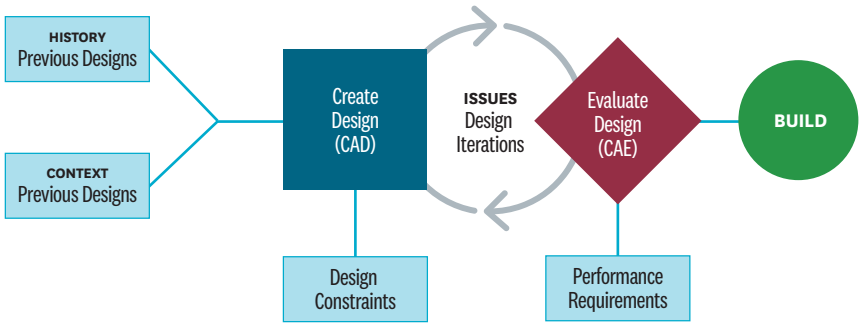
Hardware and toolmaker Stanley Black & Decker's Infrastructure Innovation team embraced generative design tools to come up with a new design for the 15.4-pound hydraulic crimpers used by workers to fix hanging electrical and telephones lines. Linemen had to lift these tools hundreds of times each day. "The weight is unwieldy," says DeSantis. "It creates user fatigue."

The breakthrough innovation team used generative design tools to

FIGURE 1

TRADITIONAL COMPONENT DESIGN PROCESS

Characterized by many evaluation iterations

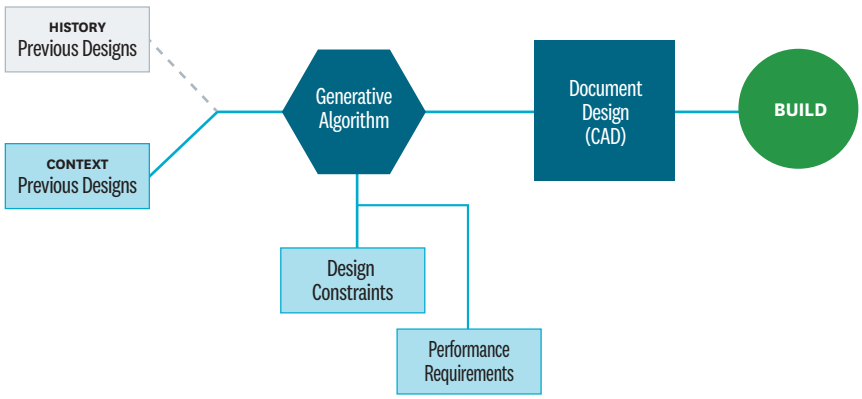


SOURCE: CIMDATA

FIGURE 2

GENERATIVE DESIGN PROCESS

Optimization should directly create feasible and buildable designs



SOURCE: CIMDATA

"The designer's **role changes from CAD jockey to curator** and empathizer," says Bastian Schäfer, innovation manager with Airbus.

prototype and test a hydraulic crimper head that was significantly lighter, but still as strong and durable. Specifically, they used the tools to redesign the metal attachment that helps make the crimp on a metal connector. They set parameters around weight, size, and manufacturing cost, and the software generated about 100 designs, from which the team chose the option providing the best combination of weight and manufacturing cost savings.

The final design weighs just over two pounds and is held together by what DeSantis describes as a lattice that looks like it's made of toothpicks. "We started on this path with the goal of solving the problem of weight saving," says DeSantis. "But what we uncovered is that there were a number of other benefits with the generative design approach."

The Benefits of Intelligent Design Automation

Indeed, while leading-edge users of generative design technology begin exploring the new tools to solve specific design conundrums—"light-weighting" an existing product, for example—they are finding that there a number of significant advantages to the approach.

Reinvigorating creativity and customer focus. Generative design can free up designers and engineers to focus on the "what" of their work rather than the "how." Instead of spending the majority of their time doing drags and drops to iterate a design, they can concentrate on customer pain points. "The designer's role changes from CAD jockey to curator and empathizer," says Schäfer.

Rather than asking, "Does this design meet the requirements?" says Meintjes, they can ask "Which design best meets the requirements?" They can home in on the best design for a particular circumstance rather than simply on a design that works.

Increasing agility and efficiency. The generative design approach can enable manufacturers to look at their design and production processes differently, saving time and money. "We can create products and parts of products that weren't even imaginable in the past," says DeSantis. That may mean using additive design to produce a product that had to be machined or molded in the past, or simply reducing the complexity and increasing the manufacturability of a design. "The ultimate benefit is speeding up the lead time," DeSantis says. "If it takes weeks to design an overall product, you can get it to market that much faster."

Improving the relationship between design and manufacturing. There's long been an awkward dance that happens between designers and manufacturers. Designers may come up with a product with little concern for how it will be made, and throw it over the wall. Manufacturing will throw it back, requesting changes to improve manufacturability. And so it goes until they find some common ground. With generative design tools, manufacturing intelligence is built into the design process from the start, with considerations for how the geometric variances in a design will impact the ability to injection mold, machine, or 3-D print it, for example, built in.

Bringing other business functions into the fold. Generative design tools are built for use by designers and engineers, but they can also benefit other areas of the business with a vested interest in product

development. "Engineers will be the ones using the tools day in and day out," says DeSantis. "But the approach enables you to bring in sales or marketing or customer service sooner in the process to begin having conversations about price, product differentiation, or weight."

Reimagining manufacturing systems. In the future, manufacturers may extend the functionality of generative design tools to help them design or redesign their manufacturing tools, factories, or supply chains. The approach can help them come up with a range of scenarios for how to create a certain part, where to locate the factory, and how to supply it.

Laying the Groundwork for the Future of Product Development

While generative design technology has the potential to transform product design and manufacturing, successful introduction and adoption of these tools require shifts in mindsets, training, processes, and infrastructure in the enterprise. The biggest challenges have to do not with the technology itself, but with the ability of humans and human organizations to truly adopt an entirely different approach, says James White, director of the additive manufacturing strategy practice at CIMData. "The way we've been designing products has been unchanged for 5,000 years. We come in with the idea of the end thing we want to produce, we deconstruct it into components, we figure out how to make those components, and we assemble the thing. It's been the same approach, from building the Pyramids to producing iPhones."

Such a significant shift will require manufacturers to address and enable changes on a number of fronts.

ADDRESSING FEAR, UNCERTAINTY, AND DOUBT

This new class of systems is more than an incremental improvement on CAD software. The automation and intelligence they introduce is likely to elicit concerns from some employees. "The first thought is often that this computer software is going to replace me," says DeSantis. Others may think the software looks too complicated, or prefer working in the ways they always have.

The key to overcoming anxiety or opposition is taking the time to illustrate how the systems work. "Once you walk them through what it actually is, they begin to see that it's another tool they can use to accomplish their work in a quicker fashion," says DeSantis. "Generative design is not going to replace engineers anytime soon. It simply allows them to apply their skills in a different way."

CHANGING MINDSETS

Indeed, generative design requires designers and production engineers to work and think differently. "It's a whole new way to design. That's the primary challenge," Schäfer says. "It's not just learning a new piece of software or some new features. It's reframing how you think." In the past, engineers would come up with several ideas, adjusting those to meet requirements. With generative design, they begin with a plethora of design solutions that all meet those requirements, and explore the trade-offs with each. It requires giving some training and time to wade in and develop new kinds of intuition with the tools.

One option is to develop a generative design center of excellence to start, as Airbus did, charged with providing generative design services to the business with the goal of extending the practice to the rest of the enterprise over time.

WITH GENERATIVE DESIGN, ENGINEERS BEGIN WITH A PLETHORA OF DESIGN SOLUTIONS THAT ALL MEET THOSE REQUIREMENTS, AND EXPLORE THE TRADE-OFFS WITH EACH.

Some **innovative solutions** that technically achieve the desired requirements may be **too unusual** for customers to accept.

EMBRACING THE CLOUD

Cloud computing provides cost-effective access to the computer power required to quickly generate multiple solutions to complex design problems.

OVERCOMING DESIGN BIAS

Designers using generative design tools for the first time may be taken aback by what the computer spits out. Unlike a human designer, the machine isn't basing designs on what's come before. "The designs can look very foreign," says DeSantis. "The first time we ran it, the computer spit out 100 options and, for about 80% of them, we were like, 'What the heck is that?' There's a little shock and awe." Some of these new forms may be impossible to make with traditional manufacturing methods, and must be built using additive manufacturing methods such as 3-D printing. A generative design solution might produce a skateboard that looks like a boomerang with three wheels or a grand piano the resembles an oversized box. The designs may yield better performance; the oblong skateboard may ride better than the symmetrical version, and there's no real reason a grand piano has to look like a sideways harp on legs other than that's the iterative way in which it was first designed. Still, each may be a bit too unfamiliar to sell. "The issue is human acceptance," says White. "There's a barrier there when you're manufacturing products for consumers."

MASTERING DESIGN SELECTION

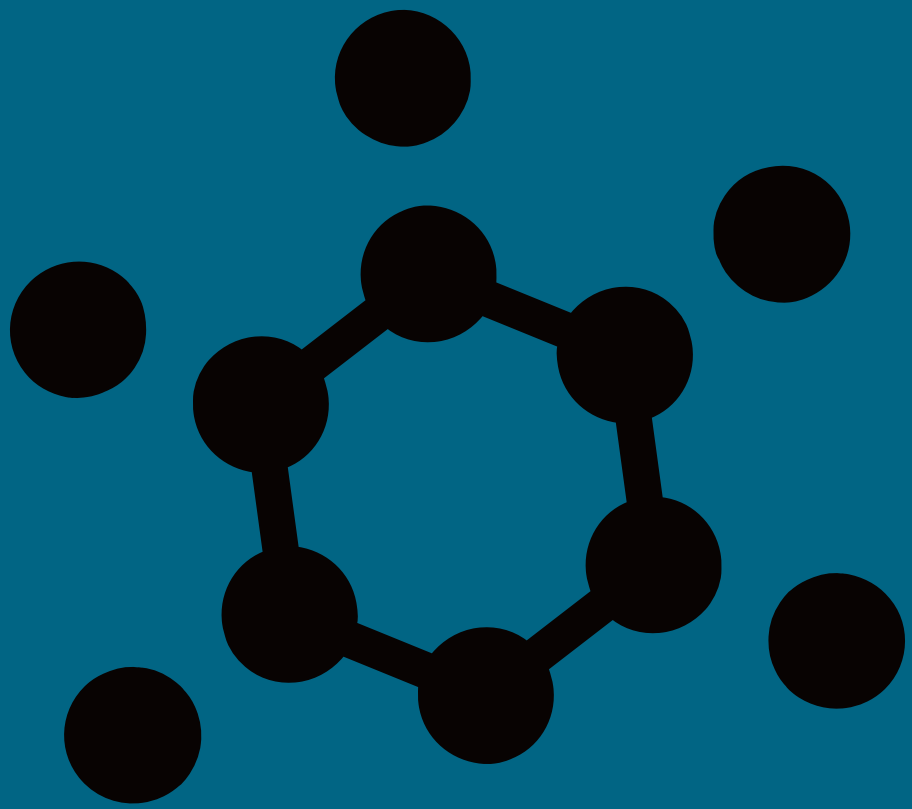
Users may also be overwhelmed by the number of choices generative design software can produce. The possibilities are 10 or 100 times more than they're used to considering. However, the makers of generative design systems have worked to refine user interfaces so that designers can easily scroll through the trade-offs embedded in each design and use a visualization tool to sort and rank them to narrow down choices.

PICKING THE BEST PILOTS

Stanley Black & Decker picked a small-scale, low-volume part to start. "It didn't distract us from what was going on in other areas of the business," says DeSantis, "and we learned a lot about where we might apply it elsewhere." It was a part that would clearly benefit from software with the computing power to figure out how to decrease its weight without impacting performance. Based on the positive results, DeSantis' team has begun educating the rest of the manufacturing and operations organization about the benefits of the generative design. The company is evaluating how it might use the systems to redesign some tooling to make it more cost-effective, user-friendly, and efficient.

THE BIGGEST CHALLENGES HAVE TO DO NOT WITH THE TECHNOLOGY ITSELF, BUT WITH THE ABILITY OF HUMANS AND HUMAN ORGANIZATIONS TO TRULY ADOPT AN ENTIRELY DIFFERENT APPROACH.

JAMES WHITE, DIRECTOR OF THE ADDITIVE MANUFACTURING STRATEGY PRACTICE, CIMDATA



THE MACHINES WILL BECOME BETTER AT UNDERSTANDING THE USERS' NEEDS AND THE USERS WILL BECOME MORE ADEPT AT UTILIZING THE TOOLS.

EVOLVING PROCESSES

"If you look at the design process in most manufacturing companies, it will need to change so that the generative design activity gets moved way up to where they're establishing design concepts and product architectures," says Meintjes. Using generative design tools may mean the need for fewer meetings later on in the process, but much more interaction among more stakeholders throughout. Generative design will benefit from "borderless, dynamic collaboration" among those charged not only with product design and engineering, but with pricing, marketing, sales, and customer service, says White.

UNDERSTANDING GENERATIVE DESIGN'S LIMITS

Knowing what these tools can't do may be as important as knowing what they can do in these early days. The future vision of these systems and the integration of more artificial intelligence holds incredible promise, but there's the risk of overblown expectations. It would be difficult to create an algorithm that enables a generative design system to consider a designer's aesthetic sensitivities, for example. That's a really sophisticated problem to try to deconstruct and have a computer help with. Right now, it's really good at weighing 10 design variables against each other—and that's more than a human brain can hold. But it's still early days for this technology.

Toward an Intelligent Design Future

There's little doubt that, over time, generative design systems will be able to tackle increasingly nuanced conditions and considerations and become a more important implement in the product development toolkit. The machines will become better at understanding the users' needs and the users will become more adept at utilizing the tools. The bigger challenges will be those with a human face—making the fundamental changes in product development roles, relationships, and organizations.

Now is the best time for manufacturers to begin addressing those issues. Companies that start down this path now will also have the opportunity to make sure the tools being developed will work for their sector, because product development use cases will vary wildly by company. "Pick a part or process in your industry and dive right in," advises DeSantis. "If you wait for the technology to get there, you will get passed by."

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