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DE Digital Engineering

April 2019

ADDITIVE'S BRIGHT PRESENT

LS-DYNA® Implicit Mechanical Analysis

LS-DYNA® Implicit Mechanics provides a comprehensive set of analysis tools for engineering applications. It is fully integrated with the Explicit counterpart, using the same element and material libraries, and thus enables users to have one model for a broad range of analyses. This also allows for seamlessly switching between Implicit and Explicit during the same simulation, thereby increasing the level of applicability. The Implicit solver provides both Linear and Nonlinear analysis options, including the additional choice of Static or various kinds of Dynamic solution schemes.

APPLICATIONS:

Implicit Mechanical Analysis can be used on a wide variety of application areas, including but not limited to;

Automotive

- Gravity Loading
- Dummy Seating
- Door Sag
- Roof Crush
- Seat Pull

Aerospace

- Fuselage Drop Test
- Jet Engine Start Up
- Analysis of Seats
- Satellite Stress and Vibration Tests

Consumer Goods

- Drop Test
- Vibration computations for Acoustical Analysis

FEATURES:

- Linear and Nonlinear Analysis
- Buckling, Vibration and Modal Analysis
- Shared Memory Parallel (SMP)
- Massive Parallel Processing (MPP)
- Hybrid Parallel-combines SMP and MPP for scalability that can exceed 10K cores.

YouTube Channel:

www.youtube.com/channel/UCPuoss7k_-IouTDXGT2EFiw

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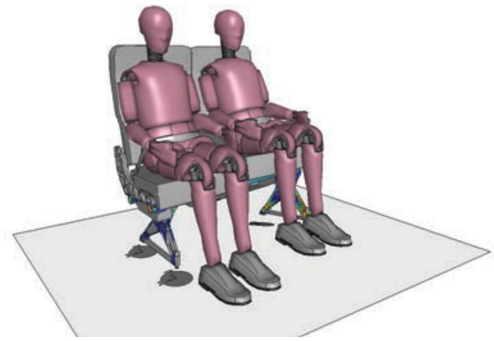
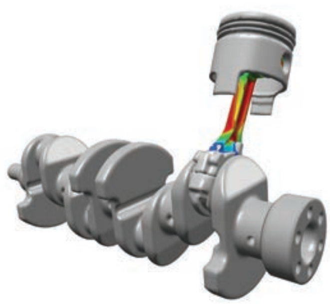


Aerospace Seat Pre-Loading

RollOver Protection Structure

Door Sag



Crank Shaft

LSTC Livermore Software Technology Corp. www.lstc.com

For demo version, pricing and learning version contact: sales@lstc.com

by Jamie J. Gooch

Trust, Technology and Being Human

MY WIFE CALLED to say the car's check engine light was on. No strange sounds, no strange smells, no odd vibrations, no smoke, no fire—so being a fallible human, I told her it would probably be OK for her to finish shopping and drive the short distance back home. This was during one of the many polar-vortex-induced cold snaps, so, also being a lazy human who doesn't like the cold, I didn't even open the hood when she returned. I dropped it off at the mechanic the next day.

"You're not going to believe this," my mechanic said. "When we popped open the hood, a rabbit hopped out." Apparently the guy lifting the hood was startled enough by the stowaway that he screamed when it appeared.

We shared a laugh until he said, "It looks like the rabbit chewed about $400 worth of wiring." Suddenly the bunny wasn't so funny, at least not to me.

Ignorance Isn't Bliss

Had I asked my wife to drive home right away and braved the cold night to investigate the check engine light, perhaps Bugs would have chomped through fewer wires as he was chauffeured about town. I can't help but wonder how a future autonomous vehicle would react to a rabbit in the engine compartment. Would a rabbit-shaped idiot light blink? Will a soothing computer-generated voice warn that an unauthorized life form has been detected? No, but hopefully the car will be smart enough not to delay rectifying the situation like I did.

That's the great thing about technology that makes suggestions based on available data vs. a human's gut reaction. However, input data and algorithms aren't perfect. A human is still required to evaluate and act on prompts—whether it's a generative design suggestion, an additive manufacturing part orientation suggestion or a red light suggesting you should check your engine. Ignored Leporidae notwithstanding, that's a good thing when it comes to engineering workflows.

Looking back on my decision-making process, I can pinpoint a number of factors that led me to react the way I did. It had been a long day, it was cold, it was dark, the chances of me figuring out what was wrong with the engine beyond its basic needs for cooling and filtration were slim. But, perhaps most importantly, I now realize that I subconsciously distrust automotive warning lights thanks to past experiences with overly sensitive tire pressure monitoring systems. I'm not alone. A friend of mine has been driving with his check engine light on for years. He might have a whole family of rabbits under the hood.

The stowaway, moments before making his escape back into the wild. *Image courtesy of Grizzly Auto.*

A Balancing Act

During *DE's* recent computer-aided optimization Hot Seat webcast (available on-demand at digitalengineering247.com/cao), the audience wanted us to ask our panelists about automated technologies taking away jobs from design engineers. The panelists agreed that their software was intended to help human experts make decisions, not make decisions for them.

With our phone apps pestering us to update, our smart watches telling us to stand up after we've gone to bed, and typing auto-corrections still highly questionable, the more immediate concern may be people ignoring data-based assistance. Engineering software vendors have the unenviable task of providing the right suggestions at the right time based on complex inputs. A few bad calls or too many nuisance notifications and automated advice may be ignored or alerts unheeded.

An engineering workflow needs to take human nature and the pros and cons of software recommendations into account. We're all trying to do more in less time, but we can't be lulled into over-reliance on automation, or afford to ignore data-based suggestions. **DE**

Jamie Gooch *is editorial director of* Digital Engineering. *Contact him via jgooch@digitaleng.news.*

DE Digital Engineering

TECHNOLOGY FOR OPTIMAL ENGINEERING DESIGN

INSIDE

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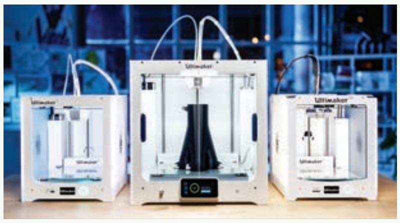
ON THE COVER: Image courtesy of 3D Systems, Getty Images/Irina Devaeva.

FOCUS ON ADDITIVE



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Adding to the AM Market

2018 **$9.9B** → 2024 **$34.8B**

The 3D printing market is expected to grow from $9.9 billion in 2018 to $34.8 billion by 2024, at a compound annual growth rate of 23.25%. The service segment accounts for the largest share of the 3D printing offerings. Prototyping was the top 3D printing application in 2018, while powder bed fusion accounted for the largest share of 3D printing technologies.

— "3D Printing Market by Offering, Process, Application, Vertical, Technology, and Geography – Global Forecast to 2024," MarketsandMarkets, Feb. 26, 2019.

10X AM shipping increase by 2030

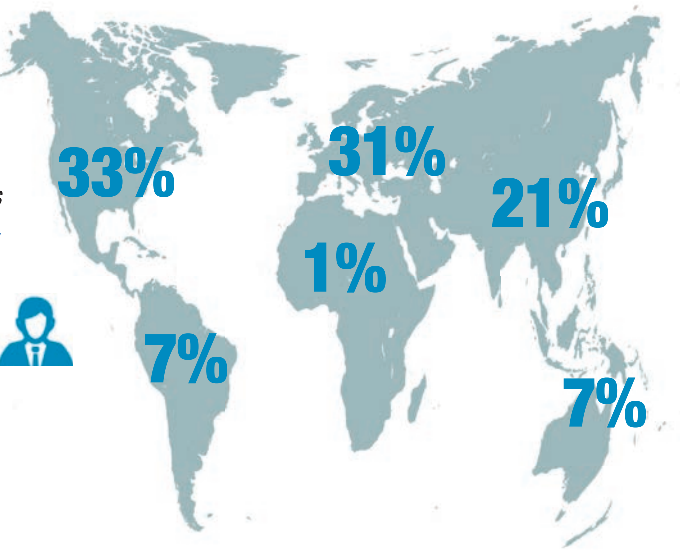
The number of production-ready additive manufacturing (AM) platforms that ship each year will increase more than 10 times by 2030. These systems will produce more than **$360 billion** worth of parts and end products each year and nearly **$2 trillion** in sum by the end of the next decade.

— "Additive Manufacturing Market Tracker," ABI Research, Feb. 27, 2019.

Additive Talent Search

The global talent pool of additive manufacturing professional continues to expand, with the Asia market booming recently and the Oceana market growing rapidly.

— "Additive Manufacturing Salary Survey," Alexander Daniels Global, March 2019.



89% of AM professionals are men. Most AM professionals have between two and five years of experience.

— "Additive Manufacturing Salary Survey," Alexander Daniels Global, March 2019.

Today, the United States leads the world in terms of additive manufacturing product value, but it will be passed by China in 2029 if present conditions persist.

— "Additive Manufacturing Market Tracker," ABI Research, Feb. 27, 2019.

AM Applications

The automotive industry represents a large opportunity globally with **$148 billion** in additive manufacturing (AM) **product value** forecasted for 2030, but it is closely followed by the machinery markets, and these figures differ from country to country.

— "Additive Manufacturing Market Tracker" ABI Research, Feb. 27, 2019.

The global aerospace parts manufacturing **market size** is expected to reach **$1.14 trillion** by 2025. The market is anticipated to register a compound annual growth rate of 3.8% between 2019 and 2025.

— "Aerospace Parts Manufacturing Market Size, Share & Trends Analysis Report By Product, Application and Segment Forecasts, 2019-2025," Grand View Research, January, 2019.

Scaling Up

83% of respondents report that their largest production run is in the hundreds of parts or less.

57% expect future production runs to be in the thousands of parts.

100% say that they face obstacles in using 3D printing for large-scale production, with cost of current printing technology being the most frequently cited obstacle.

88% believe the industry will save billions of dollars in production costs with 3D printing.

100% see benefits in using 3D printing for large-scale production manufacturing.

— "3D Printing at Scale," Dimensional Research survey of 114 stakeholders responsible for decisions regarding 3D printing for production parts. Survey conducted on behalf of Essentium, March 19, 2019.

| CONSULTANT'S CORNER |

SIMULATION 101

By Donald Maloy

Simulation Transition: Meshing and Elements

IT'S PROBABLY SAFE to assume that the majority of us had a Lego collection as a kid. They came in a variety of different shapes and sizes, from rectangular blocks to thin long ones. Each was designed with a particular purpose and application. We spent many a rainy day figuring out how to erect our favorite spacecraft or robot with these blocks.

This is exactly what meshing does for our computer-aided design models on which we seek to conduct analysis. Just as every Lego brick had a purpose, some more so than others, in the world of simulation our "Legos" are a variety of different elements. This month, we look at the array of elements and provide some insight into their application in the world of simulation analysis.

Why Mesh?

But why do we have to mesh before running a simulation? To answer this, think back to the area under the curve in math class. An accurate way to assess the area under a continuous curve is to imagine that there are tiny squares filling an area we are adding up. If we increase the quantity of these squares by making them smaller, we will eventually converge to a common value after several iterations.

This process, in theory, is precisely how we approach meshing of unique 3D CAD models. Due to the nature of CAD models, it's only natural to consider that each model may require different geometric elements. The most commonly used elements in finite element analysis can be categorized as one-, two- and three-dimensional.

Dictated by Dimensions

One-dimensional elements are commonly referred to as beams. Imagine a long, slender structure such as a bridge, steel building or a vertically erected truss structure. Most of these structures are prismatic in profile, meaning that the cross-section is uniform along the length of the columns.

During the design phase of such structures in CAD, we commonly use 3D sketching for the initial layout, and add weldments to simplify construction of the design. These types of CAD models can be suited for using one-dimensional beam elements.

One benefit of using beams is that they require less computational resources due to reduced degrees of freedom. One-dimensional elements are used in three-dimensional analysis problems. The one-dimensional categorization refers to the geometric layout, which is comprised of two nodes at each end. Both nodes are the point of reference for where translation and rotation degrees of freedom exist.

Shells are the two-dimensional elements. They are primarily used in applications such as thin parts like fuel tanks, membranes and sheet metal panels. You may be noticing a trend that the structure's geometry generally dictates which elements are used. Note that some software vendors will use draft-quality shell elements and high-quality elements. This difference relates to adding more nodes at the midpoints, increasing accuracy and computing resources.

Last, we have our three-dimensional elements. These elements are used in solid models with extrusions, lofts and organic surfacing shapes. They are by far the most commonly used element in most analyses.

Elemental Differences

Each element in this category has its advantages and disadvantages. A quick internet search will yield various technical white papers that discuss these differences.

Brick, Hexahedra and Tetrahedron are the most common used configurations across the simulation software vendors. All elements follow the same principle of having nodes at each geometrical end point, and some in their midpoints. From a geometric standpoint, mathematical efficiencies and approximations tend to be the key leading differences among them.

Next month we will dive into further detail about specifics in identifying the quality of a mesh by evaluating aspect ratios, Jacobian points and techniques for using adaptive meshing. We will set out to answer the question: What defines a great mesh? **DE**

Donald Maloy *is a consultant analyst based in the greater Boston area. He also works as a certified simulation and mechanical design instructor for a software reseller. Contact him via de-editors@digitaleng.news.*

DE Digital Engineering

DE EDITORIAL WEBCAST DISCUSSION SERIES — INSIGHTS, INSPIRATION AND INFORMATION

HOT SEAT

DESIGN FOR ADDITIVE MANUFACTURING

In the Hot Seat Webcast!

April 11, 2019 @ 2 PM ET / 11 AM PT

Moderated by
Kenneth Wong
DE's Senior Editor

IN THE HOT SEAT

SPEAKER
Greg Thompson
Global Product Manager
Protolabs

PROTOLABS Manufacturing. Accelerated.

ANSYS

As a low-volume prototyping technology, AM or 3D printing proves itself to be almost unrivaled in the range of forms it can produce at a reasonable cost.

However, as AM strives to earn a place on the manufacturing floor, it must face questions about scalability, repeatability, reliability and economics.

In this episode, *DE* asks the industry leaders:

- Can you use AM to produce uniform parts in large volume at a reasonable cost?
- Is design and simulation software smart enough to detect and reduce problem-prone geometry from reaching the printer?
- Is large-scale AM environmentally safe and sustainable?

Register for FREE Today!

digitalengineering247.com/AMhotseat

By Tom Kevan

Morphing 3D-Printed Architectures into 4D

THE LATEST ADVANCES in additive manufacturing technology require engineers and manufacturers to view design, development and production processes in a completely new way. These transformational changes push design boundaries beyond traditional parameters. No longer will designers focus solely on dimensions like height, width and depth.

What's behind this paradigm shift? The introduction of a new element to the equation: the fourth dimension—time.

This metamorphosis is triggered by the development of 4D (four-dimensional) printing technology, which creates objects that change their physical form over time. After the printing process, the objects, responding to trigger events, reshape or self-assemble themselves in pre-defined ways, which introduces novel levels of design and production flexibility.

Printing in 4D

Much like various forms of 3D printing, the new process converts design specifications into physical structures using stereolithography. The 4D-printing technique also relies on photopolymerization to bind substrates, layer by layer, before the curing process.

Unlike 3D printing, however, where the printer builds a shape according to the specifications defined in a digital blueprint, a 4D printer follows a geometric code based on the angles and dimensions of the desired shape. This "genetic code" tells the printed object how it should respond to certain environmental conditions.

The primary difference between the 3D and 4D printing technologies lies in the use of materials that can be programmed to alter an object's physical properties in a pre-defined way when exposed to a specific stimulus, such as water, heat, mechanical force, a magnetic field or electricity. These "smart" materials are often hydrogels, shape-memory polymers or cellulose composites.

Some research teams have begun investigating ways of programming the object's desired shape into the microstructure of standard materials. If successful, this technology will help engineers create solids with engineered molecular spatial distribution using 3D printers and materials already on the market.

Ramifications and Applications

Although 4D printing is still in the research and development stage, a number of promising applications would benefit fields like computer science, aerospace and mechanical engineering.

Engineers from the University of Pennsylvania have printed active polydimethylsiloxane-hydrogel-based structures that maintain elastic energy. A gate embedded in the structure is controlled by the interaction between the structural material's "genetic code" and weight, water and oil-based solvent triggers. Combined, these elements activate the gate's kinetic movement. (See the video here: https://bit.ly/2BvtQpV).

Structures like these could prove useful in microfluidics applications. For example, instead of using solid-state sensors, microprocessors and actuators, engineers could harness 4D technology to design organic gates that shut automatically when they detect contaminants.

In another project, a research team at City University of Hong Kong has developed a method of 4D printing ceramics. Ceramics have a high melting point and are prone to deformation, which makes the material difficult to use with some laser printing processes. To overcome these challenges, the research team created "ceramic ink" by combining polymers and ceramic nanoparticles, producing soft ceramic precursors that can be stretched three times their original length. The elastic energy enables the morphing of the object's shape. Heat treatment then turns the precursors into ceramics that have a great compressive strength-to-density ratio and can be used to create large objects.

One potential application might be electronic devices. Ceramic materials transmit electromagnetic signals better than metallic materials. Other uses of the technology may benefit the aerospace industry. Because ceramic tolerates high temperatures, the 4D-printed material could be used in propulsion systems. Combined, the new features of the technology could mark a major turning point in the structural application of ceramics.

The market has yet to determine 4D printing's full potential. A key benefit that promises to bring fundamental change to design, however, lies in the technology's ability to provide actuation, programmability and sensing without the use of electromechanical devices and systems. DE

Tom Kevan *is a freelance writer/editor specializing in engineering and communications technology. Contact him via de-editors@digitaleng.news.*

NAFEMS World Congress 2019

BY JAMIE J. GOOCH

EVERY TWO YEARS, NAFEMS, the international association for the engineering modeling, analysis and simulation community, hosts the NAFEMS World Congress (NWC) in Europe or North America. This year, NWC19 will take place June 17-20 in Quebec City, Canada.

NAFEMS World Congress 2019 will be held in the Quebec City Convention Centre, June 17-20. *Image courtesy of Quebec City Convention Centre.*

The hundreds of NWC19 sessions will be divided into different topic areas and themes: Driving Design with Engineering Simulation, Implementing Simulation Confidence, Deploying your Simulation Capability, and Effective Simulation of Materials. In addition, NWC19 will spotlight the role of simulation and analysis in automotive powertrain electrification technology, autonomous navigation technology and life sciences. A Technical Symposia will explore Systems Modelling & Simulation; the hype vs. reality of all things digital in simulation, such as digital twins, artificial intelligence, the Internet of Things, augmented reality and more; Manufacturing Process Simulation; and Virtual Material Data Transfer in Manufacturing. As you can see, there is something for everyone in the engineering analysis, modeling and simulation fields.

NWC19 is a great venue to confront those challenges facing simulation in engineering, such as a learning curve, quickly evolving technologies, the status quo mindset of some design engineers and managers, and the need to incorporate simulation processes and data into efficient workflows. In addition to providing training opportunities, NWC19 attracts thought leaders in engineering simulation and analysis, end users who can share their experiences, and software providers who can answer your specific questions.

NAFEMS World Congress 2019 Keynotes Announced

You can get an idea of the breadth of topics and expertise on hand at NWC19 from the speakers and presentations that have been announced. The lineup includes:

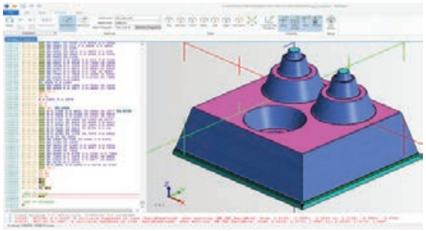
- Charles Poon, **Ford Motor Company**: "The Role of Simulation in the Transformation of the Automotive Industry"
- Rodrigo Britto Maria, **Embraer**: "Applications of SPDM in Aircraft Structural Analysis"
- Mark Meili, **Procter & Gamble**: "Diffusion of Innovation Applied to Modeling & Simulation–What can we Learn from Social Science Research and Marketing?"
- Francisco Chinesta, **ENSAM ParisTech**: "The Era of 'Twins'! A new paradigm for simulation-and-data-based engineering as applied to materials, processes, structures, and systems"
- Lyle Levine, **National Institute for Standards and Technology** (NIST): "Supporting the Simulation Community with Benchmark Measurements for Additive Manufacturing of Metals"
- Heinz Stoewer, **Space Associates**: "Systems and Complementary Engineering Disciplines Interactions"
- Vicky Pope, **Met Office**: "Achievements and Challenges in Weather and Climate Modeling"
- Christian Brix Jacobsen, **Grundfos**: "Implementation of Simulation Driven Development"
- Olivier Colmard, **Renault Technocenter**: "Numerical Simulation to Develop and Validate Autonomous Car"
- Martin Eriksson, **Validus Engineering**: "Activities and Factors Essential to the Endorsement of Confidence in Numerical Simulation and Predictions"

In addition to these, more than 450 abstracts have been submitted for potential presentation in Quebec. Plus, more than 20 short training courses will also be available to attendees, which will be delivered by an experienced team of NAFEMS Tutors, including *DE* Contributing Editor Tony Abbey. An exhibition will accompany the event. The Congress will also incorporate the 4th International Conference on Simulation Process & Data Management. We hope to see you there. DE

MORE → nafems.org/congress/registration

EDITOR'S PICKS

Each week, DE's editors comb through dozens of new products to bring you the ones we think will help you do your job better, smarter and faster. Here are our most recent musings about the products that have really grabbed our attention.



New Software Allows Work in Part/Assembly Modes

BobCAM V7 for SolidWorks has 86 upgrades and enhancements.

The new BobCAM V7 for SolidWorks lets you see what's coming so your toolpaths don't wreck your part or tools.

BobCAM V7 for SolidWorks introduces the ability to work in part and assembly files for part programming. According to BobCAD-CAM, one of the main reasons to do CAM work in an assembly is to view the fixtures being used for the various machine setups, and to be able to check them for collisions.

MORE ➜ digitalengineering247.com/r/22276

ANSYS Release Unveils Motion Body Dynamics Line

ANSYS 2019 R1 has noise-vibration-harshness workflow and more solutions.

ANSYS 2019 R1 is like a multi-course dinner special. First, there's ANSYS Motion MBD (multibody dynamics), a new product line that's part of a third-generation MBD solver from Virtual Motion. It has capabilities for rigid and flexible bodies. The line has toolkits to use to model complex mechanisms like drive and vehicle handling systems. Two, ANSYS Fluent CFD (computational fluid dynamics) software dishes up a healthy serving of enhancements.

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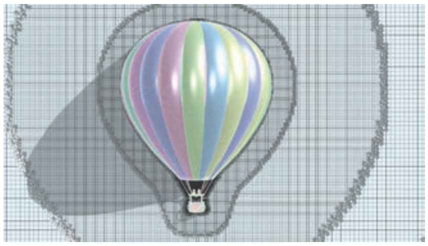
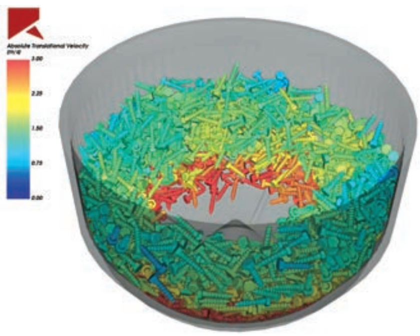




Simulation Software Extends Modeling Features

Rocky DEM 4.2 debuts enhanced particle collision analyses and other capabilities.

Rocky DEM version 4.2 sees new improvements to fiber modeling, spring and damper motion capabilities and tighter ANSYS Workbench integrated fluid-particle simulation abilities. Other enhancements include a computational fluid dynamics mesh decomposition functionality on multi-graphics processing unit workstations and a Particle Generation Preview that gives immediate feedback of an estimated number of particles to be released into a system.

MORE ➜ digitalengineering247.com/r/22224

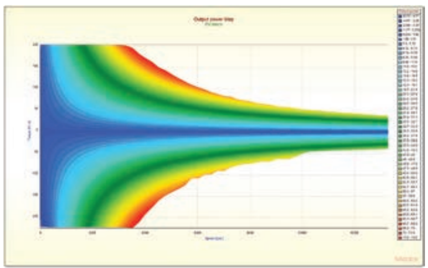
Electric Motor Design and Analyzer Updated

Simcenter Motorsolve sees performance maps for systems-level simulation.

Mentor released version 6.3 of its Simcenter Motorsolve suite of electric machine design and analysis software. One of the keys to Simcenter Motorsolve is that it has an embedded finite element analysis engine that, among other features, provides you with lots of automation that handles things like mesh refinements and post-processing.

It also has a template-based interface that seems to greatly help you work with most electric motor topologies.

MORE ➜ digitalengineering247.com/r/22196



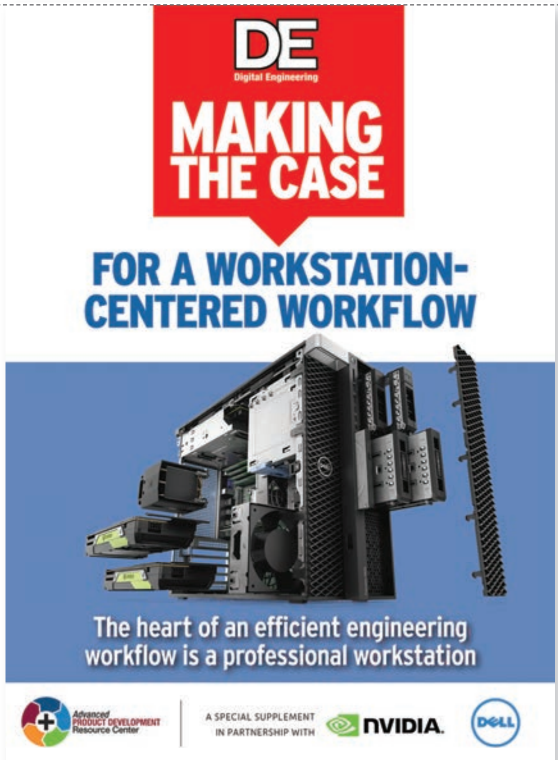
Your **Engineering Core**

Make the case for a professional workstation, the heart of an efficient engineering workflow.

IF THE POWERS THAT BE have decreed that you should integrate more upfront simulation, rendering and visualization—or even virtual reality—into your workflow to keep pace with the complexities of modern design engineering, they're probably right. If they've made that decree without investing in the hardware you need to support an efficient engineering workflow, you're probably frustrated. "Making the Case for a Workstation-Centered Workflow," a special supplement by the editors at *DE* in partnership with Dell and NVIDIA, was created to ease those frustrations by helping you better inform the powers that be.

"To support the increased digitization efforts, design engineering teams need computing solutions that can handle the load," states the paper. "However, the hardware side presents a confusing array of options, including mobile and desktop workstations, local clusters, data centers and cloud computing resources. Added to the choices are CAD and simulation software tools that are now offered via subscription/cloud models. Each option has benefits and drawbacks."

The paper goes on to explain the pros and cons of today's computing options. As the title says, "Making the Case for a Workstation-Centered Workflow," makes the argument for workstations maintaining their place at the heart of design engineering, but this isn't a hatchet job on other computing options. In fact, the paper recommends a hybrid computing approach with workstations acting as a powerful and flexible hub of engineering activity. Powerful—thanks to the latest graphics processing units, faster solid-state drives and plenty of memory—but not much more expensive.



Supporting Arguments

To support its argument, the paper includes a detailed return-on-investment (ROI) calculation for a typical employee doing design engineering work on an older workstation. The math is shown, making it easy to plug your own salary and design workload percentages in to customize your actual ROI. The paper's conservative estimate on the time it would take a professional engineering workstation to pay for itself via increased productivity? About 6 weeks.

"Making the Case for a Workstation-Centered Workflow" uses compelling graphics and stats throughout to benchmark workstation upgrade speed boosts and show how real-world companies have increased their productivity by embracing the idea of a workstation-centered design engineering workflow. It shows how workstations can deliver this performance to designers and engineers without the risks and limitations inherent in cloud-based solutions, and without the maintenance support costs of clusters and on-premise HPC resources. The paper tailors arguments to executives, engineering managers and IT managers to give you some insights on their perspectives. It also provides plenty of links to additional resources. In short, it helps you communicate the causes of your computing frustrations and plots out a path to rectify them.

Download your free copy:
digitalengineering247.com/workstation.

Pushing the Printed Electronics Envelope

The prospects are real, but we may have to wait a bit before we can experience the full benefit of additive manufacturing in electronics.

BY TOM KEVAN

PRINTED ELECTRONICS DEVELOPERS have started launching the technology into the third dimension, throwing off the constraints of flat, 2D architectures to integrate electronics directly into a product's geometry.

nScrypt's SmartPump and the 3Dn printer promise to deliver the precision to enable design engineers to print complex, conformal circuits on most surfaces. The photo shows antennas printed along the top and sides of a rough-surfaced Kevlar helmet. *Image courtesy of nScrypt.*

Until recently, electronics companies designed and manufactured components, systems and layers in 2D. Then they finished off the lengthy process by performing steps like drilling, pressing and plating to connect the separate dies to create a multi-layer circuit board.

When you say, "3D circuit," people still think of stacked planar circuits, perhaps connected vertically using vias. The inability to shake off the 2D mindset has slowed the evolution of printed electronics technology, limiting how engineers and software providers use the third dimension.

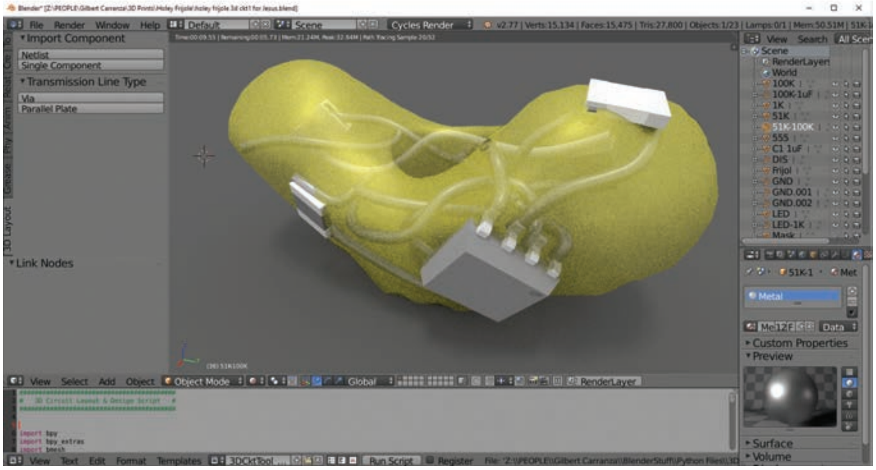
"Even though we have excellent 3D printers today, too many organizations are printing planar and conventional things," says Raymond C. Rumpf, director of the electromagnetics and photonics lab at the University of Texas at El Paso (UTEP). "We are not doing as good as we could at innovating new things that 3D printing enables."

This is not to say that developers of the technology lack a vision of what 3D-printed electronics can be; far from it. Current printing technology and recent research developments offer a glimpse of what 3D electronics might look like.

Two 3D Printed Electronics Visions

A look at some of the advanced printing technologies reveals differing perspectives on the form factors and architectures of 3D-printed electronics.

One of the most established methods of producing electronics is ink jet technol-



Researchers at the University of Texas developed this 3D/volumetric circuit design tool by programming a custom add-on for the open-source, 3D creation software Blender. The tool imports component geometries and a netlist from a schematic capture tool, allows traces to be routed along any path throughout the volume of the part and exports CAD files of the multi-material part. ***Image courtesy of the University of Texas at El Paso.***

ogy. These printers use an array of nozzles to propel small quantities of ink, typically using piezoelectric material to push the material through the small orifices. It delivers high resolution—enabling the production of crisp miniaturized components and traces—and good throughput.

One of the prominent providers of ink jet printers for electronics applications is Nano Dimension. "Nano Dimension's systems leverage a layer-by-layer build approach," says Simon Fried, co-founder and president of Nano Dimension USA. "It prints both the conductive material and the dielectric material, and so allows for a part to be built up with the two materials placed in X, Y and Z in accordance with the designer's goals, starting from the bottom and building up in layers."

Nano Dimension's systems use two families of inks. Optimized for a range of applications—from radio frequency identification components to antennas—the AgCite family of nanoparticle inks promises good conductivity, adhesion and flexibility. Unlike regular metal powders that require high sintering temperatures, these inks can achieve a sintering temperature low enough to support a range of substrates, such as paper, polymer, glass and indium tin oxide.

The second family of inks uses a dielectric nanoparticle-polymer combination that provides electrical insulation down to hundred-micron widths. The inks are ultraviolet-cured as part of the print process.

An alternative approach uses a technology called microdispensing. These systems typically use positive pressure to transfer small amounts (microliters) of print material through a small tip or nozzle directly onto the desired surface. The technology often lacks resolution and accuracy. On the plus side, however, dispensing can deposit much thicker layers of materials with much higher particle loading. This can make building 3D parts faster. Additionally, metal provides structural support, and has higher conductivity.

A proponent of microdispensing, nScrypt, counters the technology's shortcomings with the SmartPump, which controls the material volume flow at a pico-liter level (see video: youtu.be/V-vNJ8-JTZs). This feature promises to enable precision printing at high print speeds, with clean starts and stops of the dispensing/printing path.

One of the advantages offered by SmartPump technology is the expanded, compatible range of materials. "nScrypt has an optimized nozzle that reduces back pressure and allows dispensing of an extremely wide range of material viscosity—from 1 cP to 1 million cP," says Casey Perkowski, a mechanical engineer at nScrypt. "Meaning we can print materials as thin as water and thicker than peanut butter. This includes partial loaded materials with micro and/or nano particles. This gives us over 10,000 commercially available materials we can print."

Another strength of the technology lies in nScrypt's Factory in a Tool suite, which is bundled with the company's 3D printing and microdispensing systems. The tools support multiple methods of depositing materials, offer features like pick-and-place (see video: youtu.be/aXEysL2bojY), and perform post-processing functions such as milling, polishing and laser processing. Factory in a Tool accommodates many types of materials, including materials with high particle loading.

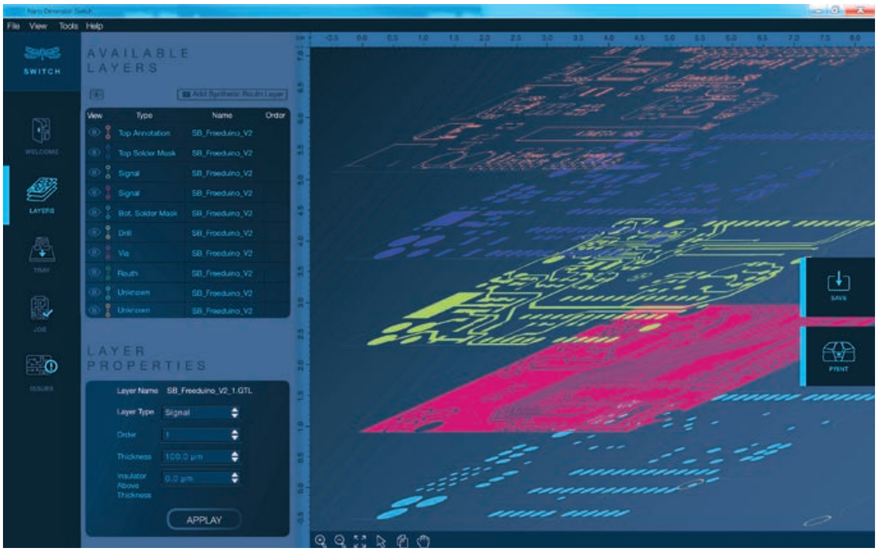
Though nScrypt's microdispensing technology is a layer-by-layer process, the Factory in a Tool suite allows the printing system to enhance 3D electronics production by interleaving disparate functions and processes throughout the operation.

"Building a 3D part works by alternating between the various tools during the print," says Rumpf. "It may start by printing a few layers of fused filament fabrication (FFF) to form a dielectric substrate, then start printing layers with small gaps, switch to dispensing to fill the gaps with conductive ink, switch back to FFF to build another layer and so on until you have a 3D multi-material part. The machine may do some drilling or milling at various intermediate stages and place some electric components."

Hurdles and Shortcomings

Though current 3D printing hardware is fully capable of producing 3D circuits, the transition to true printed 3D non-planar electronics has been slowed by the absence of adequate development tools. The reality is that the majority of investments and research still must be done in areas such as design practices, standards and manufacturing processes.

"Existing modeling and simulation software does not address 3D printed electronics directly, which can make design tedious and harnessing the extra capabilities of printing technologies difficult," says Ken Church, CEO of nScrypt. "Many experts in 3D printed electronics design have found ways to use combinations of design software packages to achieve complex multi-layer devices, using features such as adjustable material properties through selective infill percentage in different areas,



Nano Dimension's Switch software enables designers to prepare production files for electronic circuits to be printed on a DragonFly 2020 3D printer. ***Image courtesy of Nano Dimension.***

non-vertical vias and channels, embedded ICs [integrated circuits] and other design freedoms granted by the printing process."

This approach handicaps development efforts, requiring designers to spend extra time making the workaround successful.

"Current tools can be used for designing these components, but it often takes extra effort on the part of the designer to understand how to apply certain features of the tools and use different CAD programs for different parts of the design," says Vikram Lyer, a Ph.D. student in the electrical and computer engineering program at the University of Washington. "For example, electromagnetics simulators can model complex geometries, but the designer has to create those using the interface available within the program and then likely export it to a 3D modeling program for conversion to a different file format for fabrication."

The absence of automation also limits the usefulness of this approach. "The current software allows for some conformal design—such as contouring traces to a surface—but the layout is tedious, and all connections are routed by hand," says Perkowski. "The placement of components is difficult, and auto-routing of traces does not exist. Just as planar software for 3D printed electronics comes up short, 3D software is an even larger leap from traditional design software."

What the industry needs is a new breed of design software tailored for the third dimension. "There is a need for a software that is a hybrid of 3D mechanical modeling software and electronics layout software," says Church. "This would take in schematics of the electronic circuit, allow you to draw a 3D part and then place components in any orientation or position throughout the part, and route the conductive traces through the object."

Filling the Software Gap

Defining the necessary software and providing the actual tools are two different things. Research groups and AM technology providers, however, have begun to develop and introduce software that attempts to bridge the gap between traditional design tools and 3D printed electronics.

For example, Nano Dimension offers two software packages targeting the 3D market. The first, a free add-in for SolidWorks, promises to provide a design environment optimized for 3D printing multi-material electronics (see video: youtu.be/8sFfTGugmno). The software aims to help engineers design complex prototypes—consisting of polymers and metals—that can be 3D printed on the company's DragonFly Pro printer. The second, called Switch, offers a proprietary pre-processing application that enables operators to prepare printed circuit board designs for 3D printing on Nano Dimension's printer.

On another front, researchers at UTEP have begun to develop software that goes beyond enabling the design of circuits that conform to a surface and opens the door for designing and manufacturing 3D/volumetric circuits.

The first software the UTEP research team developed is a CAD tool that lets engineers lay out 3D circuits and route interconnects. The tool helps place components in any position or orientation throughout all three dimensions. Interconnects of various types—such as high-frequency, power or thermal—can be routed to follow smooth splines.

The second program is a tool that generates hybrid G code from CAD files, with arbitrary multi-material structures. "This tool allows us to drive multiple tools from a single g-code file without having to manually code anything," says Rumpf.

All of this came together during the summer of 2018, when the electromagnetic lab produced its first 3D/volumetric circuits. Of note is that these academic lab–based software systems are works in progress that have not been commercialized. Ultimately, the UTEP researchers plan to integrate all of the software tools and algorithms they have developed into a single, easy-to-use tool.

Rethinking Design of Electronics

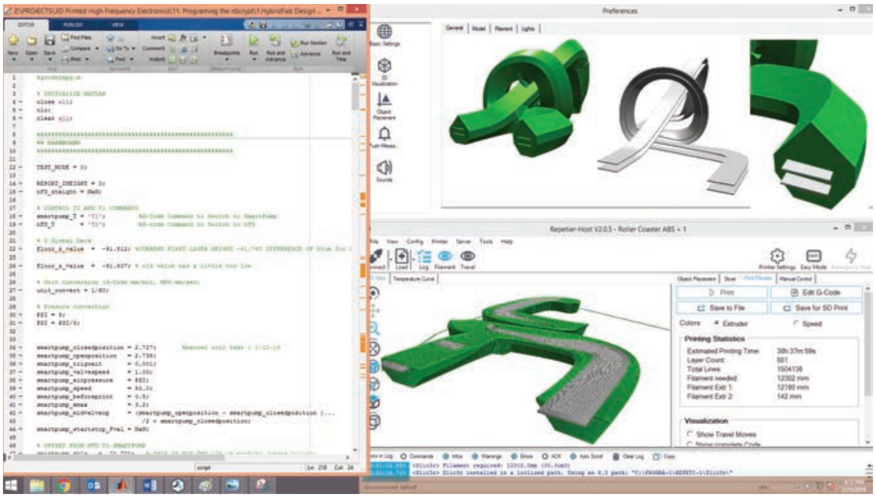
Engineers pushing the limits of design to achieve the full potential of 3D-printed circuitry will have to approach the development process from new angles, and use new design rules.

"By rethinking traditional circuit design, engineers will have much more freedom in the shape of their designs, which will impact the size and look of the final product," says Fried. "Additive manufacturing offers the opportunity to change the way electrical functionality is achieved, such as through printing passive components, as well as allowing for digital, radio frequency and passives to coexist within designs in ways that traditional manufacturing cannot attain."

This means that designers will have to find new solutions for old issues. For example, heat management is already a problem in high-density and high-power electronics. Having embedded circuits precludes the use of traditional methods of managing heat like fans and heat sinks. For future printed structures, new heat management methods must be developed—possibly using microfluidic channels spread throughout the part to dissipate heat.

Engineers will also need to identify new ways of managing electromagnetic interference (EMI). "For EMI, ground planes and via fences are traditionally used to manage EMI in circuits," says Church. "These are planar solutions and will need to be reimagined. For complex RF circuits, these are very important and have a large effect on performance. New concepts of how to do this—such as printing shielding around certain components and conductive traces—present challenges."

The transition to 3D printed electronics also redefines the role of enclosures. "If you go back a few years, the only job of the enclosure was to hold the I/O and perhaps act as an EMI shield," says Mike Dean, marketing director for Optomec, a manufacturer of Aerosol Jet Systems for printed electronics. "Today, designers are beginning to see the enclosure as an opportunity to extend the real estate of the printed circuit board. Components like antennas, sensors and interconnects can now live on the enclosure, which makes the overall device smaller and in some cases adds functionality."



University of Texas researchers have developed a slicer for hybrid 3D printing that takes the output of the circuit design tool, slices the multi-material part and generates the g-code that automatically drives the nScrypt 3Dn printing process. The top-right window shows a CAD model of a parallel plate transmission line. The bottom-right window shows the part being sliced. The "digitization" in the bottom window indicates the toolpaths for dispensing (silver) and for fused filament fabrication (green). ***Image courtesy of the University of Texas at El Paso.***

It's clear 3D printed electronics promise to redefine each stage of the development cycle. The additive approach has the potential to change workflows, turbocharge development cycles and introduce new ways to make the unmakeable. **DE**

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INFO ➜ **Nano Dimension:** Nano-di.com

➜ **nScrypt:** Nscrypt.com

➜ **Optomec:** Optomec.com

➜ **UTEP:** EMlab.UTEP.edu

Leaving the Island

With 3D printing growing increasingly mainstream, manufacturing execution systems are a tool against equipment downtime and production floor chaos.

BY KIP HANSON

WALK INTO ANY MANUFACTURING COMPANY and you'll discover the same set of challenges: Excel spreadsheets containing critical data are stored on the local hard drives of various team members' systems. CAD/CAM packages whose only integration to the rest of the business is a file share on the corporate server. Enterprise resource planning (ERP) systems that offer visibility to every department in the company, yet are somehow blind to the activities of the factory floor. And product lifecycle management (PLM) software that does a great job of managing product data but keeps that valuable information to itself.

Corralling the Chaos

Many manufacturers have addressed at least some of these disconnects by implementing manufacturing execution systems (MES), which serve to tie the factory's equipment and processes to the scheduling system, the design and programming software, the PLM and ERP and overall equipment effectiveness tools that crowd the servers of manufacturers everywhere. Those who can't afford or don't see the need for yet another software system might hire a programmer to tie their disparate software together in hopes of an all-encompassing shop floor solution; others simply live with

Accurate and timely job scheduling may prove to be even more important to additive manufacturers than to traditional manufacturing companies. ***Image courtesy of 3YOURMIND.***

Managing multiple 3D printers across multiple facilities requires robust software systems and seamless integration. *Image courtesy of Materialise*.

data disharmony, plugging along as best they can until a better solution comes along.

With 3D printing an integral part of the manufacturing landscape, however, the "let's live with it" approach is quickly becoming untenable. What appears at first glance to be a single step, black box process is actually full of discrete operations and data collection opportunities, including print preparation, build simulation, real-time monitoring and analysis, scheduling across multiple machines and facilities, and post-processing requirements.

"With the additive manufacturing market expected to grow by up to 30% annually for the foreseeable future, integration between the equipment and various software systems is a must-have," says Tim Van den Bogaert, market director of Materialise NV's software division. "Additive manufacturing has specific needs and specific challenges, and if you are truly going to embrace it as a manufacturing technology, it must not operate as an isolated silo."

Solving the Pain Points

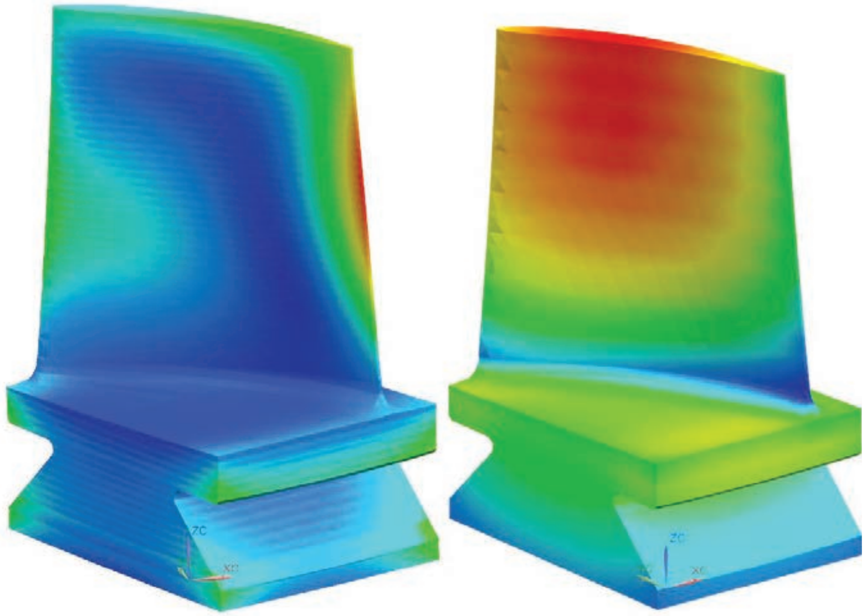
Fortunately, Materialise and other software providers are addressing this need by redefining traditional MES in favor of software products that manage every aspect of the 3D printing workflow. For example, Autodesk is collaborating with additive manufacturing automation provider Authentise to ease the handoff between design and execution. "One of the things that we as a company have observed with additive manufacturing is that it often has a very fragmented workflow, with multiple software packages, multiple data formats and a generally inefficient process," says Robert Yancey, Autodesk's director of manufacturing industry strategy.

Yancey notes that Autodesk has improved a big chunk of that process with its Netfabb additive manufacturing and design software. Additionally, Authentise has developed a planning system specifically for 3D printing, which allows shops to schedule, monitor and manage every part of the additive manufacturing workflow. The challenge, though, is what happens when the "as-designed" print job needs to be changed on the production floor?

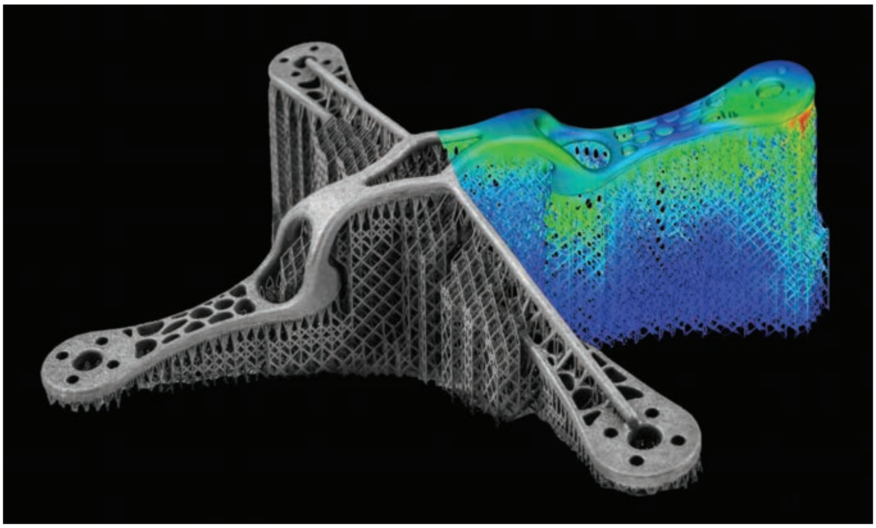
"You might need to edit the file after it [has] been released to manufacturing," Yancey says. "The part design may need to be changed, the orientation or nesting might have to be different to fit the build chamber, or maybe it has to be processed on a different printer … there are any number of reasons. But because we've worked to integrate our two software packages, a user in their system can actually make modifications that, in the past, would need to be sent back to the print preparation software. Now, it's all very seamless."

Embrace the Magic

Materialise's Van den Bogaert agrees with the importance of seamless integration. As an early adopter of additive manufactur-



An example of simulated distortion and heat buildup during a turbine blade print job. *Image courtesy of Siemens PLM Software.*



Simulation software is a valuable tool for predicting build process events. *Image courtesy of Materialise.*

ing technology and subsequent developer of 3D printing software, Materialise and its employees have learned through challenges what it takes to be successful.

"We have many different brands and types of 3D printing technologies here, each with its own proprietary format, and integrating all of that has been a bit of a hassle," he says. "At the same time, we've learned that it's very difficult to manage 3D printing production using Excel sheets and paper documents, especially as you scale upwards. You simply must have some kind of management execution system to deal with this complex environment." It's for this reason that Materialise developed its Streamics, Magics and other 3D printing software products, so as "to operate our own services, in our own environment, in the most flexible and versatile way possible."

Integration is not just about improving production efficiency, or eliminating the chance of duplicate data. There's also compliance to consider. As the aerospace, medical, and indeed any industry with detailed requirements for traceability and product quality adopt additive technology, an integrated production flow is crucial to widespread acceptance of this relatively new manufacturing process. The integration needs to start at the quoting stage and continue through to the product's end of life.

"As one of the largest 3D print factories in the world, we continuously learn from our own production needs and use this knowledge to better meet the requirements of our software customers," Van den Bogaert explains. "The result is a software solution that builds on our own internal experiences and that offers the flexibility and integration capabilities [for customers] to scale up production sites."

Building Bridges

To show further acceptance of manufacturing processes, Materialise has joined the ranks of numerous other additive technology providers by opening its arms to collaboration with what were once considered competitors.

"We understand where the market is going, what's at stake and that all of us need to help further this industry," says Van den Bogaert. "This is why we have recently invited several leading PLM and design companies to directly interface with our systems, so that they can also contribute to making the 3D printing process as efficient as possible."

One of these companies is Siemens PLM Software. Aaron Frankel, vice president of additive manufacturing software, says the company has developed a "broad spectrum of solutions for the additive space," including NX, Simcenter and Mindsphere, all of which are designed to manage the manufacturing process, additive or subtractive.

"There's a great deal of market pressure coming from companies that have invested heavily over recent years into research and development of 3D printing technology, and who are now looking very aggressively at how to take that technology out of the lab and into production," Frankel says. "Doing so, however, will require effective ways to manage the additive manufacturing production process, including MES."

Dave Madeley, Frankel's colleague and senior strategist for additive and subtractive manufacturing at Siemens PLM Software's U.K. location, elaborates: "Simply put, additive is beginning to become a mainstream technology, especially on the metals side," he says. "I don't think it's so much the case that you need MES to be successful with additive, but rather that additive is becoming robust enough that we can actually use it in mainstream production. As such, we need MES to manage it, just as successful companies use MES to manage their traditional manufacturing processes—additive is no longer on an island, and now must be industrialized in order to fit in with all the other systems that surround it."

Agile, Open and Optimized

Another software provider with its eyes on industrializing 3D printing is 3YOURMIND, which has developed its Agile MES product for managing and optimizing additive workflows. Marketing and product positioning manager Brian Crotty notes that this last part—optimization—is an important but often overlooked piece of the MES puzzle.

"For the time being at least, 98% of all 3D printing is on low-volume parts," Crotty says. "Because of this, service bureaus in particular are often faced with building a variety of parts—often from multiple customers—in a single build. You also have the situation where jobs might be produced on multiple machines or even in multiple locations."

In these situations, he adds, you need a way to optimize the available build space, schedule the work based on delivery dates, customer priority and machine availability, while at the same time managing all of the relevant production requirements associated with those parts. "As with any type of manufacturing, success is about achieving the most cost-effective method of parts production while assuring the best part quality possible, and a data-driven MES is a big part of that," Crotty says. **DE**

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INFO → **3YOURMIND:** 3YourMind.com

→ **Authentise:** Authentise.com

→ **Autodesk:** Autodesk.com

→ **Materialise:** Materialise.com

→ **Siemens PLM Software:** Siemens.com/PLM

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Plugging GPUs into the Metal AM Workflow

When it comes to metal-based AM, organizations are looking to harness the power of graphics processing units.

BY RANDALL S. NEWTON

CULTURES HAVE LONG DEFINED manufacturing design processes. In North America, product design is traditionally a handoff to the manufacturing engineers, a "make this" workflow. Other countries give more power to manufacturing engineers; design becomes an artifact of the available fabrication processes. The Japanese have a word for it, monozukuri, which roughly translates into "the thing and the act of its making."

Additive manufacturing (AM) offers to bridge the gap between what designers can envision and machinists can fabricate. As it turns out, manufacturability is just as defining for AM as it is for traditional factory processes. The thing and act of its making are still intertwined.

"AM is increasingly viewed as a complementary manufacturing technology for final products, including metal," says Bart Van den Berg, a software research engineer at Materialise. "There is a clear need to increase productivity and efficiency in the process."

Metal AM is just now "becoming mainstream enough that people are starting to talk about challenges and problems," says Chad Barden, CEO of Atlas 3D, a CAE startup with a new simulation tool for metal AM. "Before it was black art; now it is becoming more of a science. Professionals are collaborating, sharing problems and solutions ... When you have a group of professionals who say 'my gut told me to print it this way' you don't get a lot of sharing. It is hard to share gut instinct."

Metal AM Workflow Constraints

Metal AM printer manufacturer Renishaw advises its customers to consider four factors when designing for AM:

1. **Residual stress:** There is constant rapid heating and cooling as each new layer is created in a metal 3D print job. The result is constant stress that affects the new metal and the existing form. If the particulars of the part and its formation are extreme enough, stress may exceed the strength of the part.

2. **Orientation:** By default, build direction is defined as the Z axis (vertical from the build plate). How a part comes together inside the build chamber can create new problems related to surface finish, build time and the need for support structures.

3. **Support structures:** Renishaw advises its customers that it is a bad engineering practice to over-rely on supports to overcome an orientation issue in AM part production. "Excessive reliance on supports is an indicator of a 'marginal' part geometry."

4. **Optimization:** Topological optimization, including internal lattice structures, is increasingly being used in design for AM. Topological optimization should not be confused with functional optimization; tradeoffs between the two may be required to reach an optimal design for AM.

"The promise of additive manufacturing is virtually unlimited design freedom, but designers have a hard time understanding how to access that design space," says Brent Stucker, Ph.D., director of additive manufacturing at ANSYS. His colleague Justin Hendrickson tells of a situation where a company printed a metal foam structure designed to be optimal for strength-to-size ratio. A computed tomography scan revealed "the printed shape was not very close to the original," says Hendrickson, because there was no accounting for the stresses.

Adding GPUs to the Process

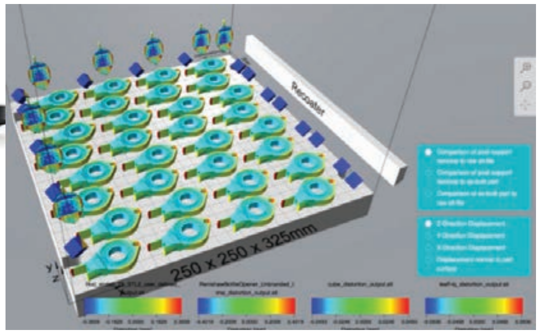
In 2018 ANSYS introduced Discovery Live, a new simulation software designed to provide designers with real-time results at the concept stage. To be fast enough for use in design, Discovery Live requires the use of graphics processing units (GPU) co-processing. "Simulation software accelerated by graphical processing units can offer designers simulation results exceptionally fast," says Andrew Rink, industry marketing strategy lead at NVIDIA.

In February, PTC released Creo Simulation Live, which is powered by ANSYS. As such, it also uses GPUs to bring real-time feedback to the company's 3D CAD modeling environment.

"GPUs are well-positioned to support the simulation process," says Materialise's Van den Berg, "by performing huge amounts of similar calculations on massive but homogenous data sets. As a result, we believe the GPU will play

LEFT: Atlas 3D uses a patent-pending process called thermal circuit network simulation to calculate the best orientation for metal additive manufacturing.

BELOW: Atlas 3D claims its Sunata simulation software can calculate the optimal orientation for 100 parts in a metal additive manufacturing print run faster than existing CAE products can calculate the orientation for one part. *Images courtesy of Atlas 3D.*



an increasingly relevant role in the AM preparation process."

AM is a multi-person workflow, notes Hendrickson. Although Discovery Live is targeted at initial design, "We want designers to think more about manufacturing. There are reasons for experts to go the last mile for design excellence," he says. "Is part orientation a designer issue? Should designers compensate for annealing processes? How do we do tolerancing? We have a suite aiding the process, but the internal workflow also must be addressed."

To directly attack the obstacles in metal AM simulation, Atlas 3D examined the existing approaches to simulation for AM. Most metal AM simulation users were applying one of two approaches. Many were using finite element analysis (FEA), breaking the unit into elements for the study of thermal effects, build processes and material-specific mechanical effects. Others were using inherent straining to look for stress effects to map as mechanical effects.

"We looked at both approaches," says Barden. "There is time delay in FEA and lack of tolerance for inherent straining, which relies on perfect process parameters and calibration." The successful designers working in metal AM got there through repeated trial and error, "with a 40% failure rate for first print runs." The biggest issue was thermal distortion during the AM process, something existing CAE tools were not equipped to study directly.

Atlas 3D decided to create a new approach specific to AM: thermal circuit network simulation. The patent-pending process can work with either GPUs or CPUs. The GPU version of the software was just finished. The product—Sunata—simulates the build process to find the optimal orientation for printing. Barden says the CPU-based Sunata can calculate 100 orientations using thermal distortion faster than most competing solutions can simulate distortion on one orientation. The new GPU version, Barden says, is "20 times faster than the CPU version."

Barden claims Sunata can run a successful optimization simulation on a full build chamber in an EOS M400 in 1 hour using GPU calculations and "several hours" on the CPU version. The software runs on Amazon Web Services, where it can attach and detach multiple GPUs as required for a job. Special instances of Sunata can run on International Traffic in Arms Regulations or other required secure formats.

"Our goal is to democratize metal additive manufacturing," says Barden. "Historically, printing in metal is reserved for those with five or more years' experience. We allow a newcomer to design a part in CAD and print successfully the first week they are in the industry. That's never been possible before."

What's Next?

In addition to creating new GPU-based methods to directly analyze thermal stress inside metal AM, research is taking place to incorporate artificial intelligence into the metal AM workflow. "Deep learning (DL) requires a massive data set; the GPU plays a prominent role," said Van den Berg of Materialise. "At the same time, we are seeing GPUs that are becoming more flexible, which will allow them to address an increasingly varied set of tasks."

Stucker at ANSYS agrees there is great upside for using AI and DL to streamline the metal AM workflow, but sees two obstacles to adoption. "We need massive data; where will it come from?" he asks. "There is no generic sharing [of data]."

The second issue is the need for specialized algorithms to take advantage of parallel processing. ANSYS wants to be a "neutral arbitrator" working with all metal AM printer manufacturers. "We want to enable the ecosystem, not a specific machine manufacturer. Our goal is to use our software with any of the machines out there."

Stucker says some metal AM vendors are offering general-purpose software tools to interface with an API, while others say "'these are our standards; write to them.'" How each vendor calculates the build "is tightly held [intellectual property]," Stucker says. "Over time, there will be international standards and a standard print file, but it won't be in the next year or two. But convergence will happen." DE

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INFO ➜ ANSYS: ANSYS.com

➜ **Atlas 3D:** Atlas3D.xyz

➜ **Materialise:** Materialise.com

➜ **Renishaw:** Renishaw.com

Metal Short-Run 3D Printing on Rapid Growth Trajectory

This growth includes expansion into markets where printing on-demand parts and components is attractive, such as healthcare, aerospace and automotive.

BY BRIAN ALBRIGHT

THE MARKET FOR 3D METAL PRINTING is expanding. IDTechEx predicts that the global market for 3D printing metals will reach $12 billion by 2028, as more companies turn to additive manufacturing to create production parts in the automotive, aerospace and other industries.

Giants such as HP and GE have launched large-scale metal printing efforts, but other companies have focused on smaller units that can be used for design and prototyping, as well as low-volume runs of metal production parts, tooling and molds.

"Metal printing has been one of the best growth stories in 3D printing, and I think that is because current powder bed technologies are uniquely suited for advanced manufacturing," says Kevin McAlea, executive vice president and chief operating officer, Healthcare, at 3D Systems. "We can process standard alloys and achieve excellent properties and address some key opportunities very effectively."

That includes expansion into markets where the ability to print on-demand parts and is especially attractive, including in the healthcare space where an increasing number of medical devices are being printed. "Medical device companies I've spoken to at high levels think that 10% to 20% of medical devices can be 3D printed. That's an enormous opportunity," McAlea says.

The number of applications that can take advantage of short-run metal printing is increasing as new materials become available. Desktop Metal recently released 316L stainless steel for its low-volume 3D metal printing systems, and a number of customers are already using the material with Desktop Metal's Studio System.

John Zink Hamworthy Combustion is using it to make a combustion fuel nozzle for marine tankers, as well as customized ring splints for medical applications. Another customer used the material to print a steel impeller for a pump, reducing the cost from $1,000 to just $70.

"With every new technology we bring to market and every material we produce, we see exponential growth in the range of applications that customers can use our systems for," says An-

Fuel nozzle printed on 3D Systems' ProX DMP 320 in LaserForm CoCrF75(A) for high corrosion, wear and high temperature resistance. *Image courtesy of 3D Systems.*

drew de Geofroy, vice president of application engineering and professional services at Markforged.

The jewelry industry is also embracing these smaller metal printers to create molds and finished pieces, and there is an emerging opportunity in the parts aftermarket for heavy equipment, machinery, automotive and aerospace, because companies can more easily produce short runs of obsolete parts.

"With legacy equipment in the field, you often end up having to do low-volume replacement part runs that end up costing a lot of money," says de Geofroy. "Customers are interested in making on-demand replacement parts, because they won't have the carrying cost of inventory or have to create new tooling or change over production lines."

Space is also an issue for organizations that have a large part catalog. "There are these huge warehouses full of shelves of tooling, and if they need a part, they pull out the tooling and stamp out parts," adds Jonah Myerberg, chief technology officer of Desktop Metal. "We're seeing a shift away from that kind of traditional factory and toward a digital factory that uses software to make the parts on demand. They are never obsolete and they don't take up any space."

Early adopter markets are also increasing their investments in these systems. "Aerospace and other related segments are also becoming major adopters of 3D printing," McAlea says. "They are focused primarily on weight reduction and enhanced performance via redesign of parts, and they are a great fit for what we do today."

Desktop Metal's Production System metal 3D printer is capable of customizing batches of generative designed gears at varying amounts with mass production efficiency (top). The spauger bit (bottom), is an example of simplified manufacturing for complex metal parts made possible by the Production System, according to the company. ***Images courtesy of Desktop Metal.***

Metal Printing on the Factory Floor

With improvements in the printers, new materials and greater acceptance of 3D printing in general, there is more overlap between prototyping and production systems, and demand to use metal printers on the factory floor.

"The cost of 3D printing has gone down, the machines are cheaper to acquire and use, and material costs are going down," de Geofroy says. "The software is easier to acquire and use. The landscape is changing."

Decentralized manufacturing, which focuses on the last mile of manufacturing rather than establishing a lengthy, expensive supply chain, will increase printer adoption and use.

"Now you can print a part anywhere in the world, on demand, where it's needed," de Geofroy says. "Because our software is cloud based, customers can have a centralized design group and print a part all the way around the world in a factory that needs it, and the person in the factory can take that part off the printer without having any specialized design expertise in that location."

There are still quite a few adoption hurdles. Speed and build volume must increase to make these printers useful for more applications, and there are still gaps in material availability.

"There are also barriers around safety," de Geofroy says. "With our Metal X printer, we've tried to make sure we didn't need a clean room and a respirator to operate it. That has a huge impact on viability of using the machines in the first place."

Metal printing also usually requires a fair amount of post-processing, including additional machining, washing and other types of finishing procedures.

"People don't always understand that if they print this part

3D Systems' ProX DMP 200 with LaserForm Ni625B produces metal parts for high strength and heat resistance with surface finish and resolution. ***Image courtesy of 3D Systems.***

Exterior of a hardened nozzle printed out of H13 tool steel on the Markforged Metal X, straight out of the sinter, with no post-processing, according to the company. *Image courtesy of Markforged.*

to cost-effectively produce a shape or structure that wasn't otherwise possible, the part that comes out does need to be post-processed. That can include everything from acid etching to hand finishing to post-machining," McAlea says.

3D Systems and other companies in the sector are working on ways to automate more post-processing workflows.

"One of our objectives is to better integrate 3D printing with other processes that are essential to creating the final part. That was part of the objective we had in partnering with Georg Fischer AG GF Machining Solutions," McAlea says. "We have a clamping system in the printer to move the part seamlessly to the post-machining operation. There is a lot of interest in how you integrate additive and subtractive in a way that makes them seamless and as easy to use."

The market also needs education about what types of parts are best suited to metal printing, and how to design for 3D printing. "We also encounter customers who don't understand when it makes sense to 3D print a part, and when it doesn't," McAlea says. "We receive part files that we could, in principle, print. But you have to ask why. They could be produced more economically through alternate technologies. The advantages of design that are inherent in 3D printing and its limitations are still not well understood."

"That's really the first question companies and designers need to ask," Myerberg says. "Is this a good part for printing? At the end of the day, 3D printing is another tool that engineers have to design around to put a part into mass production."

Companies often want to print existing parts, but they often need substantial redesigns to be optimized for 3D printing. "There are design rules, just like for other manufacturing processes, that you have to follow," Myerberg says.

Specific vertical markets also have requirements to consider when developing a part for additive manufacturing. "People have underestimated the challenge of bringing 3D printers into a certified or validated operating environment like medical or aerospace. There are still difficulties in doing that," McAlea says.

New Materials, Faster Printers on the Way

It appears that upcoming innovations in metal printing, according to companies interviewed for this article, will focus on speed, larger build envelopes and materials.

"With laser-based printers, we will continue to see improvements in speed and workflow, which will drive down part costs. I think we will see widespread factory adoption of these printers, and we're starting to see that already," McAlea says.

"We are just at parity with other technologies, and as we increase speed and reduce the cost of materials, we can operate more efficiently than die casting or stamping," Myerberg adds.

For example, Aurora Lab's RMP1 machine, which launches soon for beta customers, could have a production rate of 30 kilos per hour. The company's proposed Alpha 1 printer is supposed to be capable of printing 1,000 kg per day.

Myerberg also expects an evolution in materials. "Customers want to print a lot of stainless steel, and other materials are coming along too," he says.

All of these improvements will drive down the cost of part production and increase adoption. "The cost to produce a part will fall to the point where I think we'll see more 3D printing, and it will be the most cost-efficient way to produce many parts," de Geofroy says.

Markforged worked with Stanley Black & Decker to redesign some components that provided both significant weight and cost reductions. The company used the Metal X printer to create the actuator housing for Black & Decker's PD45 Hydraulic Post Driver and a wheel shaft for its PG10 grinder. The part's housing was resigned from four components to one, making it 53% lighter and cutting lead times by 95%. The new part was 12.5 times less expensive than machining and costs for a single component were reduced by 92%, according to the company.

However, both printer manufacturers and end users will need to close a looming skills gap regarding 3D printing in metal.

"Do we have the people who are trained to leverage this technology?" de Geofroy says. "Our customers are worried about staying ahead of the competition and attracting the right talent. There are students now with first-hand experience in 3D printing, and they don't want to work for companies that aren't leveraging the technology." DE

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INFO ➜ **Aurora Labs:** AuroraLabs3D.com

➜ **3D Systems:** 3DSystems.com

➜ **Desktop Metal:** Desktopmetal.com

➜ **Markforged:** Markforged.com

Industrial-Grade, **Mass Appeal**

A new class of desktop 3D printers marries the consistency and flexibility of expensive large-scale printers with the accessibility of consumer-based offerings.

BY BETH STACKPOLE

LIKE MOST INDUSTRIAL PLAYERS, EWIE is actively exploring how to channel emerging digital technologies to transform the way it does business. The company, which delivers commodity management services for cutting tools, abrasives and other industrial supplies, zeroed in on the potential for localized 3D printing to reimagine its spare parts supply chain.

Instead of housing, managing and shipping parts such as gripper fingers and gauging around the country to various players in the aerospace, automotive and medical industries, the company's plan is to install 3D printers at key local sites and produce spare parts on demand. By turning physical stock into a digital parts inventory, EWIE's newly formed Azoth division sees plenty of opportunity for delivering cost savings and efficiencies to its supply chain.

For Azoth to make good on the proposed business model, the company sought reliable, industrial-grade 3D printing capabilities that were a cut above consumer desktop offerings yet free from the cost and complexity of traditional large-scale industrial 3D printers.

"A $100,000 industrial system is just not realistic to put into each one of our local facilities—we needed an industrial-grade desktop printer at a more affordable price," explains Cody Cochran, key account manager at Azoth, which is currently building out its on-demand production service using the RIZE One 3D printer. "We also need a system that provides consistent quality and is low maintenance because the team at the local site might not be incredibly versed in 3D printing, post-processing and troubleshooting of machines."

Azoth and other companies are finding their requirements met by an emerging category of professional-grade industrial 3D printers that marry the accessibility of first-generation desktop units with the consistent quality and material flexibility afforded by more expensive, production-grade offerings.

The category includes companies like RIZE, Makerbot, Ultimaker, Roboze and Aleph Objects. Their latest offerings bridge the gap between industrial and desktop 3D printing by combining professional capabilities like extensive high-grade material choices, dimensional accuracy and repeatability and reliability with ease-of-use capabilities such as click-to-print functionality and less labor-intensive and messy post-processing work.

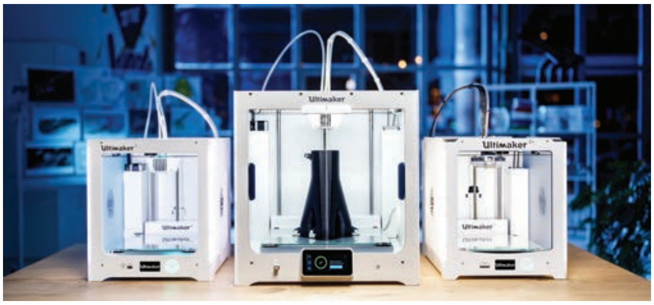
"As the market exploded, the types of users buying [desktop] printers changed from hardcore techies and makers to professionals and school teachers who use the 3D printers on the job, and with that, the needs changed," says Dave Veisz, vice president of engineering for MakerBot, a pioneer in the consumer 3D printer market, which just recently released Method, an industrial-grade desktop model.

Makerbot Method's Water-Soluble PVA material helps ensure easy support removal without compromising dimensional accuracy. *Image courtesy of MakerBot.*

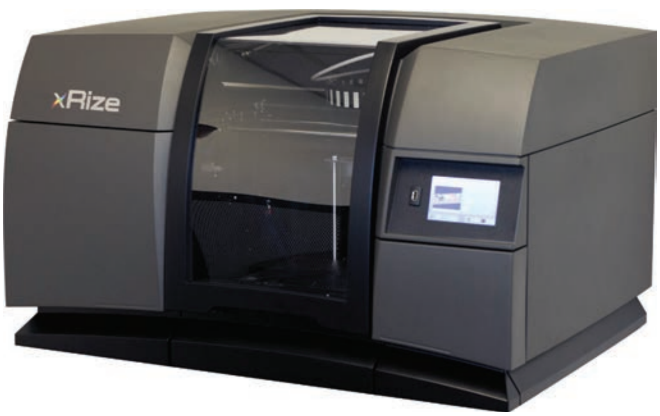
"The need has transitioned from a do-it-yourself (DIY) kit to something that comes fully assembled out of the box and can print high-quality parts," Veisz adds. "In the workplace, you are paid to be in the workplace and you need to produce. There isn't a lot of time for tinkering or coming in the next day only to find that a print job failed."

Bridging the Gap

Industrial-grade functionality for the RIZE 3D printer portfolio comes via its proprietary augmented deposition technology, a patented hybrid approach that combines extrusion and material jetting. A specially formulated release agent is jetted between the layers of the extruded material, which allows support structures to be easily and cleanly removed without relying on messy



Ultimaker's open filament system and print profiles deliver a wide array of industrial-grade material choices. *Image courtesy of Ultimaker*.



Among the industrial-grade features of the RIZE One printer are a heated build chamber and automatic filament swap. *Image courtesy of RIZE.*

and complex post-processing work and while maintaining a professional-grade surface finish, explains Kishore Boyalakuntla, RIZE's vice president of products.

The jetting technique also allows for graphics, text and digital tracing materials to be indelibly marked on any part surface. It helps address concerns about intellectual property (IP) protection, which is critical for industrial-grade 3D printing applications, he says.

In addition to the patented hybrid approach, the RIZE One system incorporates an array of other industrial-class features, including a heated build chamber to ensure parts are printed consistently with dimensional accuracy and that layers adhere properly. The system also features additional patented technology that keeps the print bed level, a design choice intended to ensure a high print success rate.

"Having a level print bed is absolutely essential to creating good quality parts, and as a user, you never have to worry about it," explains Boyalakuntla, who says that's not often the case with consumer-oriented desktop 3D printers. "A lot of people find out that with prosumer printers, the success rate of printing a part is low."

Expansive materials options are another element that sets industrial-grade 3D printers apart from past desktop offerings. In RIZE's case, the company's Rizium One thermoplastic polymer filament is designed for high strength, but it also absorbs little moisture, which leads to higher quality parts that don't expand or change shape depending on the operating environment, officials say.

Ultimaker also focused on the importance of material choices as part of its development work for the Ultimaker 3 and newer S5 3D printer offerings. Instead of the printer manufacturer being responsible for offering a full suite of industrial-grade materials, Ultimaker opted for a more open filament system, partnering with major chemical giants.

This collaboration ensures that the Ultimaker 3D printer family supports popular third-party, industrial-grade materials, but also that they deliver print profiles to ensure consistent and accurate results optimized for the specific material properties, according to Paul Heiden, Ultimaker's senior vice president of product management. The company most recently added a trio of new alliance partners, including Essentium, eSun and Polymaker.

"If you don't have a good print profile, print reliability falls back to 50%," he explains. Typically, it can take up to six months to create such a profile, but working with its partners, Ultimaker was able to shrink print profile development time down to a couple of weeks. Ultimaker started relationships with the 10 largest chemical companies, and its partner alliance now has up to 80 members, Heiden says.

Ultimaker Cura, the company's open source, cross-platform 3D printing software, complements the industrial material print profiles with out-of-the-box support for STL, OBJ, X3D and 3MF files so engineers or designers can easily slice their model and prepare it for print. The company also recently released a cloud platform that stores user settings, facilitates access to print profiles and enables remote print jobs.

This ease of use, coupled with minimal post-processing requirements due to the printers' water-soluble supports, ensure that Ultimaker 3D printers are well-suited for what Ultimaker sees as the breakout 3D printing application: localized digital production, where the digital tool path travels instead of the part, Heiden says.

"Companies are creating competency centers where they create toolpaths for thousands of parts," he explains. "But the actual 3D printing takes place where people have less CAD and material knowledge."

Aleph Objects is positioning its LulzBot 3D printers in professional markets with new leadership, material options and industrial features. In October last year, the company announced that Grant Flaharty, former president/COO of 3D Systems, would lead the company as its president. In December he also assumed the role of CEO. In November, the company introduced LulzBot HS-Series Tool Heads for printing high-strength materials like carbon-filled polyamide (nylon). Early this year, Aleph Objects released two new 3D printer bundles for metal casting using Polymaker's PolyCast filament, designed specifically to replace wax patterns for investment casting.

The ability to 3D print industrial-grade parts and post-process them quickly is one of the key requirements for HMS Industries, which is starting to incorporate RIZE industrial 3D printers into its workflows, according to Barry Aikens, vice president for the tool and die metal stamping shop.

Prior to the RIZE class of industrial desktop 3D printers, HMS wasn't willing to invest the capital or deal with the chemicals associated with large-scale, production class 3D printers, Aikens says.

"Other printers required us to take extra material off a part, dip in a solution and spend hours on [post-processing] depending on the part size," he explains. "With RIZE, the supports snap away and you have a ready-to-use part with no chemicals and no wait times."

Repeatability and Precision

Although breadth of materials and ease of post-processing are hallmarks of the latest industrial-grade desktop printers, other capabilities also set this class apart from consumer offerings. Roboze, which offers a family of commercial-grade desktop 3D printers, touts its beltless handling system and Z-axis capabilities that employ a C7 ball screw to enable its precision accuracy of up to 0.025 mm, says Alessio Lorusso, the company's CEO.

"This rack-and-pinion design is not subject to wear, so you are assured repeatability and precision on parts," he explains. The extruder has also been designed and built in stainless steel to ensure longer service life.

MakerBot, which got its start in the hobbyist 3D printer world, built its recently released Method offering with Stratasys technologies (MakerBot was acquired by Stratasys in 2013). The Method boasts heavy-duty construction to produce better part accuracy and fewer failures, including a structurally optimized metal frame and a dual-performance extruder system.

A circulating heated chamber controls the temperature of each part layer during the duration of the print process, resulting in better quality parts than those produced on a heated build plate of consumer offerings. Dry-sealed material bays keep material free of damaging humidity, and there are sensors that ensure that material is kept in an optimal environment—a feature previously available on more expensive, higher-end industrial printers.

At the same time, the Method ushers in key usability features like dissolvable supports, remote monitoring and printing, and automated material loading so users don't have to mess around with the dual extruder system.

"There are a lot of system-level things that contribute to what at the end of the day is important for engineers and that is, finished part accuracy," says MakerBot's Veisz. "The whole goal here is to bring the best of both worlds to engineers." DE

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INFO → **Aleph Objects:** LulzBot.com

→ **Azoth:** Azoth3d.com

→ **EWIE Company:** EWIE.com

→ **HMS Industries:** HMSIndustries.com

→ **MakerBot:** MakerBot.com

→ **Polymaker:** Polymaker.com

→ **RIZE:** Rize3D.com

→ **Roboze:** Roboze.com

→ **Ultimaker:** Ultimaker.com

THE CASE FOR ENGINEERING OUTSOURCING

Bringing engineering service provider benefits into focus.

BY BRIAN ALBRIGHT

MANUFACTURERS FACE VARIOUS new pressures that make it more difficult to remain competitive while they also focus on core competencies. Faced with globalization, varying demand requirements based on omnichannel fulfillment strategies and increased competition for talent, they have turned to outsourcing for a variety of different functions, from marketing to logistics to prototyping.

Engineering tasks are also increasingly farmed out to engineering service providers (ESPs). These firms can provide services such as generating drawings, designing components and full product development. The global engineering services outsourcing market is set to have a compound annual growth rate of more than 27% through 2022, according to HTF Market Intelligence.

Product complexity has driven some of this activity as firms outsource some basic engineering work so that their staff can focus on more complex components. In some cases, internal engineering staff have taken on more complicated tasks like simulation, which has put more demands on their time. In other scenarios, companies are outsourcing the more specialized design work (such as designing for additive manufacturing) because they lack the internal resources.

Manufacturing and design firms may also turn to engineering outsourcing to expand their footprint in new geographies; to update or convert outdated designs and files; or to avoid the hassle and expense of hiring new full- or part-time staffers, or hiring engineers with highly specific skill sets.

"It's like building a house," says Jeff Schipper, director of special operations at Protolabs. "Contractors use different subcontractors with different specialties. Those specialists add differentiating value."

The type of engineering work that gets outsourced varies depending on the application. Companies often contract out product development and design services, which can enable them to bring products to market faster. CAD and drafting are also outsourced frequently, either because the company lacks internal resources to handle those tasks, or because their designers have to delegate some of the grunt work of design while they work on multiple projects. In some cases, companies outsource highly specialized tasks like reverse engineering, which can be time-consuming, or simulation and analysis, which require significant compute resources and expertise.

The automotive industry has used outsourced engineering and design for decades. "In automotive, the suppliers are responsible for proving a product to spec, so it streamlines the design-for-manufacturing feedback loop," Schipper says. "When you share some of that joint development, it streamlines that upfront process."

Firms that specialize in outsourced 3D printing, manufacturing or other types of service bureau work also offer third-party engineering services in many cases. Stratasys Direct Manufacturing, for example, provides prototyping and finished parts manufacturing services, but also offers engineering services to support clients who aren't used to working in the 3D printing space.

"We have a wealth of project and manufacturing engineers to guide customers through those higher requirements," says Chuck Alexander, director of product management at Stratasys Direct Manufacturing.

In some cases, clients don't have any familiarity with CAD and other electronic design systems. Stratasys also provides generative design and design-for-additive services, which Alexander says reflects a paradigm shift the company has seen in the industry that goes hand in hand with the adoption of additive manufacturing. Stratasys also provides assistance with material properties and build orientation issues that can come up in design for additive.

"With generative design or topology optimization, you get a lot of organic shapes, and that's a fairly new thing," Alexander says. "Engineers may not be trained and focused on that kind of work. We can help them with that. Will that part actually work in production? That's the type of engineering we've added."

Communication with third-party providers is getting easier thanks to improvements in secure transfer technologies, video conferencing and file transfer protocol. "Now these systems don't require the insane amount of bandwidth that they used to," Schipper says. "That just makes communication consistently easier."

Outsourcing Risks

Outsourcing can have downsides. In the case of additive manufacturing engineering services, service partners may not be up-

Service providers can provide design for manufacturing expertise as well as on-demand manufacturing services. ***Image courtesy of Protolabs.***

to-speed on the requirements of the different types of machines and processes. Those introduce some risk. "If someone is not a molding expert but they are making a part that will be molded in production and they're using 3D printing to accelerate upfront design, then they have to keep the design for the molding process in mind," Schipper says. "Otherwise they make an unmanufacturable part and have to redesign it later."

There's also a risk of losing tribal knowledge as more work is handed down to outside engineers. "There are lessons learned during the design process that have value in future iterations," Schipper says. "If you make a new version of the same product, and you've outsourced part of the design out, you don't learn those lessons during development. You have to relearn all of those lessons with a new supplier or internally the second time around. When you are working with outside resources, it takes effort to make sure you are gaining that knowledge so it can be applied in the future."

Handing off engineering work also means that technical expertise has, in effect, been exported to a partner. In some cases, those outsourcing partners may need a significant amount of hand-holding to meet deadlines or quality standards, depending on their level of familiarity with the work they are asked to perform.

According to Alexander, that's one reason outsourcing has experienced ebbs and flows throughout the past few decades. "We've seen cycles where companies pull a lot of things they used to outsource in-house to have control, and then they go back into outsourcing driven by economics."

Finding the Right Partner

Because of the potential risks involved, it's important to select a reliable outsourcing services provider. In addition to design and analysis capabilities, companies should look for partners that offer some engineering consulting services that will help with decision-making and documentation.

The selection should be guided by identifying what competencies are required for the project, and then identifying which potential ESPs have those competencies.

Make sure you know what you are looking for and what your own internal capabilities are. Which steps in the design process (concept, design, documentation, analysis, prototyping or production) do you need to outsource, and which can you successfully manage internally?

Evaluate the ESP's portfolio, and ask for client references who you can speak to directly. The portfolio helps you gauge whether the company's previous work measures up to your current needs in terms of industry-specific experience and quality. Also, find out which engineers in the company will be working on your project, and vet them based on their education, experience and background.

A technical evaluation is also important. If you have software preferences for CAD, simulation or other functions, make sure they can support those platforms. Do they have enough compute power available to handle the simulations or visualizations you need? Can files easily be transferred back and forth? How will design reviews be handled?

Price is important, but quality and reliability are more critical. Make sure you do a thorough cost analysis to determine the long-term costs of outsourcing versus expanding your own staff.

Once you select a provider, the ESP contract should clearly spell out how responsibilities will be split between the companies, along with detailed specifications, cost and deadline targets, a method for reporting and measuring progress, incentives and consequences for failure to meet those requirements.

All deliverables should be clearly defined and include as much detail as possible. The contract should also include any details related to how communicate and make modifications. Be prepared to jointly conduct feasibility studies to make sure the design will work using the design and production processes spelled out in the contract. Companies should also identify internal staffers who will be responsible for managing the third-party provider's work, along with quality management, logistics and technical integration.

Outsourcing can be beneficial, but design firms and manufacturers should make sure they approach this strategy with an eye on maintaining control over their design data, intellectual property and their ability to easily update designs later, even if the ESP is no longer a partner. Communication and trust can make a huge difference in the success of outsourcing partnerships.

"You want to work with them strategically, not just transactionally," Schipper says. "That's where the big win is over time." **DE**

Brian Albright *is a freelance journalist based in Cleveland, OH. He is the former managing editor of* Frontline Solutions *magazine, and has been writing about technology topics since the mid-1990s. Send e-mail about this article to de-editors@digitaleng.news.*

INFO ➜ **HTF Market Intelligence:** HTFmarketreport.com

➜ **Protolabs:** Protolabs.com

➜ **Stratasys Direct Manufacturing:** StratasysDirect.com

3D Printing Services: The CAD Connection

Software-integrated plug-ins and online analysis pave the way for on-demand manufacturing.

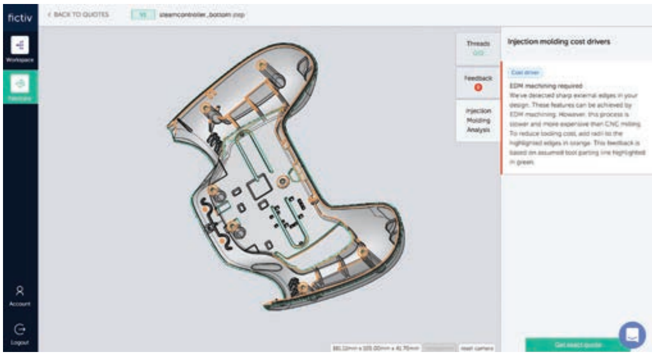
BY KENNETH WONG

FROM THE OUTSET, what Fictiv and Xometry appear to do is no more than matchmaking. It's the principle pioneered by tech disruptors such as Airbnb, applied to manufacturing. Airbnb matches those seeking short-term living accommodations with those who happen to have extra space that can accommodate travelers. Thus, a whole new ecommerce infrastructure was born to satisfy the backpackers and budget-conscious travelers who previously didn't have an option; and the homeowners who previously didn't have a good way to offer their extra bedrooms and vacation homes for rental.

Similarly, manufacturers with extra production capacity can join the Fictiv and Xometry networks, where they could be discovered by inventors, hobbyists and small startups with low-volume orders. But what makes the on-demand manufacturing economy run smoothly is much more than a simple online discovery process.

There's something beyond the algorithms that find and connect those who need parts and those who can make them. It's the CAD-integrated plug-ins and the cloud-hosted mechanism that let users inspect their own parts for manufacturing issues before pressing the "Buy" button.

A simple manufacturing check could be performed based on CAD geometry, using general computer-aided manufacturing (CAM) principles. For example, designs destined for additive manufacturing (AM) should address overhangs and thin walls before entering production; therefore, the plug-in can help identify these features and flag them for revision.



For many on-demand manufacturing service providers, an online or CAD-embedded tool is an integral part of the automated quote system. Shown here is Fictiv's online design check. ***Image courtesy of Fictiv.***

From Inside CAD

To upload your 3D design to get a quote, you can reach Xometry through its website. But for SolidWorks and Autodesk Inventor users, there's an option to use Xometry's CAD plug-in. Once downloaded and installed, the Xometry plug-in functions as a quote engine inside the CAD program that's available for you to instantly submit the part for manufacturing analysis and get a cost estimate.

"With the plug-in, we can give you the feedback you need early on, so you have a better understanding of the cost and production impact," explains Bill Cronin, Xometry's chief revenue officer.

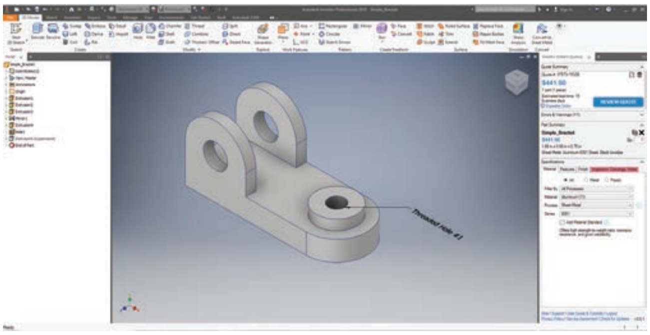
Another on-demand manufacturer service provider, Plethora, offers a plug-in for SolidWorks, Autodesk Inventor, Solid Edge and NX (the latter two from Siemens PLM Software). "The plug-in is a single download, but it figures out the appropriate plug-in depending on your CAD system," says Ben Mitchell, chief product officer of Plethora. "The plug-in can give you [a] red light or green light [depending] on whether the part can be made. If not, it can show you, in your CAD environment, the issues that need to be fixed."

Plethora is an independent manufacturer, not part of a matchmaking site. For now, Mitchell doesn't see the need for Plethora to belong to one. "Going to Plethora directly is a much better experience than going to Plethora via a matchmaking platform," he says.

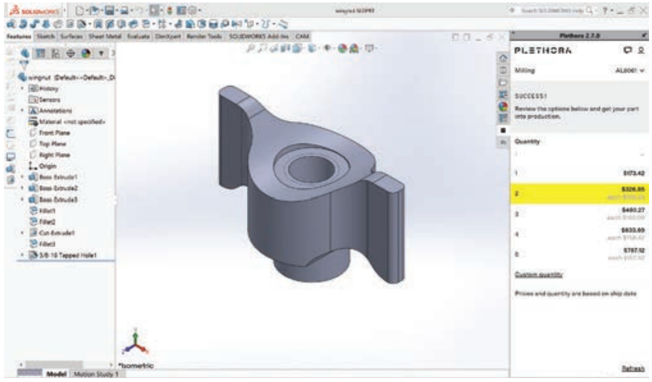
As an independent operator, Plethora has intimate knowledge about its own capacity, what it can and cannot make, and what its production queue looks like at any given moment. Therefore, Plethora's plug-in also takes these into consideration when responding to queries or issuing estimates.

From the Browser

Founded in 1999, Protolabs was originally an injection molding part producer. But in 2014, the company entered a new territory



Xometry's CAD plug-in, shown here in Autodesk Inventor, functions as a quote engine inside the CAD program. Users can submit the part for manufacturing analysis and get a cost estimate without leaving the CAD environment. *Image courtesy of Xometry.*



Plethora uses a CAD-embedded plug-in (SolidWorks version shown here) to provide early manufacturing feedback and cost analysis. *Image courtesy of Plethora.*

when it launched an industrial-grade 3D printing service. Today, it operates as an on-demand manufacturing service, churning out parts from 12 facilities (seven in the U.S.) with turnaround time as fast as a single day.

One key to Protolabs' automated submission and quote system is the cloud-hosted ProtoQuote software. It can analyze uploaded geometry for problem-prone undercuts, draft angles, surface finishes, wall thickness and material flow, and suggest sensible revisions. The company calls it their "secret weapon" in its video demo.

Fictiv doesn't offer plug-ins, but also performs automated manufacturing checks online. The company's cloud-hosted technology is tuned to provide instant design for manufacturability feedback and automatic quotes for 3D printing, computer numerical control machining, injection molding and urethane casting jobs.

But Fictiv's involvement is much more than automatic part analysis and matchmaking. "Once the order is placed, we intelligently match orders with the right manufacturer for the job. Post-order, there are several Fictiv employees working behind the scenes to ensure parts are made on time and to the customer's detailed specifications. This includes quality control engineers, customer success managers and technical project managers who communicate project details to our manufacturing partners. Fictiv takes responsibility for part quality every step of the way to guarantee customer satisfaction," says Dave Evans, co-founder and CEO of Fictiv.

From Inside PLM

The on-demand manufacturing commerce has also attracted the attention of some CAD and product lifecycle management (PLM) vendors. As developers of the primary design software tools used by engineers, they seem well-positioned to implement an instant design check mechanism and facilitate the order.

This thinking has led Dassault Systèmes to launch 3DEXPERIENCE Marketplace, backed by 180+ manufacturing partners. (See page 34 for more.) Similarly, Siemens PLM Software, a division of the manufacturing titan Siemens, has launched the Additive Manufacturing (AM) Network platform.

For the type of large manufacturers Siemens PLM Software targets, a different approach is warranted. "You can initiate the buying process from CAD, but most of them prefer to do that from the PLM system, so in our customers' case, they start with Teamcenter, then get the part made through our AM Network," says Robert Meshel, director of AM Network, Siemens PLM Software.

By navigating the PLM system, the user creates a record of the transaction, along with traceability and history.

Scalable to One

Aiming to cater to the underserved segment, vendors like Fictiv, Xometry and Plethora input measures to facilitate orders as few as one unit. "We pride ourselves on having no minimum order quantities for injection molding, which enables emerging hardware companies to reduce up-front costs and de-risk new product launches. On the high-end, today we can help customers scale to produce over 2 million injection molded units and as our network grows, this capacity will grow as well," says Evans.

"Xometry doesn't have a minimum cost. You can come and order a single part of $6 to $10," says Cronin. "We use machine learning algorithms to set the price for a job. As more people come to get quotes from us, we become more knowledgeable about market prices."

The low-volume order fulfillment is critical to attract small firms and startups, but the on-demand vendors also face the conundrum of success. "Most of the parts we're making at Plethora are in quantities of less than 10," notes Mitchell. "But what if one of our regular customers becomes a Kickstarter success and suddenly gets 10,000 orders? For those customers, we may very well be their path to growth."

The Kickstarter success dilemma, however, is not the norm. Most users will follow a longer road to success, learning through trial-and-error cycles. That means, there's still a lot of prototypes to be made, a lot more orders to be filled. DE

Kenneth Wong *is* DE*'s resident blogger and senior editor. Email him at de-editors@digitaleng.news.*

INFO ➜ **Dassault Systèmes:** 3DS.com

➜ **Fictiv:** Fictiv.com

➜ **Plethora:** Plethora.com

➜ **Protolabs:** Protolabs.com

➜ **Siemens PLM Software:** Siemens.com/PLM

➜ **Xometry:** Xometry.com

Fictiv expands to China with the opening of a new branch, Agile Manufacturing Solutions (AMS). Shown here: Fictiv co-founder and CEO Dave Evans (left-most) in the new overseas office. *Image courtesy of Fictiv.*

Aiming to be the Amazon of On-Demand Manufacturing

Vendors enter the field, adding new networks for ordering custom parts and prototypes.

BY KENNETH WONG

IN FEBRUARY 2018, when Dassault Systèmes, the parent company of SolidWorks, launched its ecommerce platform 3DEXPERIENCE Marketplace, the company said, "Our ambition is nothing shy of transforming the industrial world similar to the way companies like Amazon transformed the retail sector."

Dassault Systèmes is certainly not the first to aspire to become an Amazon-like entity for manufacturing. Although the company has a long history in CAD, simulation and product lifecycle management (PLM), in the field of on-demand manufacturing, it must compete with younger but earlier players like Xometry, Fictiv and Protolabs.

Some of these companies started out as portals catering to the inventors and hobbyists with low-volume orders that traditional manufacturers would rather ignore than fill. Others began by providing a single type of production. But many have outgrown their humble origins over time.

Fictiv was founded in 2013, a mere 6 years ago, but last May, after securing U.S. $15 million in Series B funding, the company opened a China-based division and launched its Agile Manufacturing Solution (AMS), which expanded Fictiv's product offering beyond prototyping into production volume injection molding and computer numerical control (CNC). Last month, the company closed a $33 million Series C funding round to accelerate its transformation into a global digital ecosystem to enable fast, flexible hardware product development and production.

Also launched in 2013, Xometry now counts carmaker BMW and NASA among its customers. According to the company, it now serves nine out of the top 10 Fortune 500 aerospace companies, and 44% of the Fortune 500 automotive and auto part makers.

Protolabs started in 1999 as an injection molding company and a few short years later added CNC machining to its line of service. In 2014, Protolabs began offering industrial-grade 3D printing services and added sheet metal fabrication in 2017 through the acquisition of Rapid Manufacturing. Today, the company operates 12 manufacturing facilities (seven in the U.S.) as an on-demand prototyping and production part producer, with turnaround times as fast as a day.

Dassault Systèmes' 3DEXPERIENCE Marketplace is a sign that CAD and PLM vendors now see an opportunity to get a slice of this on-demand pie and want to become part of it. But can they convince the current leading players and service providers to join them or come under their wings?

More Than Matchmaking

A manufacturer dating as far back as 1999, Protolabs has the experience and history to deliver on-demand manufacturing from its own facilities. By contrast, Fictiv and Xometry rely on a network of manufacturing partners to fulfill the orders that come through their online system. But to characterize them as a buyer-vendor matchmaking site doesn't fully capture the breadth of their services.

"First, we provide instant pricing via our platform, determined by our own pricing algorithms. We also provide manufacturability feedback to help customers understand how digital designs translate to physical parts," says Dave Evans, Fictiv's co-founder and CEO.

"Once the order is placed, we intelligently match orders

A Protolabs employee inspects a part created via HP's Multi Jet Fusion 3D printer. *Image courtesy of Protolabs.*

with the right manufacturer for the job," he adds. Post-order, there are several Fictiv employees working behind the scenes to ensure parts are made on time and to the customer's detailed specifications. This includes quality control engineers, customer success managers and technical project managers who communicate project details to our manufacturing partners. Fictiv takes responsibility for part quality every step of the way to guarantee customer satisfaction."

Consolidation and Expansion

In July 2018, while adding $25 million to its coffers from a fresh round of funding, Xometry acquired a smaller competitor, the Kentucky-based MakeTime Inc. As a result, Xometry added MakeTime's network of 1,000+ suppliers to its own, boosting the size of the Xometry network considerably.

"Companies like BMW and GE were customers of ours before they became investors," says Bill Cronin, chief revenue officer, Xometry. "But we also work with a wide range of young businesses, design and engineering firms in the midrange. We don't have a minimum cost for an order. You can order a single part for as little as $5."

Early this year Xometry launched an initiative dubbed Xometry Supplies, making it easy for the 2,500+ manufacturers in its network to acquire the Aluminum 6061-T6, tools and supplies they may need after accepting a job. With this, the company goes beyond on-demand manufacturing, dipping its toes in raw materials and tooling.

As Xometry moves into a new domain, Fictiv expands to Guangzhou, China, which resulted in the launch of its Agile Manufacturing Solutions, described as "a suite of production manufacturing services for supply chain and engineering teams who need fast, quality end-use parts at high volumes of 100 to 500,000 units."

"Fictiv employees in its China HQ inspect and onboard manufacturing partners work directly with customers to ensure design requirements are clearly communicated, and are on the factory floor during production to ensure things are running smoothly," says Evans. "In addition, Fictiv requires all of its manufacturing partners (in the U.S. and overseas) to complete quality checks with documentation for every order. Finally, Fictiv has its own quality assurance team, which analyzes parts and does quality checks before parts are shipped to the customer."

With a U.S. and China-based network, Fictiv can offer users some overseas choices that are economically advantageous. However, the advantages are also tempered by concerns over the current trade tension between the U.S. and China, specifically on how the this-for-that tariff measures affect procurement.

"We just launched our fourth annual State of Hardware Survey and early results show that over 65% of respondents experienced increases in material and component costs, over 18% have experienced project delays and almost 5% have had projects cancelled altogether due to tariffs," says Evans. "We believe this makes a strong case for the need for a globally distributed network of vetted suppliers that's easily accessible through the cloud, to help companies be more agile and defensible in response to this type of political disruption."

CAD and PLM Vendors Move in

In February, delivering his keynote address to the SolidWorks software users in attendance at SolidWorks World, company CEO Gian Paolo Bassi said, "We want to offer you this amazing concentration of knowledge, technology and know-how. We call this 3DEXPERIENCE.Works [3D Experience dot Works]."

A key component of the new 3DEXPERIENCE.Works is the 3DEXPERIENCE Marketplace, a portal for on-demand-ing services. By the company's own count, the network now includes 180+ manufacturers, offering processes such as 3D printing, CNC machines, injection molding, laser cutting and sheet metal design.

Xometry is a 3DEXPERIENCE Marketplace vendor. "Customers have different channels to gain access to us. So this is another channel," says Cronin.

On the other hand, Fictiv is not part of it. "Fictiv does not belong to any such marketplace and does not plan to join in the future," says Evans. "Our vision is to build a single destination for manufacturing needs from prototyping to production."

Xometry offers plug-ins for SolidWorks and its rival, Autodesk Inventor. The software-embedded connection allows SolidWorks and Inventor users to perform manufacturing checks and cost analysis early in the design process, from within the CAD software itself.

Autodesk, on the other hand, doesn't seem to be in a hurry to build and launch its own on-demand portal. "Our vision is to continue to support an open development environment so that [on-demand manufacturing vendors] can develop their connectivity solutions directly to the Fusion 360 platform and deliver an experience that makes sense for their customers," says Patrick Rainsberry, senior manager of strategy for Autodesk Fusion 360 and EAGLE products.

Connected to the Factory

Somewhere in the mix are vendors like Plethora, which belong neither to vendor-run networks nor buyer-supplier matchmaking portals. But Plethora shares some characteristics of these portals that result in ease of use, such as a highly automated submission and order system and CAD-connected manufacturability check tools via plug-ins.

Ordering a part to be manufactured is not as simple as ordering something already inside an Amazon warehouse, waiting to be packed and shipped. "It requires a lot of back-and-forth between the tool that the user designs the part in, and the factory that will make the part from the design," explains Ben Mitchell of Plethora.

CAD-specific plug-ins from Plethora and Xometry can verify and check whether the part as-designed can be manufactured or not. Though they don't involve CAD-embedded plug-ins, Fictiv's and Protolabs' online quoting systems also perform automated manufacturing checks in a similar fashion.

But the next part is a bit more complicated. "Assuming you can manufacture it, the next step is, when can you deliver it and how much should you charge?" says Mitchell. "To answer that, you need to know the materials you have in inventory, how long will it take you to order the materials or the tools you need to make it; and also, what [does] the current production pipeline in your factory look like." Being an independent operator, Plethora has access to such insider data and can respond to quotes more accurately, Mitchell notes.

Technically, nothing prevents Plethora from joining a buyer-supplier matchmaking site or a vendor-run network. But Mitchell says the company so far hasn't felt the need. "We feel going to Plethora directly is a better experience than going to Plethora via another platform," he says.

Certified Additive Network

Last April, Siemens PLM Software, a division of the manufacturing giant Siemens, announced the launch of Additive Manufacturing Network (AM Network). The company first hinted of it as a concept at Hannover Messe in 2017. In the press release, the company described its offering as "a new online collaborative platform designed to bring on-demand design and engineering expertise, knowledge, digital tools and production capacity for industrial 3D printing to the global manufacturing industry."

"We're working with mostly vendors from the industrial domain," says Robert Meshel, director of AM Network, Siemens PLM Software. "In this area, unlike business-to-consumer transactions, the matchmaking element is not that critical. Most manufacturers are already working with certified vendors."

Whereas startups, hobbyists and small design shops without a dedicated supply chain may need to rely on Fictiv, Xometry, Protolabs, Plethora and other on-demand vendors, the situation is the reverse for large manufacturers, Meshel says.

"With these customers, if they need to order 100,000 to 150,000 parts, they already have a list of approved vendors to go to. And it costs a lot to certify a vendor, so the appetite to add new vendors is not high among them," says Meshel. "It's more about facilitating and orchestrating the entire process with full traceability."

In the long run, Siemens PLM Software could expand the network to cover more than AM vendors, but for now, AM appears to be "digital manufacturing in its purest form, and there's still a lot of work to be done in this area," says Meshel.

The Siemens AM Network recruits and brings onboard AM service providers its customers are already using. Therefore, it's much more selective in its vendor recruitment. "Some customers start with a relatively low volume in AM, but grow the volume exponentially," Meshel says. Siemens PLM Software hopes such customers would use its cloud-hosted AM Network to manage the growth, from order to shipment.

Filling a Need

Portals and vendor-operated networks offer value as a convenient means to compare prices and order parts from a trusted pool of providers, eliminating the need for businesses to individually investigate local and overseas machine shops to identify the most suitable partners. They empower an underserved segment—inventors, hobbyists, small shops and even divisions within larger enterprises—that have creative concepts but previously didn't have a means to turn them into tangible products.

But to become the Amazon of on-demand manufacturing, one has to offer a broad spectrum of services and choices that far exceeds one's rivals and independent operators. Currently, there's no such clear leader in the segment. In time, consolidations, partnerships and acquisitions may lead to one clear dominant player. DE

Kenneth Wong *is* DE*'s resident blogger and senior editor. Email him at de-editors@digitaleng.news or share your thoughts on this article at digitaleng.news/facebook.*

INFO ➜ **Fictiv:** Fictiv.com

➜ **Dassault Systemes:** 3DS.com

➜ **Plethora:** Plethora.com

➜ **Protolabs:** Protolabs.com

➜ **Siemens PLM Software:** Siemens.com/PLM

➜ **Xometry:** Xometry.com

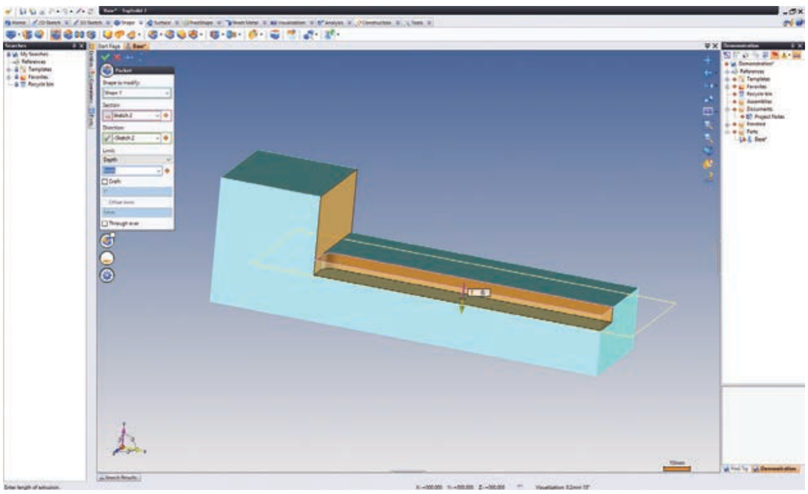
For more information on this topic, visit DigitalEngineering247.com.

TopSolid 7.12: All in the Family

A completely integrated CAD/CAM/PDM program.

BY DAVID COHN

TOPSOLID IS A FULLY INTEGRATED computer-aided design and manufacture (CAD/CAM) program developed by the French company Missler Software, based on the Parasolid geometric modeler. Founded in 1977 as Missler Mécanique, the name was changed in 1984 to Missler Informatique. After a 1992 alliance with TopCad (the original publisher of TopSolid) and several other acquisitions, all the various entities were merged in 2001 to become Missler Software.



TopSolid'Design offers a well-organized interface. Most commands open a dialog box in which you specify parameters for the current tool. *Images courtesy of David Cohn.*

Since then, the company has focused on developing an integrated family of products targeting the mechanical, sheet metal and wood industries, "wherever a machine interacts with materials to machine, shape or produce a part."

Missler initially sold individual TopSolid modeling modules covering basic design, sheet metal, wood and mold making; a separate 2D drafting module; and separate CAM components for sheet metal, wood and so on. With the release of TopSolid 7 in 2009, many of those individual modules are now included within the Standard or Professional levels of TopSolid'Design. The company also sells five different TopSolid'Cam modules (2D, 3D, 4D, 5D and Turning) as well as two separate mold modules. TopSolid'Design Standard includes solid and surface modeling tools plus drafting, while TopSolid'Design Professional adds a mechanical library, simulation, finite element analysis (FEA) and sheet metal.

In addition to offices throughout France, Missler has offices in the U.S., Italy, China, Switzerland, Turkey and Brazil, and ships products throughout the world. The company claims more than 100,000 licenses worldwide. For this review, we looked at TopSolid'Design 7.12.

The program features a Windows-compliant interface and a totally integrated product data management (PDM). TopSolid provides optimized management of large assemblies, powerful modeling and simulation tools, smart standard components containing machining information, and can produce detailed and standardized drawings.

Integrated PDM

TopSolid'Design 7 is built on a PDM foundation. The program features integrated PDM functionality that manages all documents. In local mode, the PDM manages your unshared work and does not require you to install a database server, relying instead on Microsoft's SQL Server Compact Edition. If you work in teams, you can install the TopSolid PDM Server on a dedicated computer on your network and each user can then connect to it as a client to access shared data.

Data managed by the PDM is distributed into projects, which in turn contain documents that can be arranged into hierarchical folders. As a result, when you use TopSolid you first create a project and then create documents within that project for parts, assemblies, drafting views and so on. The PDM tracks document properties including names and part numbers. You can add custom properties and even have TopSolid automatically assign part numbers. The PDM also provides a vault you can use to control check-in and check-out of documents. The PDM automatically manages revisions each time a document is modified and put into the vault. You can then access the different versions of a document, and see the history of certain actions.

Well-organized UI

When you start TopSolid, the program opens to a Start Page. From here, you can access recent documents, or start a new document or project. You can also access PDF files covering Help, separate tutorials for TopSolid'Design and TopSolid'Cam, a 372-page User's Guide, and a What's New document. There are also links to the TopSolid website, an online store, a user forum and the TopSolid Blog.

The TopSolid user interface consists of a large document window surrounded by various tools. In addition to the Start Page, each open document has its own tab within the document window. The title bar shows the name of the document currently being edited, along with an indication of whether it has been modified since the last time it was saved. Below this, the main menu provides access to currently available commands, which are organized onto a series of labeled tabs.

Each tab (or working bar) contains square icon-only buttons. Although you can change the size of these buttons (which requires a program restart), they lack text. While learning the program, you must hover your cursor over a button to see a tooltip to verify you are selecting the desired command. Some commands are also accessible via the application icon in the upper-left.

By default, a Searches panel is anchored on the left and a tabbed panel for current and recent projects is anchored on the right. Collapsed tool windows extend down the left side of the document window. When expanded, these show the entities tree (containing the result of work performed), the operations tree (representing the sequence of actions that led to the results shown by the document entities) and the parts tree (listing parts contained in an assembly). Any of these panels can be anchored, collapsed, moved and closed.

Within the document window, a compass in the lower-left helps you to orient the view, while tools in the upper-right let you pan, zoom and rotate the view; split the screen into multiple views; and so on. There is also a scale indicator in the lower-right to help you better understand the size of the objects in the window. A status bar extends across the bottom of the screen.

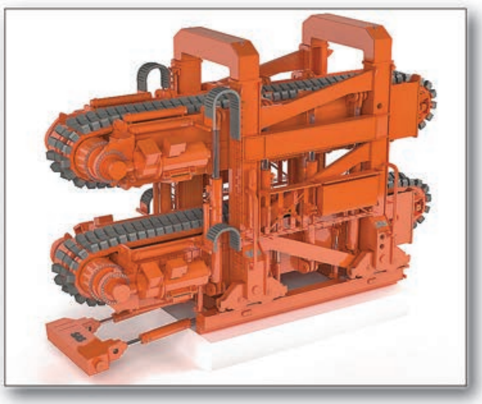
Organized Workflow

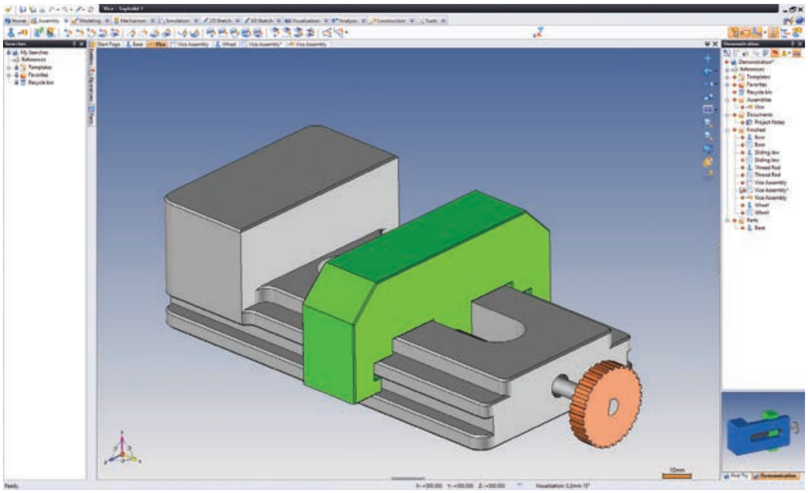
Whenever you create a new part, you can select the material and template to build the part. You can make similar choices whenever you create any other type of new document, such as an assembly, drawing, bill of materials (BOM) or exploded view. Once the part document is open, TopSolid works like many other mechanical modeling programs. In other words, you begin by creating a 2D sketch. As you sketch, contours appear purple while under-constrained and turn blue when fully constrained.

Once you have sketched a 2D profile, you can operate on it to create a 3D shape. You access most commands from the toolbar. For example, to extrude a sketch, you switch to the Shape tab and then select the Extruded tool. However, some commands can also be accessed by right-clicking to display a contextual menu.

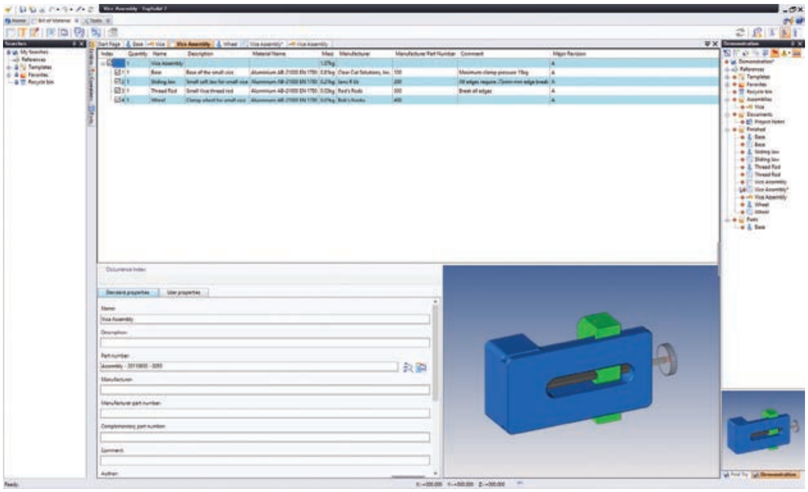
For most functions, a dialog box then opens in the upper-left corner of the document window. Here, you can enter parameters for the current tool. But you can also use controls in the workspace to work interactively or double-click a dimension to make it active and then enter the appropriate value. When done, you click a green checkmark to complete the command.

To add a feature, you must create another 2D sketch.

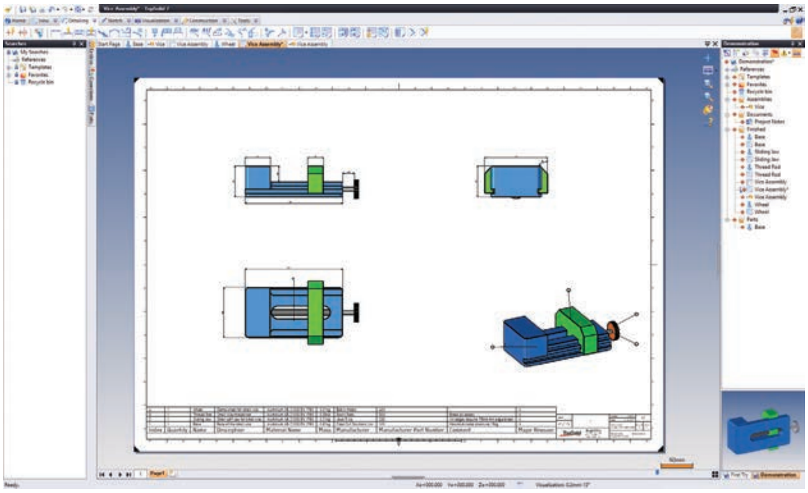




You can create assemblies using top-down, bottom-up or hybrid methodologies.



TopSolid makes it easy to create a detailed bill of materials, thanks to its integrated product data management.



Producing drawings complete with title blocks, dimensions and notes is very straightforward.

You can simply click a face to set the support plane to that face and then sketch new contours on that face. When sketching, TopSolid typically switches to a top view of the work plane, although you can create spatial sketches when you need to create profiles that are not planar (such as when modeling pipes or springs). You can also add 3D shapes—solid primitives such as blocks, cylinders, cones and spheres.

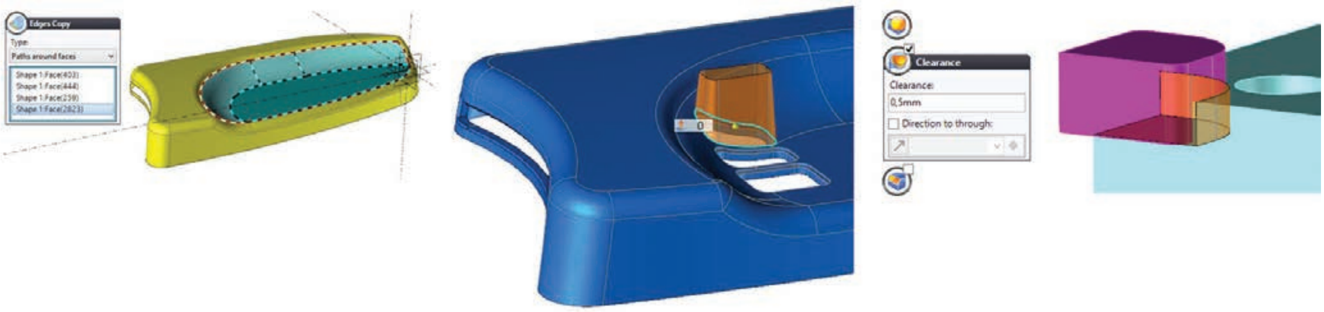
Multiple Techniques

TopSolid offers a distinct drag-and-drop technique. For example, to add the same fillet to another edge, you can press CTRL and drag the existing fillet onto another edge. If the program cannot determine onto which element you are dropping the fillet, you can tap the right mouse button while continuing to press the left mouse button until the desired edge or face is highlighted, and then release the left mouse button, a process TopSolid calls "rotary picking." You can also select a fillet and then, while editing that fillet, select another edge to add it to the definition of the fillet.

When creating assemblies, you typically bring in the base part and then drag and drop other parts from the tree. But in addition to this bottom-up method (creating parts independently and then assembling them together), you can use a top-down mode (creating parts in-place), or use a hybrid method that incorporates both. Parts initially appear purple (unconstrained). You then use positioning tools to add constraints.

Assemblies can be either rigid or articulated. If articulated, they are called mechanisms, and TopSolid provides a host of tools to define the assembly's kinematics. You can also run dynamic and kinematic simulations to study your designs. TopSolid lets you quickly produce a bill of materials and drawings (called draftings) of the individual parts in an assembly. Tools for fashioning title blocks, adding dimensions and notes, creating hatching and so on, are rather basic, but you have total control over the appearance of these drawing elements if you drill down deep enough into the various settings.

TopSolid also includes tools for working with sheet metal, such as cutting nesting parts from a single sheet. There are also functions to



From left to right: TopSolid 7.12 includes new tools for retrieving the contour of several faces, extruding with draft a shape with a non-planar selection and performing a Boolean subtraction with clearance.

generate a mechanically welded chassis, produce piping and create photorealistic renderings.

Missler also offers modules for finite element analysis (FEA), creating core and cavity block splits and sub-inserts, designing strips made by progressive dies and analyzing plastic flow. And as previously mentioned, the company sells additional CAM modules you can use to manufacture your designs while remaining within the integrated TopSolid environment.

What's New

TopSolid 7.12 offers numerous enhancements over the previous version, including support for 4K monitors. The compass now includes small spheres to help when orienting the model and you can change its size and position. There are also numerous improvements to the PDM, including better data-checking and search. When sketching, automatic hatching lets you quickly view all profiles of a sketch, and a new Paths Around Faces mode lets you retrieve the contour of several faces.

A new Extruded Faces command lets you extrude a selection of faces by specifying a direction and length. You can also add draft to an extruded shape with a non-planar section. The option to apply draft is available regardless of whether you select a 2D or 3D sketch. Enhancements to the subtraction Boolean command include a new section to define a clearance with the shape to subtract. You can also specify the direction of the operation.

When importing STL files, you can choose to import faceted shapes. This new mode lets you create shapes with meshed geometries. Sheet metal improvements include the ability to bend several coplanar faces at the same time. There are also minor appearance changes when working with assemblies and the ability to use slave parts so that you can machine a part before you have finished its design and load the part without having to load the entire assembly.

A new mechanisms command lets you analyze collisions between rigid groups, and the FEA tools now offer fatigue and thermal modules. TopSolid 7.12 also includes several drafting enhancements and updated translators for Spatial, PMI, IFC, STL, OBJ, Revit and STEP.

Getting TopSolid

You can download a 30-day free trial from either the company's website or the TopSolid blog. You must register and create an account before you can begin the trial. In addition, each time you start the program, it asks if you want to import libraries, which can be time-consuming. You can change program settings if you don't want to go through this every time you start TopSolid.

TopSolid is a complete program with lots of additional modules, each of which will take time to master. According to a Missler representative, a typical CAD/CAM installation costs around $10K. TopSolid offers lots of power once you climb its learning curve. **DE**

David Cohn *is the senior content manager at 4D Technologies. He also does consulting and technical writing from his home in Bellingham, WA. He is a Contributing Editor to* Digital Engineering *and is the author of more than a dozen books. You can contact him via email at david@dscohn.com or visit his website at dscohn.com.*

INFO → Missler Software TopSolid: TopSolid.com

SUGGESTED U.S. PRICING

TopSolid'Design 7 Standard
- **$3,995**
- **Annual maintenance:** $600

TopSolid'Design 7 Professional
- **$5,995**
- **Annual maintenance:** $900

TopSolid'Cam (each module)
- **$3,250**
- **Annual maintenance:** $488

TopSolid'Split (core/cavity mold design)
- **$1,995**
- **Annual maintenance:** $300

TopSolid'Mold (3D mold design)
- **$4,995**
- **Annual maintenance:** $750

SYSTEM REQUIREMENTS
- **OS:** Windows 10, 8.1, 8.0 or 7 (Windows Home not supported)
- **Processor:** Intel i7 or AMD equivalent
- **Memory:** 16GB minimum (32GB recommended)
- **Disk Space:** 1TB with 10GB free space
- **Display:** NVIDIA GeForce or Quadro with 1GB RAM (minimum) and 1920x1080 (minimum) display

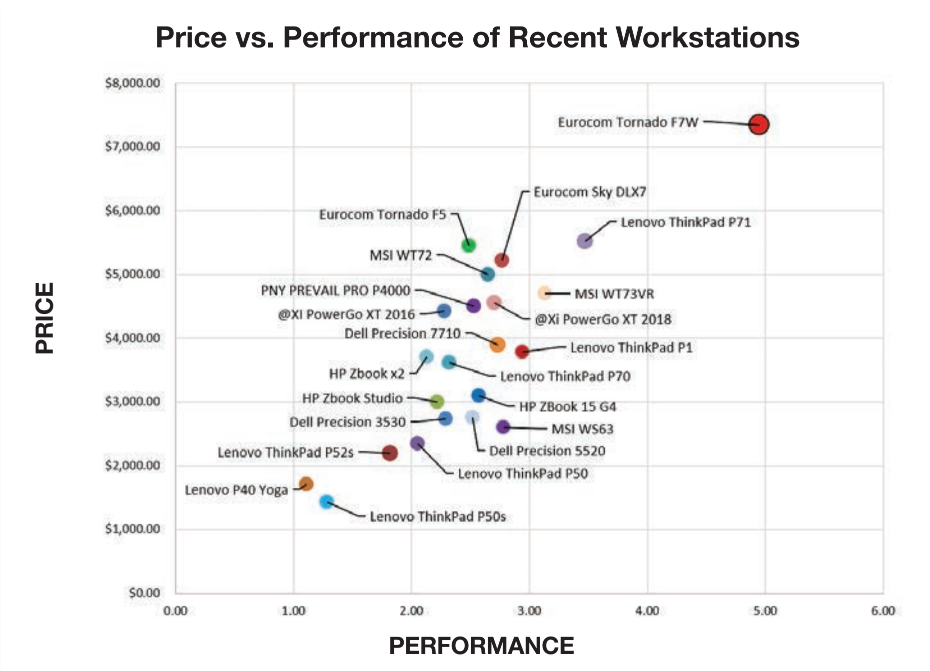
BLOWN AWAY: Eurocom Tornado F7W Mobile Workstation

Canadian system integrator delivers the fastest mobile workstation ever reviewed by *DE*.

BY DAVID COHN

EUROCOM HAS ALWAYS IMPRESSED US with its ability to deliver some very powerful mobile computers. Though with the system that recently arrived at our lab, the Canadian system integrator has taken mobile workstations to an entirely new level. Like the 15.6-in. Tornado F5W that we reviewed last year (*DE*, July 2017; digitalengineering247.com/r/16743), the new 17.3-in. Eurocom Tornado F7W includes a LGA1151 socketed CPU, enabling the system to support the latest Intel Core or Xeon processors.

The Eurocom Tornado F7W is big, fast and extremely powerful. It is also very expensive and comes with a very large 780-watt power adapter. *Image courtesy of David Cohn.*



Price/performance chart based on SPECwpc Product Development benchmark dataset.

But the new Tornado F7W—Eurocom calls it a mobile super workstation—also provides a choice of NVIDIA Quadro GPUs (graphics processing units), four memory sockets and it supports up to 22TB of storage with five physical drives.

The Eurocom Tornado F7W is based on an Intel C246 chipset and looks nearly identical to the @Xi PowerGo XT mobile workstation we recently reviewed (*DE*, November 2018; digitalengineering247.com/r/21833). That system, which broke most of our previous benchmark records, was actually manufactured by Taiwan-based MSI. The Eurocom Tornado F7W appears to use the same MSI chassis as a base.

With a starting price of $3,499 (without an operating system), the Tornado F7W base configuration is already a powerhouse, with a 3.7GHz Intel Xeon F-2176G CPU, an NVIDIA Quadro P3000 GPU with 5GB of discrete memory, 16GB of error-correcting code (ECC) system memory, a 17.3-in. 1920x1080 FHD display and a 1TB 7200rpm SATA hard drive. But that's just the starting point, and the review system that Eurocom sent us contained a host of more powerful components.

The Eurocom Tornado F7W is housed in a sculpted charcoal gray case, which measured 16.85x12.3x2.0-in. and weighed 9.4 lbs. Although the base configuration includes a 330-watt power supply (which we assume is similar to the 2.75-lb. adapter supplied with the @Xi PowerGo XT), the 780-watt power supply provided with our Tornado F7W evaluation unit was even bigger, measuring 9.25x4.37x1.62-in. and adding another 4.1 lbs. This huge device even had its own internal cooling fans and brought the total system weight to 13.5 lbs.

Raising the lid revealed the display plus an excellent 102-key backlit keyboard and numeric keypad. A U.S. English language keyboard comes standard. Keyboards for other languages, including U.K. English, French, German and Spanish, cost $83 more.

A 4.25x2.5-in. gesture-enabled touchpad with a pair of buttons and fingerprint reader is centered below the spacebar. Centered above the display is a 2-megapixel webcam and microphone array. There are also a pair of speakers for the integrated audio plus a subwoofer. A V-shaped power button is located in the upper-right corner above the numeric keypad and glows when the system is powered up. Four additional buttons below this let you switch between the discrete and integrated graphics, increase the fan speed and launch predefined programs. Small LEDs illuminate to indicate caps lock and number lock.

Massive Expandability

The right side of the case provides a pair of USB 3.1 ports, a Smart Card reader, a six-in-one card reader, a security lock slot and a large ventilator grille. The left side houses a similar air vent as well as three additional USB 3.1 ports and four audio jacks (line-in, line-out, microphone-in and a headphone jack, which doubles as an S/PDIF connector).

The rear panel includes an RJ-45 network connector, a mini DisplayPort, an HDMI port, a Thunderbolt (Type-C) port (which supports USB 3.1, DisplayPort 2.1 or HDMI 2.0), a power connector and two more large air vents. There are also lots more air vents on the bottom of the case.

Three LEDs along the front edge of the system indicate when Wi-Fi is enabled, battery status and hard drive activity. Despite its size, there is no provision for an optical drive (Eurocom sells optional external DVD and Blu-ray drives) and the battery is not user accessible.

In addition to the Xeon CPU in the base configuration, Eurocom offers a choice of six other 9th-generation processors, including the even faster 3.8GHz Xeon E-2186G as well as four different Core i7 processors. But for our evaluation, Eurocom included an Intel Core i9-9900K CPU. This eight-core Coffee Lake processor, which was just launched during the fourth quarter of 2018, includes 16MB of Smart Cache, a maximum turbo frequency of 5.0GHz and a thermal design power (TDP) rating of 95 watts. This processor, which also includes Intel UHD Graphics 630, added $250 to the total cost.

Although the base unit comes with 16GB of ECC memory using a single small outline dual in-line memory module (SO-DIMM), systems based on a Xeon CPU can accommodate up

Mobile Workstations Compared	**Eurocom Tornado F7W** 17.3-inch 3.60GHz Intel Core i9-9900K 8-core CPU, NVIDIA Quadro P5200, 64GB RAM, 500GB NVMe PCIe SSD, 2TB HD	**Lenovo ThinkPad P1** 15.6-inch mobile 2.70GHz Intel Xeon E-2176M 6-core CPU, NVIDIA Quadro P2000, 32GB RAM, 2TB NVMe PCIe SSD	**Dell Precision 3530** 15.6-inch 2.7GHz Intel Xeon E-2176M 6-core CPU, NVIDIA Quadro P600, 32GB RAM, 512GB NVMe PCIe SSD	**@Xi PowerGo XT 2018** 17.3-inch 4.0GHz Intel Core i7-8086K 6-core CPU, NVIDIA Quadro P4200, 32GB RAM, 500GB NVMe PCIe SSD	**Lenovo ThinkPad P52s** 15.6-inch 1.9GHz Intel Core i7-8650U quad-core CPU, NVIDIA Quadro P500, 16GB RAM, 1TB NVMe PCIe SSD	**HP Zbook x2** 14.0-inch detachable 1.9GHz Intel Core i7-8650U quad-core CPU, NVIDIA Quadro M620, 32GB RAM, 512GB NVMe PCIe SSD
Price as tested	$7,346	$3,788	$2,738	$4,558	$2,196	$3,710
Date tested	10/24/18	10/24/18	8/28/18	8/7/18	6/12/18	4/5/18
Operating System	Windows 10	Windows 10	Windows 10	Windows 10	Windows 10	Windows 10
SPECviewperf 12 (higher is better)						
catia-04	183.15	64.58	38.67	165.95	28.64	30.81
creo-01	151.79	52.95	42.99	138.65	33.26	34.75
energy-01	20.03	6.50	3.12	14.87	0.55	0.63
maya-04	139.69	41.74	38.42	128.84	20.96	23.25
medical-01	94.74	27.81	12.61	63.65	9.41	11.02
showcase-01	80.91	29.91	19.70	73.41	12.55	15.94
snx-02	214.49	61.50	37.25	172.95	43.91	26.33
sw-03	201.96	76.73	70.59	181.61	50.01	57.28
SPECapc SOLIDWORKS 2015 (higher is better)						
Graphics Composite	5.84	2.58	4.77	5.32	1.94	2.36
Shaded Graphics Sub-Composite	4.03	1.33	3.17	3.48	1.17	1.44
Shaded w/Edges Graphics Sub-Composite	4.99	1.91	4.06	4.38	1.64	2.22
Shaded using RealView Sub-Composite	4.49	1.76	3.59	3.87	1.48	1.72
Shaded w/Edges using RealView Sub-Composite	5.08	2.29	4.07	4.36	1.98	3.05
Shaded using RealView and Shadows Sub-Composite	5.11	2.05	4.10	4.46	1.69	1.54
Shaded with Edges using RealView and Shadows Graphics Sub-Composite	5.28	2.45	4.26	4.61	2.00	2.57
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	13.83	6.35	11.20	14.75	3.01	3.17
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	13.68	6.87	11.01	13.51	3.54	4.77
Wireframe Graphics Sub-Composite	4.45	3.06	3.85	4.15	2.43	2.65
CPU Composite	3.86	2.85	4.55	5.40	1.72	1.75
SPECwpc v2.0 (higher is better)						
Media and Entertainment	5.15	3.13	2.23	4.14	1.71	1.97
Product Development	4.95	2.94	2.29	2.70	1.82	2.13
Life Sciences	6.19	3.66	2.26	4.40	1.83	2.25
Financial Services	6.16	4.20	3.34	5.37	1.91	0.85
Energy	5.62	5.02	2.28	4.08	1.42	0.87
General Operations	1.96	1.67	1.30	1.55	1.20	1.68
Time						
Autodesk Render Test (in seconds, (lower is better)	34.10	46.40	63.10	29.30	89.70	78.00
Battery Life (in hours:minutes, higher is better)	4:40	7:08	9:26	3:56	5:33	5:00

Numbers in blue indicate best recorded results. Numbers in red indicate worst recorded results.

to 64GB of ECC memory using four 16GB memory modules. Systems like the one we received (equipped with an Intel Core CPU), however, can accommodate up to 128GB of RAM, using four 32GB DIMMs. Our evaluation unit came with 64GB of memory, using four Kensington 16GB DDR4-3200MHz SO-DIMMs, which added $900.

All versions of the Eurocom Tornado F7W include an NVIDIA Quadro discrete GPU and all but the P3000 included in the base configuration are VR-ready. There are five other NVIDIA Quadro graphics boards to choose from, including the Quadro P5200 provided in our evaluation unit. That high-end Pascal-based GPU includes 16GB of GDDR5 memory and 2560 compute unified device architecture (CUDA) cores and increased the system cost by $1,337.

The base configuration includes a 120Hz 2K display capable of displaying 94% of the NTSC (National Television System Committee) color gamut. Our system came with a 60Hz 3840x2160 ultra high-definition in-plane switching display with 100% Adobe sRGB gamut, adding $170.

The base configuration includes a 1TB SATA drive, but that's just the starting point. The Tornado F7W can accommodate up to three M.2 drives. Eurocom offers 12 different M.2 drives ranging from a 32GB Intel Optane drive to a 2TB Samsung drive. Our evaluation unit had a 500GB M.2 Samsung 970 EVO NVMe solid-state drive, which added $333. The system we received also included a 2TB Seagate Hybrid 2.5-in. drive, which added $58.

Eurocom offers standard drives ranging from 512GB to 8TB and the Tornado F7W supports up to two hard drives in addition to the M.2 solid-state drives, for a total of up to 22TB. Or, when equipped with multiple drives, both the M.2 and SATA drives can be configured as RAID arrays.

Although an Intel Wireless AC 8265 LAN comes standard, our evaluation unit included an Intel Wireless AC 9260 M.2 module providing two-in-one 802.11ac WLAN+Bluetooth 5, which added $33. A non-removable eight-cell lithium-ion battery comes standard and kept our system running for 4 hours and 40 minutes before shutting down. Throughout our tests, the Eurocom Tornado F7W remained cool and quiet, averaging just 35dB at rest (compared to 29dB ambient background noise), climbing to a peak of 65dB under heavy compute loads (equivalent to office conversation).

Record-Setting Performance

With its fast eight-core CPU and high-end GPU, we expected the Eurocom Tornado F7W to deliver great performance, but its benchmark results blew us away. On the SPECviewperf test, which measures pure graphics performance, the Tornado F7W not only delivered the highest scores we have ever recorded for a mobile workstation; its scores on all but two datasets surpassed those of the fastest desktop workstation we have tested to date.

Its performance on the SPECapc SolidWorks test did not set records, but its results were near the top among both mobile and desktop workstations. On our AutoCAD rendering test, the 34.1-second average time was less than 5 seconds behind that of the @Xi PowerGo XT and just 10 seconds slower than the fastest over-clocked single-CPU workstation we have ever tested.

And on the very demanding SPECwpc workstation performance benchmark, the Eurocom Tornado F7W outperformed every other mobile workstation we have ever tested. It not only delivered record-setting results on nearly every component of this very demanding test, but its results rivaled those of many desktop systems.

Of course, its record-setting performance comes with a very hefty price tag. As equipped, our Eurocom Tornado F7W would cost $7,346, including $166 for the Windows 10 Professional 64-bit operating system that came preinstalled. Since the base price only includes one year of return to factory depot warranty coverage and support, our as-tested price also includes $313 for a 3-year warranty.

After tallying the numbers, not only is the Eurocom Tornado F7W the fastest mobile workstation we have ever tested, it is also the most expensive. Although it certainly earns its claim as a "super mobile workstation," clearly up to the task of replacing all but the most powerful desktop workstations for power users on the go, the Eurocom Tornado F7W will likely appeal to a small but demanding set of users who prefer performance much more than a lower price. DE

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INFO → Eurocom: Eurocom.com

Eurocom Tornado F7W

- **Price:** $7,346 as tested ($3,499 base price)
- **Size:** 16.85x12.3x2.0-in. (WxHxD) notebook
- **Weight:** 9.4 lbs. plus 4.1-lb. power supply
- **CPU:** Eight-core 3.6GHz Intel Core i9-9900K w/16MB Smart Cache
- **Memory:** 64GB DDR4 at 3200MHz (128GB max non-ECC)
- **Graphics:** NVIDIA Quadro P5200 w/16GB GDDR5 memory
- **LCD:** 17.3-in. 4K 3840x2160 IPS, anti-reflective
- **Hard Disk:** 500GB M.2 NVMe and 2TB Hybrid HD
- **Floppy:** None
- **Optical:** None
- **Audio:** Built-in speakers, four audio jacks (line-in, line-out, microphone, headphone/SPDIF), built-in microphone array
- **Network:** 1.73GbE Intel Wireless AC 9260 with vPRO plus Bluetooth 5.0
- **Modem:** None
- **Other:** Five USB 3.1, one Thunderbolt 3 (Type-C), HDMI, mini DisplayPort, RJ-45 LAN, smart card reader, six-in-one card reader, 1080p webcam
- **Keyboard:** Integrated 102-key backlit keyboard
- **Pointing device:** Integrated touchpad with two buttons

Workforce of the Future

Some firms turn to internship and apprenticeship programs to develop the tech talent they need.

BY KENNETH WONG

TO START 2019, staffing firm Modis, tech education provider General Assembly and PR firm Allison+Partners published the results of a survey they had jointly conducted. Compiled from the responses of executives and senior managers, the Technology and Engineering Decision Maker Survey offers some insights into the mood, trends and hiring practices in the engineering and technology sectors.

A majority of the decision-makers (67%) say they plan to increase their company headcounts in 2019, suggesting opportunities for new graduates and those looking for jobs. But this number is down from the 79% who responded in the same fashion in 2018. However, if you're employed, you may be glad to hear that 72% of the bosses are planning to give out bonuses this year.

In recruitment, 33% of the executives in the survey believe "finding talent with appropriate technical skills" is becoming "somewhat more difficult," and 8% believe it's becoming "much more difficult." They also indicate only 57% of the applicants they encountered last year possessed the technical skills required for the jobs they want. Furthermore, 31% strongly agree and 49% somewhat agree that "there's a gap between the available talent and the type of skilled talent" they seek.

"A tight labor market coupled with the scarce availability of skilled tech workers means that employers must take a strategic approach to fostering successful and efficient hiring pipelines. To that end, General Assembly is engaging with dozens of companies to support massive upskilling and reskilling initiatives to augment the skills of current workers," explains Jake Schwartz, co-founder and chief executive officer of the company.

For staffing firms like Modis and training providers like General Assembly, the survey results indicate talent market needs to fill. Some global tech firms like Renishaw, on the other hand, are actively developing the talents they need with an apprenticeship program. Last December, announcing the 40-year anniversary of the program, Renishaw said it plans to fill 68 positions with graduate apprentices, for various vacant posts in engineering, software, embedded electronic design and development, and IT.

The Renishaw Apprenticeship

Roxanne Pollard was a Renishaw apprentice. She now works as a mechanical design engineer for the company. While working at Renishaw four days a week, Roxanne went on to achieve a first-class honors Mechanical Engineering degree at the University of South Wales and the TATA prize, given to the highest achieving part-time student at the university.

Roxanne Pollard, a graduate of the Renishaw apprenticeship program, now works for the company as a mechanical design engineer. ***Image courtesy of Renishaw.***

"An apprenticeship is a great way to get started, to work straight away and gain hands-on experience. At Renishaw, we were given a lot of responsibility straight away and worked on projects across the company, meaning that we could develop a wider variety of skills," recalls Pollard.

The path to apprenticeship usually begins with an evening at Renishaw's Gloucestershire headquarters. Attending students and their parents get to hear personal experiences from the current apprentices and graduates now employed at the company.

Entering the A-Level apprenticeship program, Pollard impressed her future employer with her design project, an innovative bicycle safety helmet. The design won her first place in the Manufacturing Technologies Association's TDI (Technology, Design and Innovation) Challenge. At the Young Engineer for Britain National Final in 2011, she was chosen to represent the UK at the Intel International Science and Engineering Fair (ISEF) held in Los Angeles, CA.

"Working on Renishaw projects from the beginning of my apprenticeship gave me the opportunity to apply what I had learned during my A-Levels a lot more quickly," says Pollard. "Working to group deadlines pushed me to understand theoretical information so that I could help the project be a success. This hands-on experience also helped me when I went on to study for a degree as I had a deeper understanding of the academic content in my lectures."

The Techtonic Software Apprenticeship

For Techtonic, a custom software development shop, success comes with its own challenges. It usually begins with a project to assemble a team and help finish a client's work on demand. But these teams become so well-integrated with the client's own teams that the client might want to hire them. It means Techtonic constantly needs to replenish its own talent pool. For this reason, its business model now includes talent acquisition as a part of its custom software development offering.

It was a chance meeting with an aspiring coder that sparked an idea, says Heather Terenzio, CEO and founder of Techtonic. At an event, after her talk on careers in technology in Boulder, CO, a young caterer approached her and said, "I love coding. I've been teaching myself how to code. If you hire me, I promise you won't regret it," as Terenzio recalls.

After that, Terenzio and her team came up with the idea to recruit promising junior developers domestically and train them to reach a higher skill level. That was the genesis of the Techtonic Apprenticeship program. There's a rigorous vetting process, involving an application, online and in-person skill assessment tests, and phone interviews.

Completing the program gives you 39 college credits. During the roughly 1,000-hour-long apprenticeship, participants are paid.

Austin Moses, an apprenticeship program participant in the summer of 2017, now works at Techtonic as a software development team lead, overseeing a number of apprentices and junior developers. Having gone through the process himself, he has a much better understanding of time management, project timelines and meeting client objectives.

Software-Specific Skills

As one of the largest Autodesk resellers, IMAGINiT Technologies, a division of Rand Worldwide, also provides intensive software training and education. For some Autodesk-centric design and engineering firms, IMAGINiT is the training partner to evaluate and/or improve the skills of new hires, frequently as part of their onboarding process.

"With some of our partner companies, when an employee is hired, one of his or her first tasks is to come to our training center for an in-person class, or to join an online instructor-led class," says Kevin Kuker, vice president of Training and Support Services, IMAGINiT Technologies. "The biggest challenge I've heard from our clients is that, in school settings, most new graduates didn't get enough training on using specific software programs and they struggle to apply their software knowledge in a real-world application."

Many engineering firms use certain software packages as the company standard for CAD modeling, simulation and testing. The proficiency and skill level desired by a potential employer may be quite different from the theoretical understanding and the basics covered in school settings.

This leaves hiring managers with two choices: Only hire candidates who already possess the required skills; or hire promising candidates and invest the time and efforts necessary to develop and nurture them on the job. For those who choose the latter, internships and apprenticeships can be an integral to the strategy.

Internships and apprenticeships are a two-way street. It's useful not only for the company to observe the capacity of a candidate, but also for the candidate to gain insights into the company's culture and work ethics before committing to a career.

"Work-based learning experiences are an excellent way for candidates to better understand the world of work before jumping into a long-term career in tech," says Lane Greever, senior vice president of Modis. "On-the-job and project-based programs provide hands-on training that is more in line with what someone would experience in a permanent position at a company."

The joint survey Modis published with General Assembly shows 70% of technology decision makers are planning to increase head count this year. "With only a shallow pool of available tech talent, more employers are considering candidates based on their potential to learn. Education and job history are still important factors in hiring decisions, but companies are realizing they must help create the talent they need," Greever points out. **DE**

Kenneth Wong *is* DE*'s resident blogger and senior editor. Email him at de-editors@digitaleng.news or share your thoughts on this article at digitaleng.news/facebook.*

INFO → General Assembly: GeneralAssemb.ly

→ **IMAGINiT:** IMAGINiT.com

→ **Modis:** Modis.com

→ **Renishaw:** Renishaw.com

→ **Techtonic:** Techtonic.com

Next-Gen Engineers

Student Design Competition Profile: VEX IQ Challenge Next Level

Building Student Teamwork via Robotics

BY JIM ROMEO

THE ROBOTICS Education and Competition (REC) Foundation hosts the VEX IQ Challenge Next Level and VEX Robotics Competition Turning Point to involve students who are in middle school through college in hands-on robotics and science, technology, engineering and mathematics (STEM).

The VEX IQ Challenge Next Level and VEX Robotics Competition Turning Point are this season's series of game challenges supported by the REC Foundation. VEX IQ Challenge Next Level brings elementary and middle school students together to compete in teamwork challenges with custom-built robots using VEX IQ.

To learn more about the competition, we spoke to Vicki Grisanti, senior director of Marketing and Communications, REC Foundation and Eleanor Honious, a past VEX Robotics Competition participant.

Digital Engineering: Can you provide an overview of the REC Foundation's VEX Robotics competition?

Vicki Grisanti: VEX Robotics Competition Turning Point brings middle school, high school and college students together with guidance from their teachers and mentors to compete against each other with robots they designed, built and programmed using VEX EDR. Two alliances—one "red" and one "blue"—are formed and consist of two teams each, where they compete in 15-second autonomous matches followed by 1 minute and 45 seconds of driver-controlled play. The object of the game is to attain a higher score than the opposing alliance by high-scoring or low-scoring caps, toggling flags and by alliance parking or center parking robots on the platforms.

Eleanor Honious: VEX Robotics competitions inspired me to pursue STEM by establishing some of my first formal, hands-on engineering experience. With VEX, I learned different design techniques and approaches. I learned about mechanisms [and] I learned how to solder and about gear ratios. I even learned how to keep a well-organized engineering notebook that was filled with design drawings, and math and physics equations for their implementations. While I was learning all of these different things, I was having the time of my life, and I was fortunate enough to realize at such a young age that this was the kind of work I wanted to pursue.

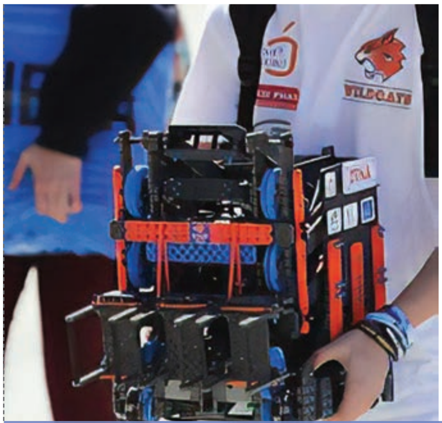
DE: What drove the REC Foundation then to coordinate the event?

Grisanti: In 2008, the VEX Robotics Competition was established [to] get students excited about STEM as they designed, built and programmed robots for competition events. The early partners changed direction, but Innovation First International remained committed to the effort and renamed it the VEX Robotics Competition. In 2010, as its popularity grew, the REC Foundation was established to manage the overall team experience, including team registration, training materials and competitions. The REC Foundation helps provide a consistent competition experience and trained event partners around the country to build interest and expand the program.

Today, the REC Foundation serves over 22,000 student-led teams to engage them in educational robotics opportunities throughout the U.S. and across 50 countries. The REC Foundation works in partnership with VEX Robotics Inc., creator of the robotics kits and educational tools used by students, educators and mentors.

Each year, the two organizations unveil new engineering game challenges for the VEX IQ Challenge and the VEX Robotics Competition. Students, led by their teachers and mentors, form teams and design, build and program a robot for competition. The REC Foundation supports the success of students and their teams with a vibrant competition experience that challenges their creativity, encourages teamwork and communication, and values hands-on engineering and programming experience.

Creating a workforce prepared to solve our future problems depends on our ability to harness students' natural curiosity, engage them in meaningful learning opportunities to incite passion, and expand their interest in a variety of subjects. The VEX Competition experience provides just that type of environment, to ensure we have lifelong learners that are excited to contribute to their future and ours. DE



A robot ready for competition. ***Image courtesy of the REC Foundation.***

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