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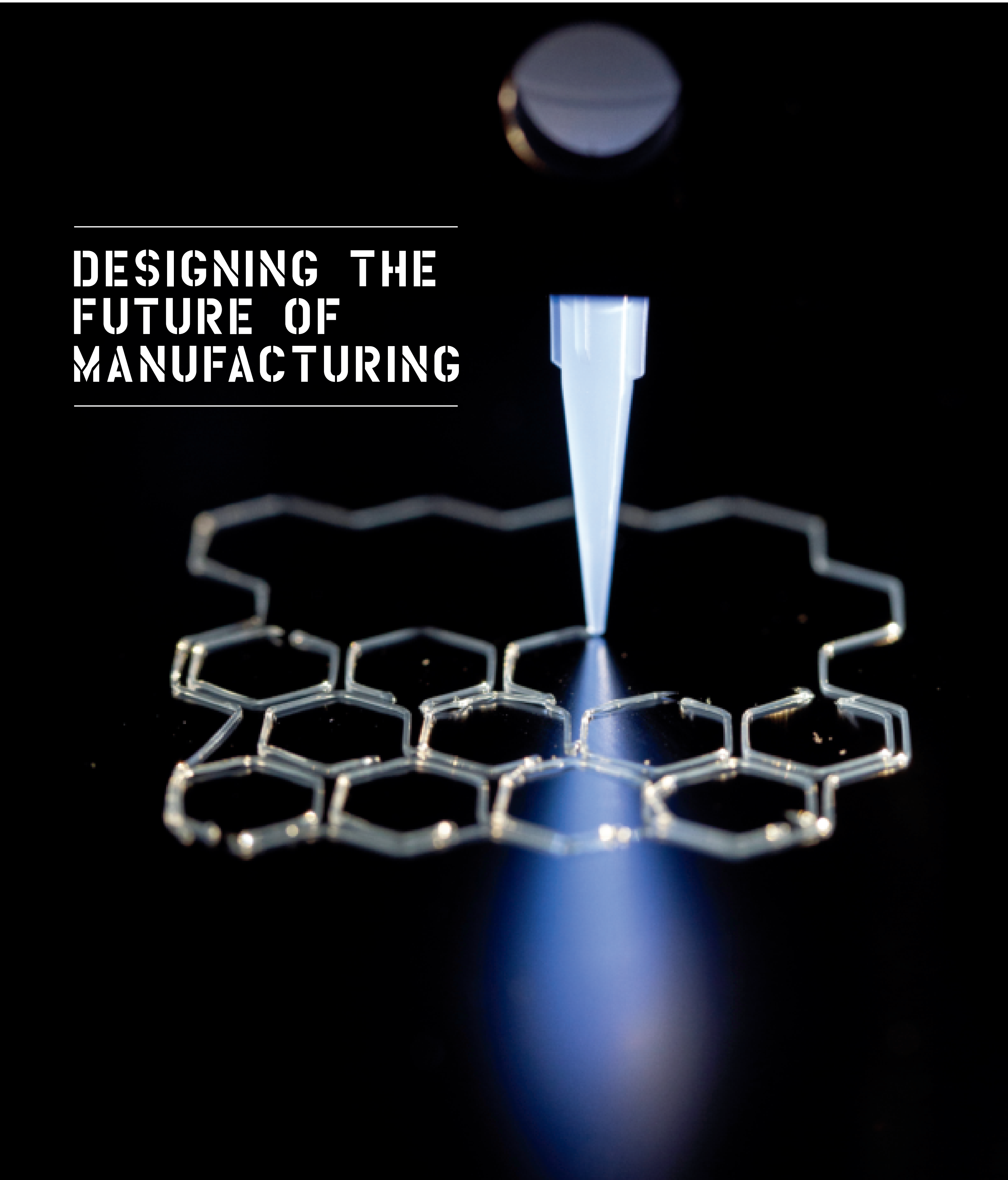
MechEConnects

Summer 2019



DESIGNING THE FUTURE OF MANUFACTURING

MechEConnects
News from the MIT
Department of Mechanical Engineering

Summer 2019 | ► meche.mit.edu

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Third year MechE students Megan Ochalek and Srimayi Tenali pose on a cliff overlooking the Treasury of Petra, one of the Seven Wonders of the World. During MIT’s Independent Activities Period in January, they taught mechanical engineering and design to high schoolers in Amman, Jordan as part of MISTI Global Teaching Labs’ first initiative to teach hands-on STEM to public school students in the Arab World. Credit: Alex Miller

MITMECHE

About MechE

One of the six founding courses of study at MIT, mechanical engineering embodies the motto “mens et manus” – mind and hand. Disciplinary depth and breadth, together with hands-on discovery and physical realization, characterize our nationally and internationally recognized leadership in research, education, and innovation.

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Cover:
Associate Professor Xuanhe Zhao and PhD Candidate Hyunwoo Yuk use 3D printing technologies to create complex 3D structures. Here, a polymer scaffold ink is being printed on a silicon wafer to provide structural support for other ink materials with poorer printability during the 3D printing process. This scaffold ink can be washed away after printing, leaving a complex 3D structure made of hard-to-print materials.

Credit: John Freidah

Dear Alumni, Students, Faculty, Staff, and Friends,

Over the past century, advances in computing, robotics, and materials have revolutionized the way we manufacture the products we use in our daily lives. The traditional factory floor has been transformed into smart spaces where robots and humans interact to efficiently manufacture products. Innovative manufacturing technologies have changed the way designers approach product design – additive manufacturing techniques, for example, have given designers the freedom to iterate and test with unprecedented speed and minimal cost.

Mechanical engineers have been at the forefront of these rapid changes in design and manufacturing technologies. As leaders in user-centered and technology-driven design and manufacturing, MIT's Department of Mechanical Engineering is positioned to innovate in these fields in a way that could have meaningful global impact. For this reason, we have identified "Design and Manufacturing Innovation" as one of our four MechE Grand Challenges.

Our researchers are developing innovative products, systems, and processes that will help address societal challenges in health, security, environment, and sustainability. Professor Timothy Gutowski's Environmentally Benign Manufacturing group is changing the way we analyze the carbon footprint of product life cycles. Principal Research Scientist Brian Anthony designs new instrumentation and measurement systems that can be used in medical diagnostics. In the Laboratory for Manufacturing and Productivity, Professor Martin Culpepper is creating next generation precision machines and mechanisms.

Mechanical engineers have been at the forefront of these rapid changes in design and manufacturing technologies.

Design and manufacturing has also been central to the education we provide our students. For most students, 2.007, Design and Manufacturing I, is their first time designing and building their own prototype. 2.008, Design and Manufacturing II, gives undergraduate students first-hand experience in manufacturing. Professor David Wallace and his team of dedicated staff work to make 2.009, Product Engineering Processes, a realistic window into what it's like to be on a design team at a product development firm. Meanwhile in 2.75, Medical Device Design, Professor Alexander Slocum pairs students with local clinicians to develop a working prototype of a medical device.

In this issue of MechE Connects, we explore new technologies our faculty, students, and alumni are using to innovate in the realm of design and manufacturing. In particular, we explore how advances in manufacturing have revolutionized the design process and unlocked new possibilities in terms of the materials we use and the scale at which we can produce products. We learn about how a number of our researchers have pioneered 3D printing technologies for applications in a variety of fields, view ship design through the eyes of a competitive sailor, encounter three alumnae working at the interface of design and assembly at Microsoft, get a peek into MIT D-Lab's Design for Scale class, and are introduced to the new online MITx Micromasters Program, Principles of Manufacturing.

We hope you enjoy this issue of MechE Connects and thank you for your continued support.

Sincerely,

Evelyn Wang, Gail E. Kendall Professor and Department Head

A New Era in 3D Printing

Seok Kim, a postdoctoral associate in Professor Nicholas Fang's lab, holds up a 3D printed porous substrate that could be used as a catalytic reactor to remove toxic gases in cars and power plants. Credit: John Freidah

MechE researchers are inventing game-changing technologies and developing novel applications in 3D printing.

By Mary Beth O'Leary

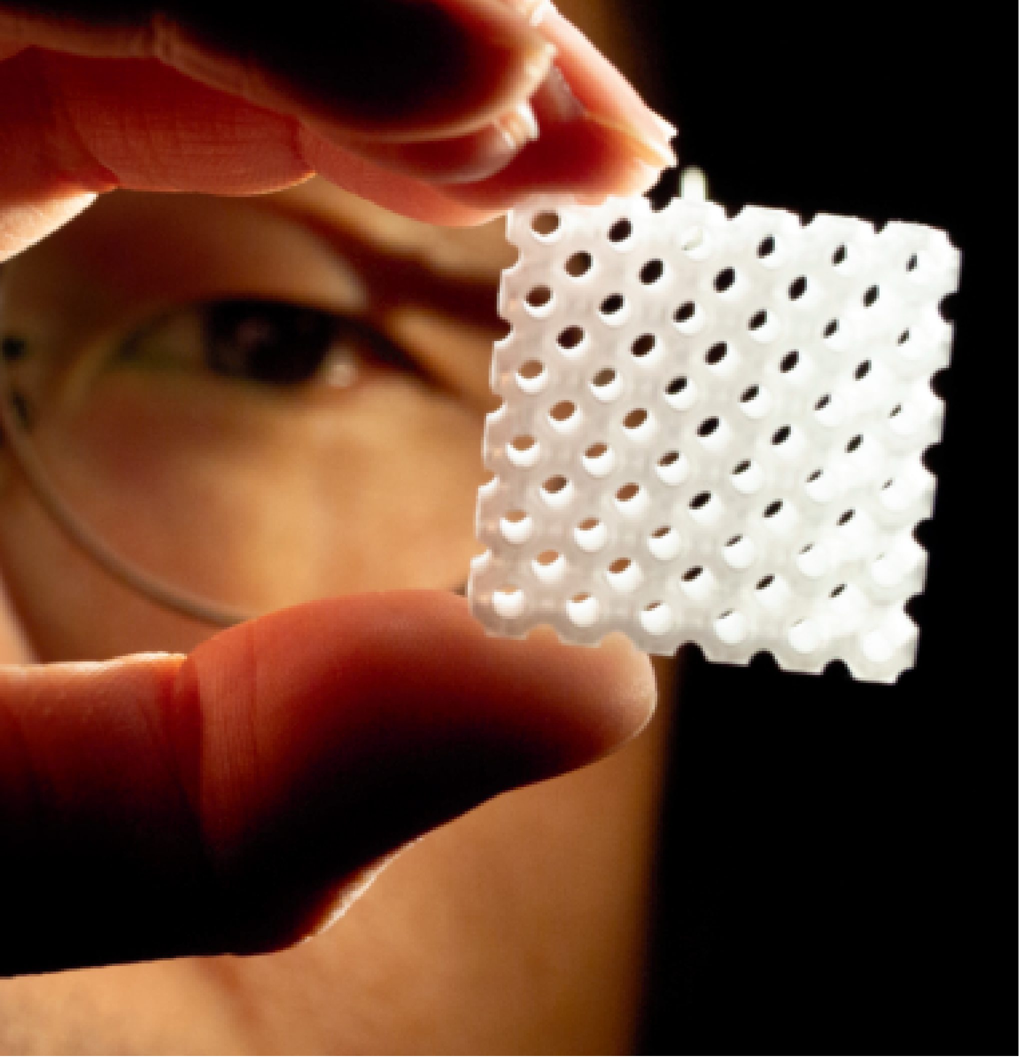
In the mid-fifteenth century, a new technology that would change the course of history was invented. Johannes Gutenberg's printing press, with its movable type, promoted the dissemination of information and ideas that is widely recognized as a major contributing factor for the Renaissance.

Over five hundred years later, a new type of printing was invented in the labs of MIT. Emanuel Sachs, professor of mechanical engineering, invented a process known as binder jet printing. In binder jet printing, an inkjet printhead selectively drops a liquid binder material into a powder bed – creating a three-dimensional object layer by layer.

Sachs coined a new name for this process: 3D printing. "My father was a publisher and my mother was an editor," explains Sachs. "Growing up my father would take me to the printing presses where his books were made, which influenced my decision to name the process 3D printing."

Sachs' binder jet printing process was one of several technologies developed in the 1980s and 1990s in the field now known as additive manufacturing, a term that has come to describe a wide variety of layer-based production technologies. Over the past three decades, there has been an explosion in additive manufacturing research. These technologies have the potential to transform the way countless products are designed and manufactured.

One of the most immediate applications of 3D printing has been the rapid prototyping of products. "It takes a long time to prototype using traditional manufacturing methods," explains Sachs. 3D printing has transformed this process, enabling rapid iteration and testing during the product development process.



This flexibility has been a game-changer for designers. "You can now create dozens of designs in CAD, input them into a 3D printer, and in a matter of hours you have all your prototypes," adds Maria Yang, professor of mechanical engineering and director of MIT's Ideation Laboratory. "It gives you a level of design exploration that simply wasn't possible before."

Throughout MIT's Department of Mechanical Engineering, many faculty members have been finding new ways to incorporate 3D printing across a vast array of research areas. Whether it's printing metal parts for airplanes, making objects on a nanoscale, or advancing drug discovery by printing complex biomaterial scaffolds, these researchers are testing the limits of 3D printing technologies in ways that could have lasting impact across industries.

Improving speed, cost, and accuracy

There are several technological hurdles that have prevented additive manufacturing from having an impact on the level of Gutenberg's printing press. A. John Hart, associate professor of mechanical engineering and director of MIT's Laboratory for Manufacturing and Productivity, focuses much of his research on addressing those issues.

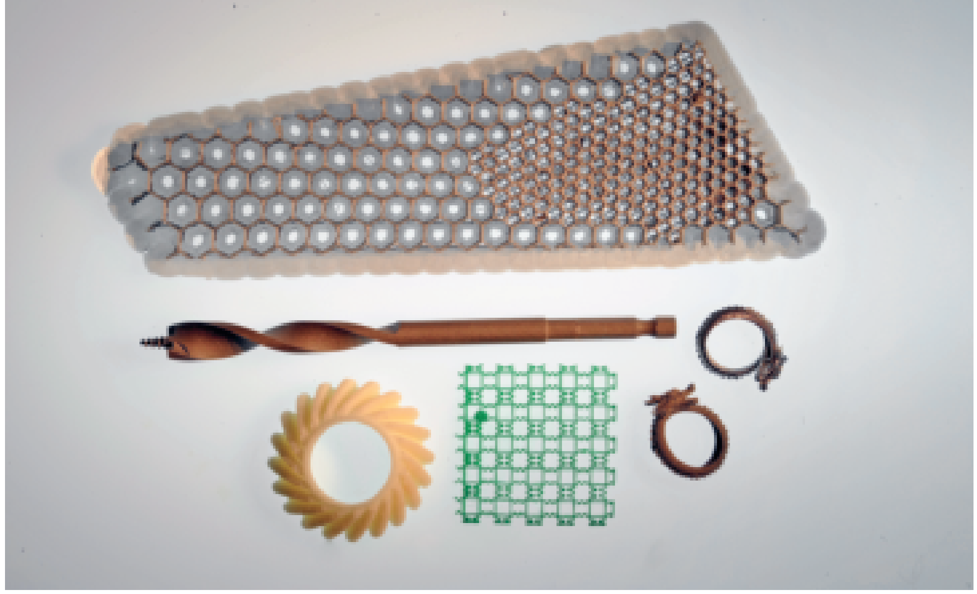
"Some of the most important barriers to making 3D printing accessible to designers, engineers, and manufacturers across the product life cycle are the speed, cost, and quality of each process," explains Hart.

His research seeks to overcome these barriers, and to enable the next generation of 3D printers that can be used in the factories of the future. For this to be accomplished, synergy among machine design, materials processing, and computation is required.

To work toward achieving this synergy, Hart's research group examined the processes involved in the most well-known style of 3D printing: extrusion. In extrusion, plastic is melted and squeezed through a nozzle in a printhead.

"We analyzed the process in terms of its fundamental limits – how the polymer could be heated and become molten, how much force is required to push the material through the nozzle, and the speed at which the printhead moves around," adds Hart.

Each component of this three-piece assembly of MIT's Building 10 dome was printed using a different commercial additive manufacturing process. The piece was modeled after an original design by Ely Sachs and Michael Cima after their invention of binder jet printing. Credit: Felice Frankel



3D printed objects related to Professor John Hart's research including: a scale model of an optimized airplane wing core (top); a metal drill bit and two rings (center and right) produced by Desktop Metal, a company Hart co-founded in 2015; a plastic gear (bottom left), printed on a high-speed machine invented by Hart's lab that is 10x faster than commercial counterparts; and a flexible mesh (bottom center) for use in customized medical braces. Credit: Felice Frankel

Armed with these insights, Hart and his team designed a new printer that operated at speeds ten times faster than existing printers. A gear that would have taken 1-2 hours to print could now be ready in 5-10 minutes. This drastic increase in speed is the result of a novel printhead design that Hart hopes will one day be commercialized for both desktop and industrial printers.

While this new technology could improve our ability to print plastics quickly, printing metals requires a different approach. For metals, precise quality control is especially important for industrial use of 3D printing. Metal 3D printing has been used to create objects ranging from airplane fuel nozzles to hip implants, yet it is only just beginning to become mainstream. Items made using metal 3D printing are particularly susceptible to cracks and flaws due to the large thermal gradients inherent in the process.

To solve this problem, Hart is embedding quality control within the printers themselves. "We are building instrumentation and algorithms that monitor the printing process and detect if there are any mistakes—as small as a few micrometers—as the objects are being printed," Hart explains.

This monitoring is complemented by advanced simulations, including models that can predict how the powder used as the feedstock for printing is distributed and can also identify how to modify the printing process to account for variations.

Hart's group has been pioneering the use of new materials in 3D printing. He has developed methods for printing with cellulose, the world's most abundant polymer, as well as carbon nanotubes, nanomaterials that could be used in flexible electronics and low-cost radio frequency tags.

When it comes to 3D printing on a nanoscale, Hart's colleague Nicholas Xuanlai Fang, professor of mechanical engineering, has been pushing the limits of how small these materials can be.

Printing nanomaterials using light

Inspired by the semiconductor and silicon chip industries, Fang has developed a 3D printing technology that enables printing on a nanoscale. As a PhD student, Fang first got interested in 3D printing while looking for a more efficient way to make the microsensors and micropumps used for drug delivery.

"Before 3D printing, you needed expensive facilities to make these microsensors," explains Fang. "Back then you'd send design layouts to a silicon manufacturer, then you'd wait 4-6 months before getting your chip back." The process was so time intensive it took one of his labmates four years to get eight small wafers.

As advances in 3D printing technologies made manufacturing processes for larger products cheaper and more efficient, Fang began to research how these technologies might be used on a much smaller scale.

He turned to a 3D printing method known as stereolithography. In stereolithography, light is sent through a lens and causes molecules to harden into three-dimensional polymers – a process known as photopolymerization.

The size of objects that could be printed using stereolithography were limited by the wavelength of the light being sent through the optic lens – or the so-called diffraction limit – which is roughly four-hundred nanometers. Fang and his team were the first researchers to break this limit.

"We essentially took the precision of optical technology and applied it to 3D printing," says Fang. The process, known as projection micro-stereolithography, transforms a beam of light into a series of wavy patterns. The wavy patterns are transferred through silver to produce fine lines as small as forty nanometers, which is ten times smaller than the diffraction limit and one-hundred times smaller than the width of a strand of hair.

The ability to pattern features this small using 3D printing holds countless applications. One use for the technology Fang has been researching is the creation of a small foam-like structure that could be used as a substrate for catalytic conversion in automotive engines. This structure could treat greenhouse gases on a molecular level in the moments after an engine starts.

"When you first start your engine, it's the most problematic for volatile organic components and toxic gases. If we were to heat up this catalytic convertor quickly, we could treat those gases more effectively," he explains.

Fang has also created a new class of 3D printed metamaterials using projection micro-stereolithography. These materials are composed of complex structures and geometries. Unlike most solid materials, the metamaterials don't expand with heat and don't shrink with cold.

"These metamaterials could be used in circuit boards to prevent overheating or in camera lenses to ensure there is no shrinkage that could cause a lens in a drone or UAV to lose focus," says Fang.

More recently, Fang has partnered with Linda Griffith, School of Engineering Teaching Innovation Professor of Biological and Mechanical Engineering, to apply projection micro-stereolithography to the field of bioengineering.

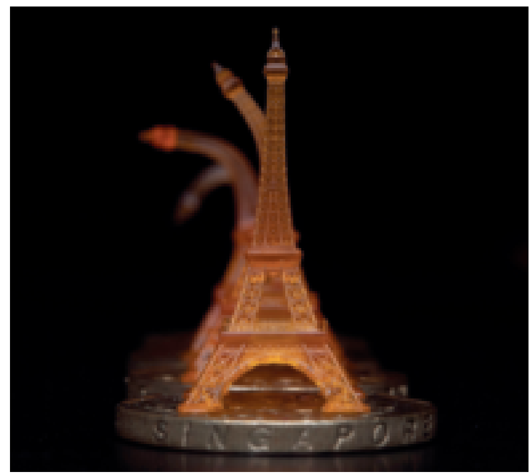
Growing human tissue with the help of 3D printing

Human cells aren't programmed to grow in a two-dimensional petri dish. While cells taken from a human host might multiply, once they become thick enough they essentially starve to death without a constant supply of blood. This has proved particularly problematic in the field of tissue engineering, where doctors and researchers are interested in growing tissue in a dish to use in organ transplants.

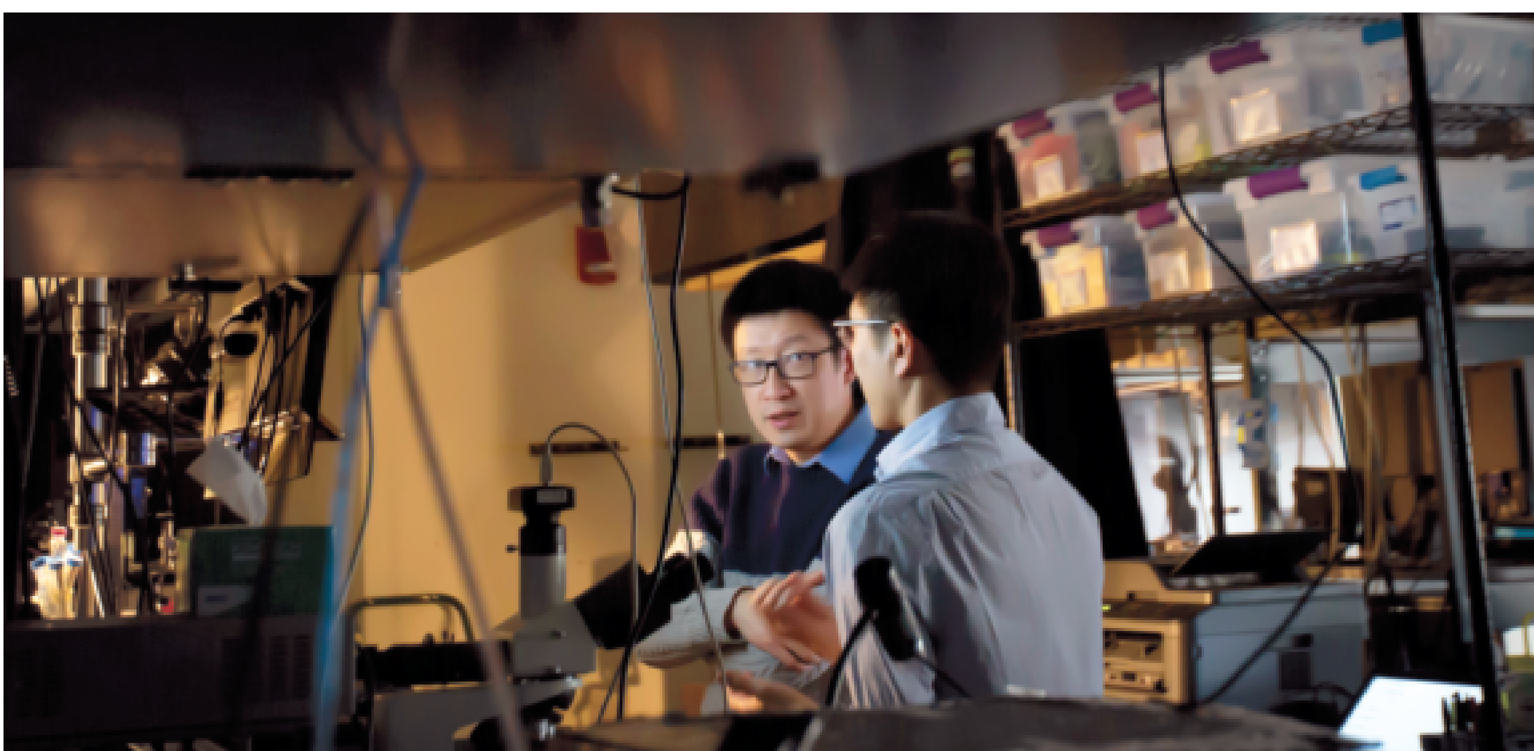
For the cells to grow in a healthy way and organize into tissue *in vitro*, they need to be placed on a structure or 'scaffold.' In the 1990s, Linda Griffith, an expert in tissue engineering and regenerative medicine, turned to a nascent technology to create these scaffolds – 3D printing.

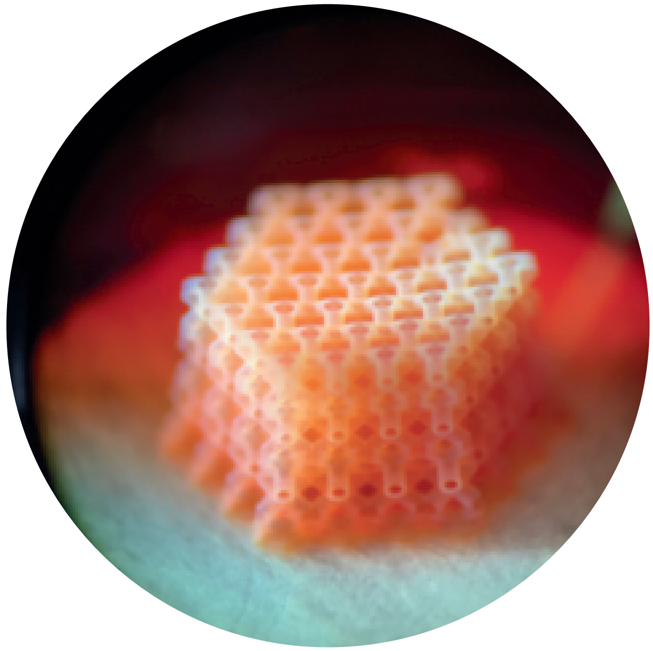
"I knew that to replicate complex human physiology *in vitro*, we needed to make

Using projection microstereolithography 3D printing techniques, Professor Nicholas Fang printed this small Eiffel Tower model that "remembers" its shape after being bent. Credit: Qi (Kevin) Ge



Professor Nicholas Fang speaks with postdoctoral associate Seok Kim in the Nanophotonics and 3D Nanomanufacturing Laboratory. Credit: John Freidah





Using projection micro-stereolithography, researchers in Professor Linda Griffith's lab have printed a scaffold that helps stem cells grow into brain tissue. Credit: Pierre Sphabmixay

microstructures within the scaffolds to carry nutrients to cells and mimic the mechanical stresses present in the actual organ," explains Griffith.

She co-invented a 3D printing process to make scaffolds from the same biodegradable material used in sutures. Tiny complex networks of channels with a branching architecture were printed within the structure of these scaffolds. Blood could travel through the channels, allowing cells to grow and eventually start to form tissue.

Over the past two decades, this process has been used across various fields of medicine including bone regeneration and growing cartilage in the shape of a human ear. While Griffith and her collaborators originally set out to regenerate a liver, much of their research has focused on how the liver interacts with drugs.

"Once we successfully grew liver tissue, the next step was tackling the challenge of getting useful predictive drug development information from it," adds Griffith.

To develop more complex scaffolds that provide better predictive information, Griffith collaborated with Fang on applying his nano-3D printing technologies to tissue engineering. Together, they have built a custom projection micro-stereolithography machine that can print high-resolution scaffolds known as liver mesophysiological systems (LMS). Micro-stereolithography printing allows the scaffolds that make up LMS to have channels as small as forty microns wide. These small channels enable perfusion of the bioartificial organ at an elevated flow rate, which allows oxygen to diffuse throughout the densely packed cell mass.

"By printing these microstructures in more minute detail, we are getting closer to a system that gives us accurate information about drug development problems like liver inflammation and drug toxicity, in addition to useful data about single-cell cancer metastasis," adds Griffith.

Given the liver's central role in processing and metabolizing drugs, the ability to mimic its function in a lab has the potential to revolutionize the field of drug discovery.

Griffith's team is also applying their projection micro-stereolithography technique to create scaffolds for growing induced pluripotent stem cells into human-like brain tissue. "By growing these stem cells in the 3D printed scaffolds, we are hoping to be able to create the next generation of more mature brain organoids in order to study complex diseases like Alzheimer's," explains Pierre Sphabmixay, a mechanical engineering PhD candidate in Griffith's lab.

PhD candidate Pierre Sphabmixay examines a tissue sample in Professor Linda Griffith's lab. Credit: John Friedah

Partnering with industry

For 3D printing to make a lasting impact on how products are both designed and manufactured, researchers need to work closely with industry. To help bridge this gap, the MIT Center for Additive and Digital

Advanced Production Technologies (APT) was launched in late 2018.

“The idea was to intersect additive manufacturing research, industrial development, and education across disciplines all under the umbrella of MIT,” explains Hart, who founded and serves as director of APT. “We hope that APT will help accelerate the adoption of 3D printing, and allow us to better focus our research toward true breakthroughs beyond what can be imagined today.”

Since APT launched in November 2018, MIT and the twelve company founding members – that include companies such as ArcelorMittal, Autodesk, Bosch, Formlabs, General Motors, and the Volkswagen Group – have met both at a large tradeshow in Germany and on campus. Most recently, they convened at MIT for a workshop on scalable workforce training for additive manufacturing.

“We’ve created a collaborative nexus for APT’s members to unite and solve common problems that are currently limiting the adoption of 3D printing – and more broadly, new concepts in digitally-driven production – at a large scale,” adds Haden Quinlan, program manager of APT. Many also consider Boston the epicenter of 3D printing innovation and entrepreneurship, thanks in part to several fast-growing local startups founded by MIT faculty and alumni.

Efforts like APT, coupled with the groundbreaking work being done in the sphere of additive manufacturing at MIT, could reshape the relationship between research, design and manufacturing for new products across industries.

Designers could quickly prototype and iterate the design of products. Safer, more accurate metal hinges could be printed for use in airplanes or cars. Metamaterials could be printed to form electronic chips that don’t overheat. Entire organs could be grown from donor cells on 3D printed scaffolds. While these technologies may not spark the next Renaissance as the printing press did, they offer solutions to some of the biggest problems society faces in the 21st century.

By printing these microstructures in more minute detail, we are getting closer to a system that gives us accurate information about drug development.

Associate Professor John Hart speaks with graduate student David Griggs in front of his lab’s custom-built selective laser melting system. In the system, a laser is precisely scanned over metal powder, melting the powder to form a 3D part layer by layer. Credit: John Friedah

Student Spotlight:

David Larson ’16, SM ’18, PhD Candidate

Solving equations to design safer ships

By Mary Beth O’Leary

David Larson spends much of his time thinking about boats. He has been a competitive sailor since high school. In his free time, he designs and tinkers with boats and is a member of the MIT Nautical Association Executive Committee. As a PhD student in MIT’s Laboratory for Ship and Platform Flows, he works on modeling ship-wave interactions to understand how ships behave in severe storms.

“I think I got into design and engineering through the sailing route,” says Larson. “I wanted to understand the physics of what was happening when I was out on the water.”

It was sailing that first drew Larson, who grew up near the water in San Diego, to MIT. On a trip as a freshman in high school, he stayed at a hotel on Memorial Drive and watched sailboats dart along the Charles River. Four years later, he enrolled at MIT.

Initially intent on studying physics, Larson quickly determined that he was most interested in mechanical engineering and ocean engineering classes. As a sophomore, he took class 2.016, Hydrodynamics, taught by Paul Sclavounos, professor of mechanical engineering and naval architecture. The class would end up shaping the rest of his academic career.

On the second day of teaching 2.016, Sclavounos told students about his experiences designing boats for the America’s Cup. Larson knew some of the sailors with whom Sclavounos had worked. The two struck up a conversation after class, marking the beginning of their collaboration.

“Professor Sclavounos was the most influential in encouraging me to continue studying ocean engineering and naval architecture,” recalls Larson. Sclavounos recognized Larson’s talent and passion, often taking time after class to explain theories that Larson hadn’t yet learned.

“He was by far the best student in the class and was eagerly sought after by other students to help them through the course,” adds Sclavounos. “It was immediately evident to me that he possessed an intelligence and maturity unusual for his age.”

After graduating with his bachelor’s degree in 2016, Larson enrolled in MIT’s graduate program for mechanical engineering and ocean engineering. The summer between his undergraduate and graduate studies, he went back to his native California for an internship with Morrelli and Melvin Design and Engineering.

During his internship, Larson applied the concepts he learned as an undergrad – like controls, geometry optimization, and fluid mechanics – to real-world ship design. “That experience gave me a lot of practical insight into what the actual ship design process entails,” says Larson.

Back at MIT, Larson has spent his graduate studies working with Sclavounos on

David Larson
Credit: Corban Swain

developing stochastic models for how ships interact with waves. While his work seems at times theoretical and abstract, it is grounded in a very real problem: keeping ships safe in extreme weather.

“What I’m doing is motivated by practical ship design and manufacturing,” explains Larson. “I’m working to create a framework that gets more accurate predictions for how ships behave in severe storms and to get those predictions fast enough to use in iterative design.”

Current models have come a long way in enhancing our ability to predict how waves move in the ocean. But many existing models that predict how ships move in waves, while extremely powerful, are constrained to one-or-two degrees of freedom or often use over-simplified hull geometries. Larson hopes to take those models to the next level.

"The key components of our method are that we can take any realistic ship geometry directly from a CAD program, put that geometry through our model that treats the full six degrees of freedom, and get predictions for how these ships will behave in waves," explains Larson.

Understanding how these ships behave in rough water could have immediate industrial applications. In addition to helping sailors find the safest route for their vessels, the predictions could be used to someday facilitate interactive ship design.

"My long-term goal is to eventually create an interface that can be used by design and manufacturing engineers for iterative design and optimization of the next generation of ships," says Larson.

When Larson needs a break from mathematical equations and modeling, he uses CAD to design boats. "My research is quite mathematical, so designing boats is my outlet for reconnecting with the experimental and practical work I loved doing as an undergrad," he adds.

Whether it's designing boats in his spare time, competitive sailing, umpiring collegiate races across New England, helping the MIT Sailing Pavilion design its next fleet of dinghies, or developing a model to predict how ships behave in choppy seas – Larson will continue to pursue the passion for sailing he developed in childhood.

What I'm doing is motivated by practical ship design and manufacturing.

David Larson (far right) skippered the MIT team during the 2013 New England Match Racing Championship.
Credit: Rob Migliaccio

Alumni Profile:

Jacklyn (Holmes) Herbst '10, MEngM '11, Isabella DiDio '16, and Ann McInroy '18

Where design meets assembly: MechE at Microsoft

By Mary Beth O'Leary

Microsoft's sprawling campus in Redmond, Washington houses over 40,000 of its employees. It contains 125 buildings across 502 acres of land. Despite the vastness of its campus, three MechE alumnae found themselves not only in the same building, but working for the same team.

"It's great having a small part of the MechE community here," says Ann McInroy '18, who joined Microsoft as a Design for Assembly Mechanical Engineer in August of last year. "We have this shared experience and knowledge base."

McInroy joined fellow alumnae Jacklyn Herbst '10, MEngM '11 and Isabella DiDio '16 as a member of the DFA – or Design for Assembly – Team. The DFA Team is a part of the overarching DFX – or Design for Excellence – Team at Microsoft.

The DFA Team helps facilitate a product's journey from initial prototype through to mass production. "In the early stages of any product, our team works with the mechanical design team to optimize the parts so they are easy to assemble," explains DiDio.

Once the team has a working prototype of a design, they analyze the product to confirm it can be made at scale. Whether it's a power button on Microsoft's Surface Pro or a screw in the HoloLens headband, the team ensures every component of a product lends itself to manufacturability.

"After the design is finished, we are in charge of outlining all of the steps for mass producing the product in the factory," explains McInroy. "It's a cool 'in-between' stage that not every company has."

While the three often work on different products or different phases of the development cycle, they bring their shared experiences studying mechanical engineering at MIT to help each other solve problems.

"There's a lot of cross-product problem solving on our team," explains Herbst. "If Ann or Isabella are stuck on some part of the process they can come to the team for guidance. Having a strong MechE connection on the team definitely helps us when we are solving those problems."

Herbst was the first to join Microsoft's DFA Team in January 2016. After earning her bachelor's in mechanical engineering in 2010, she enrolled in the Master of Engineering Manufacturing (MEngM) degree program. She worked with Brian Anthony, Principal Research Scientist, on developing a new way of producing electrodes for Daktari Diagnostics.

Herbst then moved-on to Boeing for four years before joining Microsoft. During her time at Boeing, she worked on installation planning for commercial airplanes as well as dimensional management. "At Boeing I was very specialized in what I did, but the

> It's great having a small part of the MechE community here. We have this shared experience and knowledge base.

work I do at Microsoft provides a much broader view of getting a product from design to mass production," adds Herbst. One of Herbst's first tasks was working on the Surface Book i7 model.

Eight months after Herbst started at Microsoft, Isabella DiDio walked into her office. "On my first day, my manager brought me around to everyone's office to introduce me," recalls DiDio. "When he brought me to Jackie's office he told me that Jackie also went to MIT and made us do a fist bump with our MIT class rings."

As an undergrad at MIT, DiDio was most impacted by class 2.008, Design

From left to right: Ann McInroy '18, Isabella Didio '16, and Jacklyn Herbst '10, MEngM '11 stand in front of a wall showing the history of Micrsoft's hardware since the 1980s in Building 88 of Microsoft's campus located in Redmond, Washington. Credit: Rebekah Welch

and Manufacturing II. Students in 2.008 are charged with designing a yo-yo and producing fifty copies. "That class really opened my eyes to manufacturing and the bigger picture of any consumer product," says DiDio. The experience inspired her to pursue an internship on Microsoft's manufacturing team.

After graduating with her bachelor's, DiDio joined Microsoft full time as a DFX Engineer. One of her first projects was working on the Microsoft HoloLens, a holographic computer that users wear like sunglasses.

"For the HoloLens, I helped set the entire assembly flow including the order all the parts are assembled in and instructions for operators at our contract manufacturer," explains DiDio.

About a year after starting at Microsoft, DiDio served as a peer mentor for a group of interns, one of whom was Ann McInroy.

McInroy was inspired by classes like 2.72, Elements of Mechanical Design, taught by Professor Martin Culpepper, to pursue a career in manufacturing. In the class, students design and construct a single prototype of a high-precision desktop manual lathe. "That class built my confidence as an engineer," recalls McInroy. "It helped push me toward a career that incorporated some aspects of design and manufacturing."

While applying for internships, McInroy was drawn to the blend of design and manufacturing offered at Microsoft. As an intern, she helped refine the design of various buttons – such as the power or volume buttons – to ensure they could easily be manufactured at scale.

McInroy joined the DFA Team after graduating from MIT last summer. Being a part of a small tribe of MechE alumnae working on the same team is something she doesn't take for granted.

"I really appreciate having a cohort of women engineers that I belong to here at Microsoft," McInroy adds.

While the trio are at varying stages of their careers and have taken different paths to Redmond, they often draw upon their time at MIT.

"We still talk about some of those MechE connections – we talk about our products in 2.009 or our yo-yos in 2.008," adds Herbst. "That common bond helps us when we are working together."

Class Close-Up:

2.729 Design for Scale

By Mary Beth O'Leary

In 2016, Tanzania passed a bill to cover medical expenses for expectant mothers. But pregnant women in rural parts of the country face a huge obstacle in getting the care they need: reliable transportation. Women in villages that can't be reached by traditional ambulances have to resort to walking for hours to the nearest hospital, often while already in labor, putting their health and safety in danger.

That same year, students and instructors in the MIT D-Lab class 2.729, Design for Scale collaborated with community partner Olive Branch for Children to develop a solution called the Okoa ambulance. "Okoa produces a trailer that can attach to any motorcycle, providing safe transportation from rural areas to hospitals," explains Toria Yan, a senior studying mechanical engineering at MIT.

Seven thousand miles away, Yan and her fellow students in class 2.729 worked on optimizing the design of the Okoa ambulance to minimize production and shipping costs and increase manufacturability.

Throughout the Fall 2018 semester, Okoa was one of four real-world projects students in 2.729 worked on – others included a floating water pump for agricultural irrigation in Nepal, an air quality detector for kitchens in India, and a plastic toilet that provides safe sanitation in densely populated areas of Guatemala.

"This class is unique because all the projects already have working prototypes," explains Maria Yang, class co-instructor and professor of mechanical engineering. "We are asking students to design a way to manufacture the product that's more cost-efficient and effective."

The Okoa ambulance on its first test ride in Mbeya, Tanzania.
Credit: Emily Young/The Okoa Project.

The idea for the class first came from staff and instructors in MIT D-Lab. "We were working with people who were trying to solve some of the biggest problems in the developing world, but we realized that just coming up with a proof-of-technology prototype wasn't enough," explains Harald Quintus-Bosz, lecturer at MIT D-Lab and Chief Technology Officer at Cooper Perkins, Inc. "We have to scale the solution so it can reach as many people as possible."

Scaling solutions for problems in the developing world turned out to be a challenge MIT students were uniquely poised to tackle. The main goal of 2.729 is to teach MIT students who already have analytic engineering skills how to design for manufacturability, come up with assembly methods for products, design in the context of emerging economies, and understand entrepreneurship in the developing world.

For Suji Balfe, a junior studying mechanical engineering, figuring out how to increase manufacturing output in developing countries resonated personally. "I was always interested in engineering for the developing world because my mom comes from a foreign country," she says. "I thought Design for Scale provided an interesting perspective because you're taking products that already exist in some form and making them more practical for a given audience."

Harald Quintus-Bosz (right), a lecturer at MIT D-Lab, helps students identify the material and manufacturing process of a mass produced component in class 2.729, Design for Scale. Credit: Jiani Zeng

Balfe's team worked on a product developed by the company Sensen, which uses dataloggers and sensors that provide information on air quality in kitchens and help researchers determine which cookstoves are safest.

"The devices are all Bluetooth connected, so researchers working in India can upload data to their phones and that is sent to Sensen via the cloud," explains Danielle Gleason, also a junior mechanical engineering student. "Sensen then analyzes huge amounts of air quality data to help evaluate different cookstoves and cooking methods."

Both the Okoa and Sensen teams were tasked with finding ways to make each product easier to manufacture and use. But as far as the location where these devices are produced, the two teams took different approaches.

"One of the first questions you have to answer when designing products for the developing world is where are you going to manufacture your device?" says Quintus-Bosz. Companies and start-ups have to determine whether to manufacture products globally or locally, which is partially a function of the impact objectives of the company.

For Okoa, the team focused on local manufacturing in Tanzania to create ambulance trailers. Their challenge was to find ways to optimize the design so that large parts and subassemblies could be manufactured with capable suppliers within Tanzania and then shipped to rural areas where they would be assembled locally at distribution sites. The team did this by ensuring the trailers could be flat packed and stacked on top of one another. "We optimized the design and changed the geometry of the roof so everything could be quickly assembled on site in Tanzania," adds Yan.

Meanwhile, Sensen utilized manufacturing methods available in the United States – like thermoforming and injection molding – to redesign the enclosure for the device. "We were able to reduce costs and create a box that required minimal screws and attachments using an injection molded bottom piece and a thermoformed top piece," explains Gleason.

From helping people in need of medical attention in Tanzania to improving air quality in kitchens around India, students walk away from the class with a deeper understanding of the unique challenges manufacturing in the developing world poses.

"It's clear that the students who take this class all want to make a social impact," adds Yang. By learning how to scale solutions to increase manufacturability, that social impact can have a far greater reach in the developing world.

Mona Mijthab, the founder of 2.729 client MoSan, demonstrates MoSan's ecological sanitation system to the local community in Guatemala. Credit: Omar Crespo

Talking Shop: David Hardt SM '75, PhD '78

Teaching the principles of manufacturing

The past four decades have been transformative for manufacturing. An explosive growth of new technologies has revolutionized how products are made and distributed. In the 1980s, the steep rise in Japanese manufacturing reshaped the global market. Advances in the fields of automation, robotics, and factory systems have drastically altered the landscape of the traditional factory floor. David Hardt, Ralph E. and Eloise F. Cross Professor in Manufacturing, has had a front row seat to these radical changes.

Hardt joined the faculty in MIT's Department of Mechanical Engineering in 1979 and later served as Director of the MIT Laboratory for Manufacturing for nine years. A leading expert in manufacturing process control, Hardt pioneered new equipment and control techniques in fields such as gas metal arc welding, metal forming in the aerospace industry, and micro-fluidic device manufacture.

Hardt was also involved with the initiation and management of the "Leaders for Manufacturing" (now LGO) program between Sloan School of Management and MIT's School of Engineering, serving as Engineering Co-Director for four years. Drawing from this experience, he noticed that MIT's degree programs weren't adequately preparing engineering students for careers in manufacturing. In 2010, he helped develop MIT's Master of Engineering in Advanced Manufacturing and Design (MEngM), a year-long program that prepares graduate students to be engineering leaders in manufacturing.

Last year, Hardt and colleagues like Sanja Sarma, Vice President for Open Learning, took lessons from the MEngM degree and launched the MITx Micromasters Program in Principles of Manufacturing, an online program about the fundamentals of manufacturing as developed in the MEngM.

How did you decide to spend your career focusing on manufacturing?

Well, when I got to MIT I was enamored with biomedical engineering. I studied muscle force control during walking for my PhD. By the time I graduated, the market was oversaturated and no one was interested in hiring a biomedical engineer. So I took a post-doctoral role in manufacturing at MIT. I had studied control and dynamics in graduate school and started thinking of ways I could apply that to manufacturing. That's when I took the theme of process control and ran with it. In the parlance of controls, I was expanding the control to include the whole manufacturing process – not just the machine itself.

In the forty years since you joined the faculty, what has been the biggest change you've seen in manufacturing?

The level of sophistication has been one of the biggest changes. Manufacturing has become such a highly refined activity globally. Look at any modern manufacturing operation and it has to be one of the most complex technical systems there is on earth.

It used to be that with enough labor, some skill, space, and time, you could make anything and make a profit. But the standards manufacturers are now held to are extremely high. You can't make something with poor quality and high cost and get away with it anymore. Consumers' expectations have really upped the ante.

Rethinking how manufacturing is taught has been a theme throughout your career. How did the MEngM program initially come to fruition?

I started collaborating more with colleagues from the Sloan School of Management as well as managers and operating engineers in industry. It gave me more of a ground truth in what was important in manufacturing. That opened my eyes and in some of the classes I was teaching, I shifted from a purely mechanical engineering approach to a broader, more pragmatic approach that took into account what was really happening in industry.

When the Singapore-MIT Alliance began in 1998, we knew we wanted to collaborate with researchers in Singapore on manufacturing. We developed a novel professional manufacturing degree program in Singapore. For five years, we ran it from a distance. It was a roaring success

Professor David Hardt teaches students in class 2.830, Control of Manufacturing Processes.
Credit: John Freidah

so we realized that there was an opportunity to start a similar program right here at MIT and launched the MEngM program. For our students, it's like a capstone degree. Undergraduate manufacturing classes just scratch the surface – the MEngM really educates students in the theory and practice of manufacturing.

How did you use the lessons you've learned from the MEngM program to shape the MITx Micromasters Program in Principles of Manufacturing?

There are four core classes in the MEngM program that we started calling the 'principles of manufacturing.' We realized that teaching those classes as a unit would provide great utility on their own. Someone working in industry who has a mechanical engineering background could take those classes and it would greatly enhance their ability to work in manufacturing and design. So along with my colleagues Jung-Hoon Chun, Stephen Graves, Duane Boning, Stan Gershwin, Jose Pacheco, and John Liu, I worked with Professor Sanjay Sarma and the MIT edX team to put together eight online courses on manufacturing process control, manufacturing systems, management in engineering, and supply chains for manufacturing. The courses are taught by a seasoned team of faculty from MIT MechE, MIT Leaders for Global Operations Program, and Sloan School of Management.

What are you hoping students will take away from the Micromasters Program?

Everybody knows that the biggest hurdle in manufacturing is the conversion from a groundbreaking idea to actual production. We hope that the program can help professionals across industry surmount that hurdle. Our first year of the program just launched in March 2018, and we have had students from all across the world at varying levels in their career. Our first Micromasters credential should be awarded this fall, and we hope to admit some of them to the MEngM Program. I'm looking forward to hearing more from them about how they plan to implement the skills they learned through the program throughout their careers.

To learn more about the MIT edX Micromasters Program in Principles of Manufacturing, please visit https://micromasters.mit.edu/pom/, and details on the MEngM can be found at http://manufacturing.mit.edu/

News & Awards

Rhodes Scholar Sarah Tress
Credit: Ian MacLellan

Marshall Scholar Crystal Winston
Credit: Ian MacLellan

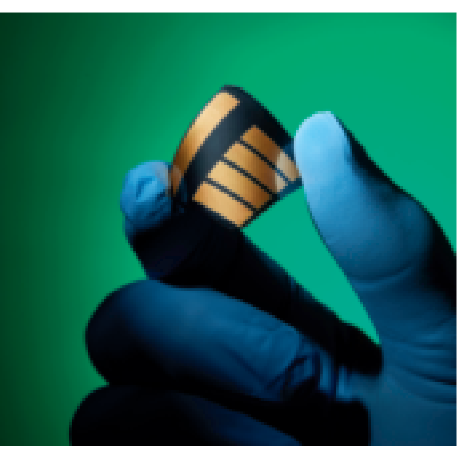
Departmental News

• MIT's Department of Mechanical Engineering has been named the number one mechanical engineering department in the world by both *US News & World Report* and QS World University Rankings.

Research News

• A team of researchers including Professor Tonio Buonassisi has developed a formula to improve the performance of perovskites in solar cells – bringing the materials closer to commercialization. Their research was published in the journal *Science*.

• Associate Professor Asegun Henry and colleagues designed a new system, published in *Energy and Environmental Science*, that stores excess heat generated by solar or wind power as white-hot molten silicon, and then converts the light from the glowing metal back into electricity on demand.



Professor Tonio Buonassisi is developing a technology that unleashes the potential of perovskites for solar cells.
Credit: Ken Richardson

• Professor George Barbastathis has trained a computer to recognize more than 10,000 transparent glass-like etchings in the dark. This method could help illuminate features of biological tissues in low-exposure. The work was published in *Physical Review Letters*.

• In a study published in *Nature*, a team of researchers including Associate Professor Mathias Kolle has found that clear water droplets can produce brilliant colors, an effect that could be harnessed for light displays, litmus tests, or makeup products.

• Associate Professor Xuanhe Zhao and visiting scientist Giovanni Traverso report in *Nature Communications* that they have designed an ingestible, Jell-O-like pill made from hydrogels and embedded with sensors that can stay in the stomach for a month to track ulcers, cancers, and other GI conditions.

• In a *Science Robotics* paper, Associate Professor Alberto Rodriguez used machine-learning and sensory hardware to develop a robot that is learning how to play the game Jenga. The technology could be used in robots for manufacturing assembly lines.

Faculty Promotions

• Tonio Buonassisi was promoted to Full Professor

• Rohit Karnik was promoted to Full Professor

• Mathias Kolle was promoted to Associate Professor

• Alberto Rodriguez was promoted to Associate Professor

• Alexandra Techet was promoted to Full Professor

• Kripa Varanasi was promoted to Full Professor

• Maria Yang was promoted to Full Professor

Faculty Awards

• Gareth McKinley was elected to the National Academy of Engineering for contributions in rheology, understanding of complex fluid dynamical instabilities, and interfacial engineering of super-repellent textured surfaces.

• Professor John Lienhard was named a fellow of the American Association for the Advancement of Science for his distinguished contributions to thermal science and engineering, particularly for developing energy-efficient desalination technologies.

• Professor Linda Griffith was named a 2018 fellow of the National Academy of Inventors. Griffith co-invented a 3D printing process for the creation of complex biomaterial scaffolds.

The Spyce team (left to right) includes Luke Schlueter '16; Michael Farid '14, SM '16; Kale Rogers '16; executive chef Sam Benson; Brady Knight '16; and culinary director Daniel Boulud. Credit: Photo courtesy of Spyce

• Professor Nicholas Makris, Director of the Center for Ocean Engineering, was a co-convener of the United Nation's first ever Roundtable on Sustainable Floating Cities, which took place April 3, 2019 in New York and included Professor Dick Yue, Professor Alexandra Techet, Associate Professor Themis Sapsis, Assistant Professor Wim van Rees, and students.

• USAID announced a $30 million fund for MIT to develop the Center of Excellence in Energy Research, Education and Entrepreneurship (COE) at Ain Shams University in Cairo under the leadership of Professor Ahmed Ghoniem and Professor Daniel Frey.

Student Awards

• Sarah Tress, a senior studying mechanical engineering, has been named a Rhodes Scholar. She will commence graduate studies at Oxford University in fall of 2019.

• Senior Crystal Winston was named a Marshall Scholar. She will embark on a PhD in aerospace materials and structures to further develop her skills in redesigning transportation systems.

• *Forbes Magazine* named graduate student Hyunwoo Yuk one of the 2019 Forbes 30 Under 30 for Science and graduate student Kishor Nayar one of the 2019 Forbes 30 Under 30 in Energy.

Alumni News

• Alumni Elizabeth Bianchini '18, Kyler Kocher '18, Ann McInroy '18, and Sam Resnick '18 won gold at the Collegiate Inventors Competition for Rhino, a product they developed in class 2.009, Product Engineering Processes, that makes brick repointing faster, safer, and more accurate.

• *Forbes Magazine* named alumni Luke Schlueter '16, Michael Farid '14, SM '16, Kale Rogers '16, and Brady Knight '16 to the 2019 Forbes 30 Under 30 in Food & Drink for co-founding Spyce, a restaurant featuring the world's first automated kitchen.

• Rivian Automotive, founded by alum R.J. Scaringe SM '07, PhD '09, unveiled its first two vehicles, an all-electric pickup truck and SUV, at the 2018 Los Angeles Auto Show.

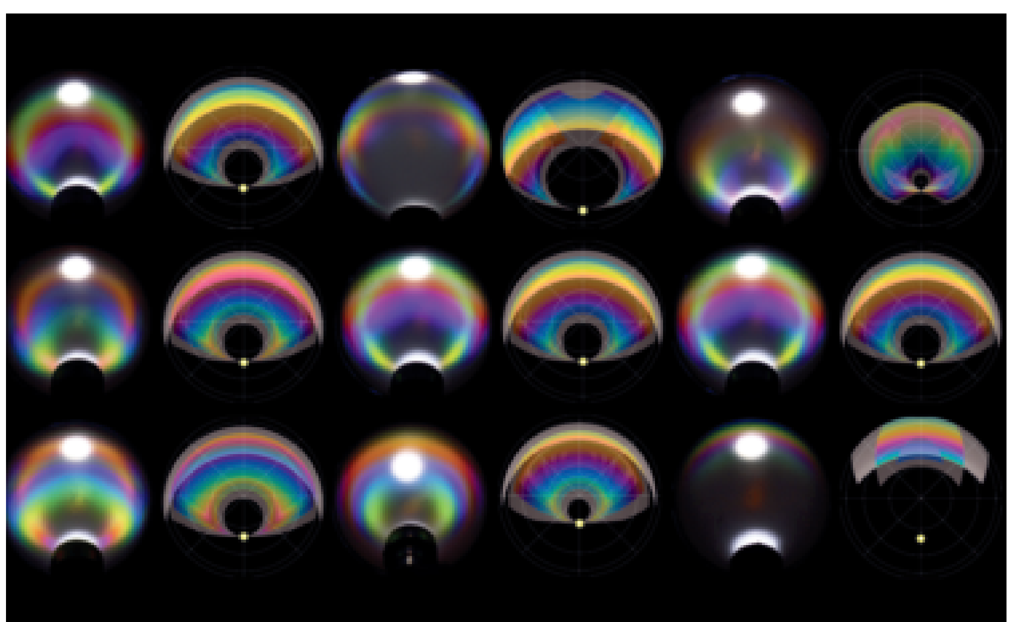
In Memoriam

• Ernst G. Frankel MME '60, SM '60, professor emeritus of ocean engineering who served on MIT's faculty for 36 years, passed away on November 18, 2018 at the age of 95.

• Richard Lyon, who was a leading expert in acoustics, vibration, and machine dynamics and served on the Department of Mechanical Engineering faculty for 32 years, passed away on January 21, 2019.

• Professor Emeritus T. Francis Ogilvie, an expert in naval architecture and former department head of MIT's Department of Ocean Engineering, passed away on March 30, 2019 at the age of 89.

Engineers including Associate Professor Mathias Kolle have found that ordinary clear water droplets on a transparent surface can produce brilliant colors. Credit: Courtesy of the researchers



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Using high-speed airgap flash imaging, postdoc Bavand Keshavarz, graduate student Michela Geri, and Professor Gareth McKinley captured two identical fast liquid jets colliding in minute detail. The image won the Van Dyke Award at the APS Division of Fluid Dynamics Meeting in November.