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Technology for Optimal Design Engineering

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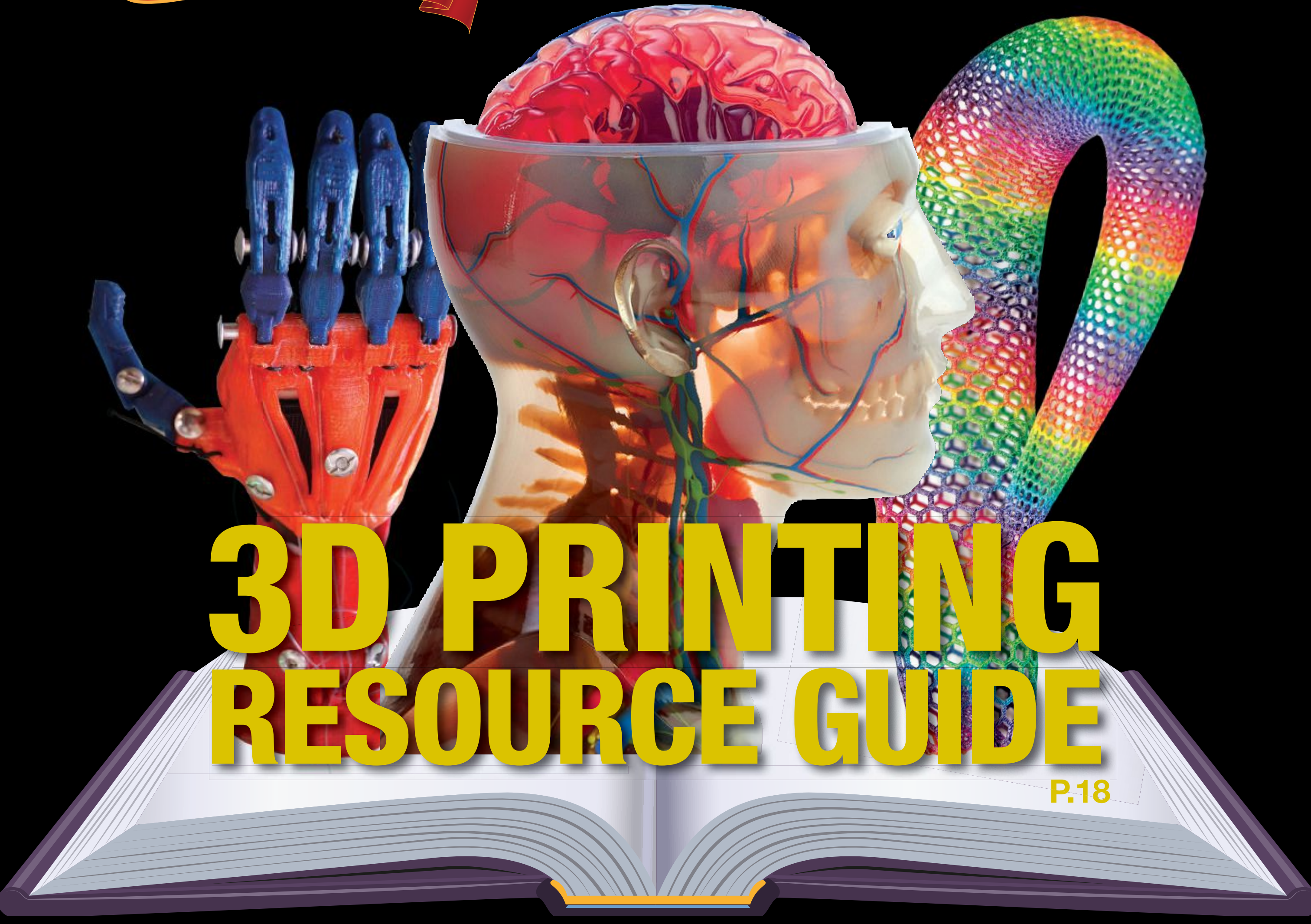
MEDICAL DESIGN FOCUS

Optimization & 3D Printing P.6

Design for Compliance P.10

Analyzing Stress P.14



3D PRINTING RESOURCE GUIDE P.18

MESHING MATTERS P.36

LOOKING AT DISPLAYS P.40

REVIEW: XI MTOWER CX P.43


72


Voltage
Coil A, Coil B, Coil C
Time(ms)
infolytic

Degrees of Freedom

by Jamie J. Gooch

3D Printing's Next Frontier

If you follow the 3D printing market in the mainstream media, it may look like it's cooling down. 3D Systems discontinued its consumer-focused Cube 3D printer. Solidoodle, once and up-and-coming manufacturer of consumer 3D printers, has ceased operations. And last year 3D printing went from making headlines for new startups to making headlines for stock market declines. But that's only part of the story.

According to *Wohlers Report 2016*, the additive manufacturing (AM) industry, consisting of all additive manufacturing products and services worldwide, grew 25.9% (CAGR) to $5.165 billion in 2015. The CAGR for the previous three years was 33.8%. The firm reports that despite challenges, growth continued in many segments of the diverse industry, particularly in metal AM and the desktop 3D printer segments. In 2015, 62 manufacturers sold industrial-grade AM systems (those valued at more than $5,000), compared to 49 in 2014, and twice as many as the 31 companies that sold industrial systems in 2011.

3D printing technology isn't slowing down. It's getting real.

So while consumer 3D printing hype may have plateaued for now, the 3D printing industry as a whole is still growing at an impressive rate thanks in part to industrial investments. At the Inside 3D Printing Conference last month in New York, Terry Wohlers said even most of the sub-$5,000 3D printers were sold to industrial users, not consumers. Given the amazing success the dental and medical sectors are seeing with their adoption of 3D printing (see pages 30 and 32), it's no wonder other industries are following in their footsteps. The path to industrial 3D printing is being paved by 3D printing materials and more advanced 3D printing software.

Materials Moving Forward

Not long ago, materials were a significant question mark that gave many industrial users pause when considering 3D printing. Are the materials we need capable of being 3D printed? Are 3D printed materials strong/flexible/chemical-resistant/flame-retardant enough? Is there enough supply?

Those questions have been answered to the affirmative for many industries. For example, Wohlers said Airbus is on track to print 80 tons of metal monthly by the end of 2018. According to Frost & Sullivan, the additive manufacturing formulations market earned revenues of $428.1 billion in 2014 and should reach $920.4 billion in 2020.

An impressive amount of research and development has gone into 3D printing materials — from composites to ceramics to 3D printing multiple materials at the same time — and it is already paying off. See page 22 for some examples.

Software Playing Catch Up

"Software isn't keeping up with the technology," said Hod Lopson, professor of engineering at Columbia University and a co-author of the book "Fabricated: The New World of 3D Printing." Lopson was addressing journalists at a recent Stratasys launch event for the company's new J750 3D printer. "These printers now can make so much more than the software allows us to access.

"The CAD companies, I think, need to do more to keep up with the technology," Lopson continued. "There's a big, big gap, and in fact I think software is holding us up from exploring the true potential of the (3D printing) technology right now."

Where there's a technology gap, there's an opportunity. Will it be filled by traditional CAD software companies, 3D printer manufacturers, industry titans or startups? Perhaps it will be a combination.

Through its Spark Investment Fund, Autodesk has invested in Optomec, an additive manufacturing provider. The companies intend to corroboratively develop software tools using Autodesk's open source Spark 3D printing platform (see page 24) to better connect hardware and software for additive manufacturing, according to the press release. GE Ventures has also invested in Optomec to advance 3D printed sensors, electronics and metal applications.

3D Systems and Stratasys — known primarily as leading 3D printer hardware makers — have both acquired design software companies. 3D Systems acquired Geomagic in 2013 and Stratasys acquired GrabCAD in 2014.

But 3D printers are capable of building complex parts with cores of intricate lattice structures that no human designer is going to manually push and pull their way to in any 3D CAD application. The cutting edge of 3D printing lies in software's ability to suggest optimized structures (see page 6) based on engineering requirements and materials.

Advances in materials and software are the next frontier of 3D printing. Rather than slowing down, the technology is getting real for more and more industries as the return on investment is proven, the materials are formulated and easy to use, powerful software is being developed. **DE**

Jamie Gooch *is the editorial director of* Desktop Engineering. *Contact him at DE-Editors@deskeng.com.*

DE May 2016 VOLUME 21/ISSUE 8

3D PRINTING RESOURCE GUIDE

18 Adding 3D Printing to Manufacturing

An introduction to 3D printing technologies, materials and terms.

By Jess Lulka

22 Industrial-Grade Materials

An overview of industrial additive manufacturing material options from manufacturers worldwide.

24 Reclaiming 'Rapid' in 'Rapid Prototyping'

Improving speed is key to industrial-scale 3D printing.

By Kenneth Wong

30 Educators Inspire with 3D Printed Prosthetics

Initiatives ignite efforts toward low-cost 3D printing expansion.

By Michael Belfiore

ON THE COVER: A multi-material, full-color anatomical model 3D printed by the new Stratasys J750, a colorful part 3D printed via HP's yet-to-be-released Multi Jet Fusion technology and a 3D printed prosthetic hand courtesy of e-NABLE. Book illustration courtesy of Thinkstock.

32 3D Printing Applications

3D printing applications from Stratasys, Mcor and 3D Systems.

34 3D Printing Briefings

A roundup of news and new products.

WORKFLOW

10 Automation: A Compliance Lifeline for Medical Device Makers

PLM and document management platforms can help medical device companies balance innovation agility with compliance requirements.

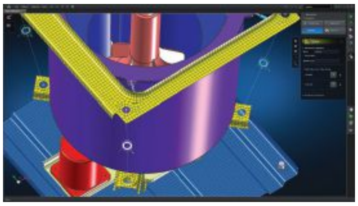
By Beth Stackpole

SIMULATE

14 Stress in FEA: Part 2

A deeper look at how to study this phenomenon.

By Tony Abbey



36 Notes From the Mesh-Making Frontline

A roundup of the latest efforts to improve meshing in simulation.

By Kenneth Wong

ENGINEERING COMPUTING

40 A Closer Look at Displays

New display options can give designers a more realistic and comfortable view of their work.

By Brian Albright

43 And Now For Something Completely Different

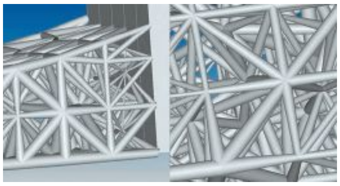
The Xi MTower CX workstation is a powerful over-clocked system in a curious cube-like case.

By David Cohn

DEPARTMENTS

2 Degrees of Freedom
3D printing's next frontier.
By Jamie J. Gooch

6 Consultant's Corner: Optimization
Topology optimization advances to support additive manufacturing.
By Bruce Jenkins



8 Making Sense of Sensors
Design in the fast lane: integrated systems.
By Tom Kevin

9 *DE*'s Take on Tech
It's high time for CAD interoperability.
By Beth Stackpole

28 Spotlight
Directing your search to the companies that have what you need.

46 Advertising Index

47 Editor's Picks
Products that have grabbed the editors' attention.
By Anthony J. Lockwood

48 Commentary
Designing better products faster.
By Todd McDevitt, ANSYS

Online Now @ Deskeng.com

AutoCAD 2017 Review: Subscribing to a A New Beginning
By David Cohn
deskeng.com/de/?p=29544

OtterBox Speeds Product Development with the New Stratasys J750 3D Printer
By Jamie Gooch
rapidreadytech.com/?p=10123

NVIDIA GTC 2016: The GPU Wants to Accelerate VR, AI and Big Data Analysis
By Kenneth Wong
deskeng.com/virtual_desktop/?p=11654

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BPA WORLDWIDE

by Bruce Jenkins /// Optimization

Topology Optimization Advances to Support Additive Manufacturing

Among the various methods for finding the optimal structure of a product or component, topology optimization is one that software vendors today are working to make more accessible and easier to use by engineers and designers. A key driver of these efforts is the surge of activity around additive manufacturing (AM). In marked contrast to the over-hyped but currently under-performing category of consumer 3D printers, AM is garnering high interest from manufacturing industries today because of advances in materials and processes that make it an increasingly practical method for manufacturing actual production parts and assemblies.

One of AM's prime attractions for engineers is how it enables design and production of objects with new levels of geometric complexity. These geometries can deliver functionality that's either impossible or not feasible to achieve with conventional manufacturing methods. In particular, AM is ideally suited to creating lightweight designs, often using fewer parts than a comparably functioning design produced with subtractive manufacturing.

> **Software features are growing in response to increasing use of AM.**

Topology optimization is a design method that tends to yield biomorphic-like shapes ideally suited to production using AM. Indeed, they often cannot be produced by conventional subtractive manufacturing without modifications that would substantially dilute the optimal balance of light weight vs. high strength achieved in the optimization process.

Topology optimization software generates a conceptual 3D structural design that best meets the design requirements specified by the user. It does this by optimizing material layout within a given physical design volume for a specified set of loads and boundary conditions, so that the resulting layout meets the prescribed performance targets.

nTopology Element Built for Additive Manufacturing

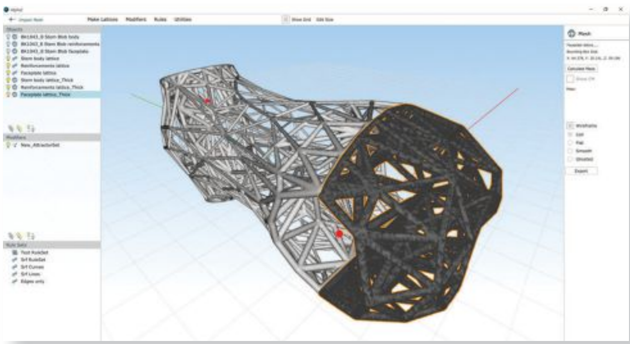
An intriguing new market entrant is nTopology, Inc., which describes its nTopology Element software as "purpose-built to harness the power of additive manufacturing." The software offers a combination of generative, manual and simulation-based design tools to let engineers create parts whose functional requirements are "baked right in," as the company puts it. Element lets users optimize lattice structures with respect to user-defined inputs, imported data or the software's integrated finite element analysis (FEA) capabilities.

Element's workflow and structural analysis engine are designed to help users exploit the strengths of AM. Instead of a traditional feature tree, nTopology organizes elements into Objects, Modifiers and Rule sets. Objects are imported or created from scratch. Lattices are created using Rule Sets, and those lattices are thickened using Modifiers that can be generated either explicitly or based on built-in FEA (finite element analysis) simulation data. By integrating simulation data into the design process early, nTopology Element is intended to help designers create structures for specific functional outcomes. Then, by recombining elements, users can iteratively tune those structures to improve mechanical performance and reduce cost.

ESI Group Targets AM Design Challenges, Process Optimization

ESI Group is another of the growing number of software vendors developing tools to address additive manufacturing design challenges and process optimization. It has developed advanced topology optimization tools that take account of functional constraints — for example, minimizing weight while bearing a given functional load — and at the same time addressing manufacturing constraints such as minimum wall thickness.

At the same time, ESI's manufacturing process simulation tools are being used in the DARPA Open Manufacturing (OM) initiative to develop what DARPA terms Integrated Computational Materials Engineering (ICME) tools and methodologies to support the application of AM technologies in the aerospace industry. For example, in the AM method known as direct metal laser sintering (DMLS), a laser aims at a succession of points



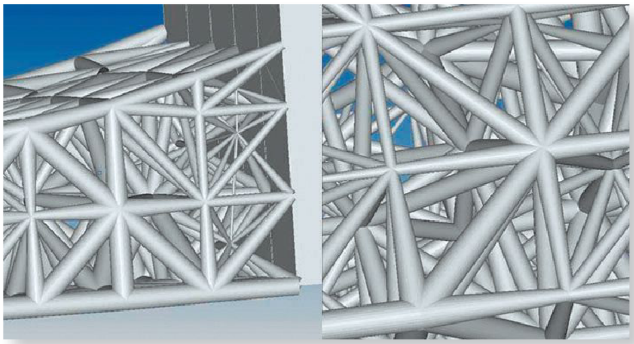
nTopology Element. *Image courtesy of Topology.*

in space defined by a 3D model, firing into a bed of powdered metal and thus welding the metal particles together to create a solid structure in the shape of the 3D model. ESI's software for simulating multi-scale, multiphysics phenomenona has been used to model and optimize the DMLS (direct metal laser sintering) manufacturing process.

Altair Debuts New AM Capabilities

Yet another notable vendor focused on topology optimization for additive manufacturing is Altair, whose recently announced OptiStruct 14.0 includes a new solution for design and optimization of lattice structures to support AM. Leading the way in giving users fine-grained control over topological details, OptiStruct 14.0 enables design of lattice structures consisting of tapered beams, for example, and supports smoothing and remeshing throughout lattice optimization.

Meanwhile, Altair's subsidiary solidThinking just released solidThinking Inspire 2016, its generative design software targeted at helping design engineers, product designers and architects investigate structurally efficient concepts quickly and easily. One key advance is a new PolyNURBS tool and related aids that let users quickly and easily flow optimized designs into manufacturable products by wrapping topology results with NURBS geometry. Before, users had to import optimization results from Inspire into their CAD system to generate manufacturable geometry. Now, the new NURBS tools let users create solid organic geometry in Inspire more quickly than in CAD, then bring that near-production-ready geometry into CAD to add final details needed for production. **DE**



Tapered lattice beams modeled in OptiStruct. *Image courtesy Altair Engineering.*

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Making Sense of Sensors

by Tom Kevan /// SoCs

Design in the Fast Lane: Integrated Systems

It's no longer enough for engineers to produce technically sound sensor designs. Now they have to get their products to market within dramatically abbreviated development cycles. On top of that, designers no longer have the luxury of iterative testing; products have to work well right out of the gate or face the wrath of an unforgiving marketplace.

Some industry pundits attribute these changes in the design environment to the rise of the Internet of Things (IoT). But the fact is that the metabolism driving the consumer market has been gaining speed for some time. What the IoT has done, however, is increase the complexity of even simple sensing devices. Today, a sensor node typically has a wireless transceiver, a processor or microcontroller, a bit of memory and some form of security.

These factors combine to make it impractical for engineers to build their own components. Reinventing the wheel simply isn't an option — even assembling compatible discrete components has become too cumbersome an approach. As a result, designers have begun to turn to off-the-shelf subsystems that incorporate all of the necessary elements and offer verified performance. To meet this need and to help jump-start design processes, chipmakers have started to offer SoC (system on chip) solutions that incorporate the necessary hardware and software in one unit.

> **Designers have begun to turn to off-the-shelf systems to meet time requirements.**

By taking advantage of these integrated platforms, designers combine multiple functions and eliminate many concerns surrounding interoperability, interference, database dependency, transceiver performance and the interconnections between the sensors, processor and radio. In addition, these integrated platforms provide the necessary communication protocols and interfaces to ensure IoT-level connectivity.

While the integrated platform promises to shorten time-to-market cycles, it also streamlines the design process, making it easier for novices. This fits in well with the way the industry is moving. *Forbes* recently stated that many of the estimated 50 billion connected devices expected to be a part of the IoT in 2020 will be produced by startups. This group of developers will certainly benefit from pre-packaged integrated systems.

A View of the Future

To get a preview of what lies ahead, consider the Artik family of SoCs introduced by Samsung. These platforms aim to support a wide variety of applications, ranging from wearables to smart home appliances. The heaviest hitter of these is the Artik 10, which comes in a 39x29 mm package and includes ARM Cortex-A15 and ARM Cortex-A7 processors, 2GB of DRAM and 16GB of storage, camera and display interfaces, a full complement of digital I/O and analog inputs, and Wi-Fi 802.11 g/b/n, Bluetooth and ZigBee connectivity. All of the SoCs in the family offer multi-level security and power management. As with other platforms in this genre, the Artik family embraces the open-platform concept.

A more recent example, Invensense's ICM-30630 FireFly provides a three-axis accelerometer and a three-axis gyroscope in a 3x3x1 mm LGA package, taking aim at the mobile market. The ICM-30630 optimizes its performance and reduces power consumption with its impressive processing capability. The turnkey system sports three processors. The DMP3 handles all motion processing tasks; the DMP4 offloads computationally intensive operations, and the ARM Cortex-M0 with its RTOS performs sensor management tasks. The SoC includes both flash and SRAM memory. The FireFly includes a sensor hub that supports sensor fusion, leveraging its I2C port to connect with magnetometers, barometric pressure sensors, humidity sensors, or any other specialized sensors. Unlike the Samsung device, however, the ICM-30630 does not include built-in wireless capability.

Universal Application

While the previous two examples target consumer applications, this design approach is being applied in a broad range of markets. You can see evidence of this in Texas Instruments' SoC for analog and digital position sensors that aims to simplify the development of industrial robots, elevators, CNC (computer numerically controlled) machines, material conveyance systems and servo applications.

These turnkey systems might meet resistance from design engineers who prefer to build their own, but it's hard to argue against an approach the cuts both development time and cost. **DE**

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by Beth Stackpole

DE's Take on Tech

It's High Time for CAD Interoperability

For nearly two decades, major CAD vendors have operated under an "every man for himself," mantra, justifying their proprietary formats and 3D modeling standards as the best for their individual toolsets. Every once in a while, the vendors would make an attempt to play nice with the competition, but their efforts never really went far enough to end customers' frustration over incompatible CAD formats.

Because of this standoff, dealing with multiple CAD formats has been a long-standing pain point for engineering organizations, many of which have doled out millions of dollars and devoted thousands of manhours to getting 3D models to a place where they could be easily shared for design collaboration. While the costs vary among organizations, industry sectors like automotive and aerospace spend heavily each year on 3D model exchange, including data migration software and the labor expenses associated with manual data re-entry.

> **The new agreement between Autodesk and Siemens is a positive step.**

To be sure, there are myriad tools and data format standards — such as STEP, IGES and JT Open — that have been rolled out to help alleviate some of the pain points. Still, 3D CAD data exchange remains a thorny problem, perhaps even more so today because of an increasingly heterogeneous CAD landscape. While CAD users and engineering organizations have been crying foul for years, their complaints never seem to be loud enough to push the CAD vendor community to take more decisive action — perhaps until now.

A Turning Point?

Autodesk and Siemens PLM Software recently inked a new interoperability agreement that could be a sign that things may finally change. The agreement calls for both companies to share toolkit technology and do regular application exchanges so they can build future products that will be interoperable. They aren't just talking about CAD, either. The idea is to infuse interoperability across a range of products between the two software leaders, including CAD, high-end visualization applications and PLM (product lifecycle management), said Stefan Jockusch, Siemens PLM Software's vice president of Strategy.

Jockusch acknowledged that this isn't Siemens' first time to the interoperability rodeo. The company has made a mark fostering industry-wide support for its JT Open format, but he said that standard is designed as a lightweight format for collaboration, thus doesn't fully address the scope of interoperability needs. "A lot of interoperability efforts have existed before this agreement, but the big step this takes is to make integration easier," he explains. "We envision creating built-in integrations in a more native, integrated way."

The advantage for customers could be big. According to Jockusch, the goal is to make it more cost effective for users to exchange data. "It should be less error prone and problematic — the problem you always have when trying to import or export file formats," he says.

How do we know that things will be different this time around? We don't, necessarily, but the landscape has shifted so that 3D model interoperability is something few vendors — or engineering organizations — can choose to ignore.

Interest in Interoperability

Few companies, even the big automotive and aerospace behemoths, have any one standard CAD offering in place. Thanks to a flurry of mergers and acquisitions, and an increasingly global design chain, most shops have many flavors of CAD, simulation and PLM tools in house. Moreover, products are far more complex today, requiring a lot more software besides CAD for design and far more reliance on integrated workflows between cross-functional engineering domains. Couple that with this idea of an open ecosystem of apps, driven by the cloud, and there's no longer any room for application silos, let alone 3D file incompatibilities.

Jockusch acknowledges the dramatic changes and says Siemens' vision for openness and interoperability is critical to the firm — both now and moving forward.

"More integrated solutions are being proposed, development processes are coming together, and the need for an open ecosystem of apps has become more visible," he says. In addition to the latest deal with Autodesk, he says Siemens will continue to work on interoperability with the other vendors in all of its software segments. "You can't expect that a customer will replace a certain application they are benefiting from so they can better integrate the application you're pushing," he says. "It's easier for us to grow if we are open."

As companies move more of their enterprise systems and critical intellectual property to the cloud, they will expect the same interoperability and openness from all of their systems — including on-premise CAD and design tools. This time around, I don't think Siemens and Autodesk — or any of the CAD vendors — can afford to pay lip service to interoperability. DE

Beth Stackpole *is a contributing editor to* DE. *You can reach her at beth@deskeng.com.*

Automation: A Compliance Lifeline for Medical Device Makers

PLM and document management platforms can help medical device companies balance innovation agility with compliance requirements.

BY BETH STACKPOLE

When organ transplantation is your business, it's critical to stay on the leading edge. TransMedics, known for its next-generation Organ Care System used to transport hearts, lungs and livers in a "living state" outside the body as opposed to the traditional biohazard ice cooler, struggled to strike a balance between innovating under time-to-market pressures and industry requirements around compliance.

After nearly a decade relying on mostly manual processes, TransMedics conducted an internal audit and found its compliance efforts in need of some serious resuscitation. The paper-based processes provided little visibility into design changes or approval workflows, and action items associated with specific projects would often get lost in a pile of documents or stuck in someone's inbox. It was hardly a remedy for fast-tracking products through the FDA approval process and out to the open market.

"We decided that given the size of our company, the complexity of what we were developing, and our growth, it was time to move to an automated system," says Progga Das, quality systems engineer at the medical device manufacturer. "You can achieve much higher visibility when you have online systems."

TransMedics, like so many start-up medical device companies, found documenting repeatable processes to meet regulatory compliance to be more of a struggle than designing and engineering innovative products. Trying to meet requirements for regulations like the FDA 21 CFR Part 11, for electronic signatures, ISO standards for quality management and the CE Mark, to sell a product in Europe, is a complex drill that is often enforced and managed by personnel who aren't facing the same time-to-market demands as engineers.

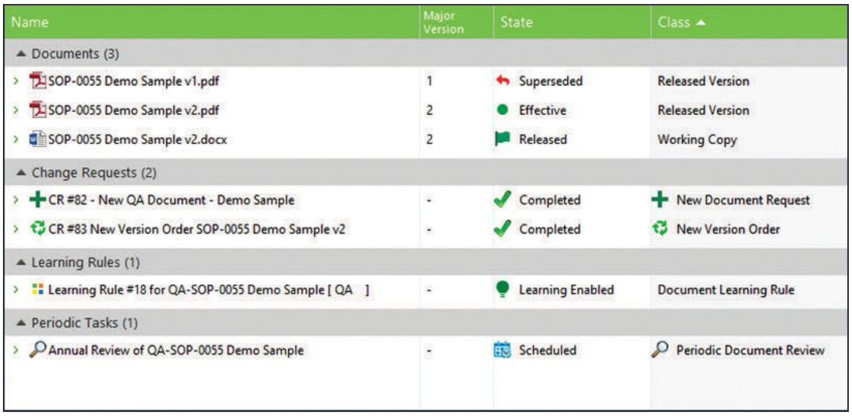
Meeting the compliance challenge involves an array of formal processes and procedures along with documentation and audit trails to prove everything has been kept in check. Manual processes, coupled with disparate design, quality assurance (QA) and homegrown systems, have been the norm. But with product complexity on the rise and a greater focus on quality, medical device makers are looking for a lifeline. They may have found it by automating compliance processes with document management systems and PLM (product lifecycle management).

"As an engineer, you always want to design the coolest products with the greatest feature set and you don't want to waste time separating yourself from design to follow some due diligence process for compliance," says Chuck Cimalore, CTO of Omnify Software, maker of Omnify Empower PLM. "The question is how to maximize time doing design work while retaining the confidence that you're not stepping outside of the due diligence boundaries so you won't run into regulatory issues downstream."

TransMedics' OCS HEART delivers warm, oxygenated, nutrient-enriched blood to the donor heart and keeps it in a living state until the organ is ready to be transplanted. ***Image courtesy of TransMedic***

Eliminating the Busy Work

Validation is the key to any compliance initiative. Document management systems provide numerous capabilities, including electronic audit trail, workflow and electronic signature functions, that ensure processes are repeatable and do so in a way that's less time consuming and expensive than human oversight, says Todd Cummings, vice president of Research and Development at Synergis Software, the provider of the Adept engi-



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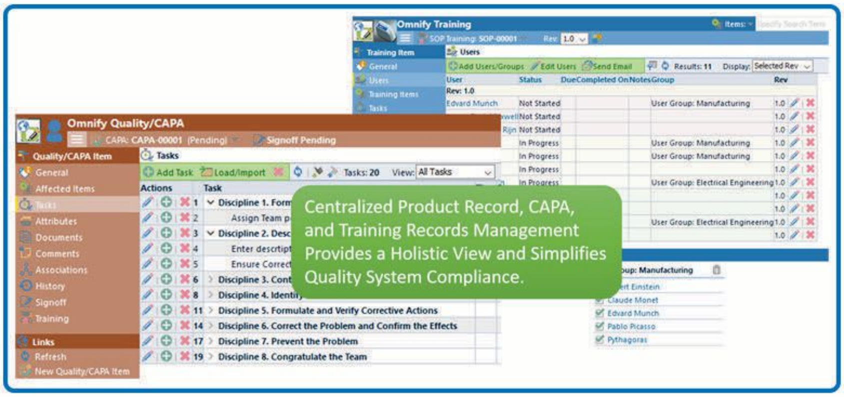
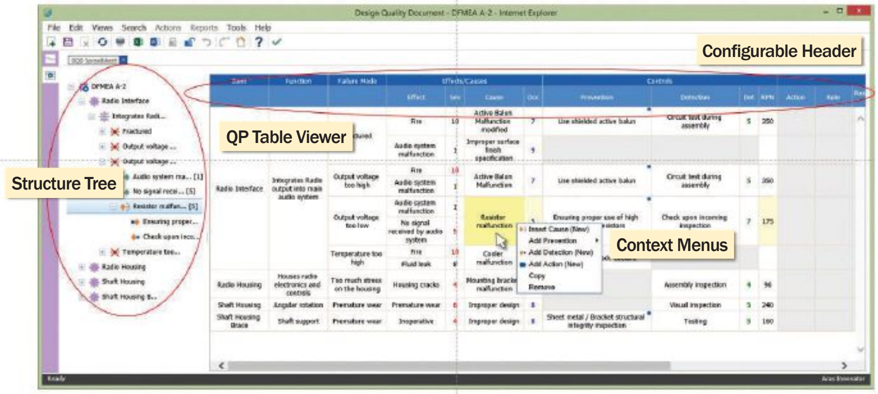
› CR #83 New Version Order SOP-0055 Demo Sample v2	-	✓ Completed	New Version Order
▲ Learning Rules (1)			
› Learning Rule #18 for QA-SOP-0055 Demo Sample [QA]	-	Learning Enabled	Document Learning Rule
▲ Periodic Tasks (1)			
› Annual Review of QA-SOP-0055 Demo Sample	-	Scheduled	Periodic Document Review

M-Files QMS includes built-in change request features, version history, audit trail and proofed evidence of document learning to ensure that employees adhere to policies related to compliance. *Image courtesy of M-Files.*



Omnify automates many quality and compliance processes, including training. *Image courtesy of Omnify Software.*



Aras PLM supports Failure Modes and Effects Analysis (FMEA) procedures to help identify potential failure modes within a system, process, design or item while helping to design those failures out with minimum time and resources. *Image courtesy of Aras.*

neering document management system. "We can take a lot of the details and busy work out of the process and automate it," Cummings says. "That provides a massive leg up by allowing humans to focus on more creative thinking work."

For example, version control, one of Adept's features, keeps an audit trail of what documents or CAD models were checked in or out during the product lifecycle, ensuring everyone, not just engineers, are working off of the most current and accurate information, Cummings says. Electronic signatures, a critical piece of compliance directives, can also be streamlined in systems like Adept, through the use two-factor identification, which validates that a person signing off on something is who they say they are, he adds.

Quality, another big piece of compliance, can also be addressed more naturally within the context of a document management system, contends Greg Milliken, vice president of Marketing for M-Files, an enterprise document and content management system. As opposed to storing quality manuals on a shelf somewhere or in a separate siloed system where they are likely to be ignored, Milliken says moving that data and those processes under the domain of a document management system used every day is more likely to result in repeatable processes and as a result, compliance.

"Our philosophy is to move away from a separate, siloed quality system to a system where it becomes day-to-day quality management," he explains. "The first responsibility of maintaining quality is to document things that should be done to the best standards of the industry. Now imagine doing that within the same system that you're doing everything else in."

PLM and the Case for Quality

With the FDA shifting its compliance focus to quality, PLM vendors are making the case that their platforms are the best fit. Along with key industry partners, the FDA has been pushing the Case for Quality, an initiative launched in 2011 to identify and promote best practices for medical device quality after research revealed that the number of adverse event reports — particularly among cardiovascular and surgical devices — has increased significantly and is outpacing industry growth by a wide margin. The number of recalls on medical devices has also escalated, with a third due to design flaws and another quarter related to issues in manufacturing, the FDA found. Improving quality measures presents an enormous opportunity to the medical device industry — to the tune of about $4.75 billion to $6 billion, according to research from the McKinsey Center for Government.

Driven by Data

As opposed to a document-centric take on compliance, the new quality mandates require a data-driven approach, something only supported by PLM, notes Swapan Jha, PTC's vice president of go-to-market for PLM. "When the design engineer or quality engineer is working on a 3D model of a medical device, a lot of data gets added to that model from a compliance and traceability perspective," he explains. "Today, a lot of customers take that 3D model and create a PDF and all of that information that's supposed to be tracked is lost and the dots are disconnected."

With its model-based, product-centric view, Windchill PLM can provide access to the artifacts required for a quality initiative and for compliance throughout a product's lifecycle, Jha says. With Windchill 11, PTC is making compliance easier by providing out-of-box configurations for certain regulations — CFR Part 820 for quality system regulation, for example, as well as several of the ISO standards.

For its part, Aras is touting its model-based environment as one of the primary reasons its PLM platform is gaining traction among medical device companies as a means to automate compliance, according to Doug Macdonald, the company's product marketing director. The flexibility of Aras' modeling approach for customizing business processes, coupled with PLM's ability to serve as a digital thread, providing traceability from a product sitting in a warehouse all the way back through manufacturing and to design, makes it much more effective in streamlining compliance processes compared to any manual approach. "Without PLM, information could potentially be spread everywhere," he explains.

> **The number of recalls on medical devices has escalated, with a third due to design flaws and another quarter related to issues in manufacturing.**

A Layered Approach

Some Aras customers like Carestream Health Inc., are layering Aras on top of existing PLM systems to facilitate compliance and quality initiatives. Carestream, which manufactures medical imaging equipment among other health care-related offerings, uses Siemens PLM Software's Teamcenter to manage engineering CAD and assembly files. However, the company has also brought in Aras PLM as the system of record for Device Master Records (DMR), which capture all the drawings, documents, work instructions and processing information related to a particular device, along with the Design History File (DHF), which captures the complete record of design decisions.

"Aras gives us more flexibility to work with from a configuration management perspective," says David G. Sherburne, Carestream executive IT director. As for why PLM in general for compliance: "It helps us be more efficient while reducing compliance risk in a global environment — we want our cycles going into product innovation, not trying to figure out what version of the truth is out there," he explains.

For TransMedics, Omnify PLM was the prescription for balancing compliance requirements with the need to accelerate time to market. The platform automates many compliance processes, including QA training to ensure manufacturing operators stay up-to-date. "It's critical that we make sure they have training before completing a specific process and we're out of compliance if it's not documented," Das explains. "Training was one of the areas we thought we could improve by managing it in Omnify versus having someone remember what person was trained in what and losing all of that closure."

Specialized Service Providers

While PLM and document management tools can automate and streamline compliance, they can't do so without knowledge of the regulatory landscape, which continues to evolve. That's where specialized service providers come into play. Sterling Medical Devices, for example, provides design and consulting services to medical device manufacturers, including in the area of compliance, which is only going to get more complex as medical device makers integrate state-of-the-art technologies like smartphones, the cloud and the Internet of Things (IoT) into their offerings.

The FDA is starting to adapt, but it's a few years behind the technology, says Bruce Swope, vice president of Engineering at Sterling. "The FDA, ISO and CE bodies are constantly coming out with new versions of regulations," Swope cautions. "You could be designing for old standards and if you're not done in time when the new regulations are out, you won't get approval if you don't meet the new regulations." **DE**

Beth Stackpole *is a contributing editor to* DE. *You can reach her at beth@deskeng.com.*

INFO ➜ **Aras:** Aras.com

➜ **M-Files:** M-Files.com

➜ **Omnify:** OmnifySoft.com

➜ **PTC:** PTC.com

➜ **Sterling Medical Devices:** SterlingMedicalDevices.com

➜ **Synergis Software:** SynergisSoftware.com

➜ **TransMedics:** TransMedics.com

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

Stress in FEA

Part 2

A deeper look at how to study this phenomenon.

BY TONY ABBEY

Editor's Note: Tony Abbey teaches live NAFEMS FEA classes in the U.S., Europe and Asia. He also teaches NAFEMS e-learning classes globally. Contact tony.abbey@nafems.org for details.

In part one of this series (deskeng.com/de/stress-in-finite-element-analysis), we looked at the fundamentals of forces and stresses. In this month's article we are going to look at how we use these stresses in a practical example. The structure we shall use is shown in Fig. 1. It is a cross brace, supported at the left-hand edge by two lugs and loaded at the right-hand edge through two lugs. It is sitting in the global XY plane.

We are going to investigate the stresses throughout the structure and relate them to the fundamental ideas we looked at in the last article.

Last time we established the meaning of the direct normal stresses at a point and these were labeled as SXX, SYY and SZZ. The structure we have is three-dimensional, but the loading and constraint system gives a stress distribution acting mainly in the global XY plane. We can ignore the stresses through thickness i.e. the SZZ terms. We will abbreviate the normal stress terms to SX and SY.

Fig. 2 shows a plot of the stresses in the X direction, the SX stresses, throughout the structure. Many of you are probably wondering: At this stage why not just plot Von Mises stresses? I will come to that in the next article, but I want to progress in a logical way, building up our knowledge of stress types.

Searching for Stresses

The stress distribution in Fig. 2 doesn't give us a good overall picture of what's happening in the component. However, some of the zones of interest are aligned with the global X direction and that makes it convenient to look at stresses in those regions. If we think of this structure as a space frame, we can picture an overall bending response, with tension in the top ligament and compression in the bottom ligament. Looking at zone C, it must be a tensile load path. The X direction stresses are useful here.

Fig. 3 shows the distribution of X direction stresses local to zone C. The stress contours have been clipped

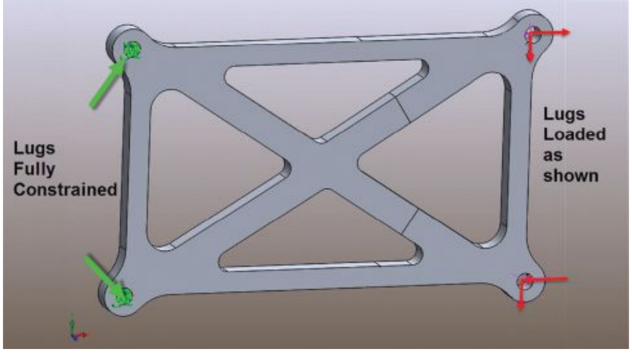


FIG. 1: Cross brace structure showing constraint and loading set up.

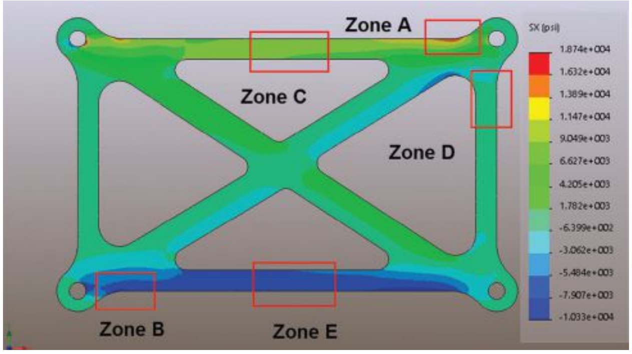


FIG. 2:. Zones of interest A through E and the SX stress distribution.

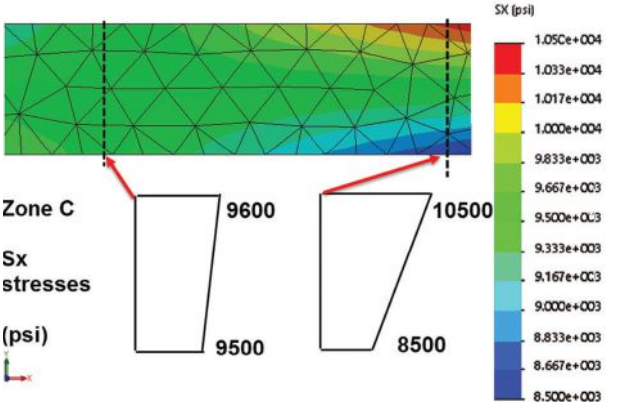


FIG. 3: Zone C X direction stresses showing membrane and bending distributions.

to the local regional values. Inspecting the contours shows a variation in axial loading from almost pure membrane tension loading to membrane plus bending loading. The stresses could be easily summated over the cross-section to give the Fx axial force and Mz bending moment at these two stations. Many post processors are able to do free body diagram section cuts like this automatically. It is well worth investigating these and comparing the stress distributions with resultant forces and moments.

If we set up a simple beam model of this cross brace structure, we should be able to get bending moment and shear force diagrams, which would give similar values to those found here.

We can carry out a similar exercise on the lower horizontal at zone E. Intuitively we know that this is going to be a compression loaded member and the X direction axial stresses confirm that, as shown in Fig. 4. Again, we can see a buildup of bending moment as we move toward the right-hand lug.

Where else on the X direction stresses of any use in predicting the behavior of the component? Reviewing Fig. 2, we can see that the only areas that may be of interest are zones A and B. These look like the most highly stressed regions, but the X direction stresses alone are not giving us the full story.

The cross braces and vertical members are not aligned with the global X direction, so the X direction stresses are not much use here. However, if we use the same logic, we can look at the Y direction stresses as being meaningful for the vertically orientated members. Fig. 5 shows the Y direction stresses plotted on the structure. Now zone D is showing up clearly as an area of interest. There is a similar region at the bottom of this vertical member, with a reversed stress sense.

We can zoom into zone D, plotting the Y direction stresses, and clipping the values to the local region maximum and minimum. The result is shown in Fig. 6 and clearly indicates a small compressive load path with a relatively large bending moment. This bending moment in the vertical member is complementary to the bending moment we can see in the horizontal member at zone A. We need to look at Fig. 2 to see this.

As mentioned earlier, there is a reversed bending moment just above the bottom lug in this member. The design of the lugs is not very good as the line of loading action is offset from all the bracing members. This is introducing large kick moments. It is also interesting to note

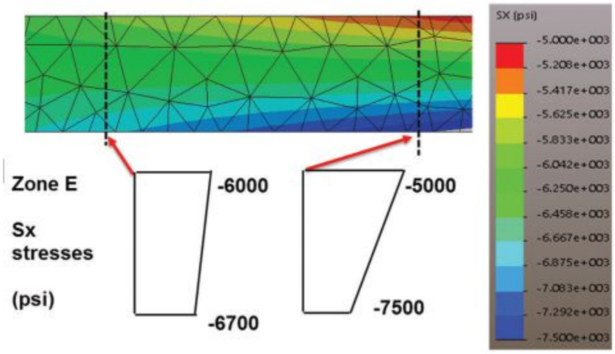


FIG. 4: Zone E Axial X direction stresses showing membrane and bending distribution.

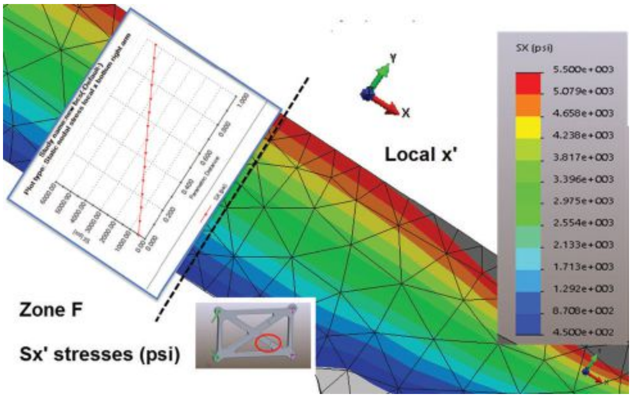


FIG. 7: Local X direction stresses aligned with the cross member at Zone F, showing act axial and bending distribution.

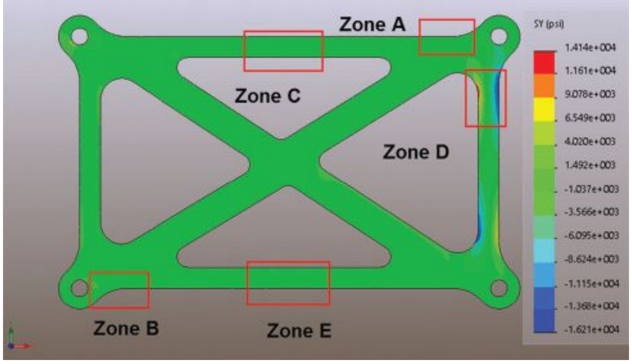


FIG. 5: Vertical Y direction stresses throughout structure.

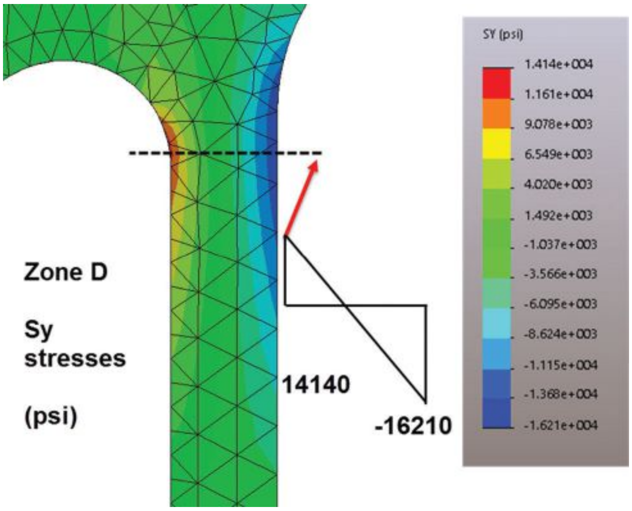


FIG. 6: Vertical Y direction stresses in zone D showing compressive membrane and bending behavior.

that there is a low compressive axial load in the right-hand vertical member. Both top and bottom lug are loaded in a downward sense, rather than just the bottom lug.

Local Coordinate Systems

So far we have investigated global directional stresses SX and SY. This has given a good indication of the response of the horizontal and vertical members. However, what happens if we want to investigate the diagonal cross members at Zones F and G? Global stresses are useless to us here, as it is impossible to picture the stresses and the resultant forces.

The answer to this is to set up local stress coordinate systems. Almost every FEA (finite element analysis) post-processor will be able to transform stresses from the basic global coordinate system to any desired local coordinate system. In Fig. 7, I am plotting local X direction stresses at zone F, aligned with the bottom right-hand cross member axial direction. This requires defining the local coordinate system and then making sure the stresses are transformed into this coordinate system.

Fig. 7 shows the net tensile axial force and bending moment distribution in both contour plot form and xy plot form.

In preparation for the xy plot, I split the geometry to form a regular face of nodes at the split face. This was done at zone F and G. This is the best way to produce accurate results at a station cut. If a virtual cut section is used instead in post-processing, it will use interpolation across what can be a very ragged set of elements. Results can be very poor.

In part one of this series we also looked at shear stresses. For this component, we can imagine the shear stresses running across the cut face, at right angles to the axial stresses. Fig. 8 shows the contour plot of the local shear stress and also an xy plot of the distribution across

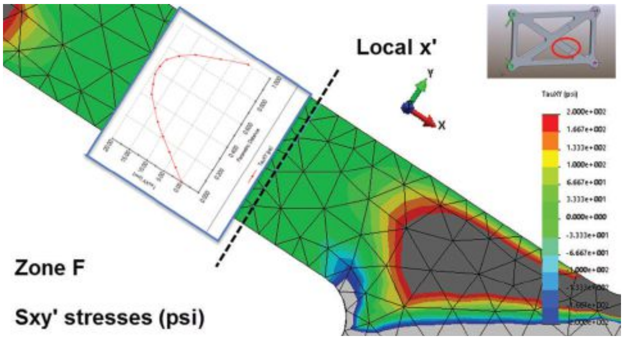


FIG. 8: **Local XY shear stress plotted for the bottom right cross brace at Zone F.**

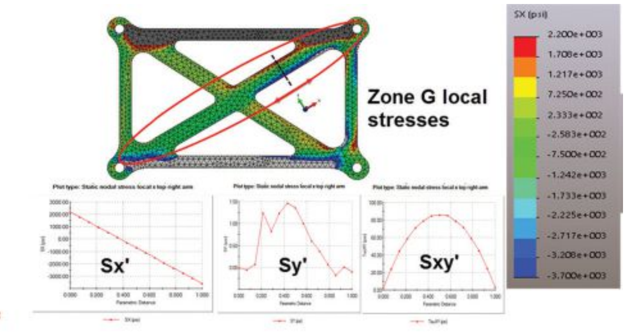


FIG. 9: **Zone G stress distributions; SX, SY and SXY in the local coordinate system.**

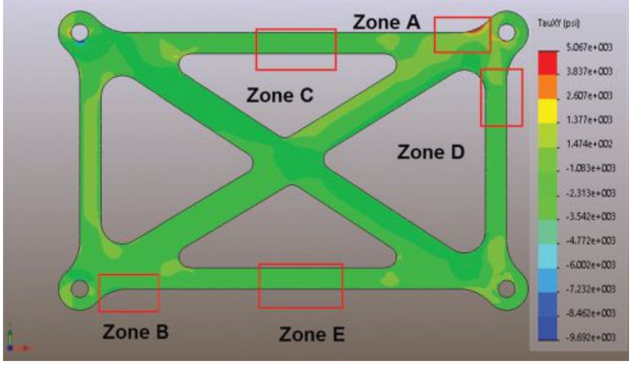


FIG. 10: **Global shear stress XY disparate distribution throughout the component.**

the section. The distribution of the xy plot shows the classic parabolic shear stress distribution across a rectangular section as we discussed before. Shear must be zero at the free edges. The value of the shear stresses and the resultant integrated force is very low.

A second local coordinate system is used to recover local stresses in zone G, which is the upper right cross brace. Fig. 9 shows a contour plot of the local X direction stresses. Only the mesh highlighted is relevant for these directional stresses. The stresses are valid in the other parts of the structure, but the directional components are useless in attempting to understand the nature the stresses. This type of partial directional regional plot is very common in a detailed post processing report. An extreme example of this is the use of local coordinate polar plots that show radial and circumferential stresses around specific bolt holes.

Zone G is showing predominantly axial compression loads, combined with local bending. The lateral direct loading SY is also plotted, and shown to be negligible. The shear stress SXY across the section is also very low, again showing a parabolic distribution.

By inspection of Fig. 9, we see the bottom left-hand brace is also in compression, but with no local bending present.

Fig.10 shows the global XY direction shear stress plotted for the complete structure. Not much can be deduced from this other than that there is a shear stress contribution at peak stress zone A.

Heading in the Right Direction

In summary, directional stresses are very useful in understanding the load paths within component regions. We have been able to identify the overall response of the structure by using a series of local coordinate systems. Transforming stress coordinate systems is usually a very straightforward post processing task and it is something well worth practicing. Using these transformed stresses, described as Cartesian stresses, is just part of the set of tools that we have available to understand the response of the structure.

In the next part of this series we will look at the theory behind stress transformations, which leads us onto principal stress definitions. We will discuss practical application of principal stresses.

Finally, we will look at Von Mises stress and dig a little deeper into what it means. It is tempting to only use Von Mises stress when reviewing structures. By discussing it last, I hope to show the importance of the other methods. **DE**

Tony Abbey *is a consultant analyst with his own company, FETraining. He also works as training manager for NAFEMS, responsible for developing and implementing training classes, including a wide range of e-learning classes. If your Company is interested in a customized training class on any topics discussed contact tony.abbey@nafems.org.*

Adding 3D Printing to Manufacturing

BY JESS LULKA

Most engineering professionals know 3D printing technology isn't new — it's actually been around for several decades. As the technology has evolved, more industrial users are applying it to address product complexity, time and budget constraints, as well as prototyping. Industries leading the way for industrial applications include aerospace, medical, automotive and dental.

According to research firm Gartner, in its 2014 report titled "3D Printer Market Survey Reveals Enterprise Demand Drivers for Technology, Printer and Vendor Decision Making," early adopters of the technology were able to easily identify cost savings. "Respondents felt overwhelmingly that using a 3D printer as part of their supply chain generally reduces the cost of existing processes, especially research and product development costs," said Pete Basilier, research director at Gartner. "The mean cost reduction for finished goods is between 4.1% and 4.3%, which is an impressive figure. It shows that early adopters of the technology are finding clear benefits, which are likely to drive further adoption."

The market doesn't show any sign of slowing down. *Wohler's Report 2016* stated the industry grew to $5.165 billion with a CAGR of 25.9%, and the number of industrial-grade AM system vendors rose from 49 to 62.

3D Printing Technology Primer

Since the invention of 3D printing, engineers and researchers have developed a variety of technologies that let users choose the optimal material and production method for their prototyping needs. While the processes vary in design constraints, material type and speed, most start by dividing a CAD file into thin layers to build a part, layer by layer. Here's a brief look at each type of technology.

Stereolithography: To build a layer, a platform is lowered at set increments to expose a laser onto liquid photopolymer, hardening each layer until the part is fully built. After production is complete, the part is then treated with a solvent and exposed to ultraviolet light. Seen in both industrial and desktop systems, SLA can be used for prototyping and casting applications in aerospace, automotive, medical, consumer goods, dental and entertainment industries.

Fused Deposition Modeling: In addition to creating layers in the CAD file, FDM also accounts for support structures during a build. After heating thermoplastic to a semi-liquid state, an extruder deposits each layer on a print bed. Supports are printed in a removable material and then either broken away manually or dissolved with a liquid solution. This method is also known as fused filament fabrication (FFF) and is available in both large-scale, industrial and desktop 3D printers. It is the most common consumer/hobbyist 3D printing technology. Applicable industries for FDM prototyping and end-use parts include aerospace, automotive, consumer goods, medical and manufacturing.

Laser Sintering/Melting/Electron Beam Melting: Using a mirror, this process guides a laser or electron beam across a bed of powder-based polymers, ceramics and metals, fusing the particles. Once the print run is finished, the part is left to cool and may be smoothed out in postprocessing. Used in mainly industrial 3D printers, it is suited to aerospace, automotive, medical (including implants) and manufacturing sectors.

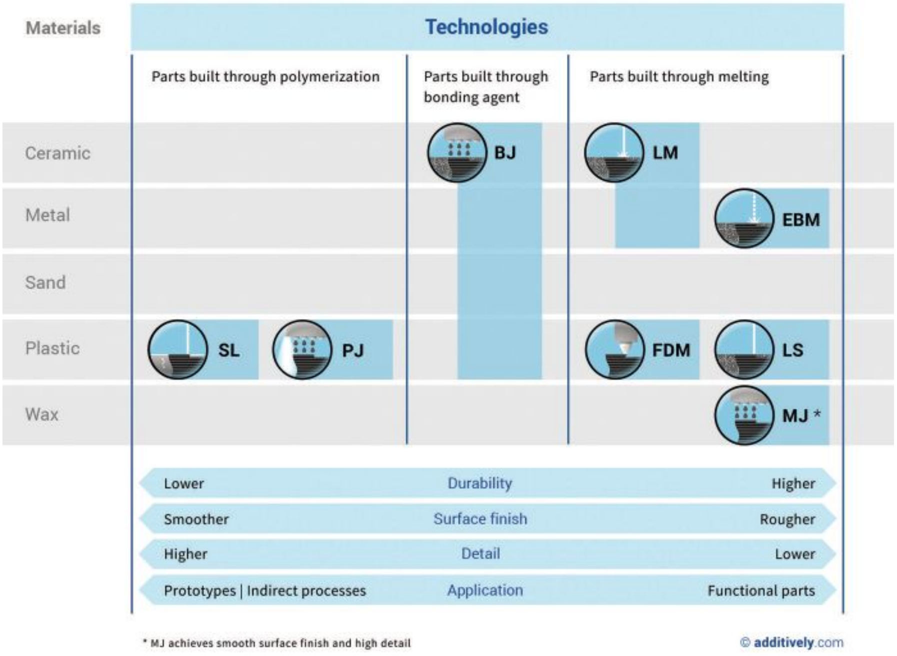
MultiJet/PolyJet/Photopolymer Jetting/Inkjet: The system's extruder deposits a photopolymer layer while curing it with ultraviolet light to solidify the material. Support materials are printed in a separate material for simplified removal. Engineers can use this technology in both industrial and desktop systems for medical, dental, electronics and hobbyist use.

3D Printing Timeline

1981
Hideo Kodama of Nagoya Municipal Industrial Research Institute publishes the first account of a rapid prototyping system

1984
Charles Hull, co-founder of 3D Systems, invents stereolithography

1986
Carl Deckard develops Selective Laser Sintering at the University of Texas



An overview of how 3D printing materials and technologies combine for different outcomes and applications. *Illustration courtesy of Additively.com.* Technology key: BJ (Binder Jetting), EBM (Electron Beam Melting), FDM (Fused Deposition Modeling), HP (Hybrid Processes), LM (Laser Melting), LS (Laser Sintering), MJ (Material Jetting), PJ (Photopolymer Jetting), SL (Stereolithography).

Digital Light Processing: Similar to stereolithography, this method will cure a photopolymer resin to build a prototype. The liquid photopolymer is exposed to light via a projector and solidifies. Upon completion, the production vat is drained of any excess liquid. Available for both industrial and desktop systems, DLP is often used for aerospace, automotive, dental, medical and manufacturing prototypes.

Laminated Object Manufacturing/Selective Deposition Lamination: Using a continuous sheet of plastic or paper, LOM uses heated rollers to spread the material and adhesive across the print bed and then cuts the desired design with a laser. SDL uses sheets of papers, selectively applies adhesive where needed and uses a blade to cut the paper. LOM/SDL is suited for manufacturing, medical, entertainment, engineering and educational uses.

Binder Jetting: To build each layer, these systems have a printhead that dispenses a binding material onto a layer of powder to form the part. Once the layer is completed, a roller will add a new powder layer. Postprocessing will vary depending on material; polymers require a secondary material for strength and metals and ceramics need to be thermally treated. Binder jetting is often used to create molds for casting, as well as color prototypes.

Material Jetting: For each layer, an extruder dispenses a melted wax material. Once the material cools and solidifies, a new layer is added. This technology is implemented for jewelry, electronics and dental applications.

Bioprinting: This process uses living cells and nutrient-rich microgels to create printed organs. A bio-ink of cells is extruded onto the print bed, together with — or separately into — the microgel that supports the living cells. To solidify the model, these systems can UV light, heat or other chemicals until the organ is finished. After a build, the tissue is set to mature for several weeks in a bioreactor. This technology is used specifically for medical applications.

Materials 101

Beyond the 3D printing technology itself, materials are a key consideration for prototyping and end-use parts. Materials can either be purchased directly from the 3D printer company or a third-party provider. However, some materials are proproetary. This means the type of materials that are available and compatible with your system will depend on the system itself and the 3D printing technology it uses.

Regardless of the technology, material selection does require some research. You should consider your application, the functionality you require from the 3D printed part, its geometry and postprocessing needs to help determine the appropriate material.

In narrowing down your application, it's important to note

1987

Larry Hornbeck creates Digital Light Processing technology

1988

Scott Crump, co-founder of Stratasys, invents Fused Deposition Modeling

1992

Stratasys releases the 3D Modeler, its first commercial machine.

3D PRINTING GLOSSARY OF TERMS AND MATERIALS

- **ABS:** Acrylonitrile butadiene styrene; a tough thermoplastic commonly used with FDM/FFF systems.
- **Additive Manufacturing:** A term used to describe any process where a 3D model is built in stages. It is used synonymously with 3D printing.
- **Alumide:** A mix of aluminum and polyamide powder that provides a shiny look to plastic parts.
- **Build Envelope:** Maximum physical size of a print that can be produced by a specific system.
- **Curing:** The process of hardening a liquid or material to produce the final form.
- **Extruder:** Parts that handle the feeding and depositing of a build material.
- **Filament:** Material used for 3D printing; often refers specifically to plastic-based spools used in FDM/FFF 3D printing.
- **Fill:** Interior structure of a 3D-printed model, which may be solid, hollow or latticed.
- **Functional Prototype:** Representation of a final object to test form, fit and function without necessarily using the final materials, colors or texture.
- **G-Code:** File format used by 3D printers and CNC (computer numerically controlled) machines to store and interpret data. It contains all the instructions for the machine to build the object.
- **Hot End:** Part of the extruder that heats the filament to the required temperature to deposit it onto the printbed.
- **Layer Resolution:** The thickness of one layer of the print.
- **Micron:** Description for one millionth of a meter, which is roughly 0.00039 in.
- **OBJ:** An abbreviation for Wavefront Object File, a file format that contains geometry definition information from 3D modeling programs.
- **Overhang:** Part of a 3D model without any support below it. Generally refers to sections that protrude at over 45°.
- **Photopolymers:** Plastic resins that change properties when exposed to light.
- **PA:** Polyamide; a strong material (often nylon) used in laser sintering; less brittle than PLA and ABS.
- **PAEK:** Polyaryletherketone; a group of thermoplastics used for 3D printing applications that require high temperature stability, strength and chemical resistance.
- **PBT:** Polybutylene Terephthalate; a thermoplastic in the polyester family that is resistant to solvents, stains and heat.
- **PC:** Polycarbonate; a widely used industrial thermoplastic that is often used in tooling and fixtures; can withstand functional testing; often used for complex prints.
- **PEI:** Polyetherimide; a thermoplastic resin with a high strength-to-weight ratio that is inherently flame retardant.
- **PEEK:** Polyether ether ketone; an organic thermoplastic polymer in the PAEK family.
- **PETG:** Glycol-modified polyethylene terephthalate (PET); a thermoplastic in the polyester family that is durable and flexible; transparency is an option.
- **PLA:** Polylactic acid; a bioplastic used for 3D models and DIY prototyping; less flexible than ABS.
- **PMMA:** polymethyl methacrylate; an acrylic plastic; often used for investment casting applications.
- **PP:** Polypropylene; a tough, flexible thermoplastic polymer; suitable for snap-fit parts.
- **PPS:** polyphenylene sulfide; a thermoplastic polymer with high chemical and thermal resistance.
- **Powder Bed Fusion:** Generic term for any process that adheres powder together to build a 3D object.
- **Print bed:** Surface of the 3D printer where the part is formed. Can also be referred to as bed or build plate.
- **PS:** Polystyrene; a clear thermoplastic that can be used for 3D printed molds requiring fine details.
- **PVA:** Polyvinyl alcohol; support material often used because it is water-soluble.
- **Refractory metals:** A group of metals known for their resistance to high heat, corrosion and wear.
- **Retraction:** The process of pulling the filament back from the hot end during printing.
- **Skirt:** A thin bounding line a distance from the object edge that ensures the design will fit on the print bed.
- **SLA:** Stereolithography apparatus, a type of 3D printer that uses sterolithography.
- **Slice:** A single layer of a 3D printed model.
- **STL:** Stereolithography file format used to describe the surface geometry of a 3D object that is to be 3D printed.
- **Thermoplastic:** Any plastic that can be transitioned to a molten form through heat and then solidified by cooling.
- **TPE:** thermoplastic elastomer; a plastic and rubber copolymer that provides flexibility and elasticity.

1992

3D Systems creates the first SLA 3D printer

1992

DTM creates first SLS 3D printer

1993

MIT's 3DP powder bed printing process is licensed to Z Corp.

any regulatory guidelines for material certification if your 3D-printed products are going to be on the market. This will help ensure that your materials won't cause any compliance issues later in the development process.

Material properties such as heat and stress tolerance can help or hinder a product's ability to function properly. If you know your part will require specific characteristics to function, be sure to include those properties in your material search.

With geometry, consider the dimensional tolerances, minimum feature execution and wall thickness. Materials can offer different resolutions and finishes depending on the 3D printing technology, and depending on how complex your geometries are, you may find that certain materials are more suitable than others.

Postprocessing is usually a part of the 3D printing process, and might add extra cost and time. Determine if your workflow has the time and/or resources for a 3D printing material with postprocessing needs, such as sanding, painting or surface finishing.

For more on specific materials, see the material glossary entries to the left, which correspond with the table of industrial materials on the next page. **DE**

Jess Lulka *is associate editor of* DE. *Send e-mail about this article to DE-Editors@deskeng.com.*

What They Said

DE ANNIVERSARY 20th

As we celebrate our 20th year, here's a look at how coverage of 3D printing has changed – or stayed the same – in *DE*:

"Just a year ago rapid prototyping had a strong following among engineers who were especially interested in using the technology for concept modeling and the production of one-off prototypes. While these are still valuable applications, some vendors and end users are advancing toward genuine production mold creation and techniques, and materials that can stand up to production demands."
— "Trends in Rapid Prototyping," Glenn Hartwig, March 1999

"[Ken] Cooper notes that in his 13 years in the industry, he has seen RP (rapid prototyping) machines get faster, more accurate, more user-friendly and reliable, but there's still a way to go to reach true 'manufacturing.' He adds, 'Perhaps most important are the advances in materials, from waxes and acrylics to titanium and steel.'"
— "RP&M: Then and Now," Pamela Waterman, March 2006

Material Supplier	Specific Material Types	Selected Examples
3D Systems	ABS, ABS/PP, Acrylic, Aluminum, Cobalt, Gypsum, PA, PA-Glass, PC, PP, Rubber, Steel, Titanium, Wax	Accura ClearVue, DuraForm Flex, VisiJet M5-Black
3DXTech	ABS-Carbon, PA, PA_Carbon, PEEK-Carbon, PEI, PETG-Carbon, PETG-Glass,	3DXMax, Firewire Carbon Reinforced PEEK Filament, iOn Nylon Filament
Additive Metal Alloys	Aluminum, Cobalt, Nickel, Steel, Titanium	AM 155, AM 625, AM Co75
Addwii	Gypsum	CMYK Full Color
Allied Photopolymers	ABS	KZ-1860-CL, KZ-1862-ICE, KZ-1870-WH
ALM	PA, PA-Carbon, PA-Glass, PA-Metal, PA-Mineral, PS	FR-106, PA-650, PS-200
AP&C	Titanium	Cp-Ti, Ti-6Al-4V
Arcam	Cobalt, Titanium	Arcam ASTM F75 CoCr Alloy, Arcam Grade 2 Titanium, Arcam Ti6Al4Vm
Arevo Labs	PAEK, PAEK-Carbon, PARA-Glass, PEEK, PEEK-Carbon	Katevo, PEEK F1, Quantevo
Argyle / Bolson Materials	ABS	ABS (P400), ABS B31 (M-TYPE), ABSmax
Arkema	PA	Orgasol Invent Smooth, Rilsan Invent Black, Rilsan Invent Natural
Asiga	ABS/PP, Wax	Plas, PlasCLEAR, SuperCAST
CMET	Epoxy, Silicone	HS-680, TSR-510, TSR-884B
Concept Laser	Aluminum, Bronze, Cobalt, Gold, Nickel, Silver, Steel, Titanium	CL 100NB (Inconel 718), CL 42TI (Commercially Pure Titanium), Remanium star CL
Cookson Gold	Gold, Platinum, Silver	18K 3N Yellow Gold, 950 Pt/Ru (Platinum), Brillante Sterling Silver
CRP Technology	PA, PA-Carbon, PA-Glass, PS	Windform EL, Windform GT, Windform XT 2.0
Diamond Plastics	—	Laser HDPE HX 17, Laser PP CP 22
D-MEC	Epoxy, Oxycetane	SCR11120, SCR751, SCR950
Dreve	—	PLASTCure Cast 100, PLASTCure Clear 100, PLASTCure Flex 100
DSM Somos	ABS, ABS/Acrylic, ABS/PBT, PP	Somos 14120, Somos NanoTool, Somos ProtoTherm 12110
DWS Systems	ABS, Gypsum, PP, Rubber, Wax	AB 001 (White), GM08B (Black), TEMPORIS
EnvisionTEC	ABS, Gypsum, PP, Silicone, Wax	ABS Flex M Series, Ortho Tough M, PolyPro MAX 3SP
EOS	Aluminum, Bronze, Cobalt, Nickel, PA, PA-Carbon, PA-Glass, PA-Metal, PEEK, PS, Silicate, Steel, Titanium, TPE	EOS Titanium Ti64ELI, PA 1102 Black, PrimePart Plus PA 2221
ExcelTec	PA	Innov'PA 1350_Etx, Innov'PA 1550_Xs, Innov'PA 3450_GBx
ExOne	Carbon-Metal Composite, Chromite, Cobalt, Glass, Iron, Nickel, Refractory Metal, Silicate, Steel, Zircon	316 Stainless Steel, FS 001 ExOne silica sand, Tungsten Carbide
Fabrisonic	Aluminum, Copper, Gold, Refractory Metal, Silver, Steel, Titanium	Aluminum 1100-H18, Pure Copper (99.9), Stainless Steel 309
H.C. Starck	Cobalt, Nickel, Steel	AMPERSINT 0032 CoCrMo, AMPERSINT 0168 Ni-SA, AMPERSINT 1556 FeNiCoMo (18Ni300)
Hoeganaes Corporation	Titanium	AncorTi Ti6Al4V Grade 23, AncorTi Ti6Al4V Grade 5, AncorTi Ti6Al4V Grade 5

Material Supplier	Specific Material Types	Selected Examples
Hunan Farsoon	PA-Carbon, PA-mineral	FS3250MF, FS3400CF
Kevvox	ABS, PP	Beige (LC 120), Dental Stone, Castable
Lithoz	Alumina, Zirconia	LithaCon 3Y 610 Purple (ZrO2), LithaLox HP 500 (Al2O3)
LPW	Aluminum, Cermet, Cobalt, Copper, Nickel, Steel, Titanium	LPW 316 (316L), LPW AlSi12, LPW WC CoCr
Mcor	Paper	Letter, A4
MarkForged	PA, PA-Aramid, PA-Carbon, PA-Glass	Carbon Fiber FFF, Kevlar FFF, Nylon FFF
NanoSteel	Steel	BLDRmetal J-10, BLDRmetal J-11
NextDent	—	NextDent C&B, NextDent Model Ortho, NextDent SG (Surgical Guide)
Oerlikon Metco	Cobalt, Nickel	MetcoAdd 718A, MetcoAdd 75A, MetcoAdd 78A
Optomec	Aluminum, Carbon-Metal Composite, Cobalt, Copper, Nickel, Refractory Metal, Steel, Titanium	Composite CrC, Aluminum 4047, Stainless Steel 420
OSAKA Titanium Technologies	Titanium	TILOP64-150, TILOP64-45
Oxford Performance Materials	PEEK	OXPEKK OXFAB
Praxair	Cobalt, Nickel, Steel, Titanium	Fe-271 (316 Stainless Steel), Ni-914 (Pure Nickel), Ti-201 (Ti Aluminide)
Prodways	PA, PA-Carbon, PA-Glass, PA-Mineral	PA11-GF 3450, PA12-GFX 2550, PLASTCure Model 200
Renishaw	Aluminum, Cobalt, Nickel, Steel, Titanium	CoCr-0404, Renishaw Inconel 718, Ti6Al4V ELI-0406
Sandvik	Cobalt, Copper, Nickel, Steel	430L (Sandvik), F75 (Sandvik), IN625 (Sandvik)
Sintergy	PA, PA-Glass	FS3200PA, FS400GF
Sinterit	PA	Sinterit PA12
Sintratec	PA	Polyamide 12
SLM Solutions	Aluminum, Cobalt, Nickel, Steel, Titanium	SLM Solutions Inconel 625, SLM Solutions Pure Titanium, SLM Solutions CoCr ASTM F75
Solidscape	—	3Z LabCAST, 3Z Model
Solvay	PA	TECHNYL XP 1501/F, TECHNYL XP 1537/A
Stratasys	ABS, ABS/PP, Acrylic, ASA, PA, PC, PEI, PP, PPS, Rubber, Wax	TangoBlackPlus FLX980, VeroClear RGD810, ULTEM
Structo	ABS, PP	Structomer META, Structomer PROTO+
Tekna	Refractory Metal, Titanium	TEKMAT Mo-45, TEKMAT Ta-75, TEKMAT W-25
Valimet	Aluminum	AM-103, AM-205, AM-7075
Victrex	PEEK	PEEK 450G
voxeljet	PMMA, Silicate	PMMA - Polypor B, PMMA - Polypor C, Silica Sand - Inorganic Binder
Xi'an Bright Laser Technologies	Aluminum, Nickel, Steel, Titanium	BLT-G09 (17-4PH), BLT-S22 (HX), BLT-T08 (TA15)

The information in the table above is courtesy of Senvol, a provider of data for additive manufacturing. One data product Senvol provides is the Senvol Database, which is a comprehensive database for industrial additive manufacturing machines and materials. For more information on any of the above materials, visit the Senvol Database – which is online and free to use – at senvol.com.

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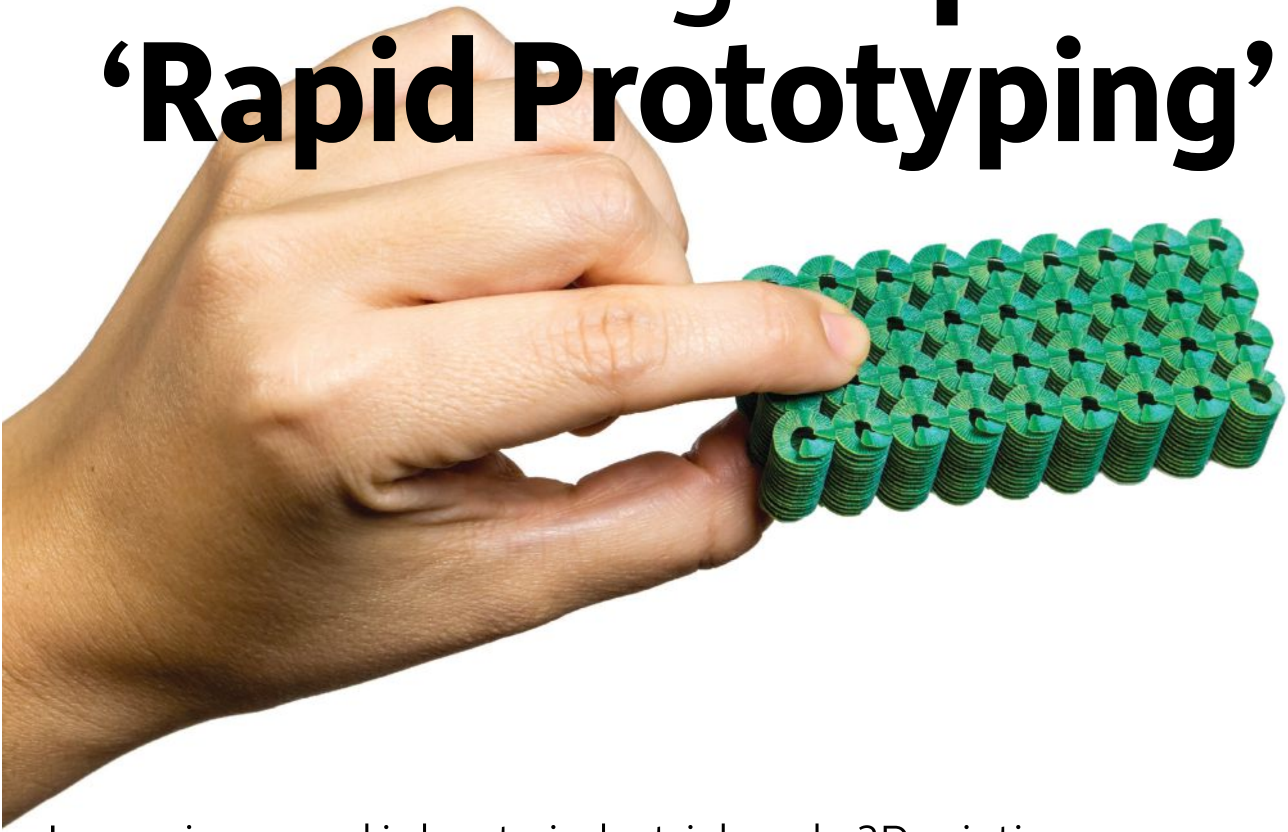


Improving speed is key to industrial-scale 3D printing.

BY KENNETH WONG

In his TED Talk titled "What if 3D Printing Was 100x Faster?" (March 2015), Carbon's CEO and co-founder Joseph DeSimone remarked: "3D printing takes forever. There are mushrooms that grow faster than 3D printed parts." The tech-savvy TED audience greeted it with an outburst of knowing laughter.

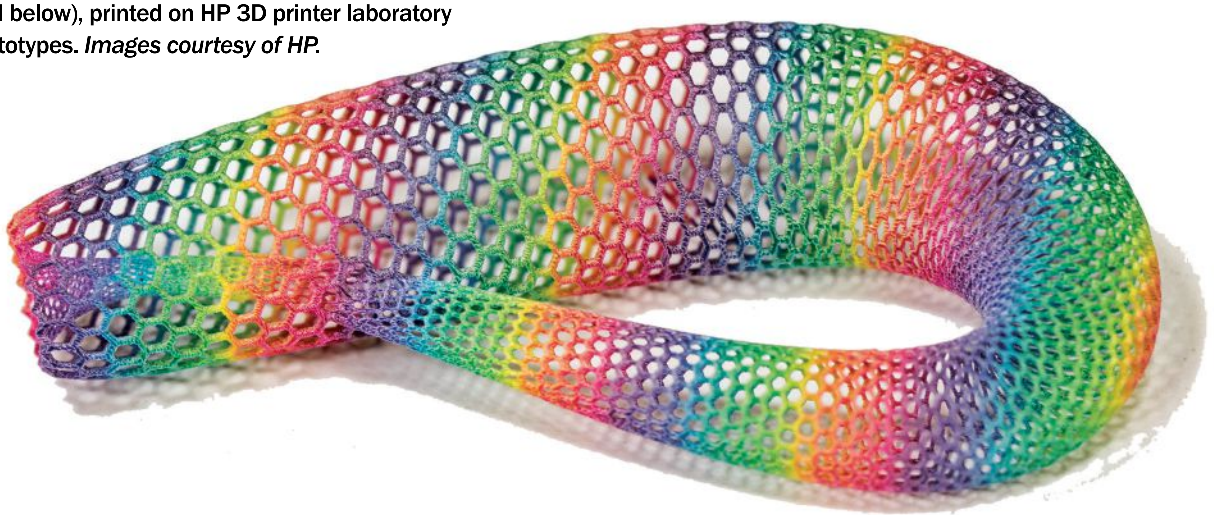
DeSimone, a chemistry professor, wants to speed up 3D printing by "marrying the intricacies of molecular science with hardware and software technologies." The result — a process that grows parts out of a pool of liquid material Carbon calls CLIP (Continuous Liquid Interface Production).

In 2015, when it emerged from stealth mode, the Redwood City-based Carbon got a $10 million boost from 50 miles north, from the San Rafael-headquartered design software giant Autodesk. Aside from investing in its own additive manufacturing (AM) initiatives, Autodesk also supports burgeoning, promising R&D in AM with its Spark Investment Fund.

3D Printing Timeline

1994	1996	1997	1998
Solidscape develops wax jetting	Stratasys debuts Genisys sysem	Arcam is established	Objet Geometry launches with its photopolymer 3D printing process

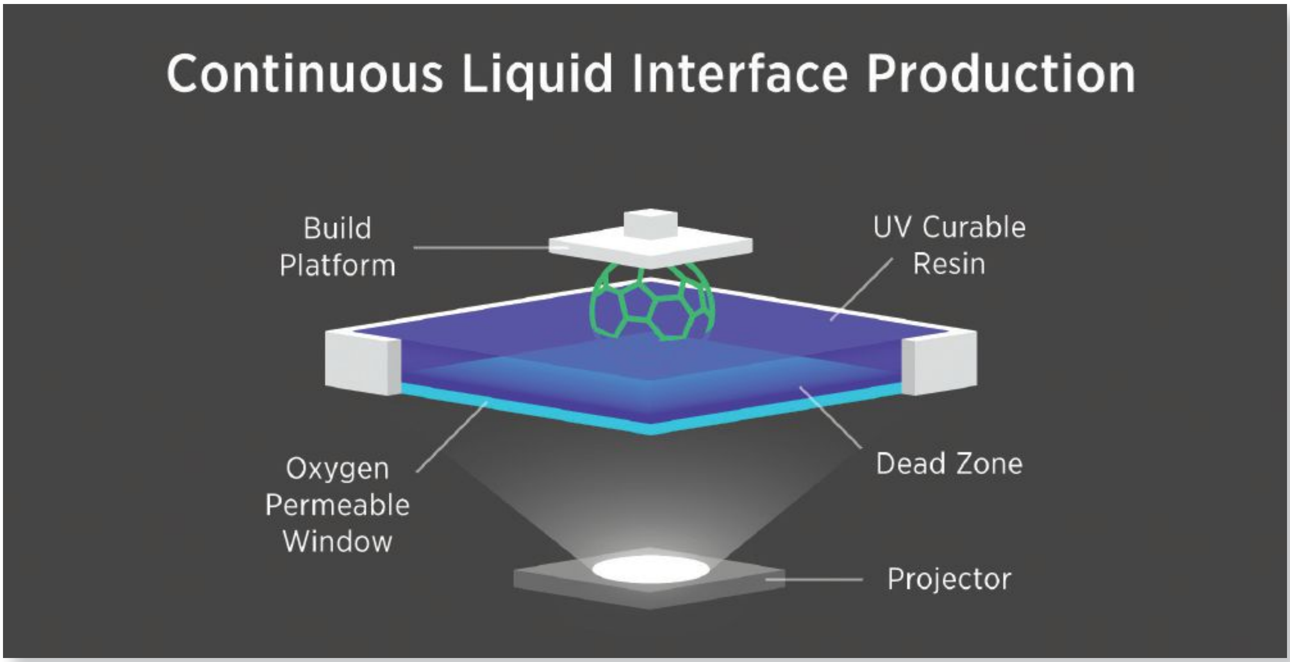
HP Multi Jet Fusion technology part samples (left and below), printed on HP 3D printer laboratory prototypes. *Images courtesy of HP.*



This March, in a special event Autodesk organized at its Pier 9 workshop by the San Francisco Bay, Pierre Lin, the lead engineer for Autodesk's Ember 3D printer, showed rapid prototyping could be truly rapid.

"This print job usually takes overnight to finish," he said, pointing at an intricate lattice structure the size of a thermos. "I'm going to see if I can get it to print in Ember in less than the time it takes me to finish my presentation." His presentation would run roughly 15 minutes.

The source file for the print job was a STL file, measuring 63.5x39.5x133.5 mm, with 314,928 polygons. Lin explained how he was able to dramatically accelerate the print job: "Based on the geometry, I modified the print settings to optimize the printing speed. In order to opti-



Carbon (formerly Carbon3D) uses a 3D printing method called Continuous Liquid Interface Production (CLIP). It allows its hardware to "grow" a part out of liquid materials, in a manner of speaking. ***Image courtesy of Carbon.***

mize the print settings, I need to thoroughly understand the hardware and material limitation," he said. One way to overcome the speed bottleneck is to "give the customers the ability to develop their own solution and workflow," proposes Lin; something possible only under the open source model.

The existing crop of AM hardware and software are more than adequate to build one-of-a-kind prototypes, to satisfy the needs of consumers, hobbyists and enthusiasts. But to earn a broader spot in industrial operations — to manufacture a high volume of end-use parts in automotive, medical, life sciences and consumer goods, for example — the technology has to evolve. Speed is a critical evolutionary characteristic that can decide who survives and who gets left behind in the race to industrial-scale AM.

Opening Up to Tinkering

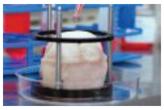
Though primarily a software company, Autodesk didn't hesitate to develop its own hardware when it decided to go after a slice of the AM pie, estimated at more than $5 billion by AM industry watcher and consultant Wohlers Associates (*Wohlers Report 2016*). Autodesk's Ember 3D printer is described as "the first open source, production-quality 3D printer." The print preparation software, Spark, is also open source.

The concept of open source software is straightforward: It's free. But the hardware equivalent is a bit of a novelty. It doesn't mean the hardware is free. (An Autodesk Ember kit, which includes the printer and a basic set of materials, would cost $7,495.) It means the specs, architecture and design of the hardware is freely available. The open source advantage, Lin suggested, is the permission to tweak the software and the hardware and configure both to work efficiently for the job at hand.

Of Lin's print acceleration demonstration at Pier 9 workshop, Autodesk writes: "Printing at the speed of 440mm/hour is possible with a change to Ember settings.

1999

Researchers at Wake Forest University bioprint a bladder with the patient's own cells



2000

MCP Technologies introduces SLM technology

2002

EnvisionTEC is founded

2003

EOS starts shipping EOSINT M 270 direct metal laser sintering system

DATA

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Autodesk is also releasing the research on the formulation for PR48-high speed, a resin formulation we developed as part of our efforts in speeding up the 3D printing process to address a common challenge within the industry … With this resin formulation, along with optimized hardware and software, print speed has increased from 18mm/hour to 440mm/hour — 24 times faster."

The Distributed Print Job

If the typical approach of depositing materials with a single inkjet nozzle takes too long to build an object, why not deploy a series of nozzles? That seems to be the thinking behind Project Escher, unveiled by Autodesk at its Pier 9 workshop in March. Escher is described as "a new technology that combines software and hardware for unprecedented speed, scale and detail in extruded prints."

The strategy is to deploy a system with multiple nozzles that can attack a job in a coordinated fashion. Cory Bloome, the hardware lead for Autodesk, explained that Escher's software "takes an object, divides the geometry into parts that several printers can independently print, and optimizes the job so each printer can print most efficiently."

Bloome and his colleagues clarified that Autodesk isn't planning to develop and deliver a printer as part of Escher. The company hopes a hardware partner or an AM vendor would develop hardware that can be driven by its Escher technology. Although the Escher approach is new, it could work with a modified version of existing hardware, Bloome points out. "The printing system is essentially a three-axis gantry system. People have been using it for 30 to 40 years."

HP's AM Approach

Because many AM methods are based on 2D printing technology, leading printer maker HP is a logical candidate to make the leap to 3D printing. HP's upcoming entry is dubbed Multi Jet Fusion Technology. As HP explains it, it's the 3D version of its Thermal Inkjet printing technology.

"We see a massive untapped opportunity in the industrial 3D printing market. HP Multi Jet Fusion technology is targeted to manufacturing companies, medium and large in-house model shops, and service bureaus. We are working to provide individual units to enterprise clients and service bureaus, while providing consumers with affordable access to our solution through service bureaus," says Alex Monino, director of Worldwide Marketing & Sales Strategy director, HP 3D printing.

In its white paper on Multi Jet Fusion, HP reveals: "Using HP Thermal Inkjet arrays with their high number of nozzles per inch, HP's proprietary synchronous architecture is capable of printing over 30 million drops per second across each inch of the working area … A key feature of HP Multi Jet Fusion technology is the potential to modify material properties to produce controlled variability in mechanical and physical characteristics within a part. This can enable a host of new possibilities in the design and performance of parts built by 3D printing."

Monino outlined the company's roadmap for the development and implementation of Multi Jet Fusion. "The first HP 3D printing platform will bring significant improvements in speed, quality, and cost versus existing solutions in the market," he says. "Future HP 3D printing platforms will continue to deliver on these benefits and will enable further

features, such as color printing and a more expansive range of materials with even more flexibility."

John Hornick, the author of *3D Printing Will Rock the World* remarks: "HP seems to combine as many as four types of 3D printing processes: Binder Jetting, Material Jetting, Powder Bed Fusion and possibly Directed Energy Deposition (DED)."

Terry Wohlers, founder of Wohlers Associates, says: "HP's technology, as I understand it, is really quite special. This can really take this industry to another level."

The Growth Model

Carbon's Continuous Liquid Interface Production process has Hollywood roots. "We were inspired by the 'Terminator 2' scene for T-1000, and we thought, why couldn't a 3D printer operate in this fashion, where you have an object arise out of a puddle in essentially real time?" explained DeSimone in his TED Talk.

The speed, based on a test commissioned by the company and performed by a third party, reveals CLIP can finish in 6.5 minutes what usually takes a polyjet printer 3 hours, SLS 3.5 hours and SLA 11.5 hrs. Currently Carbon technology works with polymeric materials, with characteristics that can reproduce the flexible feel of athletic footwear and the strength of plastic automotive parts. But no T1000-like liquid metal parts for the time being, according to Kirk Phelps, VP of Product Management at Carbon.

"CLIP technology is used with industry standard STL files," says Phelps. "A part file needs to be assessed for necessary support structures for the printing process. Carbon's software enables automated supports to be generated for the part file before it's printed." The approach, as demonstrated by Carbon, seems promising.

Breaking the Speed and Size Barriers

Author and industry watcher Hornick listed a number of major players working to break the speed barrier in 3D printing. "High Speed Sintering (HSS) is a powder-bed method that fuses polymer powders with infrared heat and infrared-absorbing inks. Developed by Neil Hopkinson at the United Kingdom's Sheffield University and Loughborough University, HSS reportedly works as quickly as injection molding, and can build parts as large as a washing machine," he says.

"Canon and Toshiba are also entering the market with faster machines. Canon has not revealed much about its machine, but says its resin-based lamination process will be fast and precise, for both prototyping and production work. Toshiba says its laser metal deposition (DED) machine, scheduled to be available in 2017, will make large parts and will be 10 times faster than Powder Bed Fusion machines, depositing 110cc/hour," Hornick adds.

HP's Monino says: "HP MultiJet Fusion technology has the potential to enable systems that are 10 times faster with breakthrough economics and top-level part strength relative to existing systems in the marketplace today." He confirmed the company is on-schedule to bring the first HP 3D printer in later this year, "at a significantly lower purchase price than comparable systems."

Additive manufacturing is also moving beyond the confines of a typical build chamber, another development that could make 3D printing a viable option for automotive, aerospace, and even architecture.

"Some of Voxeljet's Binder Jet machines are continuous build, which means that they are not limited by a build chamber. Sciaky's wire-based Directed Energy Deposition machine has a large build chamber of 9x4x5 ft. Massivit's Material Extrusion machines have a 6x5x4 ft. build chamber. Whatever cannot be built in any particular build chamber can be built in pieces, then assembled," says Hornick.

Introducing HP's AM initiative in a video, AM market watcher Wohler says: "What we do know about [3D printing] is exciting, but what we don't know about it, is even more exciting." **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. Email him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook.*

INFO ➜ **Autodesk:** Autodesk.com

➜ **Carbon:** Carbon3D.com

➜ **HP:** HP.com

➜ **Wohlers Associates:** WohlersAssociates.com

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

2004

Optomec releases first commercial Aerosol jet system for 3D-printed electronics

2005

RepRap project begins

2006

Multiple material printing debuts from Objet

2006

Selective laser sintering becomes commercially viable for mass customization

Educators Inspire with 3D-Printed Prosthetics

Initiatives ignite efforts toward low-cost 3D printing expansion.

BY MICHAEL BELFIORE

Five years ago, when eighth grade science teacher Rich Lehrer found out that his son, Max, would be born without the fingers of his right hand, he was filled with distress. That's in sharp contrast to now, at the age of 53, when he's following a new calling inspired by his son's disability. These days he works to similarly inspire budding engineers to design and 3D print low-cost prosthetics and other devices. Along the way, Max has been the beneficiary of a succession of new, 3D-printed hands that match his growth and improve in function with each iteration.

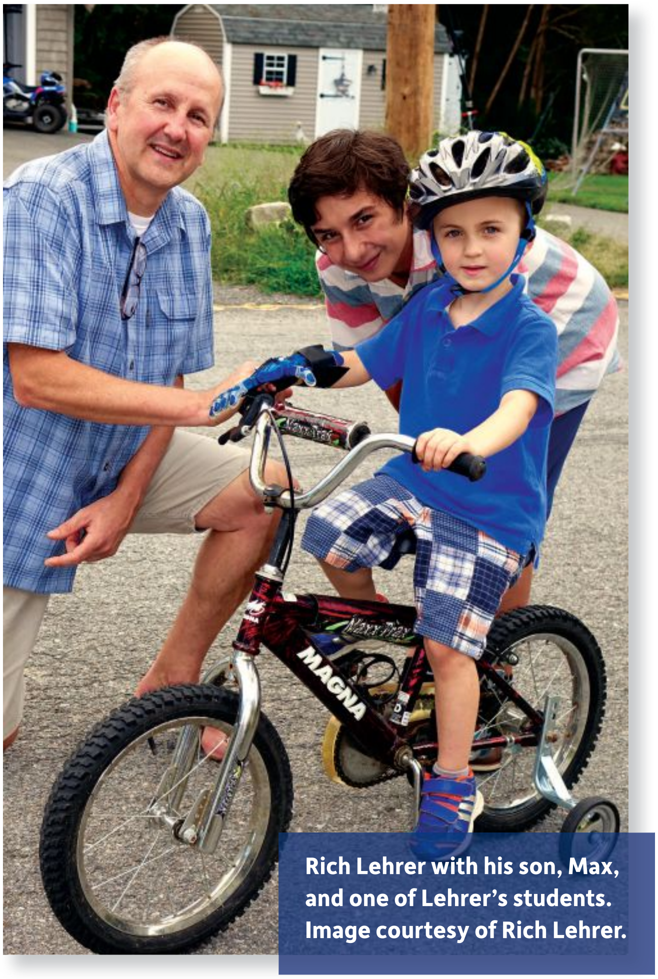
Lehrer, his students and Max are part of a growing movement to train a new generation of engineers and bring affordable prosthetics and other devices to people who need them — all over the world. In the process, they're spreading engineering know-how and bringing design software and 3D printers to people who might not have access to them otherwise.

A Helping Robohand

For Lehrer, it all started with an online video in 2013. In it, South African carpenter Richard Van As demonstrated how he had restored some of the function of his right hand with the help of designer Ivan Owen in Washington state after losing four fingers in a shop accident. Van As and Owen collaborated to create a prosthetic they called the Robohand.

Lehrer was so inspired by the video that he contacted Van As that very week to find out how he could get a hand for Max. But in the space of that 30-minute conversation, Lehrer came away with much more.

Realizing that building a hand for his son could be a great learning experience for the students at Brookwood School, the private school in Manchester, MA, where he teaches, Lehrer


Rich Lehrer with his son, Max, and one of Lehrer's students. Image courtesy of Rich Lehrer.

3D Printing Timeline

2007

3D Systems releases its first system priced under $10,000

2009

Organovo bioprints the first blood vessel

2009

MakerBot is founded and starts offering DIY 3D printers for the consumer

asked Van As for advice on how to teach the skills needed to build prosthetic hands.

Van As wasn't optimistic about Lehrer's chances for pulling off such an ambitious educational project. Even so, Lehrer managed to interest a dozen students at his school in the project as an afterschool activity. It turned out to be the start of a new career path for Lehrer, facilitating build projects for students.

Lehrer says the contrast between classroom science projects that get sent home to sit on a shelf or get tossed in the recycling bin, and build projects that actually do some good in the world makes all the difference for him as a teacher — and for his students who become fully engaged in their work. "For kids to see that what they do matters," he says, "that's transformative."

In addition to building prosthetics, Lehrer also teaches his students basic engineering and product design concepts. *Image courtesy of Brookwood School.*

Teaching the Teachers

After leading students through building prosthetics for his son, Lehrer became the education coordinator for e-NABLE, a community of prosthetic hand designers and builders started in 2013 by Rochester Institute of Technology professor Jon Schull, who was also inspired by Van As and Owen. Schull says e-NABLE has over 8,000 members and adds new participants at the rate of about 100 a week. In what started as a volunteer position with e-NABLE, Lehrer now helps other educators teach everyone from second graders to post doctorates to design and print prosthetic hands.

According to Schull, there are currently about 200 schools, concentrated mostly in North America, in the organization's Enable Education Exchange, or e3STEAM initiative. The group is working to bring schools in Rwanda and Kenya into the fold. "These kids are becoming desktop engineers at age 11," says Schull. He sees this as an important trend for the worldwide engineering community, and a positive one for the world as a whole. "You can predict the future if you know what kids are doing," he explains.

Dara Dotz, principle designer and co-founder of Field Ready, a non-profit organization bringing humanitarian supplies to Haiti and Napal via 3D printing, and who also helps develop 3D printed prosthetics, says design and 3D printing technology still has a ways to go before it can realize its full potential. "The machines themselves aren't ready for prime time," she says. She'd like to see a tighter integration between software, materials and printers to make them all easier to use — something like the ecosystem that has made Apple products so popular. "I would like to design myself out of a job. I would like tools to be easy enough so that people can actually make their own [devices]."

Andreas Bastian, a 3D printing research scientist at Autodesk, sees groups like e-NABLE as having an important role in the kind of advances that Dotz advocates. "One way of looking at what e-NABLE is doing is that it's a massive experiment in 3D printed products designed for distributed manufacturing," he says. "It turns out that that's a complex and interesting challenge that current design and manufacturing tools do not support, and it's important for us to learn about the need space in order to build better design and manufacturing tools."

In the meantime, Lehrer is preparing to reduce his hours as a full-time school teacher and join e-NABLE part-time in one of its first paid positions. And e-NABLE, says Schull, "is actively seeking partnerships and contributions that will help us expand the reach of what we're doing." **DE**

***Michael Belfiore's** book* The Department of Mad Scientists *is the first to go behind the scenes at DARPA, the government agency that gave us the Internet. He writes about disruptive innovation for a variety of publications. Reach him via michaelbelfiore.com.*

INFO ➜ Autodesk: Autodesk.com

➜ **Brookwood School:** Brookwood.edu

➜ **e-NABLE:** EnablingTheFuture.org

➜ **Field Ready:** FieldReady.org

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

2010

Kor Ecologic designs Urbee, the first 3D-printed car

2011

i.materialise starts offering 3D prints in gold and silver

2011

University of Southampton makes the first 3D-printed robotic aircraft

Metal 3D Printing for the OR

How 3D Systems and EIT are transforming surgical implants.

From preoperative planning to patient education to surgical guide production, 3D printing for medical applications is on the rise as physicians and researchers are increasingly taking advantage of the technology's flexibility. A new generation of metal 3D printing technology along with biocompatible metals are adding yet another layer of possibilities, allowing medical implant companies to 3D print patient-specific implants for immediate use in a fraction of the time of traditional methods.

German medical device manufacturer Emerging Implant Technologies (EIT) recently demonstrated the potential of medical additive manufacturing by supplying the first anatomically adapted, 3D-printed titanium fusion implant to a patient with a degenerative cervical spine condition. The technology behind the effort was 3D Systems' Direct Metal Printing (DMP) technology, which is capable of building metal objects layer by layer in a variety of metals, in this case biocompatible titanium.

Designed in partnership with 3D Systems and produced using its cloud-based manufacturing services, the porous EIT cervical implant imitates the structure and characteristics of natural trabecular bone, say the developers, allowing the surrounding structures to fuse with it more easily and significantly accelerating the healing process. This sophisticated medical device — with its precise micro-, macro- and nano-structural components — demonstrates the power and potential of complex 3D printed parts and the accuracy of DMP technology.

The capabilities of DMP, and medical applications like EIT's, are already capturing the medical community's attention. "We are fascinated by the possibilities of this new technology combining modern computer-aided design and custom-made manufacturing of a high-tech cervical implant," said Professor Uwe Spetzger, the surgeon who performed the surgery, and the chairman of the neurosurgery department at Klinikum Karlsruhe, in a press release. "The future of patient individualized spinal implants has begun."

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Plastic Surgery Faces Change

AVSAR Aesthetic uses full-color 3D printing to create realistic reference models.

Clear communication and understanding between a surgeon and his or her patient is vital before emotion-filled plastic or reconstructive surgery. That's why Dr. Yakup Avşar, founder of AVSAR Aesthetic Surgery Clinic in Istanbul, Turkey, combines his knowledge and expertise as an aesthetic, plastic and reconstructive surgeon with his talent as a sculptor to create physical three-dimensional "before" and "after: images of his patients' faces.

Originally, Dr. Avşar hand-sculpted the masks of his patients' faces. After seeing a demo of 3D scanning and 3D printing, Dr. Avşar began using a powder-based 3D printer for this application, but switched to an Mcor full-color 3D printer because of Mcor's superior color capability, operating costs (it uses paper as the 3D printing material) and environmentally-friendly process.

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Just What the Doctor Ordered

In-House Objet 3D printer helps medical device firm reduce prototype turnaround time.

Arch Day Design is a medical device design firm specializing in minimally invasive devices. Its clients range from individual surgeons to large health care companies such as Allergan.

Prototypes are used in the medical device design process to check everything from form, fit and function to manufacturability. They often have small, intricate parts that are difficult to produce.

"We knew that with an in-house system we could turn around prototypes much more quickly and probably reduce our overall costs," said Tom Weisel, president of Arch Day Design. "But the initial purchase price scared us away."

Then a colleague recommended the Objet30 Pro 3D Printer, a compact office-friendly system that can be used to create smooth surfaces, complex geometries, small moving elements, fine details, standout text and whatever else a design demands.

MORE → deskeng.com/de/?p=29734

3D Printing Timeline

2011

Researchers at Cornell begin work on a food 3D printer

2012

Doctors and researchers design and implant a 3D-printed jaw for a patient with a chronic bone infection

2013

Stratasys Objet 500 system enables multicolor, multi-material 3D printing

Sponsored by Proto Labs /// **3D Printing Profile**

Custom Prototypes and Parts Fast

Proto Labs is the world's fastest digital manufacturing source for custom prototypes and low-volume production parts. It's a technology-enabled company that uses advanced 3D printing, CNC machining and injection molding technologies to produce parts within days. The result is an unprecedented speed-to-market value for designers and engineers, and an on-demand manufacturing resource throughout a product's life cycle.

Company History

Proto Labs began in 1999 specializing in the quick-turn manufacturing of custom plastic injection-molded parts. In 2007, the company introduced its CNC machining service and in 2014, expanded into 3D printing with the addition of additive manufacturing. Proto Labs is a global company with full-service manufacturing operations in the United States, Europe and Japan.

Why Proto Labs?

Proto Labs has radically changed the economics and lead times traditionally associated with manufactured parts. The rapid manufacturer provides a fast, easy and cost-effective way to obtain 1 to 10,000 parts within days, routinely shipping parts before conventional suppliers can even quote them. These quick delivery times are possible because it has automated the manual process of mold design and toolpath generation through the use of proprietary software.

Interactive Quoting

Product developers can upload a 3D CAD model online at any time and receive an interactive quote with real-time pricing information and free design analysis within hours. The manufacturability analysis helps eliminate problems, like sink or warp, so modifications can be made before any actual production begins. Upload a part at protolabs.com/quote.

3D Printing

Proto Labs uses the latest 3D printing technologies to provide precision accuracy to plastic and metal part production — from small pieces with complex geometries to large, highly detailed patterns. 3D printing is ideal for 1 to 50 parts and works well for form and fit testing, reducing multipart assemblies, and creating fully functional components in some cases.

CNC Machining

The company's CNC machining service uses three-axis milling and turning with live tooling to machine up to 200 parts from more than 30 stocked plastic and metal materials. The result is functional parts made from engineering-grade materials for prototype testing, jigs and fixtures, and end-use applications.

Injection Molding

For those who need low-volume production, bridge tooling or on-demand parts throughout a product's life cycle, Proto Labs' rapid injection molding can manufacture up to 10,000 parts from hundreds of different engineering-grade plastic and liquid silicone rubber materials.

> "Industrial 3D printing has been a critical part of prototyping and product development for years, and its value to product designers and engineers is only increasing as the technology's capabilities to build functional, end-use parts continue to expand."
>
> *— Rob Connelly, VP of Additive Manufacturing, Proto Labs*

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Silicon Nitride for Medical Applications

Amedica Corporation has announced its first fabrication of complex, three-dimensional structures by a 3D printing process called robotic deposition, or robocasting. The final products have been examined under scanning electron microscopy to confirm the integrity and validity of the 3D printing method, according to the company.

Robocasting is a freeform fabrication technique for dense ceramics and composites that is based on layered deposition of highly colloidal slurries. Amedica says the process is essentially binder-less, and that a device can be completely sintered in less than 24 hours.

MORE ➜ Amedica.com

Uses for 3D Bioprinted Liver Tissues Presented

Five presentations at the Society of Toxicology's 55th Annual Meeting and ToxExpo in March demonstrated the applicability of Organovo's exVive3D Human Liver Model for the assessment of drug safety and the detection of liver injury, including steatosis and fibrosis. In addition, an Organovo session included presentations on advances using bioprinted 3D human liver tissues to assess drug-induced liver toxicity.

"Drug-induced liver injury remains a major cause of late-stage clinical failures and market withdrawal, often due to poor translation from preclinical animal studies to clinical outcomes," says Dr. Sharon Presnell, chief technology officer and executive vice president of research & development, Organovo. "Organovo's exVive3D human liver model replicates complex cell-cell interactions and key elements of native tissue architecture. When a preclinical or clinical-stage asset presents a challenging safety or efficacy signal, exVive3D provides the unique resolving power of a controlled human tissue microenvironment to investigate mechanism and develop solutions."

MORE ➜ Organovo.com

Bioprinting Research Presented at ACS

Research presented at the 251st National Meeting & Exposition of the American Chemical Society in March included 3D printing's use in cartilge repair.

"Three-dimensional bioprinting is a disruptive technology and is expected to revolutionize tissue engineering and regenerative medicine," says Paul Gatenholm, Ph.D. "Our team's interest is in working with plastic surgeons to create cartilage to repair damage from injuries or cancer. We work with the ear and the nose, which are parts of the body that surgeons today have a hard time repairing. But hopefully, they'll one day be able to fix them with a 3D printer and a bioink made out of a patient's own cells."

Photo: American Chemical Society

MORE ➜ ACS.org

Materialise to Expand Hospital 3D Printing

Materialise has launched 3D printing software and services it says will help increase and ease adoption of the technology in hospital settings.

The Materialise Mimics Care Suite includes planning and design software tools, 3D printed anatomical models and surgical guides, and patient-specific implants. It also includes the new Materialise Mimics inPrint software for creating and printing medical models. The inPrint tool connects data from imaging systems to 3D printers.

MORE ➜ Materialise.com

Harvard 3D Prints Vascular Tissue

A team at the Harvard John A. Paulson School for Engineering and Applied Sciences (SEAS) and the Wyss Institute for Biologically Inspired Engineering at Harvard University has invented a method for 3D bioprinting thick vascularized tissue constructs composed of human stem cells, extracellular matrix and circulatory channels lined with endothelial blood vessel cells. This enables fluids, nutrients and cell growth factors to permeate uniformly throughout the tissue. The advance was reported March 7 in *Proceedings of the National Academy of Sciences*.

"This latest work extends the capabilities of our multi-material bioprinting platform to thick human tissues, bringing us one step closer to creating architectures for tissue repair and regeneration," says Jennifer A. Lewis, the Hansörg Wyss Professor of Biologically Inspired Engineering, the senior author on the study.

MORE ➜ seas.harvard.edu

3D Printing Timeline

2013

The first 3D-printed gun is created by Defense Distributed

2014

The International Space Station uses its Made in Space 3D printer to create the first 3D printed part in space

2015

MIT 3D prints molten glass via an extruder

Stratasys Launches J750 Multi-Material 3D Printer

The Stratasys J750 3D printer enables customers to mix-and-match full color gradients and a range of materials in one 3D print. The company says it allows users to reduce post-processing.

"The time saved by eliminating the painting and assembly process can lead to faster product delivery times," said Josh Claman, chief business officer, Stratasys. "The J750 is a multi-purpose system that can also produce production tools, manufacturing moulds, teaching aids, and other models – truly raising the bar in 3D printing versatility."

The J750 has a 19.3 x 15.35 x 7.9 in. build volume and a six-material capacity to help minimize downtime associated with material changeovers. The newly designed print heads deliver a layer resolution as fine as 14 microns and accuracy as high as 0.1 mm. The print heads (up to eight per year) are included in the J750's three-year warranty.

Stratasys has also released its new PolyJet Studio software. The software's interface allows users to choose materials, optimize the build, manage print queues, and assign colors, transparencies and rigidity. Color textures can be loaded fully intact via VRML (Virtual Reality Modeling Language) files imported from CAD tools.

MORE ➔ Stratasys.com

Carbon Unveils its M1 Industrial 3D Printer

The M1, from Carbon (formerly Carbon3D, Inc.) is the company's first commercial 3D printer. It uses the Continuous Liquid Interface Production (CLIP) technology that promises fast printing of high-resolution parts.

Carbon also unveiled a subscription pricing model for the M1. An annual subscription will cost $40,000 per year. The subscription includes a service team that uses operational data collected by the connected 3D printer to deliver predictive service and machine updates.

The M1 collects over 1 million process control data points per day, according to the company. This makes it possible for Carbon to provide remote diagnostics, assist with print optimization, and improve print quality over time via updates.

"An internet-connected architecture ensures the latest features, performance enhancements and resins are always available to users, while the browser-based interface enables printer operation inside a network without the hassle of software installs or compatibility problems," states the company's press release.

Carbon also introduced seven new resin materials for use with the M1, including rigid, flexible and elastomeric polyurethanes, as well as a Cyanate Ester-based resin with a heat deflection temperature up to 426°F.

MORE ➔ Carbon3D.com

3D Systems' ProJet MJP 2500 Series Released

3D Systems' ProJet MJP 2500 series is designed for in-office 3D printing. It is equipped with the company's new MJP EasyClean System, which offers hands-off, chemical-free finishing.

The ProJet MJP 2500 is available in standard and Plus models. Each printer in the series is compatible with VisiJet M2 materials in white and black plastic. The ProJet MJP 2500 Plus offers additional material capability with rigid clear plastic as well as flexible elastomeric black and elastomeric natural, each newly developed for printing rubber-like parts.

"We have been extremely impressed with the results from the ProJet MJP 2500," said Haleigh Doremus, rapid prototyping manager, Nike, a 3D Systems beta tester. "It complements our current technologies and processes and allows us to print complex geometries that were previously impossible on other printers in this class. The consistency of parts and hands-off post-processing it provides gives us time to accomplish more in a day, adding even more value to our team."

The 2500 Series is capable of printing 790 DPI in z, or over half a billion droplets of material for every cubic inch printed. The series also includes 3D Systems' 3DSPRINT software.

MORE ➔ 3Dsystems.com

2015

Researchers at Monash University in Australia 3D print a complete jet engine

2016

Nano Dimension launches Dragonfly 2020 for 3D printing printed circuit boards

2016

ULA Atlas V rocket engine with 3D printed parts launches into space

Notes from the Mesh-Making Frontline

A roundup of the latest efforts to improve meshing in simulation.

BY KENNETH WONG

MSC Software's Apex CAE software constantly re-assesses and meshes the geometry in the background to keep up with the user's edits and changes. *Image courtesy of MSC Software.*

Almost everything in meshing — subdividing a 3D model into thousands of tiny geometric elements in preparation for finite element analysis (FEA) — is about weighing the pros and cons. If the model contains a high level of details (like rounded corners, holes, bolts and nuts), the computation required to mesh the geometry may take longer than necessary, or (worse) bring the hardware to its knees. The alternative is to reduce the amount of details, but that alternative carries its own risks. If you're not sure which features are critical to the analysis, you could accidentally compromise the accuracy of the simulation by removing what should be included.

Some simulation software takes the burden off the user with full or partial mesh automation. Because it requires fewer expertise-driven decisions, this approach allows a wider range of users, including novices, to perform a greater volume of simulation. However, such automation is achievable only if the software is allowed to make sweeping generalizations in its treatment of the geometry. For those seeking a simple design validation (for example, is this three-legged chair strong enough to support a person weighing 250 lbs.?), this may be acceptable. For others seeking to squeeze the last gram of weight out of an airplane part already heavily edited, this may not be the right approach.

To improve the meshing process, some software developers come up with new algorithms to tackle complex, organic geometry well beyond the bounds of classic mechanical shapes. Others propose using the detailed model, not the simplified geometry, for better accuracy. A few even propose skipping meshing altogether and performing FEA directly on the CAD geometry itself. The solutions and strategies featured in this article represent a small sampling of the latest thinking in the mesh-making frontier.

Hex Mesh for Bones and Brains

In its early days, additive manufacturing (AM) was a prototyping method, but the more mature AM technologies of today are well on their way to becoming viable manufacturing options. AM can build biomimicry-inspired design like organic shapes and honeycomb structures previously dismissed as impractical or too costly to produce. So simulation and analysis technologies, too, have to keep up. One area where such irregular shapes can present a challenge is in automated meshing.

According to csimsoft, the traditional pave-and-sweep method "[decomposes] the model into sweepable volumes," which "sometimes takes hours or days to prepare." Paul Ressler, csimsoft's director of Sales and Marketing, explains how Bolt deals with irregular shapes: "We use a grid overlay — we build a bounding box around the model, create a Cartesian grid, and cut away everything else outside the model." The key to its approach, he added, is "the algorithm that creates high-quality hex meshes at the surface." That means generating meshes for bones and brains without cutting them up, in a manner of speaking.

By user request, csimsoft is now developing what it calls "adaptive meshing," capable of capturing fine features, like sharp edges. "This will have the ability to snap to features and capture very precise edges," explains Ressler.

Does Meshless Analysis Use a Mesh?

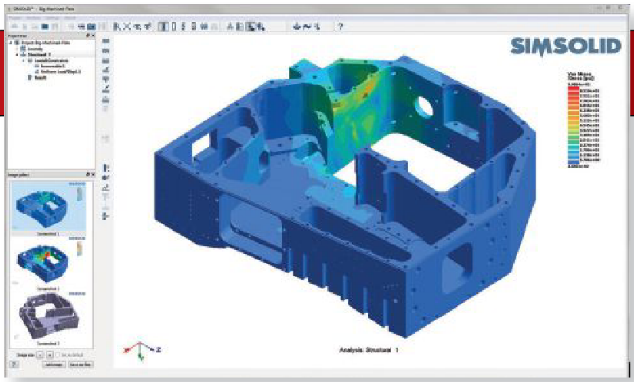
When SIMSOLID debuted its commercial release in early 2016, the company announced that SIMSOLID "eliminates geometry simplification and meshing, the two most time consuming and expertise-extensive tasks done in traditional FEA."

Previous to launching SIMSOLID, Ken Welch held executive roles at MSC Software and Moldflow. "Our method does not create a mesh. It works directly on the fully featured CAD model. Defeaturing is not required," he says.

Some argue so-called "meshless FEA" actually does use a mesh, but hides the process from the user. "If you're talking about isogeometric analysis, also called meshless, you still need a coarse mesh in reality. There is always an underlying mesh whether you see it not," says csimsoft's Ressler.

John Chawner, president of Pointwise, says: "A method could be deemed meshless if a mesh is generated without the user knowing. There are also numerical techniques for solving field equations that are called mesh-free because they work on a cloud of points without connectivity, but they still rely on some sort of organization of the points to be able to compute derivatives of the governing field equations."

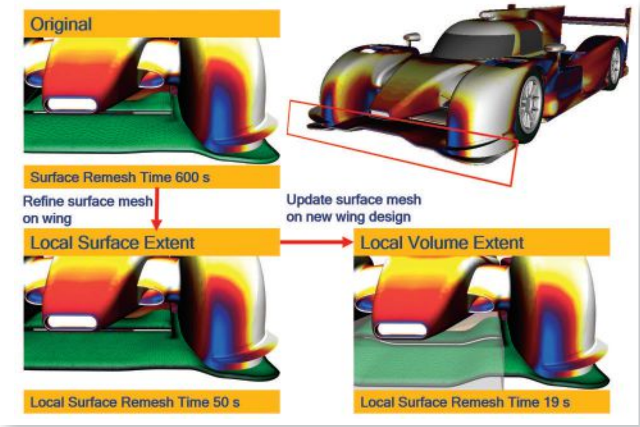
SIMSOLID's Welch clarified that SIMSOLID's method is not the same as isogeometric analysis. "Historically, structural FEA have used simple linear or quadratic elements to represent the geometric domain and to associate simple basis functions with the mesh nodes. Then, P-elements drastically changed the requirements for domain discretization by increasing the polynomial level of basis functions. This allowed elements with much larger aspect ratios and distortion. SIMSOLID is the next step in this evolution in that it drastically changes the discretization requirements by associating basis functions with a variety of geometry supports in form of volumes, surfaces, lines and point clouds. They are distributed in the part volume and adapted to part geometry on the fly during the solution phase. This provides the ability to handle geometrical imperfections, as well as assembly contact imperfections like gaps, penetrations and ragged contact areas. While classical finite elements are not created, in terms of formulation SIMSOLID is equivalent to FEA in that it uses the same variational principles," he says.



SIMSOLID works directly on the fully featured CAD model, and therefore does not need to defeature, the company points out. ***Image courtesy of SIMSOLID.***

Automatic Repair and Simplification

Geometry cleanup and repair is often the prelude to meshing, because flawed or imperfect geometry usually results in mesh failures. Most simulation software has a way of identifying and



The latest release of STAR-CCM+ comes with a feature called Local Surface Remeshing, which allows the user to choose what is remeshed. *Image courtesy of CD-adapco.*

flagging problematic geometry during CAD data import.

"There are many well-known defects in design geometry that can be identified before meshing starts," Chawner explains. "Some of the obvious defects to look for are sliver or degenerate geometry, duplicate geometry, and missing geometry. There are less obvious potential problems such as odd parametrizations of the geometry (speaking specifically here about NURBS). In Pointwise, we take several actions on geometry import up to and including assembly of the geometry into solid models that have allowed the user to go right from geometry import to meshing."

The next step, defeaturing, involves removing small details not critical to the simulation. Automating this portion is trickier. Chawner says the degree of automatic defeaturing possible depends on the requirements placed on the geometry by the meshing technique, the intended use of the simulation, the source of the geometry, and even the phase of the design process you're in.

"Imagine the extreme case of a full-scale submarine, which by most CFD definitions is a very large object," Chawner says. "The Reynolds number of the flow requires a very small near-wall spacing to resolve the boundary layer. Now magnify that by creating an outer boundary around the submarine that's multiple body lengths away. The length scales are now pushing what can be done accurately with double precision floating point operations. Now consider how to deal with tolerancing the gaps between adjacent surfaces in the submarine geometry."

Welch says SIMSOLID is able to bypass defeaturing because it is tolerant of geometric and contact imperfections.

Background and Local Meshing

In 2014, MSC Software launched its Apex software. It supports automatic geometry repair and geometry simplification, plus it constantly regenerates meshes in the background. Hugues Jeancolas, MSC Apex's senior product manager, says: "Mesh regeneration operations are managed by the Apex generative framework, which is optimized for performance and aims at only regenerating local portions of the mesh that are affected by a change."

With some simulation software, a new mesh needs to be regenerated for the entire model every time something changes in the design, even if the change is confined to a small region of the entire design. In such an environment, the computing penalty for design changes can be high.

In the latest release of its STAR-CCM+ software, CD-adapco tackles this with what it calls "Local Surface Remeshing." In a recent blog post, James Clement, STAR-CCM+ product manager, wrote: "Local Surface Remeshing will allow the user to choose what is remeshed, be it a single surface or most of the model, and it will only change the mesh in the area specified by the user. To me this means I can spend more time getting engineering results and less time waiting for a mesh to finish."

The Ongoing Debate with Meshing: Hide or Expose?

NASA's "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences" asserts that "the mesh generation process should be invisible to the CFD user." Chawner ponders: "Invisibility is something even an expert analyst would love to have. Unfortunately, meshing is often a lot more visible than we'd all prefer. Some would say it's not just visible — it's up in your face."

Chawner also cautioned the automated meshing procedure wouldn't be of much help to the user if "it fails quite frequently and when it fails, the user receives no feedback on how to fix it. That's a complete dead end."

There may be a happy medium if the automated systems are designed and implemented by experts in meshing, simulation, and the domain of application. "Those systems should have limits on their applicability that are well known through validation and verification and well communicated to users," Chawner says.

The meshing needs of different application domains such as CFD and structural mechanics are vastly different, Welch says. "For structures, a tightly integrated method that closely links model preparation, analysis and automatic solution refinement is a more efficient and robust way to approach the problem," he says. "By controlling the entire simulation workflow, more automation is possible than with a loosely coupled mesh-solve approach."

Some experts see hope for success in template-driven, app-like simulation for well-defined, repeatable scenarios. For example, simulation apps for turbine blades or transport aircraft with wings. "The simple act of narrowing the field of application vastly improves the odds of automating a system," Chawner reasons. **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. Email him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook.*

INFO ➜ **CD-adapco:** CD-adapco.com

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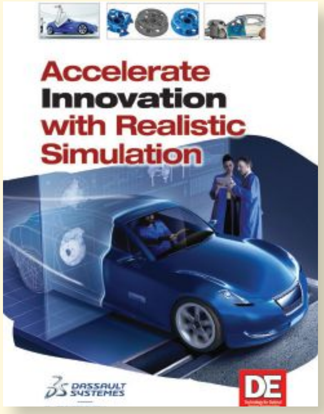

This 12-page digital supplement to *Desktop Engineering*, sponsored by Dassault Systèmes, shows how Transportation & Mobility manufacturers can use Realistic Simulation powered by a collaborative platform to meet their unprecedented product complexity, collaboration and timeline challenges.

Check out the articles, videos and case studies in this digital issue at deskeng.com/de/transportation.

The transportation industry is facing the most significant disruptions since the transition from carriages to motorcars. Advances in technology, new materials and heightened customer expectations are raising the innovation stakes and fostering a more symbiotic relationship between OEMs and suppliers as they try to outpace the competition.

The supplier role is rapidly shifting from servicing original equipment manufacturer (OEM) design directives to becoming a strategic collaboration partner driving new vehicle innovation. Trends such as hybrid and electric powertrains, onboard consumer electronics and autonomous vehicle operation fuel a level of specialized complexity that has many OEMs pushing to share research and design responsibility with suppliers.

These close-knit partnerships are being forged against the backdrop of a market changing at a frenetic pace via new government regulations, consumers' focus on value purchases and shorter time-to-market cycles. According to market research firm IHS Automotive, new vehicle model launches will increase from 35 in 2016 to 47 in 2019 — a surge of about 25%.

To effectively engage in a more tightly-integrated relationship, suppliers and OEMs must leverage technology and establish better global collaboration processes that can support requirements management, engineering changes, compliance tracking and product data management while providing visibility into performance, quality, reliability and safety of components and subsystems. This requires an open, robust platform tuned for innovation so they can successfully and rapidly navigate the industry changes as a strategic co-pilot along side of OEMs.

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A Closer Look at Displays

New display options can give designers a more realistic and comfortable view of their work.

BY BRIAN ALBRIGHT

The HP Zvr display, part of the company's approach to "blended reality" within the design process. *Image courtesy of HP.*

Designers on the market for a new workstation spend a lot of time making sure they've got the right graphics cards, the right applications and enough computing horsepower to do their work as efficiently as possible. One sometimes overlooked element of the workstation, however, is the display panel. Display technology is rapidly evolving, however, and it is increasingly important to make sure the monitor is matched correctly to the workstation, the applications, and the type of work the user is doing. Not doing so can lead to frustrating latency issues, as well as clarity and even ergonomic problems.

There are three basic types of display panels available: twisted nematic (TN), vertical alignment (VA), and in-plane switching (IPS). TN panels are the oldest and most commonly available, but for designers, the experts *DE* spoke to recommend IPS monitors, which typically offer better color reproduction and better viewing angles.

Beyond monitor type, there are a number of other key considerations to take into account when selecting a new display.

Resolution. When it comes to resolution (the number of distinct pixels that can be displayed in each dimension), higher is generally better when it comes to design work. The higher the pixel density, the more detail you can see on the screen.

"To do detailed work on CAD files and in other application, you need to understand what level of detail you need to be able to drill into," says Michael Turner, product manager at Dell.

For many users, that has meant Quad HD (or 2K) resolution, but the general trend is now toward 4K ultra high definition (UHD) displays. Both your applications and your workstation hardware have to be able to support that resolution in order to see any benefit, however. "Be aware that if you are using a graphics card that is a few yeas old, it probably can't drive the 4K displays," says Art Marshall, product manager at NEC.

"For design, you want to go with more resolution and a larger display," says Rodrigo Mancilla, product manager at Lenovo. "You can improve your work by being able to look at the full project instead of having to constantly navigate across the design."

There are also 5K displays, but they haven't gained much market traction because there isn't as much noticeable difference between 4K and 5K displays. The next big shift upward in resolution will likely come in the form of 8K displays — although the benefit of that upgrade is more apparent with larger-than-desktop displays.

Size. How big a panel you can use is more often dictated by available space, but larger displays allow you to see more of your work with less scrolling. "A 27-in. display is not that much larger than a 24-in. display physically, but it does make a difference in CAD applications," says Greg Staten, chief architect, Professional Display Business at HP. "That bit of acreage gives you better resolving detail when looking at a model."

Aspect ratios (the width and height) are largely standardized at 16:9 (or in some cases, 16:10), but there are some other options emerging that designers should keep an eye on. "We're now seeing a trend toward 21:9 ultra-wide panels, but there are not a lot of applications that can support that yet," says Jenny Lai, product manager at BenQ North America.

Size also affects the number of monitors on a designer's desk. Dual monitors are increasingly common (in some set-ups, design applications are displayed on one unit, while other applications are relegated to others). If you want additional monitors, then having a graphics adapter with multiple outputs is becoming standard in the industry," Mancilla says. "We see a day not too far away when users will go from dual monitors to quad monitors."

Thin-bezel designs are also making it easier to align two or even three monitors side by side for a multi-display arrangement that allows you to view a full image across all screens.

Ergonomics. Size also has an effect on ergonomic considerations. The monitor should be a reasonable distance from your eyes, and offer enough tilt and rotation so that it can be effectively adjusted. The brightness of the panel should be equivalent to the lux in the environment to reduce eye fatigue. If the display is brighter than the ambient environment, it can cause eyestrain.

"Having the ability to do a proper tilt and proper size adjustment is a big deal, and one of the mistakes people make is putting their displays up too high," Staten says. "The display should be just below eye level, so you are looking down at the display rather than straight ahead or up."

Color Accuracy and Contrast Ratio. As noted before, IPS panels have greater color accuracy and better viewing angles. "IPS panels give you the best overall contrast ratio and color reproduction," Marshall says. "If you are looking at simulations and stresses, being able to see color accurately is very important."

Larger displays with good off-axis performance are critical for collaboration as well, because more viewers gathered around a display can see an accurate representation of the picture.

"If the contrast ratio is not good, you can't see crisp details, and it would be harder to manage your work," says Lai. "In the design field, you need color-accurate monitors."

This has become more important over time. HP now offers its Dreamcolor displays with factory calibration and better color accuracy out of the box. Dell offers color-critical (10-bit) and non-color-critical (8-bit) monitors, with a roughly $200 difference between them. "If you don't need the color-critical performance, you could purchase a product that delivers comparable performance for less," Turner says.

Connectivity. How you connect the monitor to the workstation and other peripherals also affects performance. Most manufacturers have standardized on DisplayPort (which has replaced VGA, DVI and other standards). There are some users that require HDMI. Other emerging possibilities include USB Type-C and Thunderbolt.

Critically, you have to have enough throughput from the workstation to the display to support the resolution of the monitor. "You have to have the connectivity to get the right resolution," Dell's Turner says. "Just because you have DisplayPort doesn't mean you can support 4K at 60Hz. Understanding the throughputs on the connections is important. If you have a 4K display and get a 30Hz refresh [rate], that latency is going to be discouraging."

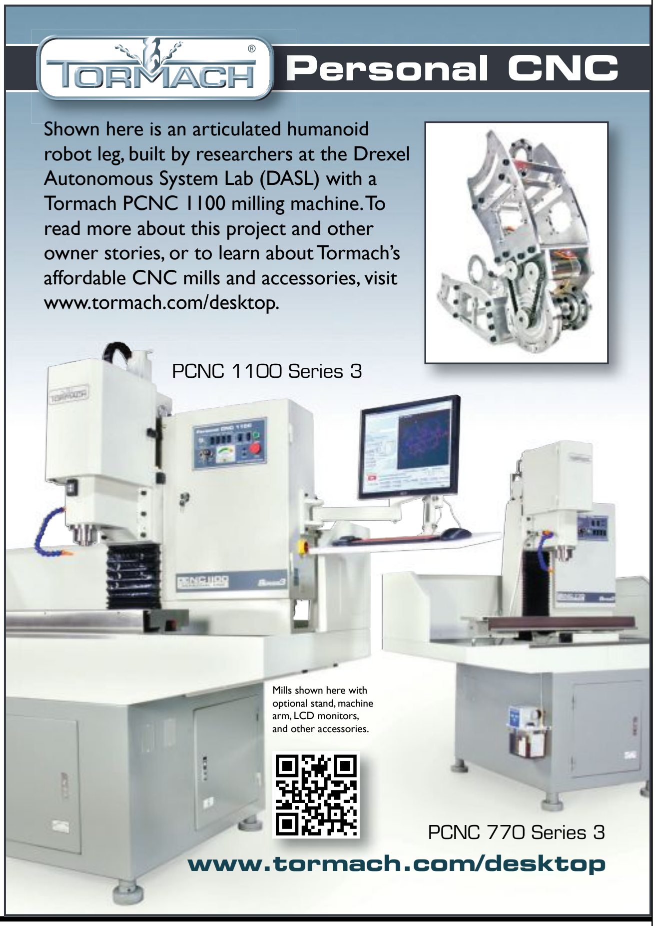
Thunderbolt and USB Type-C allow for data and video via the same connector, but these options are more expensive than HDMI and DisplayPort, and there aren't yet many video cards that support USB Type-C.

Eventually, most monitors will have USB 3.0 ports on them so users can connect high-speed peripherals directly to the monitor. Thunderbolt makes it possible for a monitor to serve as a hub for multiple devices, including high-performance storage. How you plan to use the hardware will drive decisions about connection technology.

"Investigate how you are going to set things up beforehand," Turner says. "If you need PCI pass through to run a large external storage drive, then you have to be equipped for that. Understand the docking scenario or connectivity scenario before investing in USB Type-C or Thunderbolt."

Application Support. This is another evolving consideration. While more people are buying 4K resolution displays, not all software can support that resolution. In particular, text and icons might be difficult to view on older Windows systems because of scaling issues.

"Windows 10 has helped with those applications that have been updated for high pixel density displays," HP's Staten says. "If they have not been updated, then the icons are very small, which makes some tools difficult to use. Text can also look very fuzzy and indistinct, which contributes to eye fatigue. You need to have a proper scaling engine."



Dell's UltraSharp U2717D has InfinityEdge bezels for super-thin bezel design. *Image courtesy of Dell.*

The current trend for CAD/CAM applications is to use ultra high definition (UHD) displays. *Image courtesy of NEC.*

Important Trends

Over the next few years, vendors anticipate continued demand for larger displays and higher resolution, including more interest in UHD displays, larger display size and higher resolution. There is increasing demand for 4K UHD screens and high-dynamic-range (HDR) imaging displays.

HDR panels provide incredible levels of detail and much better blacks and whites. However, the displays are more expensive.

"I think HDR is going to start being adopted more in the video production and photography area rather than design," Marshall says. "But in five years we may see more mainstream models coming out with that option."

"HDR can give you a very high contrast ratio, and they are good for media and entertainment where you want to be able to show a wide dynamic range that a digital camera can capture," Staten says. "The challenge I see in an office is wrapping your brains around what the user needs to see. We know that a bright image is fatiguing. It could be useful for fly-throughs or presentations to customers."

Another emerging technology that likely won't have much impact on the market for another few years is OLED (organic light emitting diode). Most current panels use liquid crystal display (LCD) technology. OLED doesn't require a backlight to function, and can provide power savings as well as much higher refresh rates (up to 1KHz) and vivid contrast and black levels.

However, OLEDs are more difficult to manufacture and present a few other challenges. According to Marshall at NEC, OLEDs present color reproduction and fidelity challenges over time because the OLEDs burn out more quickly based on the type of content you put on the screen. Very bright or white content can fade the screen faster.

"There is a big challenge with differential aging," Staten adds. "The red, green and blue OLED material decomposes as you push voltage through it, and the crystals do so at different rates. That can't be color corrected out because it happens on a per-pixel level."

It could be another two years before OLED displays are available for standard workstations, although Dell has already debuted its first OLED UltraHD panel, the UltraSharp 30 UP3017Q, which will retail for around $5,000. It can display 1.07 billion colors, and is rated at 100% of the AdobeRGB color space, and 97.8% of the DCI-P3 color space.

That focus on contrast and color will likely supplant resolution, which appears to have hit a wall in terms of user requirements. "You can only go so far in terms of density before the human eye cannot perceive the benefit," Mancilla says. "Going from 4K to 5K, there isn't much of a difference. 8K is impressive, but you really have to have a large display. If you are using a 24-in. monitor, you probably won't see much of a difference."

Also, 5K nor 8K displays are supported with a single display port; you have to have two or four display port inputs.

Better color presentation, on the other hand, has a direct impact on design and simulation work. "We're seeing a trend toward people adding that dynamic range of image so the human eye can see the differences in the darkest and brightest sections of an image," Mancilla says. "That is an area that will benefit design." **DE**

Brian Albright *is a freelance journalist based in Columbus, 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@deskeng.com.*

INFO ➜ **BenQ:** BenQ.us

➜ **Dell:** Dell.com

➜ **HP:** HP.com

➜ **Lenovo:** Lenovo.com

➜ **NEC:** NECDisplay.com

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

And Now for Something Completely Different

The Xi MTower CX workstation is a powerful over-clocked system in a curious cube-like case.

BY DAVID COHN

Last year, California-based @Xi Computer Corporation (pronounced "at-ex-eye") shipped us an updated version of its over-clocked tower PCIe workstation (see deskeng.com/de/?p=22421). This time around, the company sent us something different. Unlike traditional towers, which are typically tall and narrow, the Xi MTower CX workstation that arrived at our test lab was nearly a cube. And its shape proved to be just one of its unique qualities.

Housed in a Carbide series AIR240 case manufactured by Corsair, the Xi MTower CX measured 10.2x15.6x12.6 in. (WxDxH) and weighed in at 23 lbs. The front panel is split almost equally down the center. Six air intake grilles with the @Xi logo in the center fill the left side and conceal a radiator with a pair of 120mm fans, while a nearly blank panel occupies the space on the right. An illuminated power button sits nearly centered in the blank panel, flanked by a reset switch and hard drive activity light to its left, with microphone and headphone jacks and a pair of USB 3.0 ports to the right. There is no provision for any front panel drive bays — the first time we have ever seen this (or the lack thereof) on anything other than a mobile workstation.

The front panel air grilles appear to wrap around onto the top of the case where they conceal a second pair of 120mm fans. Removing the top panel reveals three SSD (solid-state drive) bays with removable plastic trays. Removing a cover on the rear panel exposes three similar bays for 5.25-in. hard drives. There is yet a fifth fan behind the rear panel.

The rear panel also provides a PS/2 mouse/keyboard port, two USB 2.0 ports, a USB BIOS flashback button, two USB 3.1 ports, four USB 3.0 ports, two RJ45 network jacks, an optical S/PDIF out port and five audio jacks including line-in, line-out/front speaker out, microphone, center/subwoofer and rear speaker out. The NVIDIA graphics card in our evaluation unit


The rear panel of the Xi MTower CX workstation provides lots of expansion options. A removable panel reveals three 5.25-in. drive bays. *Image courtesy of David Cohn.*


The Xi MTower CX workstation is housed in a rather distinct Corsair Carbide Series AIR240 case, which has no externally accessible drive bays. *Image courtesy of @Xi Computer.*

Single-Socket Workstations Compared

	Xi MTower CX one 3GHz Intel Xeon E5-1660 v3 8-core CPU over-clocked to 4.1GHz, NVIDIA Quadro M5000, 16GB RAM	**BOXX APEXX 2 2401** one 4GHz Intel Core i7-4790K 4-core CPU over-clocked to 4.5GHz, NVIDIA Quadro K5200, 16GB RAM	**Digital Storm Slade PRO** one 3.1GHz Intel Xeon E5-2687W v3 10-core CPU, NVIDIA Quadro M4000, 32GB RAM	**Computer Direct Volta Pro** one 4GHz Intel Core i7-4790K quad-core CPU, NVIDIA Quadro K5200, 16GB RAM	**Xi MTower PCIe** one 3.7GHz Intel Core i7-5930K 6-core CPU over-clocked to 4.32GHz, NVIDIA Quadro K5200, 16GB RAM	**Lenovo P300** one 3.6GHz Intel Xeon E3-1276 v3 quad-core CPU, NVIDIA Quadro K4000, 8GB RAM
Price as tested	$4,997	$5,806	$6,187	$4,441	$4,985	$2,072
Date tested	1/25/16	1/30/16	10/18/15	7/12/15	12/13/14	11/9/14
Operating System	Windows 7	Windows 7	Windows 10	Windows 7	Windows 8.1	Windows 7
SPECviewperf 12 (higher is better)						
catia-04	126.16	133.05	78.54	103.66	98.53	38.19
creo-01	107.44	108.3	65.60	91.62	86.66	34.31
energy-01	11.65	11.44	6.31	3.73	3.49	0.65
maya-04	97.68	101.53	63.79	75.92	72.18	32.31
medical-01	45.78	45.12	25.99	31.33	28.84	12.38
showcase-01	61.65	60.37	42.26	49.76	48.98	22.64
snx-02	219.48	121.01	74.62	152.32	150.42	36.79
sw-03	149.88	158.22	110.74	134.67	126.08	69.37
SPECapc SOLIDWORKS 2013 (higher is better)						
Graphics Composite	2.83	3.20	2.16	11.24	8.82	6.29
RealView Graphics Composite	3.64	4.11	2.77	13.32	10.03	6.88
Shadows Composite	3.69	4.17	2.80	13.37	10.05	6.89
Ambient Occlusion Composite	8.48	9.57	6.44	28.08	17.58	9.65
Shaded Mode Composite	2.77	3.13	2.10	11.25	8.95	6.17
Shaded with Edges Mode Composite	2.90	3.28	2.21	11.22	8.69	6.41
RealView Disabled Composite	1.04	1.18	0.80	5.69	5.28	4.39
CPU Composite	4.92	5.11	3.39	4.87	4.50	4.18
Autodesk Render Test						
Time in seconds (lower is better)	25.30	41.88	47.33	50.83	42.33	64.08
SPECwpc v2.0 (higher is better)						
Media and Entertainment	3.84	3.52	3.67	n/a	n/a	n/a
Product Development	3.38	3.06	3.89	n/a	n/a	n/a
Life Sciences	4.19	3.65	4.46	n/a	n/a	n/a
Financial Services	2.59	1.54	2.55	n/a	n/a	n/a
Energy	4.37	3.17	4.57	n/a	n/a	n/a
General Operations	1.78	1.99	1.47	n/a	n/a	n/a

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

Buy it or Build it Yourself?

Because the @Xi MTower CX is built using readily available parts, we priced out the individual components from reputable online retailers. Had we assembled an identical system, the parts themselves would have cost $4,097, a savings of less than 20%. Considering the skill, confidence and time required to complete such a project, having the finished product delivered to your door with a three-year warranty is likely money well spent.

also provided four DisplayPorts, a DVI-I connection, and a 3D stereo jack.

While built-in Wi-Fi is something not typically found in workstations, the Xi MTower CX breaks that rule as well. The ASUS X99-M WS motherboard provides 802.11 a/b/g/n/ac and supports dual-band frequencies of 2.4 and 5GHz as well as Bluetooth 4.0. Three tiny jacks on the rear panel provide connections for a small external antenna with a 30-in. cable that you can place on top of the computer or on your desk.

Abundant Options

The Xi MTower CX has a base price of $1,199. That buys you a quad-core Xeon CPU, 4GB of RAM, an entry-level NVIDIA NVS graphics card, 500GB hard drive, keyboard and mouse. But as we have come to expect from @Xi, there are lots of options. For example, you can choose any of eight different CPUs and our evaluation unit was equipped with an eight-core Intel Xeon E-1660 v3 Haswell processor. Although this CPU typically runs at 3.0GHz, with a maximum 3.5GHz turbo speed, ours came over-clocked to 4.1GHz and cooled using a Cooler Master sealed water cooling system with its dual fan radiator concealed behind the front panel (adding $1,399 to the system price).

Instead of a solid panel, the left side of our Xi MTower CX case included a clear plastic window, providing a view of the inside. The internal space is split by a backplane, which aligns with the division of the case's front panel. You can remove the left side panel to access the half housing the motherboard and the right side panel to access the power supply and a fair amount of empty space. Due to the power demands of our system, @Xi included an 850 watt Rosewill Glacier 850M 80 Plus Bronze certified power supply, which added $65 to the overall cost.

The motherboard includes a single LGA2011-v3 processor socket flanked by four DIMM (dual in-line memory module) slots. Although the system supports up to 64GB of unbuffered or ECC memory, our unit came with 16GB, installed as a pair of 8GB Corsair Vengeance LPX 2666MHz modules (adding $109).

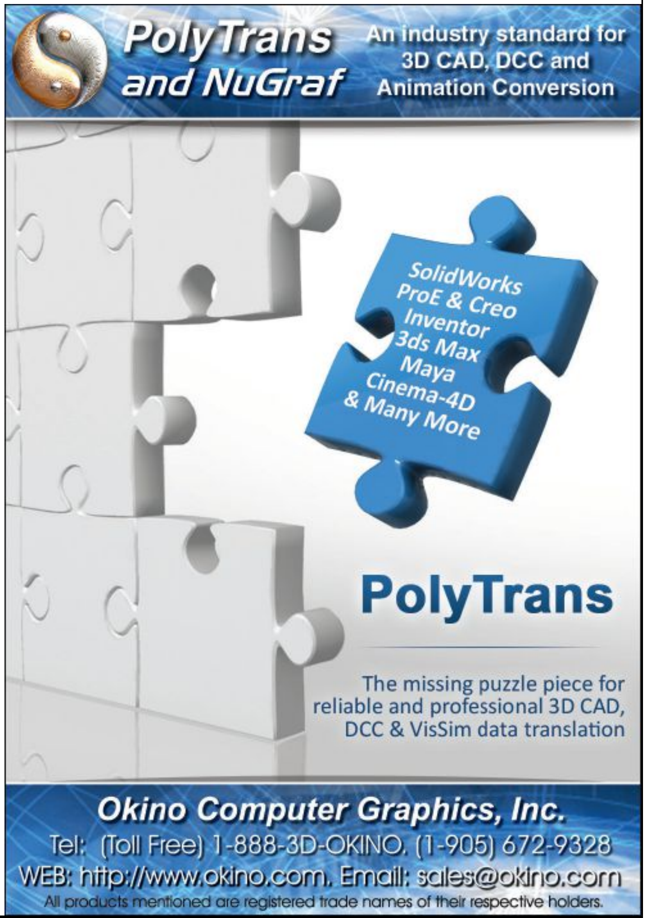
There are also three PCIe X16 3.0 expansion slots and one PCIe 2.0 slot. @Xi offers a choice of 17 different NVIDIA graphics boards. Ours included an NVIDIA Quadro M5000 GPU (graphics processing unit) installed in one of the PCIe 3.0 slots. Based on NVIDIA's latest Maxwell architecture, the Quadro M5000 features a 256-bit interface and provides 8GB of dedicated GDDR5 memory and 2048 CUDA (compute unified device architecture) parallel processing cores while delivering a bandwidth of 211GB/sec. Because the M5000 consumes up to 150 watts, it requires an auxiliary power connection. Its thickness also means that it blocks the adjacent PCIe 2.0 slot, with the board's optional 3D stereo connector routed to the adjacent rear panel bracket. The M5000 added $1,659 to the system price. The Xi MTower CX can accommodate up to two Quadro boards, or one GPU and an NVIDIA Tesla board.

Storage choices include conventional hard drives of up to 4TB as well as solid state drives ranging from 250GB to 2TB. For our review, @Xi included a 256GB Samsung M.2 PCIe 3.0 solid state drive ($229) hosting the operating system and a 1TB 7200rpm Seagate Barracuda SATA drive for data storage (a $29 upgrade from the base configuration).

Although the case makes no provision for an optical drive, @Xi sells external USB DVD-Writer and Blu-ray Writer drives for $69 and $119, respectively. But we found the identical drives from other online retailers at $24 and $80.

Blazing Performance

With its SSD, the @Xi workstation booted up very quickly. But its seven fans (including those on the GPU and power supply) and



a case lacking acoustic damping results in a noisy system. The Xi MTower CX averaged 38dB at rest (compared to 29dB ambient background noise), increasing to 46dB during heavy compute loads (about equivalent to a typical office conversation).

Thanks to the NVIDIA Quadro M5000 GPU, the Xi MTower CX workstation performed great on the SPECviewperf benchmark, turning in some of the best results we have ever recorded for a single-socket workstation. On the AutoCAD rendering test, which clearly shows the benefits of multiple fast CPU cores, the Xi MTower CX blew us away, completing the test in 25.3 seconds—faster than any single socket workstation we have ever tested. And on the SPECwpc benchmark, the Xi MTower CX scored at or near the top on every component of this very demanding test.

For our SOLIDWORKS tests, we have recently begun using the SPEC SOLIDWORKS 2015 benchmark. This new evaluation performs nine graphics tests and two CPU tests. Although we have run this test on several mobile workstations, this marks the first time we have done so on a full-fledged workstation. While we therefore have nothing similar to compare it to, the Xi MTower CX turned in excellent results on this new real-world performance evaluation. For comparison's sake, we included the SPEC SOLIDWORKS 2013 benchmark results on page 44.

Although Windows 10 Home is included in the Xi MTower CX base price, for our review @Xi pre-installed Windows 7 Professional Edition 64-bit, adding $179 to the overall cost. Customers can also purchase their system without an operating system or choose Windows 8.1, Windows 10 Professional, or one of eight different versions of Linux. A free one-year license to McAfee AntiVirus Plus as well as one-year usage of the SplashID 8 Pro password manager software is also included. @Xi rounded things out with a Logitech 104-key keyboard and Logitech USB 2-button wheel mouse, but here again, the company offers lots of other options.

The standard Xi warranty includes just one-year coverage on system parts and three years for labor. We always find this type of coverage a bit puzzling, since most of the actual components (hard drive, graphics card, etc.) come with their own three-year warranties. @Xi offers warranties up to five years, and included a full three year parts warranty on our system (a $129 option).

Once all of the extras were tallied, our evaluation unit priced out at $4,997. Considering that price is less than other over-clocked systems we've tested yet beat their performance, the MTower CX once again proves that @Xi delivers plenty of bang for your buck. **DE**

David Cohn *is the technical publishing manager at 4D Technologies. He also does consulting and technical writing from his home in Bellingham, WA and has been benchmarking PCs since 1984. He's a Contributing Editor to Desktop Engineering and the author of more than a dozen books. You can contact him via email at david@dscohn.com or visit his Website at www.dscohn.com.*

INFO → @Xi Computer: XiComputer.com

Xi MTower CX workstation

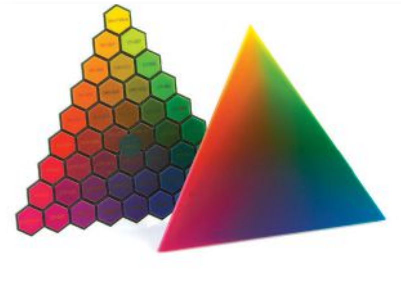
- **Price:** $4,997 as tested ($1,199 base price)
- **Size:** 10.2x15.6x12.6 in. (WxDxH) cube tower
- **Weight:** 23 lbs.
- **CPU:** 3.0GHz 8-core Intel Xeon E5-1660 v3 over-clocked to 4.1GHz
- **Memory:** 16GB DDR4 at 2666MHz
- **Graphics:** NVIDIA Quadro M5000 w/four DisplayPorts and one DVI ports
- **Hard Disk:** 256GB Samsung M.2 PCIe 3.0 SSD and 1TB 7200rpm Seagate SATA HD
- **Floppy:** None
- **Optical:** None
- **Audio:** Integrated HD audio (front panel: microphone, headphone; rear-panel: line-in, microphone, line-out/front speaker out, center/sub-woofer, rear speaker out, and SPDIF out)
- **Network:** Integrated gigabit Ethernet, two RJ45 ports, 802.11 a/b/g/n/ac W-iFi plus Bluetooth 4.0
- **Modem:** None
- **Other:** Six USB 3.0 (2 front/4 rear), two USB 3.1 ports (rear), two USB 2.0 ports (rear), PS/2 keyboard/mouse port
- **Keyboard:** 104-key Logitech USB keyboar
- **Pointing device:** Logitech USB 2-button optical wheel mouse
- **Power Supply:** 850 watts, 80 Plus Bronze certified
- **Warranty:** Three years parts and labor

Advertising Index

by Anthony J. Lockwood

Editor's Picks

Each week, Tony Lockwood combs through dozens of new products to bring you the ones he thinks will help you do your job better, smarter and faster. Here are Lockwood's most recent musings about the products that have really grabbed his attention.



Stratasys Updates Connex 3D Printers

Creative Colors software links Adobe Photoshop to 3D printing capabilities.

Stratasys Creative Colors creates a direct connection between Adobe Photoshop CC (Creative Cloud) digital imaging software and an Objet Connex3 3D printer. It works with Objet Studio software for prepping files for 3D printing, and it now comes bundled with the Objet Connex3 series. It can be added to existing units.

Stratasys Creative Colors offers a direct design-to-3D-print workflow: Users open a design in Photoshop CC, add colors and textures, color preview their work, export and print. The Adobe 3D print engine gives users gradient color palettes with expanded color spectrums and textures.

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FARO Launches Cobalt Array 3D Imager

Non-contact scanner offers LED light projection technology and configurability.

The Cobalt non-contact scanner offers blue LED light projection technology, 5-megapixel stereo cameras and onboard processing.

Another notable capability this imager brings to the shop floor is that you can configure an unlimited number of Cobalt imagers into an array where each unit simultaneously scans while you control the array on one computer. You don't have to do that. You can also just use one Cobalt scanner.

The FARO Cobalt Array 3D Imager has other interesting attributes like user-configurable lenses and a high dynamic range.

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BOXX Offers GoBOXX MXL and SLM Workstations

The systems are now equipped with Skylake GPUs.

These hyper-threaded BOXX offerings can cruise along anywhere from 2.6GHz to 4GHz, depending on the model. With turbo-boosted power when users need it, that 2.6GHz jumps to 3.5GHz. Now, couple that with up to 4GB of Quadro graphics and anywhere from 16GB to 64GB DDR memory, and your SOLIDWORKS modeling or 3ds Max rendering applications should pop.

The GoBOXX can be rigged with 15.6- or 17-in. 1080 pixel panels and even drive up to three additional external displays. Additionally, the GoBOXX SLM weighs in at 4.36 lbs.

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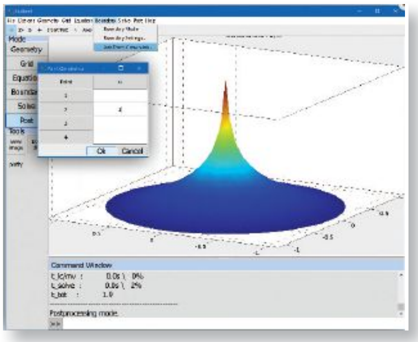

FEATool Multiphysics 1.4 Now Available

Engineering tool offers integration with MATLAB and Octave.

This tool is based on FEA (finite element analysis) for modeling and simulating multiphysics couplings — structural stresses, heat transfer, fluid flows and the like. It is designed to work seamlessly with the MATLAB algorithm development, data analysis and visualization environment or the Octave interpreted language for numerical computing.

What FEATool Multiphysics brings to the engineering toolkit is a suite of functions and subroutines for pre-processing, grid generation, FE model assembly, solvers, post-processing and visualization.

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by Todd McDevitt, *ANSYS*

Designing Better Products Faster

Whether your company is beating the competition to a new market or responding to customer demand, seizing the window of opportunity when customers are most receptive to your product is critical.

Releasing a product at the right time requires engineering and process efficiency — from first concept through final manufacturing. The old practice of developing a design, building a physical prototype, testing, redesigning and then building a new prototype is no longer sustainable. This is especially true as products become more complex, using mechanical, electrical and embedded software subsystems. Not only are physical mockups expensive, testing them tends to find isolated problems rather than address systemic design issues.

Engineering simulation and virtual prototyping have reduced reliance on physical testing and pushed verification activities to earlier in the design. Engineers using these tools assess designs more comprehensively and at a fraction of the time and cost. Simulation will never fully replace physical testing, but it can reduce the number of physical prototypes and testing cycles that are necessary, shaving months off development lead times.

> **To be efficient, simulation has to be applied throughout the design cycle.**

The demand for shorter time to market, however, is relentless. In the automotive industry, average lead times have been reduced from over four years to two and a half years. Yet the industry is pushing to drive this below two years, despite the dramatic increase in product complexity. This trend holds true for almost every industry. Simply applying simulation to verify design and reduce physical testing is not sufficient; simulation has to be applied efficiently throughout the design cycle.

Process compression centers around three main strategies:

1. compressing each design cycle,
2. reducing the number of cycles and
3. parallel — or concurrent — engineering.

At most companies, engineers, designers and analysts spend considerable time performing routine, repetitive tasks and procedures. Often, these procedures differ between teams, are undocumented, or are inconsistent. One way to compress each design cycle is to create custom, repeatable simulation workflows so teams can focus on results and make the best decisions earlier.

High-performance computing (HPC) is paramount for faster design cycles. The growing complexity and size of simulations can bring a well-equipped desktop computer to its knees for hours or even days. HPC enables engineers to create large, high-fidelity models that yield accurate and detailed insight into the performance of a design. Not only can engineers solve larger models faster, but they can also perform more simulations using different design parameters to explore a larger design space.

Consolidation is Key

Compressing the time spent on each cycle is important, but you can attain even greater results by reducing design iterations. An enterprise platform for executing and managing a broad set of simulation applications and performing multi-objective optimization are key to finding the best design, faster. For example, an automotive supplier might need to maximize the heat transfer coefficient of its disk brakes while at the same time meeting braking performance, durability and noise requirements. Finding the design that satisfies all of the requirements involves a variety of engineering disciplines and simulating different physics. Many companies today address this situation by using siloed design teams that deploy multiple tools from separate vendors. This approach is hardly efficient; the Aberdeen Research Group found that reconciling data formats over multiple platforms alone costs companies an average of 3.6 hours per analysis, with some companies reporting a loss of eight hours — an entire workday — per project. With a consolidated simulation platform, designers can effectively execute efficient multiphysics simulations that enable them to make design decisions earlier. Not only do these platforms support multi-objective optimization, but they make it possible to analyze and evaluate trade-offs in complex architectures, requiring fewer iterations per cycle.

And to parallelize design activities, model-based system engineering (MBSE) tools are being adopted to better manage and communicate the complexities of today's product architectures. MBSE principles use living, executable models, rather than static CAD models, documents or spreadsheets as the source of truth for product design. These models provide a thorough understanding of the dependencies, data and interfaces between subsystems so that engineering teams break linear, waterfall development processes and adopt concurrent engineering practices.

By adopting process compression best practices, you can respond to constantly changing market conditions faster and more precisely while designing better, more innovative products for your customers. **DE**

Todd McDevitt *is director, Corporate Marketing, at ANSYS (ANSYS.com). Contact him about this commentary via de-editors@deskeng.com.*

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Join *DE’s* Senior Editor Kenneth Wong in this online discussion of lightweight design technology. Kenneth interviews expert panelists from Lightweight Innovations for Tomorrow (LIFT), CIMdata and Advanced Engineering Solutions to show how simulation and optimization software is keeping pace with new, lightweight materials and manufacturing processes.

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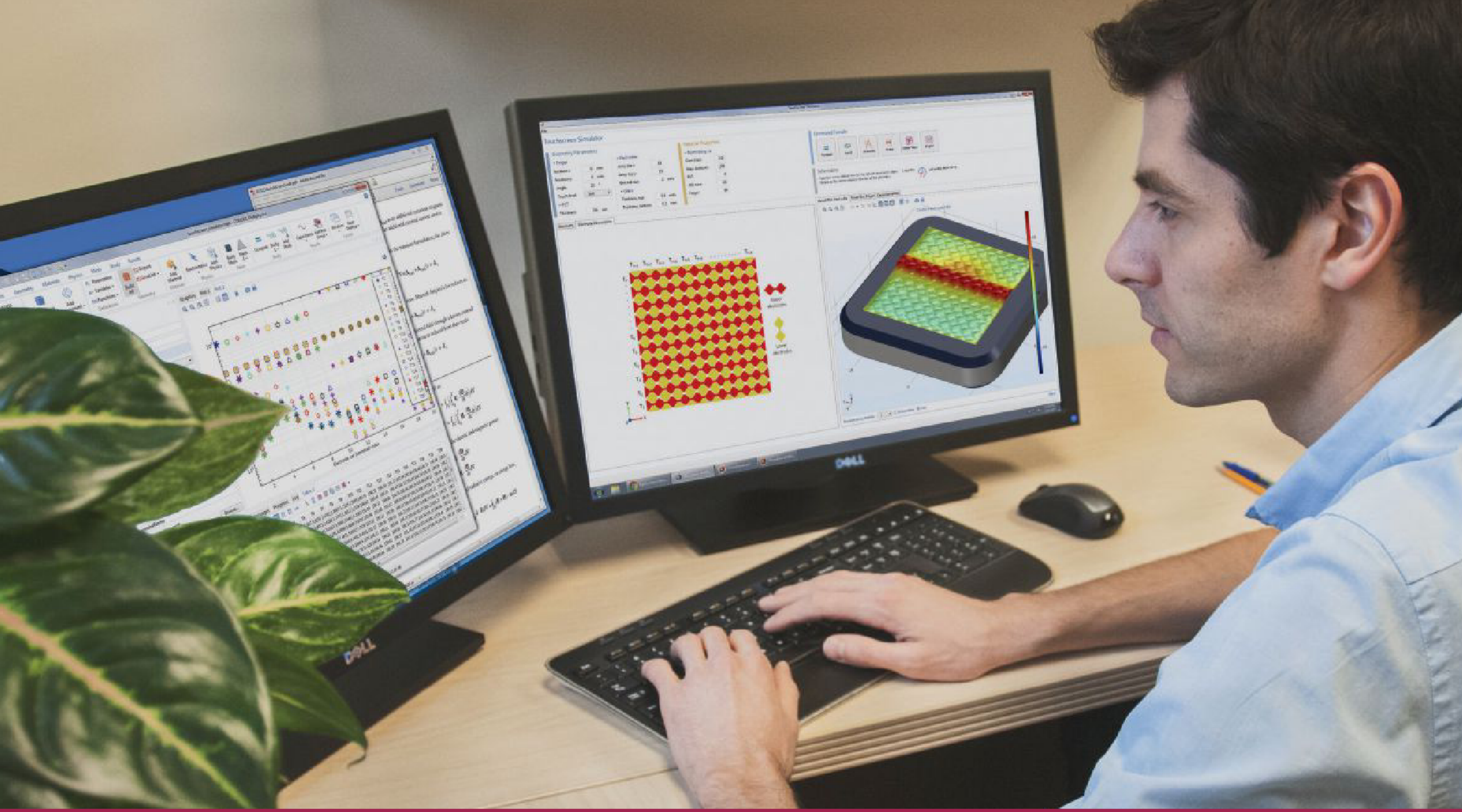

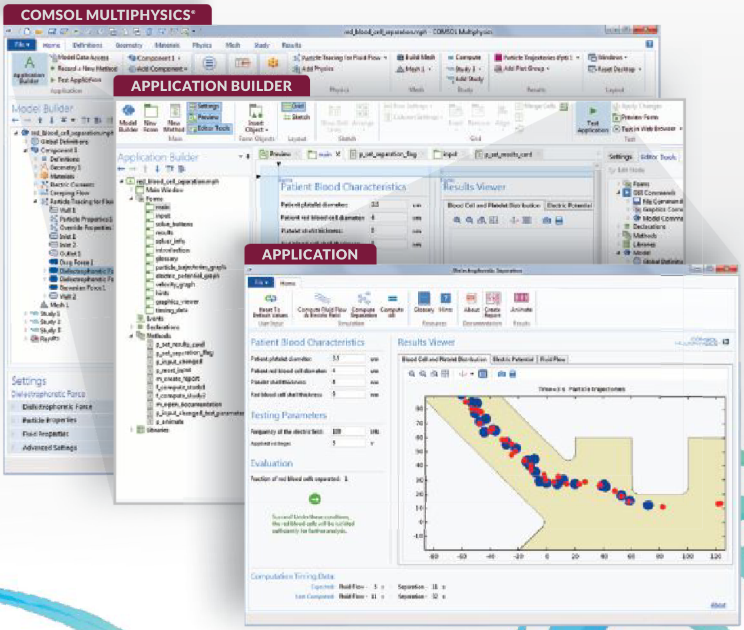
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