Research | Penn State

VOLUME 40 | NUMBER 2 | FALL 2021

From the Ground Up

The future of 3D printing

› ALSO IN THIS ISSUE:

Past and Present in Madagascar
A Focus on Prevention
Adaptive Architecture
The Challenge of Sustainable Housing

EMERGING FROM THE PANDEMIC

The last 18 months have been an unprecedented period for our nation and the world. Throughout this time, Penn State's research community has stepped up in so many ways that the efforts by everyone are to be commended. Our researchers pivoted to focus on COVID-19 in response to national and international need, yet they also maintained focus on their specific research interests.

In the spring of 2020, our interdisciplinary research units rapidly mobilized to kick-start more than 50 research projects, addressing all aspects of the pandemic, from the need for vaccines to supply chain upheavals and short- and long-term psychological and social impacts. At the same time, a grass-roots effort harnessed our 3D printing capabilities to address critical supply shortages, aiding hospitals across the Commonwealth and beyond.

Throughout the following year, Penn State's research enterprise has been faced with a two-fold task: to maintain safe and effective operations despite ongoing pandemic restrictions while also strategically growing and nurturing new and impactful research directions, some aligning with national research priorities, and others fostering unique innovations.

Research in physics, computing, the environment, economics, and many other disciplines has continued, despite quarantines, social distancing, childcare shortages, supply chain interruptions, and other COVID-19 challenges.

The stories in this issue show some of the ways we are advancing non-COVID related research during the pandemic. These accomplishments reflect the extraordinary dedication of our researchers and their tremendous flexibility, patience, and adaptability.

Penn State's research expertise combined with its unrivaled research infrastructure make us one of the top institutions in the world in the field of additive manufacturing, and the researchers whose work is presented here are exploring 3D-printing of everything from airplane components to human tissue.

Our leadership in prevention science—applying the latest research to head off substance abuse and mental health issues before they occur—is reflected in an article celebrating the 20-year history of the Edna Bennett Pierce Prevention Research Center.

Historic strengths in materials science, engineering, biology, and design come together in the newly established Convergence Center for Living Multifunctional Material Systems, a research partnership between Penn State and the University of Freiburg in Germany. Known as LiMC², the center is one of a handful in the world focused on this emerging field. One of its core goals is to develop living materials that will enable buildings and other structures to adapt to their environments, critical to the sustainable smart cities of our future.

Environmental archeologist Kristina Douglass works at the boundary between two fields, tying past and present, people and landscapes, to powerfully explore the human effects of climate change in southwest Madagascar, a vulnerable front-line community that offers valuable lessons for the rest of us.

And Esther Obonyo , leader of the Global Building Network, an initiative of Penn State and the U.N. Economic Commission for Europe, offers her vision for addressing the growing challenge of affordable, adequate housing around the world.

Together, these stories highlight the breadth of our research enterprise, the depth of our world-class expertise, and our commitment to tackling the complex challenges facing our world as we emerge from a global pandemic.

Lora Weiss

Lora G. Weiss
Senior Vice President for Research

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This publication is available in alternate media on request.

ON THE COVER:
A support bath used for bioprinting of living cells in the lab of Ibrahim Ozbolat. See story on Penn State's leadership in the burgeoning field of 3D printing, page 12.

Photo by Patrick Mansell

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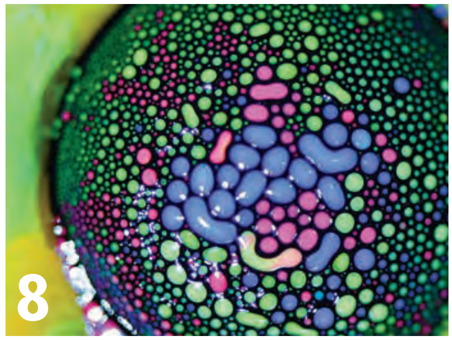


» Cells in 3D

An image created using X-ray histotomography shows cells containing melanin pigment in a 5-day-old zebrafish. X-ray histotomography, a cellular form of CT imaging, was developed in 2019 by a team led by Dr. Keith Cheng, distinguished professor of pathology, pharmacology and biochemistry and molecular biology at Penn State College of Medicine, as a method for investigating the 3D architecture of cells and tissues in biological samples at unprecedented resolution and clarity. Spencer Katz, a member of Cheng's team, modified the technique to specifically investigate melanin, a pigment scientists are studying in human skin color and melanoma research. To perform the imaging, the Cheng Lab partnered with Dilworth Parkinson at the Advanced Light Source at the Lawrence Berkeley National Labs in Berkeley, California. In this image, the different colors were assigned based on the depth of the melanin in cells within the sample from top to bottom.

Keith Cheng Lab, Penn State College of Medicine

Surviving the Worst

Nuclear war, asteroid strike, supervolcano eruption…oh my! In the midst of a global pandemic, it is hard to imagine potentially worse global catastrophes, but the chance that they could happen and wreak havoc on our food systems, while small, is very real.

With a new $3 million grant from Open Philanthropy, an interdisciplinary team of researchers is studying food resilience in the face of such catastrophic global events, which could block sunlight and impair our ability to grow food. Specifically, the team's goal is to develop, test, and optimize strategies for emergency food resilience.

A salad with a mix of microgreens freshly harvested from an indoor "garden."

"Although they are infrequent in Earth's history, global catastrophes have caused massive extinction events," says Charles Anderson, an associate professor of biology and the lead investigator on the project. "We aim to predict how much food could be produced in limiting environments using conventional agricultural methods and provide novel strategies for supporting human nutrition."

The team's initial work has involved modeling the potential effects of a post-nuclear or post-asteroid winter on crop productivity, as well as experimentally growing and testing the nutritional content of potential emergency foods like microgreens that families could grow at home and mushrooms that could be grown on wood chips.

In a recent study, the team found that microgreens can be grown in a variety of soilless production systems in small indoor spaces, both with and without artificial lighting.

"The current COVID-19 pandemic revealed the vulnerability of our food system and the need to address malnutrition issues and nutrition-security inequality, which could be exacerbated by potential future emergencies or catastrophes," says Francesco Di Gioia, assistant professor of vegetable crop science. "Nutrient-dense microgreens have great potential as an efficient food-resilience resource."

Anderson notes that by thinking innovatively about how to ensure human nutrition under extremely challenging conditions, the team hopes to make discoveries that will improve food security under many different scenarios and raise the prospects for improved health and economic productivity for everyone.

—SARA LAJEUNESSE

DON'T STRESS ‹‹

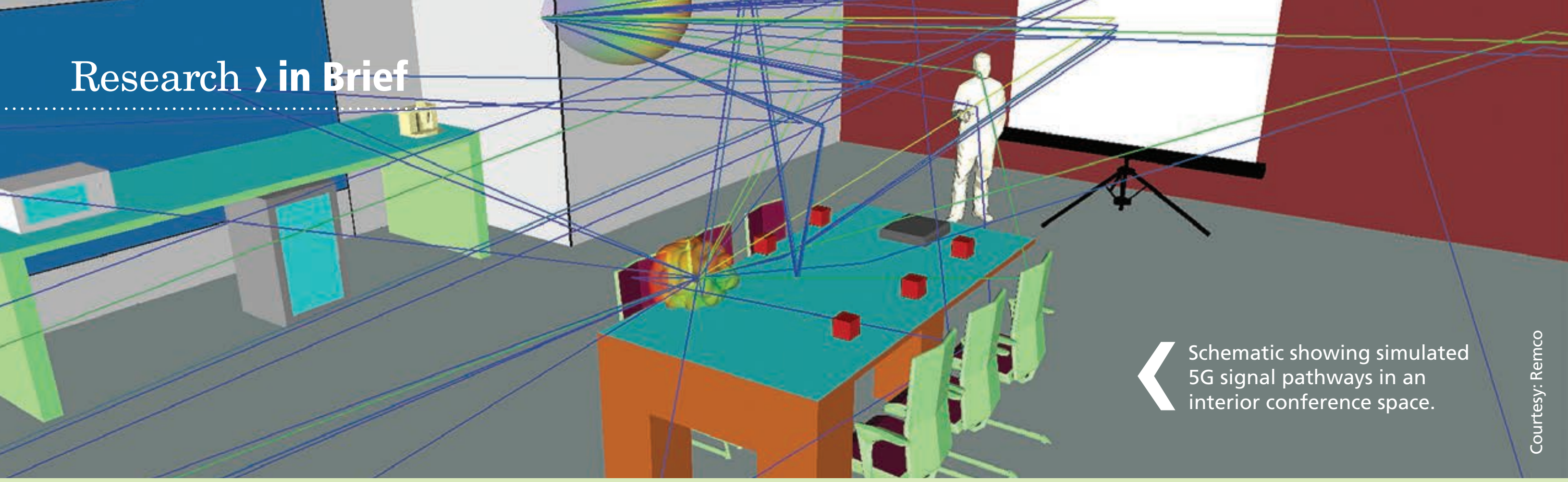
No one really enjoys life's stressful moments, but a recent study found that while there may be benefits to a stress-free life, it comes with a downside, too.

Analyzing data from some 2,700 participants, the researchers found that people who experienced no stressors—no arguments with family members, traffic jams, or untimely computer freezes—were indeed more likely to report better daily well-being and fewer chronic health conditions, as prior research has shown. However, these chilled-out folks also tended to score lower on a cognitive function test.

"It's possible that experiencing stressors creates opportunities for you to solve a problem, for example, maybe fixing your computer that has suddenly broken down before an important Zoom meeting," says David Almeida, professor of human development and family studies at Penn State. Being forced to come up with a quick fix under pressure, while not exactly pleasant, "might actually be good for cognitive functioning, especially as we grow older," he adds.

Almeida says the findings — published in the journal Emotion — suggest that it may not be as important to avoid stress as it is to change the way you respond to it. An upset or worried reaction might be more unhealthy than the sheer number of stressors you encounter.

—KATIE BOHN



Schematic showing simulated 5G signal pathways in an interior conference space.

Courtesy: Remco

ENABLING 5G ‹‹

Although you might see the notation on your cell phone, 5G is not here quite yet. When it does become universally available, it may lead to unexpected opportunities. First, however, engineers will have to solve the problems inherent in millimeter wave technology.

“5G is going to change the way we operate,” says Mike Lanagan, professor of engineering science and mechanics. “When we moved from 3G to 4G we knew we could transmit more data, but we didn’t expect the ability to see, on our phones, an Uber driver arrive. With 5G there might be new applications that we don’t know about yet.”

With potential benefits come difficulties in adapting the technology. 5G transmissions travel shorter distances than 3G or 4G—about 1,000 feet—and they bounce more. The shorter wavelength uses smaller antennae, allowing placement inside buildings and on telephone poles.

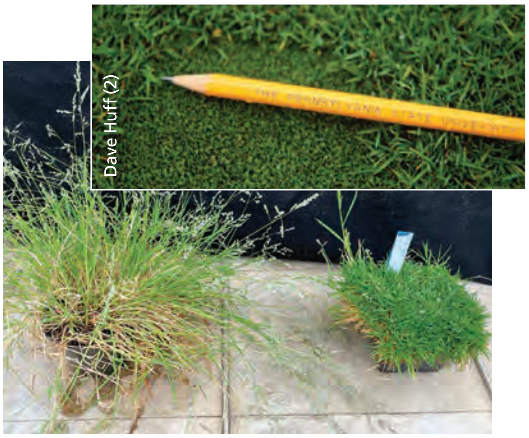
Lanagan and Prasenjit Mitra, professor of information sciences and technology, and Ram Narayanan, professor of electrical engineering, are studying how 5G will be used inside buildings and how buildings and their materials will interact with 5G. Understanding these interactions is important for both simple data transmission and for operating an automated assembly line or communicating with a moving, human product picker in a high-tech warehouse. Eventually, 5G may enable autonomous vehicles and the vaunted Internet of Things.

As signals bounce around a factory building, artificial intelligence will be needed to direct the path from antennae to antennae. Lanagan’s team is working with Tarun Chawla from Remcom, a supplier of software, to simulate signal pathways, focusing on how building materials affect transmission.

A 2020 Industry Xchange Multi-disciplinary Research Seed Grant aimed at the use of AI and machine learning allowed the researchers to explore how signals react when they bounce off various materials in windows, walls, ceilings and beams. Using the software, they simulate the AI directing the signal and the many alternate paths the signal could take.

“The next step is to put people into the room with random motion and see how the system reacts to that,” says Lanagan. “This is where the AI really comes in. What happens when a person walks through and what are the odds of this path and how will that effect the signal? That is what we are going to eventually have to figure out.”

—A’NDREA ELYSE MESSER



Dave Huff (2)

Greens-type Poa annua before and after three years of seed production increase. The “after” version at left has reverted back to a more “wild-type” annual bluegrass. Inset: Poa annua surrounded by creeping bentgrass.

Grass That Doesn’t Forget

Poa annua, a turfgrass species found on golf course putting greens around the world, possesses transgenerational memory, “remembering” whether its parent was mowed or not mowed, according to a new study by Penn State researchers.

The discovery solves a mystery that has vexed David Huff, professor of turfgrass breeding and genetics, for the last two decades.

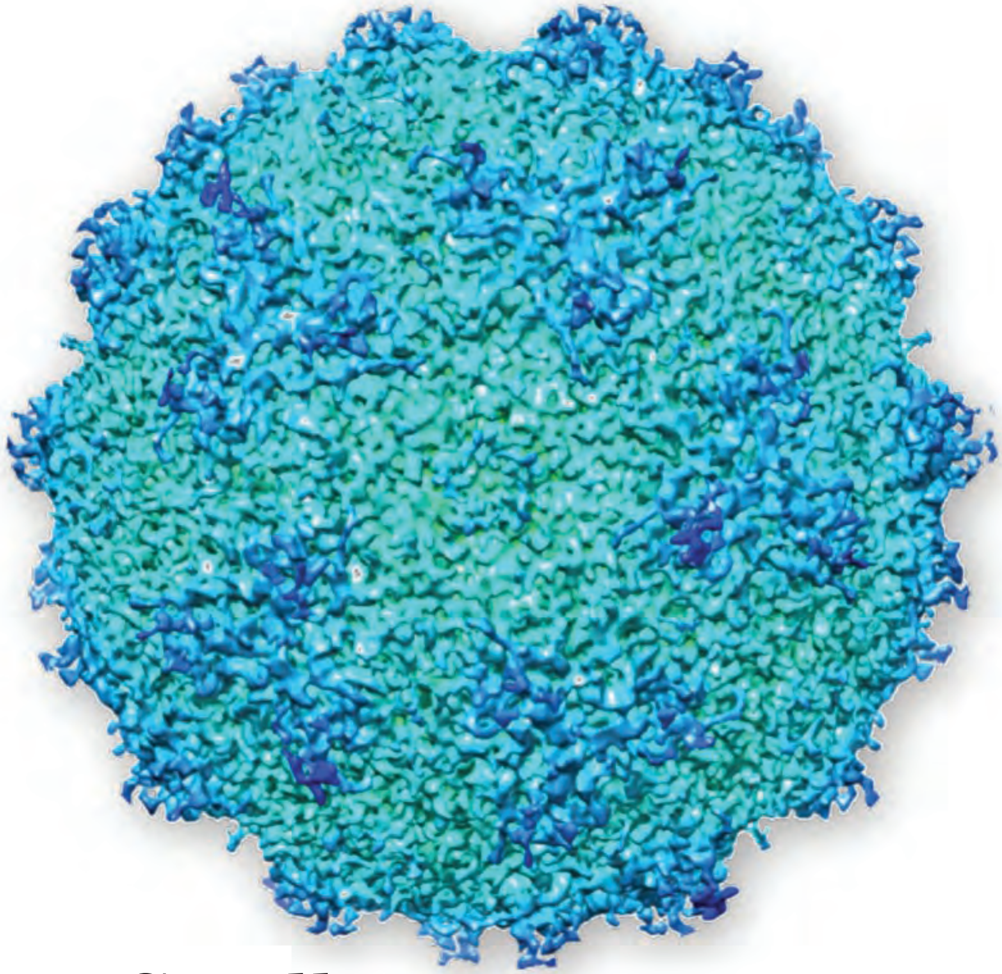
Poa annua is valued for its ability to survive in conditions where other turfgrass species struggle, Huff says. He began breeding the species in 1994, with the goal of developing a commercial variety. But to Huff’s dismay, each time he tried, the grass eventually reverted back to the big, ugly weed form that lies buried in its genetic makeup.

In a study published in the journal Crop Science, Huff and his students discovered the reason why: The inherited “stress” of mowing was affecting the grass’s development.

“Mowing Poa annua increases global DNA methylation, a process allowing it to pass on the environmental effects of mowing to its unmowed offspring,” Huff says. “The transgenerational ‘plasticity’ in Poa annua — the ability of the grass to adapt to changes in its environment—is conferred, in part, by an epigenetic mechanism that modifies the function of the genes and affects gene expression.”

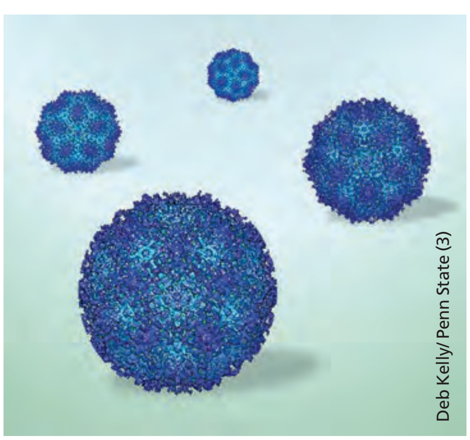
Now that they know more about this mechanism, Huff and his team say, they may be able to overcome the genetic handicap and produce more stable varieties.

—JEFF MULHOLLEM

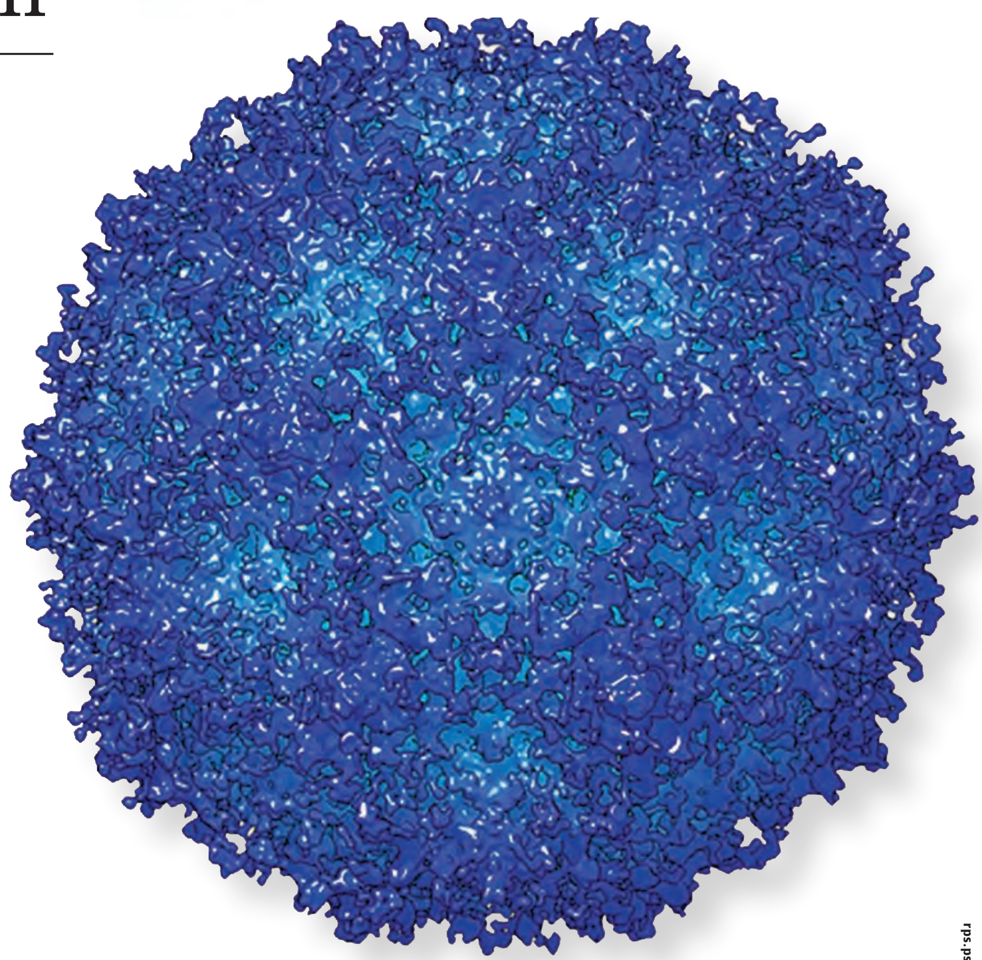


» Seeing Small

A team led by Deb Kelly, Huck Chair in Molecular Biophysics and professor of biomedical engineering, has used advanced electron microscopy to film human viruses in liquid droplets at near-atomic detail. The visualization technique can reveal information about the structure and dynamics of soft materials in real time, while a 3D reconstruction (shown here) can confirm the findings. The advance could lead to improved understanding of how vaccine candidates and treatments behave and function as they interact with target cells.



Deb Kelly/Penn State (3)



Spring Creek, Houserville, PA. Detritivores at work.

» Breakdown Breakdown

Like city sanitation workers carrying away waste, detritivores are the garbage collectors of streams, breaking down and removing dead plant and animal material. They're essential "employees," but the diversity and numbers of these aquatic species is decreasing at an alarming rate.

While bacteria and fungi do their fair share of decomposing plant and animal remains in waterways, researchers from Penn State and the University of the Basque Country, Spain, found that without larger detritivores—invertebrates like stone flies, caddisflies, mayflies and crane flies and crustaceans like scuds, freshwater shrimp and crabs—much less decomposition takes place, and what does occurs at a slower pace.

"The plant matter that doesn't get eaten by animals ultimately must be recycled so that biologically essential nutrients are rereleased into the environment where they can be used again," says Bradley Cardinale, professor of Ecosystem Science and Management at Penn State. "If the process of decomposition doesn't occur, or slows significantly, then life comes to a screeching halt. Phosphorus, nitrogen and other nutrients that we need as humans don't even exist in a biologically available form unless they get decomposed and recycled.

By creating an experiment where large detritivores were unable to reach this food supply—enclosing the plant material in fine mesh bags—the researchers showed that, contrary to assumptions, microscopic organisms did not take over for insects and crustaceans. They also found that species diversity was increasingly important for decomposition in the tropics, while the sheer number of detritivores and amount of dead plant material was also important in northern and temperate areas.

"When we excluded these animals, we saw a huge drop in decomposition rates, which means other organisms didn't compensate for them," says Cardinale. "When the detritivores were excluded, simulating extinction, we lost way more than 50% of the decomposition in the streams."

—JEFF MULHOLLEM/ A'NDREA ELYSE MESSER

Inset, Aedes aegypti mosquito, carrier of Dengue fever. Top: Infected mosquitoes in sealed vials.

Penn State (2)

Heat Treatment

It might be tough to think of a benefit to global warming, but when it comes to the deadly mosquito-borne disease dengue fever, climate change could be a good thing. Sort of. In a recent study, Penn State researchers found that Aedes aegypti mosquitoes infected with dengue virus are much more sensitive to warmer temperatures.

This is important, says Elizabeth McGraw, head of the department of Biology, because "aided by increasing urbanization and climate change, this mosquito's range is expected to overlap with 50% of the world's population by 2050, dramatically increasing the number of people who could potentially be exposed to the virus."

In an experiment, the team exposed mosquitoes to a realistic temperature extreme such as they might encounter in the wild and measured how long it took for the mosquitoes to become immobilized, a sign of decreased survival. The infected mosquitoes were immobilized three times faster than uninfected controls.

Unfortunately, however, the researchers observed a similar effect in mosquitoes infected with the bacterium Wolbachia, which has recently been used to control viral infections in mosquitoes. Like dengue-infected mosquitoes, the Wolbachia-infected mosquitoes were sensitive to higher temperatures.

In the end the news is mixed, says graduate student Fhallon Ware-Gilmore: "Our findings suggest that global warming could limit the spread of dengue fever but could also limit the effectiveness of Wolbachia as a biological control agent."

—SARA LAJEUNESSE

KIDS WHO CAN'T SLEEP ‹‹

Some parents might consider childhood snoring cute, while others might not be aware their child is having trouble falling and staying asleep. What these caregivers may not realize is that childhood sleep issues can have long-term health consequences if they become persistent and are not adequately addressed.

Researchers from Penn State College of Medicine and Penn State Health Sleep Research and Treatment Center are studying how ongoing obstructive sleep apnea and insomnia may affect children's health as they age.

In one sleep-lab study of more than 500 children, researchers found that those with insomnia symptoms persisting through adolescence had a nearly three-fold increased risk of developing anxiety, depression and other mood disorders. Children whose symptoms improved before the transition to adolescence had no increased risk.

In another study, children with obstructive sleep apnea, a condition where a person briefly and repeatedly stops breathing during sleep, were three times more likely to develop high blood pressure as adolescents than children who never experienced sleep apnea. According to the researchers, sleep apnea and its risk factors should be screened for, monitored and targeted early in life to prevent future cardiovascular disease.

"Our team continues to identify the adverse impact of poor sleep on health in both pediatric and adult populations," says Julio Fernandez-Mendoza, lead researcher and associate professor of psychiatry and behavioral health. "The results of these studies emphasize the need for parents of children with sleep issues to address these challenges with their child's health care provider. If these issues persist into adulthood, greater health complications could arise."

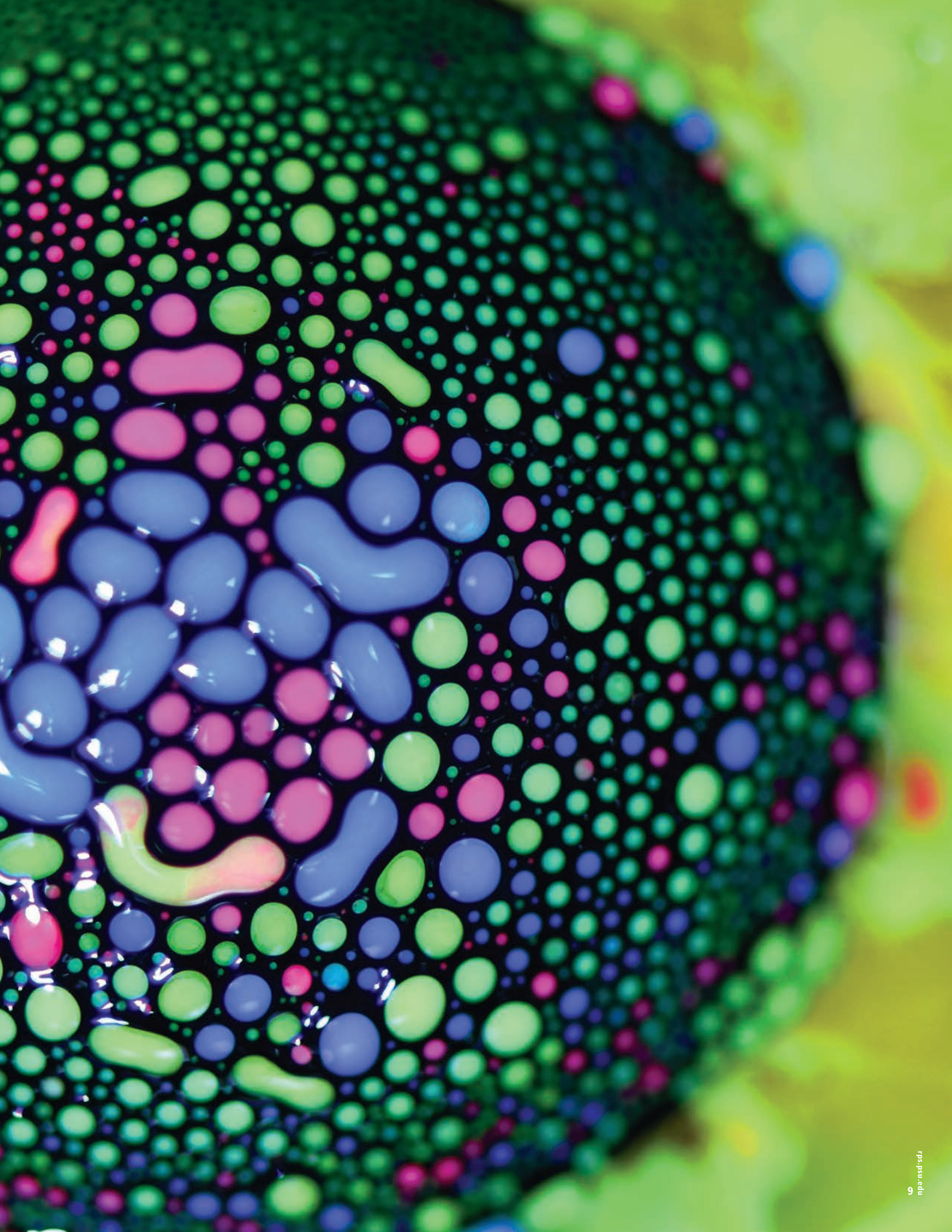
—ZACHARY SWEGER

Getty Images / AndreyPopov

FLUID BEAUTY ‹‹

This spectacular dome, about the size of a thumbnail, was created by a mix of water-based paints with a magnetic solution called a ferrofluid, interacting on top of a magnet. The ferrofluid, made of iron-oxide particles suspended in an oily solution, is paramagnetic: While not magnetic itself, it reacts in the presence of a local magnetic field. This reaction creates "spikes" of various sizes and densities as the iron-oxide particles are repelled outward. Water-based paint injected inside the dome does not mix with the oily ferrofluid. Instead, because it is lighter, it rises to the surface, creating small channels throughout the ferrofluid spikes. The higher viscosity of the paint allows it to hold its shape while maintaining its liquid properties. This work was created in the fluid dynamics lab of Azar Eslam-Panah, associate professor of mechanical engineering at Penn State Berks, in collaboration with photographer Heidi Reuter and students Lisa Panczner and Cooper Kovar. It won a Milton van Dyke award from the American Physical Society's Division of Fluid Dynamics.

Photo by Azar Eslam-Panah, Heidi Reuter, Lisa Panczner, and Cooper Kovar



From the Ground Up

3D printing is increasingly used to manufacture a wide range of objects, from automotive parts to artificial teeth. Penn State researchers are taking the technology to the next level.

BY SARA LAJEUNESSE

Timothy Simpson is the proud owner of a custom wristwatch, one of only a few made entirely in the United States these days. Created by Vortic Watch Company, a firm owned by Penn State alumnus R.T. Custer, the piece is a beautiful 1908 pocket watch made in Waltham, Mass., that is encased in a 3D-printed titanium outer shell and fitted with a custom leather strap.

With 3D printing, "Vortic was able to give new life to an antique, and create a niche high-end luxury good," says Simpson, interim department head of the School of Engineering Design, Technology, and Professional Programs and Paul Morrow Professor in Engineering Design and Manufacturing.

A big part of the technology's appeal, Simpson adds, is that it allows for a level of customization not possible with traditional manufacturing. With 3D printing, Vortic can create custom titanium fittings for each unique timepiece using the same machine and placing orders after receiving payment. For Custer and a growing number of others, 3D printing has lowered barriers to manufacturing. "It democratizes entrepreneurship, especially for hardware-based startups," says Simpson. "Entrepreneurs don't have to invest millions of dollars in machines and equipment. They can just buy a couple of printers and start making things."

Indeed, for about $150, anyone can walk out of a Walmart with a 3D printer capable of creating a growing array of tools, toys, and other trinkets. In recent years, however, the technique has grown considerably more sophisticated; its products moving beyond just bits and bobs made of plastic to include high-tech items fabricated from metal, concrete, clay, and even biomaterials. Researchers at Penn State are at the leading edge of the field now known as additive manufacturing, working to advance the capabilities of 3D printing with a goal of addressing pressing problems in human health, housing, and transportation, among other areas.

ILLUSTRATIONS BY PETER HOEY


3-D PRINTER

Courtesy: Tim Simpson

Tim Simpson in replica, 3D-scanned and 3D-printed in color plastic.

A DIFFERENT BALLGAME

"Anyone can buy a printer, learn how to put material in it, and hit go, but designing parts that really take advantage of 3D printing—so they are better, faster, and cheaper than traditionally made components—is another ballgame," says Simpson. "You have to understand the economics, the materials, the design, the process. It's a contact sport; you have to rub shoulders and talk to experts in a lot of other disciplines to really do additive well."

The ability of Penn State's researchers to do just that—collaborate with colleagues across disciplines to address every component of a problem and its solution—is a strength of the University, Simpson says. "Because of this," he adds, "from a capability standpoint, we are among the top institutions in the world in additive manufacturing, and we continue to expand into new areas as a result."

The term additive manufacturing, Simpson explains, describes the use of 3D printing to make functional components in a manufacturing setting. The process is "additive" because it produces an object by building it up one layer at a time. "Think of water dripping from the ceiling of a cave and depositing thin layers of minerals to form stalagmites on the cave floor," he says. By contrast, subtractive manufacturing creates components by removing material until the final part is complete. The additive process, by its nature, is both more flexible and far less wasteful.

The process begins with a 3D model: a computer-aided design (CAD) representation of the object that specifies precisely how much material—plastic, metal, clay, or some other substance—needs to be deposited, and where. As the 3D printer reads its instructions, it extrudes a plastic filament from a nozzle onto the print bed in the specified manner or a laser melts metallic powder layer by layer to form a part. After completing the base layer, the printer adds additional layers until the item is complete.

In this way, users can print almost anything they can imagine. "We're using 3D printing to make car and airplane parts, hip and knee implants, you name it," says Simpson. "Several years ago, there was an episode of 'Grey's Anatomy' where doctors reconstructed a patient's ear by growing a new one. We can do that now. This is actually happening, and Penn State has some of the leading experts in the field of 3D printing."

PRINTING WITH BIOMATERIALS

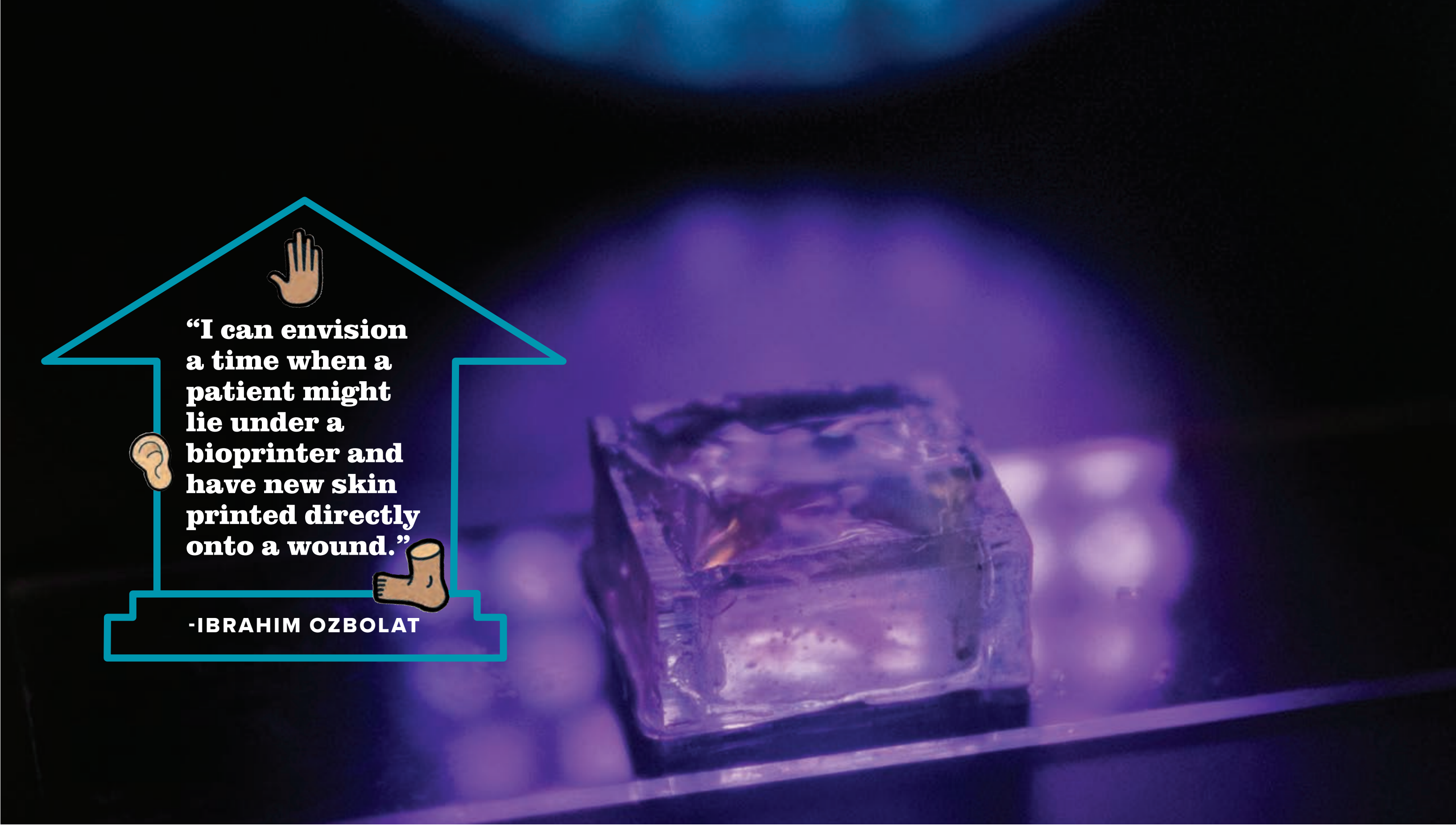
Imagine yourself a patient in an MRI machine. Likely you're familiar with the concept of lying motionless within that snug tunnel as rotating scanners produce fine-grained images of your tissues and internal organs. Now imagine that such a machine could directly repair these tissues by depositing new layers of muscle or skin, even creating and installing new organs. Such is the dream of Ibrahim T. Ozbolat, an associate professor of engineering science and mechanics, biomedical engineering and neurosurgery. Ozbolat is using 3D printing to create a range of materials for use in human health.

"I can envision a time when a patient might lie under a bioprinter and have new skin printed directly onto a wound," he says. Already, Ozbolat and his lab group have reported success in printing both bone and soft tissue onto the skulls of rats.

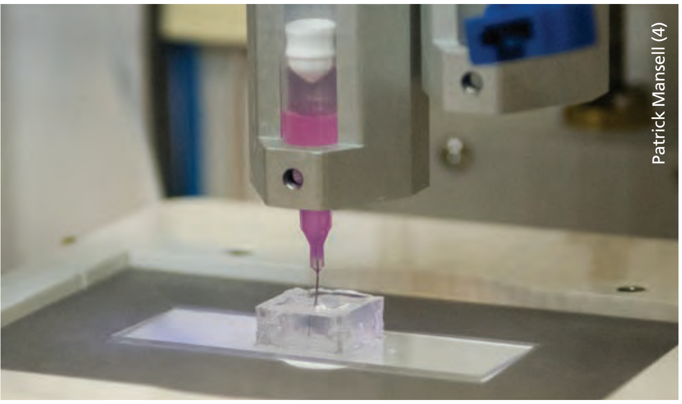
"Repairing injuries to the skin and bones of the skull is particularly difficult given the many layers of different types of tissues involved," he says. "Trying to work with these two materials at one time is an even greater challenge."

Currently, he explains, fixing skull injuries requires the use of skin and bone from another part of the patient's body, which requires additional surgery, or from a cadaver, which runs the risk of rejection by the patient's immune system. For their study, Ozbolat and his colleagues instead created a printable bone material using a mixture of collagen; chitosan, a sugar from the outer skeleton of shellfish; nano-hydroxyapatite, a component of tooth enamel; and bone morphogenetic protein-2, an FDA approved growth factor for bone regeneration. For the skin, they used collagen and fibrinogen, a protein made in the liver that aids in blood clotting.

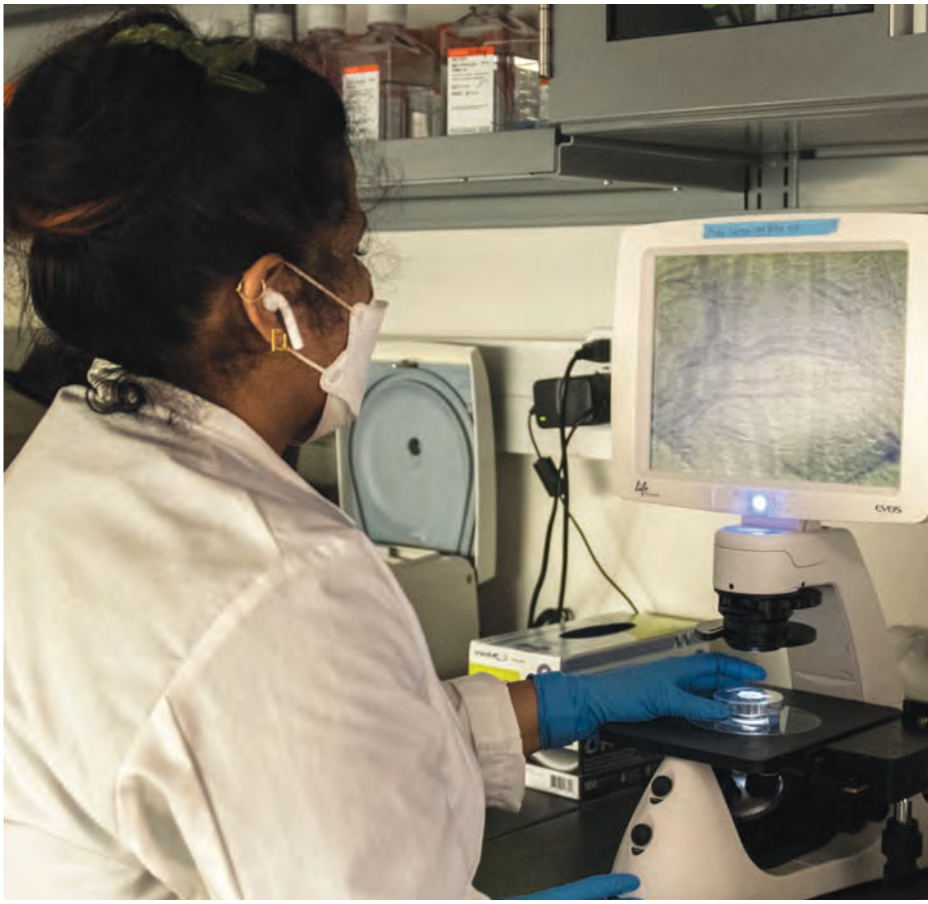
After precisely scanning the rat's skull defect, Ozbolat explains, the 3D printer followed the 3D "blueprint," extruding the bone material onto the wound, followed by a barrier material, and then the skin material. The whole process took less than five minutes. After separately repairing the 6-millimeter-wide hole in the skin and the 5-millimeter-wide hole in the bone, they moved on to repair both during the same surgical procedure. "There is no surgical method for repairing soft and hard tissue at once," notes Ozbolat.



> **"I can envision a time when a patient might lie under a bioprinter and have new skin printed directly onto a wound."**
>
> **-IBRAHIM OZBOLAT**



Patrick Mansell (4)



Bottom left: Miji Yeo, a postdoctoral fellow working in Ibrahim Ozbolat's lab, micro-valve bioprinting living cells for skin tissue fabrication. Bottom right: Postdoctoral fellow Dishary Banerjee analyzing samples with a microscope. Center left: Freeform bioprinting of living cells in a support bath. Top: A support bath used for supporting the structural integrity of printed tissues, enabling printing with anatomical complexities.

The next step, he says, is to add compounds that can help to facilitate vascularization, since blood flow to bone is especially important for healing. He and his team are already working with neurosurgeons, craniomaxillofacial surgeons, and plastic surgeons at Penn State Hershey Medical Center to translate this research to human applications.

In addition to repairing skin and bone, Ozbolat and his team are using 3D bioprinting to help in the study of breast cancer. In a recent study, the team generated tumor models, called tumor spheroids, to study how a tumor cell's distance from nearby endothelial cells—cells that line the walls of blood vessels—and fibroblasts—connective tissue cells—influences its ability to grow. The closer a tumor cell is to an endothelial cell or fibroblast, they found, the more aggressively it is likely to spread.

"In research like this, it is important to maintain precision in the variables that are being tested," says Madhuri Dey, a PhD candidate in chemistry. "In this project, 3D printing allows us to precisely adjust the position of the tumor with respect to the main blood vessel so we can observe the effects of distance on tumor growth. Using a natural tumor would introduce too much variability."

PRINTING WITH CONCRETE

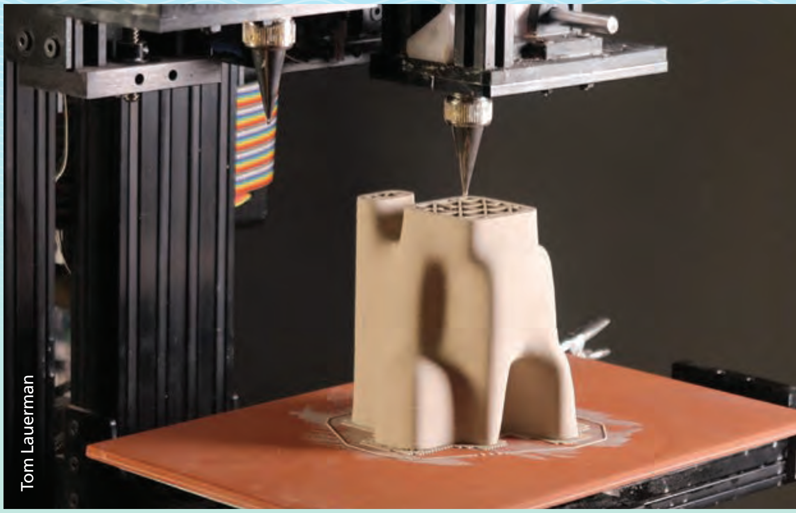
While 3D printing of biological materials has the capability to transform healthcare, the technique may also overhaul the way we design and build our living structures—not only on Earth, but perhaps even in space.

Recently, Jose Duarte, Stuckeman Chair in Design Innovation, and Shadi Nazarian, associate professor of architecture, co-led an interdisciplinary team of students and faculty that took second place in a NASA competition. The goal? To design an autonomous system capable of creating a human shelter on Mars using 3D-printing technology. With their entry, the team managed to build the world's first fully-3D-printed structure to include a roof built in place without formwork or molds, Duarte says. "The other teams printed the roof separately and raised it to its position afterward, or else used formwork to avoid its collapse during printing."

Duarte credits Sven Bilén, professor of engineering design, technology, and professional programs, for his unique contribution to the printing system. "Sven added an ingenious extension to the robotic arm that allowed it to reach far enough to print the entire structure, thereby increasing what we call 'design freedom,'" he says.

Patrick Mansell

Top, "Stairs," by Tom Lauerman, printed in terra cotta clay. The black surface is created using an ancient technique called "terra sigillata" which translates to "sealed earth." Bottom, A clay object being printed using a custom printer designed and built by Lauerman and a team of undergraduate engineering students participating in a Penn State "Learning Factory" capstone project.



Another challenge of the competition was to 3D print with a specialized concrete that can withstand extreme environmental conditions as a finished structure. Aleksandra Radlinska, associate professor of civil engineering, brought to the team her expertise in cement and concrete behavior. 3D printing with concrete can be tricky, Radlinska explains, because the mixture needs to be fluid enough to be extruded through a printing nozzle, but afterward stable and strong enough to support additional layers. When done right, researchers have shown, 3D printing with concrete can result in structures that are equally strong to those traditionally built, while using less material.

Although the Mars shelter competition took place entirely on Earth, the team's final product could feasibly be built in space. The knowledge gained, however, will be used to create sustainable, low-cost housing options here, by simplifying and speeding up construction processes and saving on materials, Duarte says. He and his colleagues are already developing the technology to deploy structures in remote areas of Alaska, where temperature extremes rival those on Mars.

Coordinated by Ali Memari, Bernard and Henrietta Hankin Chair in Residential Building Construction, and with help from Ming Xiao, a professor of civil engineering, and Nathan Brown, a professor in architectural engineering, the team is designing an Alaska-ready 3D-printed model that includes a foundation, walls, and a roof. "The model is essentially a room, and you can combine rooms to build unique houses with a variety of configurations," says Duarte. "By doing this, you can build a large house with a small printer, one room at time. You can print the entire thing on site."

PRINTING WITH CLAY

Assistant Professor of Art Tom Lauerman is using 3D printing to build structures of another sort. Although much smaller in scale than a house, they are equally intriguing. And the material he is using—clay—can be found in his own backyard.

"As a sculptor, the medium I've worked with for many years is ceramics, but I've always been really interested in technology as well," says Lauerman. "So, I began learning 3D-modeling programs, like what an architect or industrial designer would use to design things. That was partly because it was an effective way for me to draw out ideas. I would make these 3D models basically as a blueprint for something that I would then go and try to make by hand."

As 3D printing advanced, Lauerman began to use the technology to make plastic molds, and from them to cast ceramic objects. "That worked really well," he says, "but it was time-consuming and cumbersome."

It was when Lauerman sought out Simpson for technical advice that the idea of 3D printing directly with clay was born. Because there were no off-the-shelf printers that suited his purpose, Lauerman, at Simpson's suggestion, went to the College of Engineering's Learning Factory to work with a team of students to build one.

The Bernard M. Gordon Learning Factory is a hands-on facility for engineering students to use in conjunction with capstone design and other courses. For the past five years, Lauerman has worked with these students to design and build custom 3D clay printers.

"The objects we were able to create at first were really crude; they were teeny, tiny little things," he says. Today, however, Lauerman's creations are much more sophisticated, and he is planning to display them in a formal exhibition in the coming year. "3D printing allows me to experiment with nearly unlimited possibilities," he says. "I can make things with really intricate repeating patterns that would be very difficult to do by hand, and if I want to make a tiny tweak, I can do that without having to go through the immense effort of rebuilding from scratch."

PRINTING WITH METAL

While biological materials, cement, and clay are opening doors to exciting possibilities through 3D printing, Simpson says, “What’s really supercharged additive manufacturing in the last 10 years is metals.” The technology has developed to the point of allowing metal parts to be made with complex curves or cavities very difficult to achieve with subtractive processes, he explains. The results have already started to impact the manufacture of automobiles and airplanes, among other industries.

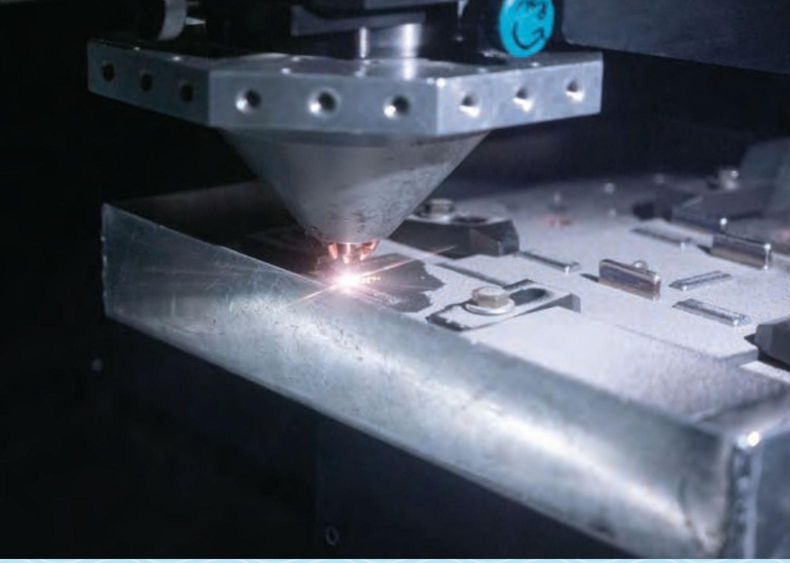
Simpson’s colleague Edward (Ted) Reutzel is one of more than a dozen researchers in the Applied Research Laboratory at Penn State who are advancing metal 3D printing. Reutzel directs the Center for Innovative Materials Processing Through Direct Digital Deposition (CIMP-3D), an 8,000 square-foot facility located at Innovation Park whose cutting-edge capabilities and expertise allow it to serve as the Additive Manufacturing Demonstration Facility for the U.S. Defense Advanced Research Project Agency (DARPA). In the past ten years, CIMP-3D has hosted more than 6,000 visitors, spun out three start-up companies, created more than 30 new jobs in the region, and supported the launch of the world’s first additive manufacturing and design graduate program, which now enrolls over 200 industry practitioners from more than 80 different companies.

Working with the U.S. Navy in 2016, Reutzel led a team that supported the U.S. Naval Air Systems Command in designing and building the world’s first 3D-printed flight-critical component—a titanium link that helps to secure the engine to the frame of a Navy tiltrotor aircraft. Today, Reutzel and his colleagues at CIMP-3D are focused on additive manufacturing technology from early-stage research to applications for industrial use, and on helping to develop methods to efficiently assess and improve additive manufacturing part quality.

“Additive manufacturing has the potential to revolutionize manufacturing by providing on-demand production, decreasing material and manufacturing costs, allowing highly flexible designs for production, and producing features and material combinations that are not currently feasible,” says Reutzel. But obstacles remain, he says. For one, “the lack of established quality control practices for built parts poses a challenge to wider adoption.”

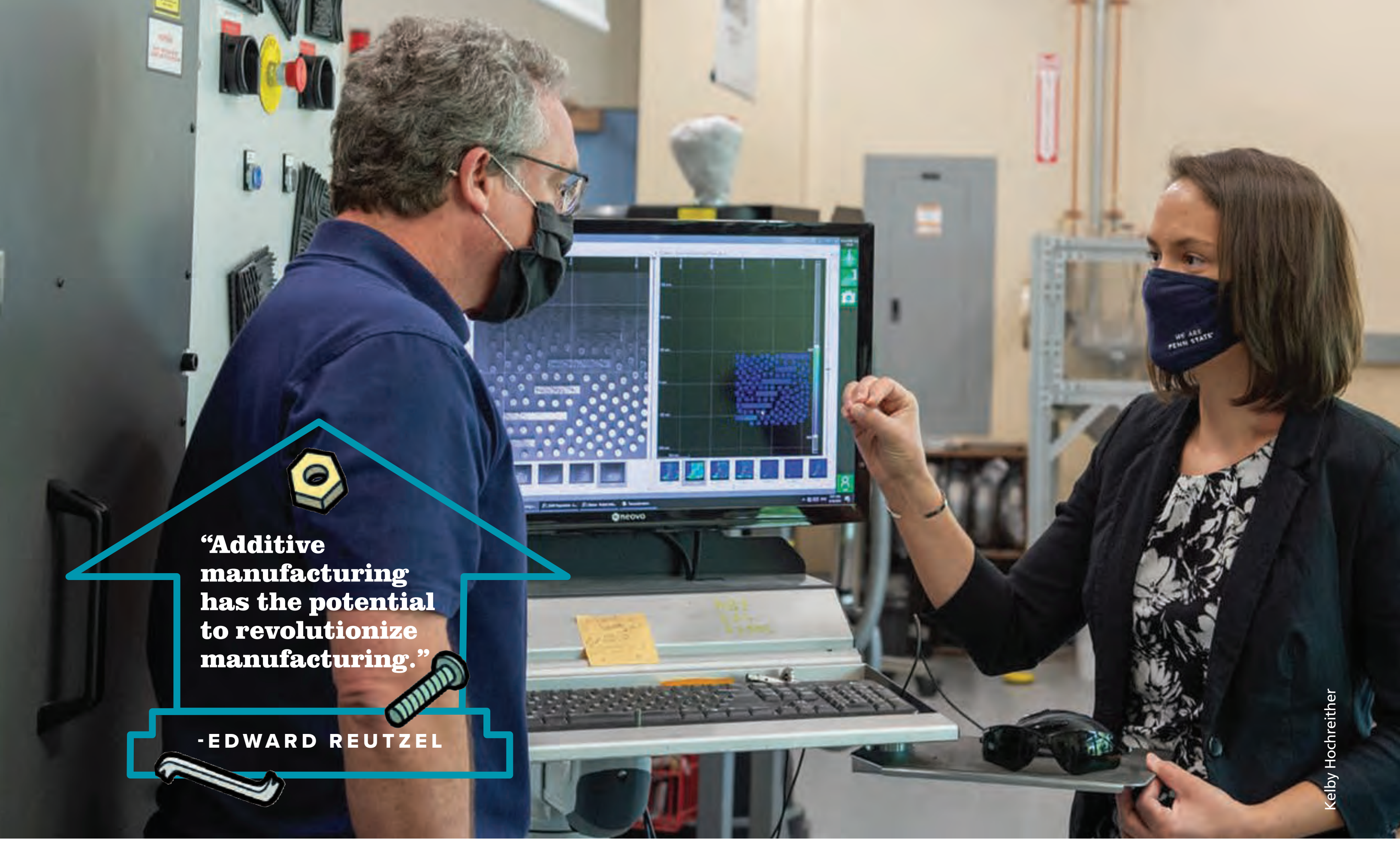
As Reutzel explains, the 3D printing process that enables rapid fabrication of complex parts is itself quite complex, and small process perturbations can be correlated to material defects such as voids or porosity—essentially holes in the material that are smaller than a human hair. These defects can lead to cracking and instability, jeopardizing durability and safety.

Reutzel and colleagues including Parisa Shokouhi, associate professor of engineering science and mechanics, are investigating various processes for identifying such defects, including nonlinear resonance ultrasonic spectroscopy, which can predict how long an object will last before failing, and X-ray computed tomography, which enables visualization of interior flaws within solid objects.



Jason Bolt, Applied Research Laboratory at Penn State (3)

Top, Directed energy deposition additive manufacturing experiments explore the impact of pulsed laser processing on material microstructure and properties. Middle, Undergraduate engineering student Marissa Stecko holds an aluminum test article produced with a multi-laser powder bed fusion additive manufacturing system. Bottom, 3D-printed samples including a polymer acoustic tile.



Ted Reutzel and Allison Beese discuss sample specimens of Ti-6Al-4V, a titanium alloy widely used in the aerospace industry, being fabricated in a laser powder bed fusion machine at the Center for Innovative Materials Processing Through Direct Digital Deposition (CIMP-3D) in Innovation Park.

Allison Beese, associate professor of materials science and engineering and mechanical engineering, is also working toward quality control in metals. Beese, who directs Penn State’s Additive Manufacturing & Design Graduate Program, focuses much of her research on functionally graded materials, which combine materials with different attributes to achieve desired properties.

Beese also examines the relationships between temperature, microstructure, and mechanical properties related to the printing process. When additively manufacturing metals, for example, the raw material fed into the printer is often in the form of a metallic powder or wire feedstock. These materials are melted with a laser or electron beam, and as each layer of the desired object is added, it cools and solidifies and fuses to the layer below. This process introduces rapid heating and cooling cycles, resulting in microstructures within the material that differ drastically from those seen in cast or wrought counterparts. “To reliably use metals in structural applications, their mechanical properties must be understood and be predictable,” says Beese. “My lab’s work may ultimately aid in defining metrics for quality control and repeatability, and lead to the development of new materials.”

While safety and quality are top priorities as more and more consumer and industrial products are manufactured this way, 3D printing with multiple materials is another promising area for future research. “If we want to print a house, currently we print the concrete, but leave spaces for the windows,” Simpson explains. “Could we just switch to a transparent polymer during the process of putting in the concrete to get a window?”

The digital nature of additive manufacturing means that 5G, the next generation of wireless network technology, will create new opportunities for remote monitoring and operation, Simpson says. “Our hope is to build a 5G testbed on campus that will serve as a platform to develop, deploy, and test new protocols for additive manufacturing and other digital manufacturing technologies.” With 5G in place, he says, “We can open up entirely new avenues for quality assurance and quality control.”

From the custom watches that are already available to the artificial organs being tested for the future, 3D printing and additive manufacturing is allowing us to produce traditional products more affordably and sustainably and to create entirely new products that may transform the way we travel, build homes, and manage our health. At Penn State, researchers are using the technology in novel and exciting ways that are already impacting the world. “Our faculty and students are working directly with industry to help solve real-world problems,” says Simpson. “It’s very exciting to be at the leading edge of the additive revolution at Penn State, and our ability to collaborate so easily strengthens our impact far beyond what any of us could do alone.”

Getty Images/ sezer ozger

When Kristina Douglass first went back to Madagascar, as a doctoral student from Yale, she went with a specific archeological question in mind.

The Texas-sized island where she spent a part of her childhood sits in the Indian Ocean 300 miles east of southern Africa, and is known for its amazing biodiversity. Until about a thousand years ago, its fauna included large-bodied animals long since extinct in most of the world: pygmy hippos, giant tortoises, and elephant birds among them. Previous scientists had theorized that humans contributed to this relatively recent wave of disappearances. If so, Douglass, wanted to know how. By overhunting? By modifying habitat? By introducing domesticated animals—sheep, goats, cattle, and dogs—that out-competed native species?

"I was just looking for archeological sites that could help me answer that question," remembers Douglass, now an assistant professor of Anthropology and African Studies at Penn State. "But then, as I became more embedded in the work, I've been driven to connect the knowledge that people hold today with the archeological record."

The attempt to bridge past and present came naturally to her. "I always saw my role as something that had to be relevant to people who are living today," she explains. "The production of archeological knowledge just as an esoteric thing is not compelling to me."

In large part, she says, her perspective is a result of her upbringing. Born in Togo, West Africa, she was adopted along with three siblings by parents who were international aid workers and also worked in public health. While she was growing up, the family lived at various times in Madagascar and several other African countries, as well as in Ukraine. "So I experienced a lot of different cultural contexts, and also saw a lot of need—and the importance of development work to tackle pressing challenges."

That experience made a lasting impact. "Archeology to me," she says, "has always been a way of reconciling, on the one hand, deeper histories that I struggled as a child to piece together because we have this unique family and background, and on the other hand, posing questions of the past that can in some way inform how we tackle the problems of today."

Kristina Douglass with historian Manantsoa Kely in the Mikea forest.

SURVIVING

PHOTOGRAPHY: GARTH CRIPPS, MOROMBE ARCHAEOLOGICAL PROJECT

AN ENGAGED, INCLUSIVE APPROACH TO ENVIRONMENTAL ARCHEOLOGY IN MADAGASCAR YIELDS BROADER LESSONS IN RESILIENCE—AND CONNECTEDNESS.

❯ Drone image of the Mikea dry forest in southwest Madagascar shows perennial stream channels (called *saha* in Malagasy), and crop cultivation areas.

G IN PLACE

BY DAVID PACCHIOLI

Getty Images/ rbiedermann

> **I ALWAYS SAW MY ROLE AS SOMETHING THAT HAD TO BE RELEVANT TO PEOPLE WHO ARE LIVING TODAY.**
>
> **— KRISTINA DOUGLASS**

Ricky Justome and Kristina Douglass excavating a small test pit at an archaeological site.

CARVING A NICHE

Douglass arrived at University Park in 2017, a co-funded faculty member in both Liberal Arts and the Institutes for Energy and the Environment. In 2020, she was named the Joyce and Doug Sherwin Early Career Professor in the Rock Ethics Institute. Her titles reflect what she says is "a genuine commitment to interdisciplinarity, and to supporting younger faculty," that she has found at Penn State.

As an environmental archeologist working in southwest Madagascar, her work is indeed interdisciplinary. Douglass seeks to understand the dynamics of this remarkable place—how humans have managed to carve out a niche here in order to survive in a constantly changing climate. And how, over two thousand years, the impacts of human adaptation have in turn altered the landscape.

The Velondriake Marine Protected Area, including a network of fishing villages along the island's southwest coast, is home to diverse communities of fishers, herders, foragers, and farmers descended from 13 ancestral clans, who continue to make their living from a landscape that includes coral reefs, estuaries, dry forest, and grasslands, among many other local ecologies.

Understanding the complex dynamics requires an integrated approach. In addition to archeological surveys and excavations, the Morombe Archeological Project (MAP), which Douglass started in 2012, relies on ecological and geospatial methods, including remote sensing combined with predictive modeling. A recent study published by Dylan Davis, one of her graduate students, demonstrated how remote sensing combined with predictive modeling can be used to quantify changes in land use over time.

The MAP also incorporates oral history. For a two-year project led by Douglass and postdoctoral fellow Tanambelo Rasolondrainy that ended in 2018, team members interviewed over 100 local elders in 32 communities within Velondriake. In a related oral history project in the Mikea forest the team also used live drone footage played through virtual reality headsets to help jog participants' memories related to specific archeological sites.

Drone image of the Mikea dry forest with edge of perennial lakebed at bottom right areas.

Among other things, the oral history project captures generations of local knowledge about how these communities have managed to adapt to environmental challenges; the researchers were looking for patterns of mobility and settlement, cooperation and resource use in response to drought or scarcity or other variable conditions. Understanding these responses, Douglass says, in turn informs the team's exploration of Velondriake's deeper past.

She is working to reconstruct that past using archeological materials—shared artifacts and technologies, trade items, as well as animal and plant remains—as proxies for the social connections between ancient communities. Douglass employs both standard methods, like measuring carbon and nitrogen istopes in cattle bones to infer past diet and response to drought, and more innovative techniques. For a recent study she devised a method using microstructural variations in fossil eggshell to help determine whether Pleistocene-era hunter-gatherers may have already been experimenting with avian husbandry.

Comparing the archeological evidence she is amassing against the existing paleoclimate record, Douglass then looks for correlations between climate change and human response across the span of the region's ecological history. Ultimately, she says, "What you end up with is a localized understanding of what it means to be resilient, to weather a storm."

EQUAL PARTNERS

At least as important to Douglass as this integrated approach is a commitment to working collaboratively—not just with other scholars but also with members of the local community. A cover story in the journal Nature in 2018 recognized her as a leader in what has come to be called community-based participatory research, or co-produced science.

For Douglass the concept links back to the idea of relevance, her belief that the people and communities she studies should share in the benefit of that research. In this case, sharing means active participation: The MAP team in Madagascar is made up mostly of Vezo fishers. Although many team members have a limited school-based education, she regards them as equal partners in the production of scientific knowledge.

Top: François Lahiniriko (left) and Ricky Justome (right) excavating a deposit rich in extinct megafauna remains near the village of Tampolove, southwest Madagascar. Bottom left: Historian Ramosety Kely (right) and a community member of the village of Namonte. Bottom right: Community members processing their freshwater catch.

"To me there's nothing more precious than place-based knowledge," Douglass explains. "These are people who have lived in and derived their livelihood from this area, and have multi-generations worth of knowledge of all these ecological and geological and climate processes that I am interested in."

Nor does she dismiss their expertise as "other ways of knowing," something outside the bounds of academic science. "All humans engage in empirical observation, asking questions and posing hypotheses," she says. "I consider everyone that I work with in Madagascar to be a scientist."

Thinking inclusively comes easily to her because of her own early experience of feeling like an outsider in science. "There weren't a lot of role models, people who looked like me," she says, reflecting on her educational path. "In tandem with that, I love to learn in a very hands-on way. I always felt that bringing people with all kinds of backgrounds to the table was them helping me to learn all these things that I needed to know."

In return, Douglass takes seriously her responsibility to the community she has become a part of. When a wave of COVID infections hit Velondriake in April 2021, she and the MAP team dove in to help, raising money from afar for personal protective equipment and coordinating with team members on the ground to distribute to local villages. "As anthropologists in particular, I think we're often working with communities that are vulnerable, that will become more vulnerable as climate change intensifies," she says. "There's an obligation to contribute."

Though she acknowledges some resistance among her colleagues to the idea that researchers thus embedded within their communities can produce rigorous science, she believes the opposite is true. As she told a reporter for Nature in the wake of the COVID effort, "Having strong community relationships—especially when they are transparent, mutualistic and reciprocal—improves the quality of the science you do, and they make you ethically more responsible for the outcomes."

Community members washing dishes and processing produce near a lake in the Mikea forest.

"TO ME THERE'S NOTHING MORE PRECIOUS THAN PLACE-BASED KNOWLEDGE."

A FULLER PICTURE

The dominant archeological narrative regarding Madagascar links the arrival of humans with an immediate wave of extinctions, effectively blaming the ancient Malagasy people for wiping out whole sectors of the island's fauna. After years of study, however, Douglass argues that this narrative is overly simplistic, based on insufficient evidence. Furthermore, she says, it has negatively impacted present-day conservation and development efforts in the country, which, she writes, "are often guided by relatively short-term perspectives on how the region's landscapes and ecologies have co-evolved with human communities."

To help remedy this situation, the MAP team wants to provide a fuller picture of Velondriake's ecological history. Ten years into the work, that picture is beginning to emerge.

In 2018, for example, the team published the first comprehensive study of animal fossils collected from archeological sites in the area. Results of both morphological and DNA analysis present a more nuanced view of ancient fishing practices, and suggest that ancient communities selectively exploited marine resources. In addition, comparison with current practices revealed that the intensive fishing of sharks, acknowledged today as a serious environmental issue, is a recent phenomenon tied to increased demand for shark in international markets. Nor did they find any evidence for wholesale slaughter of megafauna.

A more recent study, involving examination of radiocarbon data, suggests that humans may have been present on Madagascar much earlier than previously thought, and therefore may have co-existed with now-extinct species for a thousand years or more before the populations of those animals began to crash.

Not surprisingly, Douglass says, the inclusion of place-based knowledge often up-ends assumptions imposed by outsiders. "We tend to have an idea of what constitutes disturbance, climate stress, events that could lead to community disintegration, but what we're learning is that some of the things that we recognize as highly stressful may be things that the local niche, the local system, had adapted to dealing with," she says.

Similarly, she says, while theories about migration patterns within Madagascar posit that communities have tended to move when pushed to do so by a scarcity of resources, the local historians the team has interviewed often speak instead in terms of being pulled to pursue new opportunities. "We need that place-based knowledge to understand how over time people have coped."

TIES THAT BIND

Douglass frequently cites a proverb of the Vezo, fisher people of southwest Madagascar: Translated into English, it means, "The land that sustains you is the land of the ancestors."

ALL HUMANS ENGAGE IN EMPIRICAL OBSERVATION, ASKING QUESTIONS AND POSING HYPOTHESES. I CONSIDER EVERYONE THAT I WORK WITH IN MADAGASCAR TO BE A SCIENTIST.

Mikea historian Remisy viewing live footage from a drone surveilling archaeological sites, assisted by Eric Rambeloson.

These connections, the ties not only between people and the land but between generations of inhabitants, are the key to survival in such a challenging environment, she says. And social memory is the glue that holds it all together.

Social memory, Douglass explains, is the transmission of knowledge from one generation to the next. Its central importance to the creation of a sustainable human niche in Madagascar became increasingly clear as Douglass and Tanambelo Rasolondrainy analyzed the oral history data the MAP team has collected.

"Mobility, use of resources, the creation and maintenance of social ties among communities… all of these are mediated by social memory," Douglass and Rasolandrainy say. "People's ability to recount and transmit the stories of their individual and family ties to particular places, people, and livelihoods are key adaptive mechanisms."

In Madagascar, much of this transmission has been accomplished via a tradition of storytelling known as tapasiry, sometimes translated as "tales of proper conduct." Through tapasiry, groups of migrating fishers, herders, foragers and farmers acknowledge connections and past cooperation, share strategies, and negotiate access to resources, Douglass says. When a group arrives in a new community, "the first thing that happens is people gather and start exchanging stories."

Unfortunately, Douglass says, and due to a number of factors, this tradition is starting to break down. "The local storytelling traditions are disappearing. Children are not being exposed to tapasiry," she says. The fraying of social memory is exacerbated by rapid changes linked to globalization and the emergence of a market economy, including, for the first time, industrial-level resource extraction—mining, forestry, and fishing on a scale that dwarfs subsistence-level activities. An added pressure, she says, is the in-migration of displaced populations from other communities. And all of this is amplified by the impacts of intensifying climate change that have Madagascar, according to the United Nations, on the brink of experiencing "the world's first climate change famine."

How will the communities she studies adapt to deal with these changes? What are the strategies that have sustained them in the past? Will those strategies be enough to sustain them now? These are some of the questions that Douglass hopes to answer in the next phase of the Madagascar Archeological Project.

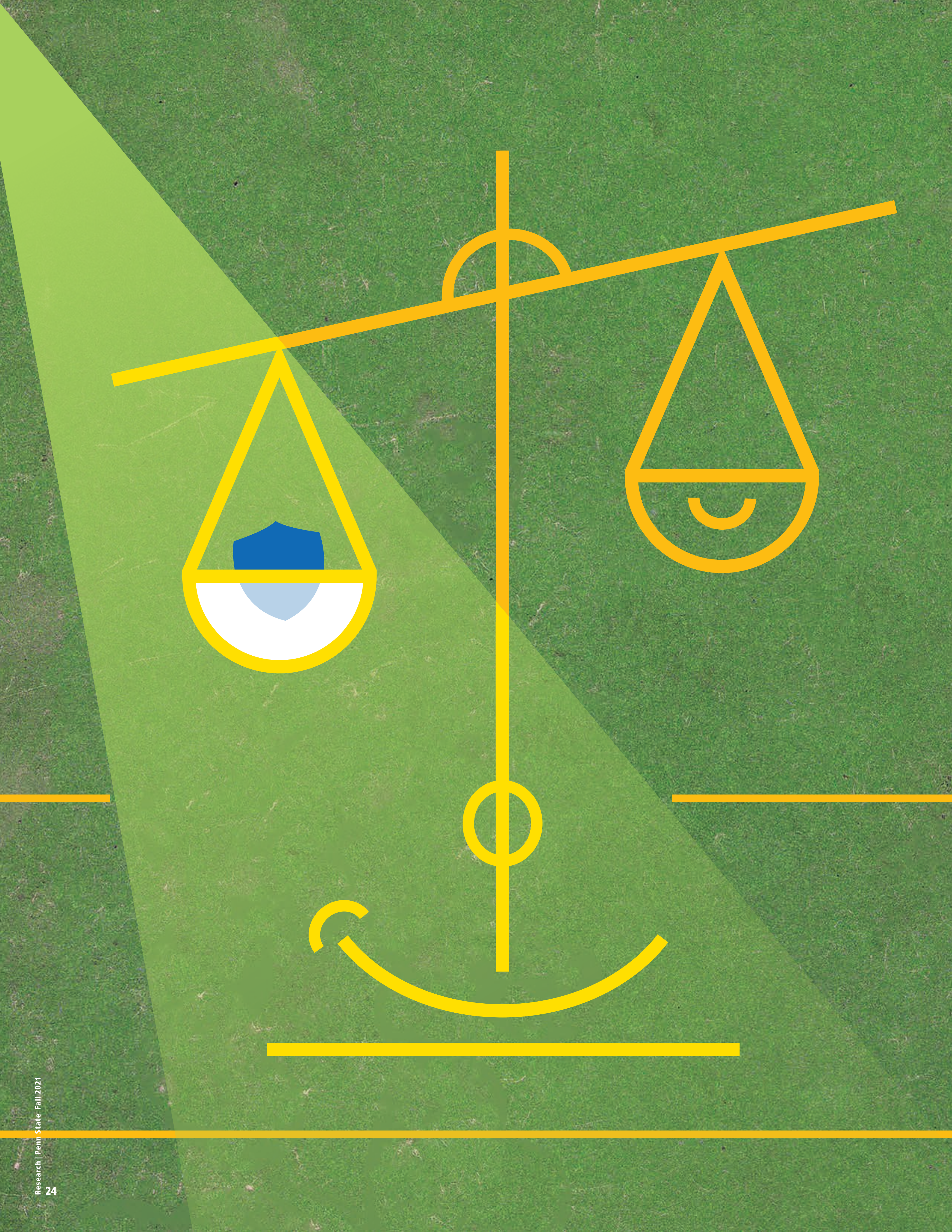
A prestigious Carnegie fellowship will allow her to expand the oral history work, in tandem with a coral coring project to reconstruct the paleoclimate record, looking for clues to how local fishing communities have dealt with climate change in the ancient past. What the team is learning, Douglass believes, "can help us ultimately understand and better deal with the challenges ahead."

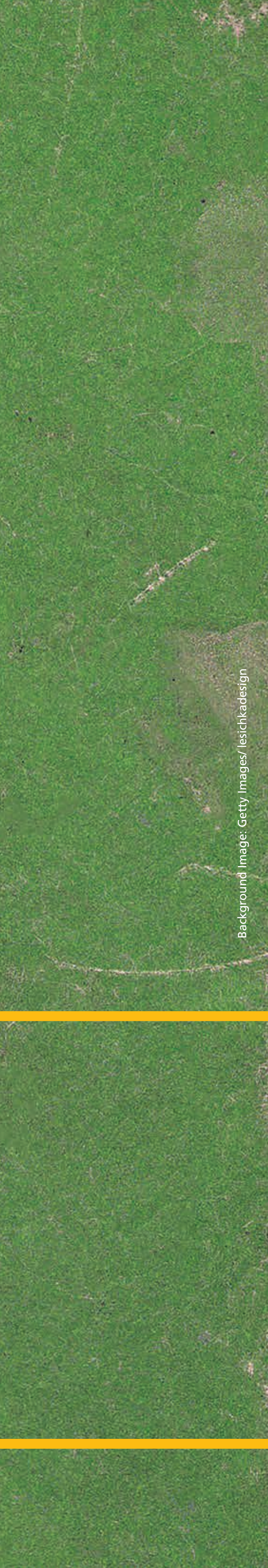
To her, that's a critical part of MAP's role as a member of the Velondriake community. But the answers she seeks echo far beyond southwest Madagascar. Douglass is part of a pending proposal that would extend the study to subsistence communities around the world facing similar challenges—in Puerto Rico, Ethiopia, Fiji, and the Arctic. "These communities may look different from one another," she says, "but they are completely interconnected."

Her core idea is to try to understand how and when successful adaptive behaviors emerge in these embattled communities, and also how they spread. Ultimately, she concludes, those lessons will be valuable for the rest of us.

"There's a lot we can learn from the witness testimony of communities on the front lines."

Community member holding a tenrec (*Echinops telfairi*), a commonly hunted species in the Mikea forest.




Background Image: Getty Images/ lesichkadesign

An Ounce of Prevention

A Penn State research center looks to the future by stopping problems before they start.

by Katie Bohn

ILLUSTRATION BY KEVIN CARLINI

For much of history, health care professionals have dealt with issues like substance abuse and mental health disorders by playing defense.

Problems were usually addressed as they appeared. A person struggling with alcohol addiction entered a rehab program. A child who was chronically unable to pay attention at school started seeing an occupational therapist. But while treatment in response to a problem can often be effective, it sometimes comes too late.

More than twenty years ago, a team of researchers at Penn State asked what would happen if they flipped the paradigm and went on offense: putting their efforts into preventing problems before they occur.

PREVENTATIVE BEGINNINGS

Back in the 1990s, Mark Greenberg was a developmental and child-clinical psychologist working with children who were experiencing anxiety, aggression, and other mental health issues. A decade earlier, he and Carol Kusché, a colleague at the University of Washington, had written the Promoting Alternative THinking Strategies (PATHS) Curriculum, a program for preschool and elementary schools that aims to enhance social and emotional development of all children.

But while these accomplishments were fulfilling, Greenberg was also interested in using an emerging approach called prevention science as a way to help even more children and their families.

“The idea of using high-quality science to improve the lives of children and families, and to do this before there was a need for clinical treatment, really inspired me,” Greenberg says. “Instead of treating an existing problem, the idea was to build children’s resilience and protective factors so that we reduced the number of children that needed extra services for mental health issues, drug abuse, or school failure.”

In 1998, he brought this idea to Penn State as the Bennett Chair in Prevention Research in Penn State’s College of Health and Human Development. With a generous endowment from Edna Bennett Pierce—a Penn State alumna from the first freshman class of women admitted to the university following World War II—Greenberg and Bennett Pierce created what is now called the Edna Bennett Pierce Prevention Research Center.

“My primary goal in creating the Center was to promote the well-being of children and to reduce the prevalence of high-risk behaviors and poor outcomes in children and families through applying science to everyday practice,” Greenberg says. “We wanted to achieve this through cutting-edge research, training the next generations of prevention scientists, and reaching out to assist Pennsylvania communities.”

Mark Greenberg

Gregory Fosco

“The idea of using high-quality science to improve the lives of children and families, and to do this before there was a need for clinical treatment, really inspired me.” –Mark Greenberg

In the twenty-plus years since its inception, the center has developed a wide variety of evidence-based programs to help children and families. The Family Foundations program, for example, provides training for expectant parents about effectively parenting as a team. The REDI program (Research-Based Developmentally Informed) aims to improve social and emotional skills in low-income preschool children. And PROSPER (PROmoting School-community-university Partnerships to Enhance Resilience) works with middle school students and their families to help students make good choices and promote family bonding.

Today, says Stephanie Lanza—director of the center and C. Eugene Bennett Chair in Prevention—the center is broadening beyond its early focus to include research on issues facing people at all stages of life.

“The center is built around this tradition of a need to understand the problems society is faced with today,” Lanza says. “While some issues like alcohol abuse and cigarette smoking unfortunately remain relevant, our research has also evolved to include more recent problems like the opioid epidemic and COVID-19. We are also looking at ways to promote overall happiness.”

Today, the center’s dozens of projects, helmed by more than sixty affiliated faculty, run the gamut from preventing substance abuse and promoting healthy eating habits to better understanding Alzheimer’s risks and using mindfulness techniques to help people of all ages flourish at home, school, and work.

Not surprisingly, the center responded quickly to the COVID-19 pandemic, initiating a number of projects assessing impacts on various populations. One study, for example, looked at increased risks of child maltreatment caused by added family stress during lockdown. Another is examining how researchers can best communicate with policy makers about the inequities that children and youth may be facing as a consequence of the pandemic.

BRANCHING OUT WITH TECHNOLOGY

Gregory Fosco, associate professor of human development and family studies and associate director of the center, says that regardless of a project’s theme, the use of technology to enhance the ability to collect data has become one of the center’s priorities.

In the past, Fosco explains, researchers might send out a one-time survey to collect data from a study’s participants, or use video to record a session of how a family interacts together. Now, with the ubiquity of smartphones and other devices, researchers have the opportunity to collect data not just on a day-to-day level, but potentially hour-by-hour.

For example, he says, a researcher studying alcohol use in college students may “ping” study participants daily, using an app on their phones to ask about their drinking and also about other behaviors and activities that may reveal patterns that could lead to alcohol use.

This allows us to understand life as it’s being lived, instead of in a lab setting that may not reflect real life,” Fosco says.

"If we can identify these day-level factors and moments, it could allow us to develop technologies that can catch them in the moment they are at risk and deliver an intervention right to the phone in their pocket. We become a companion to them rather than them having to wait to come to a session in our office."

One project using tech in an innovative way is led by Sunhye Bai, an assistant professor of human development and family studies, who is exploring the use of dashboard cameras to record family conversations in the car as a way to gain real-life insights into how families communicate.

"Especially in middle childhood and early adolescence, the car ride is a time when kids open up and share, at least in my experience," Fosco says. "If I was driving my son to a school activity, for example, I would learn more about what was going on in his life in those fifteen minutes than if I was going to sit down with him and chat over a milkshake. In those car rides, the guards get dropped."

In addition to allowing researchers to gather data in different ways, technology can sometimes be a part of the solution.

Fosco is currently leading a team that's developing a smartphone app intended to help parents connect with their adolescent children. The app will help families choose meaningful activities they can enjoy together, with the ultimate goal of reducing the adolescents' risk of depression, problem behavior, substance use, and academic difficulties. For example, one activity encourages family members to share ways in which they are proud or impressed with each other. Another encourages parents to share stories about their own childhood with their kids, and for kids to reciprocate with stories or memories of their own. The project is a collaboration with Benjamin V. Hanrahan, assistant professor of information sciences and technology, an indicator of the center's interdisciplinary approach.

A project Lanza is involved in is using Amazon Alexa devices to deliver mindfulness-based interventions to the homes of chronic pain sufferers.

"Now that everyone is carrying a smartphone, we can do studies that give us a better understanding not just of broad risk factors but of the more personalized, day-to-day events that may trigger a negative event," Lanza says. "It allows us to be more precise in our interventions, and also allows us to deliver those interventions in a more immediate, personalized way."

EXTENDING IMPACT

The center's impact extends far beyond research being done at Penn State.

The PATHS® Curriculum created by Greenberg and his colleagues in the 1990s continues to be implemented in schools across the United States.

The center has a strong and long-standing partnership with the state of Pennsylvania, providing oversight, technical assistance and expert advice to help policymakers and agencies identify and fund prevention programs that are effective and ensuring that communities who adopt these programs are implementing them correctly.

"We see that as one of the ways we're fulfilling the land-grant mission," says Fosco. "There is some form of evidence-based programming supported by the center in every county in Pennsylvania."

With support from private foundations, the center's experts create policy briefs about social and emotional learning, and are working to understand how to most effectively translate prevention science for policymakers and other audiences.

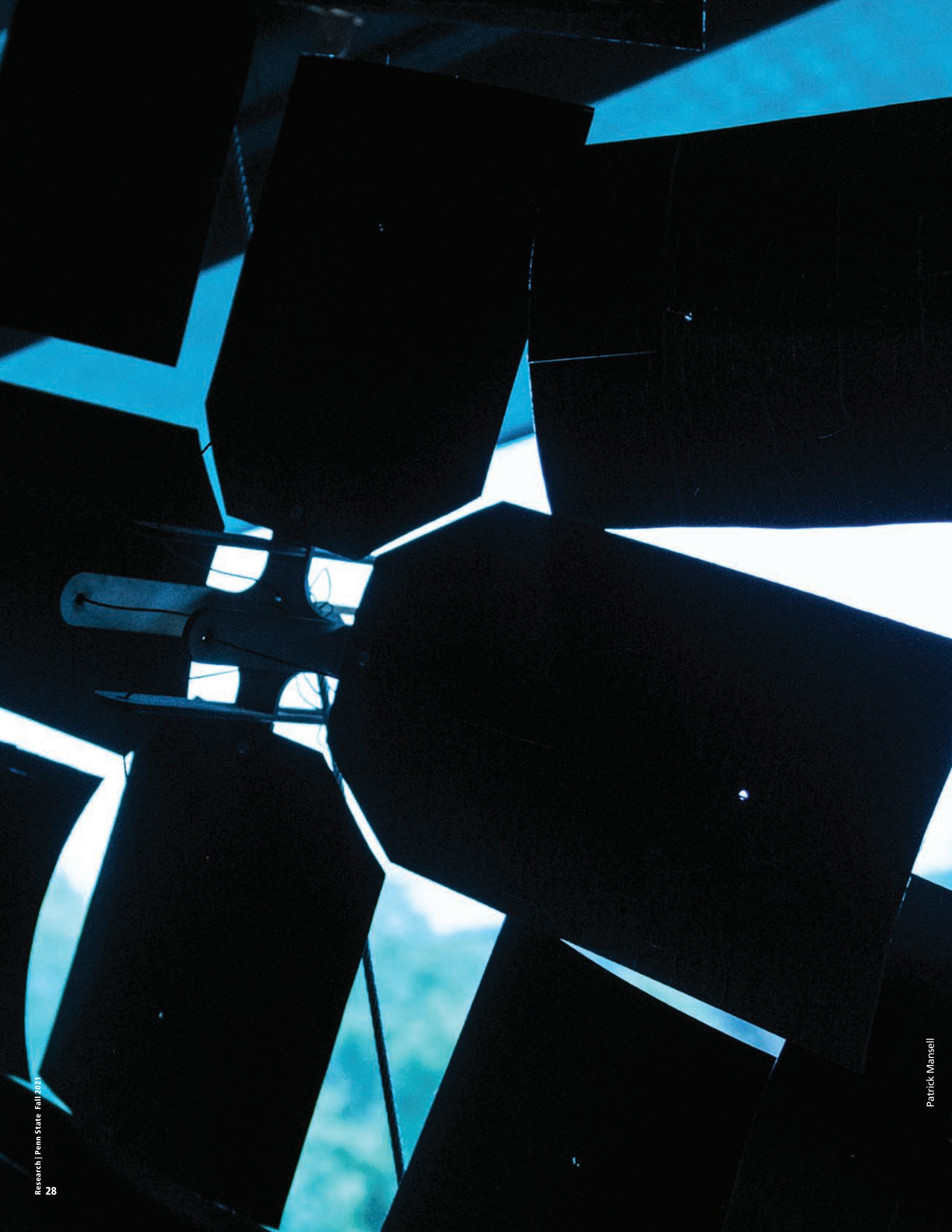
Additionally, the center has received funding since 2005 from the National Institute on Drug Abuse for the Prevention and Methodology Training Program, which focuses on training the next generation of scientists in preventing substance use and addiction. Almost 100 of the program's Ph.D. graduates have gone on to faculty positions in substance use or prevention science, seeding research institutions all over the country.

Twenty years on, it's clear that the center is fulfilling Greenberg's original vision—and that the benefits of prevention science have been firmly established. "People are more and more aware of the value of this approach," Fosco says, "and this center has made a very important contribution to that."


Patrick Mansell

Stephanie Lanza

"The center is built around this tradition of a need to understand the problems society is faced with today." –Stephanie Lanza


Patrick Mansell

A transatlantic partnership explores living materials for sustainable building.

DESIGNED TO ADAPT

By David Pacchioli

The coming decades present a host of challenges for our built environments: a rising global population combined with increasing urbanization; crumbling infrastructure and dwindling resources to rebuild it; and the growing pressures of a changing climate, to name a few.

To become more livable for more people, cities themselves will need to become smarter, with buildings, bridges and infrastructure that are no longer static but dynamic, able to adapt and respond to what's going on around them. If not exactly alive, these structures will need to be life-like, in important ways. And for that, they'll need to incorporate living materials.

"Engineers and scientists have worked for hundreds of years with so-called smart materials," says Zoubeida Ounaies. "Piezoelectricity was discovered in the 1880s." Smart materials can sense and respond to their environment, she explains, "but they always need an external control system or source of power. Living materials that adapt, respond to the environment, self-power, and regenerate—in the way that materials in nature do—are the next logical step."

Ounaies, a professor of mechanical engineering at Penn State, is director of the Convergence Center for Living Multifunctional Material Systems, a research partnership between Penn State and the University of Freiburg in Germany. Known as LiMC², the center is one of only a handful in the world focused on this emerging field.

A NEW PARADIGM

Living materials, Ounaies explains, are engineered materials that are inspired by nature. Sometimes they even incorporate biological elements. Their dynamic properties, at any rate, enable them to adapt to changes in their environment, responding to external stimuli. They may change shape, heal themselves, even make simple decisions.

Zoubeida Ounaies

Patrick Mansell

Close-up of a dynamic shading system mounted in the Stuckeman Building at University Park. The system, designed by Penn State doctoral student Elena Vazquez, is made up of panels incorporating a bistable material that allows them to open or close in response to sunlight, without human intervention.

Zoubeida Ounaies studies particulate-modified polymers with the goal of fabricating stimuli responsive sensors and actuators. In the background photo, lithium glass embedded PVT polymer scintillates in response to light, demonstrating its applicability as a neutron detector. Credit: Patrick Mansell.

Ounaies's counterpart at Freiburg is Jurgen Ruhe, director of the Cluster of Excellence in Living, Adaptive and Energy-autonomous Materials Systems (*liv*MatS). At a webinar last summer Ruhe put it this way: "If we look at the materials of today, one of the very key features is that materials have properties which do not vary in time. But if we turn our view to nature, nothing is really constant. For living systems, adaptivity is the key to survival. The goal of our *liv*MatS cluster is to generate materials systems which can adapt to changes in the environment based on sensory input and then improve over their lifetime."

Importantly, Ounaies says, living materials are multi-functional. They don't just provide strength or elasticity or hardness, they reduce environmental impacts and promote health; they monitor their own status, and when used up they can be recycled or reabsorbed. They harvest energy from their surroundings, store it, and use it for what they need. They do these things, ideally, while self-powering and without external sensors or motors.

Above all, perhaps, engineered living materials aim to be sustainable. "The concept requires us to look at the whole life cycle," Ounaies says. "To think about the starting material, the extraction and manufacturing processes, the waste generated, the energy required." The design must account for all. Thus, unlike many smart materials, living materials don't put a harmful load on the environment.

"If you think about it," she says, "adaptive behaviors happen in nature all the time. Maybe not in a material form, but certainly in systems. There are plant systems that do this. There are animals that do this. " Nature does the original design work. "For example, if one investigates the hierarchical pattern of a mollusk shell or the intricate structure of bird wings, one is inspired to apply them to human made structures in ways that integrate multiple functionalities."

Thomas Speck has been fascinated by biomimetics for 30 years. Trained as a biophysicist, Speck is now professor of botany at the University of Freiburg. He studies the functional morphology of plants—the relationship between structure and function—and how these "biological role models" might be applied to the world of technology. As director of the University's Botanic Garden, he has over 6,000 species from which to find his inspiration.

Plants, says Speck, have important lessons to offer. "First, they are mobile, although their movement is often hidden from us," he explains. "A lot of plant movements are very aesthetic—think of a flower opening. We want to transport this aesthetics into our architectural solutions."

What's more, Speck says, plants work their magic with a very limited number of structural materials. "Cellulose, hemi-cellulose, lignin, a bit of pectin. Three polysaccharides and one complex polyaromatic polymer. With these materials, which are all relatively easy to recycle, they are able to make fantastic structures, fantastic systems which work incredibly well."

A simple example is the pine cone, whose paddle-shaped scales open and close in response to changes in environmental humidity. At the Botanic Garden, Speck and his colleagues have analyzed fossilized pinecones 50 million years old and found that they still perform like modern specimens. "And it costs no energy, because humidity changes are brought by sunlight," he says.

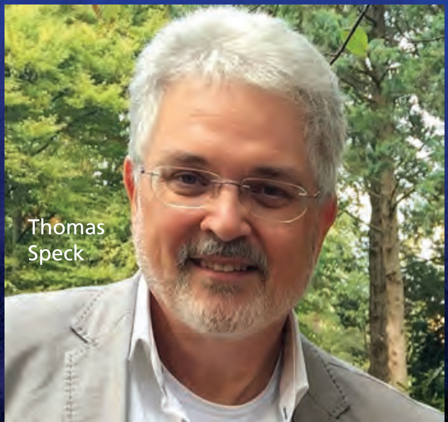
As amazingly robust as the natural mechanism is, the pinecone is merely reactive, Speck notes. "If it's wet, it's closed. If it's dry, it's open." In adapting this principle, he says, "We want to design systems that are interactive, that can combine movements, that make decisions. Biomimetics for us means we get inspiration from nature and then reinvent nature. We don't copy it. We want to combine the best of both worlds: living nature and technics."

A CENTER IS BORN

Engineering living materials requires a daunting combination of expertise: in biology, materials, engineering, and design, to name a few. It's exactly the sort of problem that Penn State's interdisciplinary institutes were set up to solve. LiMC^2 got its start when the directors of two of those institutes, Tom Richard of the Institutes for Energy and the Environment and Clive Randall of the Materials Research Institute, saw this emerging field as one in which the University could excel.

Penn State already had a strategic partnership with Freiburg, one of Germany's top universities, and the two institutions had both overlapping and complementary strengths in the area of living materials. Working together, through both research collaborations and educational exchanges, they could become a worldwide leader.

"Biomimetics for us means we get inspiration from nature and then reinvent nature. We don't copy it. We want to combine the best of both worlds." —THOMAS SPECK



Thomas Speck

Courtesy: Thomas Speck

Getty Images/ Waltkopp

Plant Biomechanics Group

Examples of natural systems whose mechanisms have inspired engineering solutions. At bottom right, pine cones open and close in response to changes in humidity. A sun-shading system being developed by Thomas Speck and colleagues at the University of Freiburg combines the distinct opening and closing movements of the waterwheel plant, at bottom left, and the Bird-of-paradise, top.

The idea was supported and facilitated by Penn State Global Programs and the International Office in Freiburg, and in July of 2019, Penn State President Eric Barron and the University of Freiburg's Rector Hans-Jochen Schiewer signed the formal partnership that made LiMC² a reality. Soon after, the center announced that adaptive architecture would be one of its core research areas.

Adaptive architecture, Ounaies says, is a "no-brainer" for a center built around living materials. "It's a natural core area for us because of the focus on materials discovery and sustainability, as well as our strengths in smart materials, advanced manufacturing, architecture and design, where the needed expertise spans multiple department and colleges. And it's also a great platform where all these things can come together to demonstrate what living materials can do."

Before the center even existed, in fact, Ounaies, whose research focuses on responsive soft materials for sensing, actuation, energy storage and energy harvesting, was collaborating with Penn State architecture professor Jose Duarte and Ph.D. student Elena Vazquez, both in the College of Arts and Architecture.

Patrick Mansell

Boris Khvostichenko, Wikimedia Commons

Courtesy: Linnea Hesse

CatalpaSpirit, Wikimedia Commons

Top, Jose Duarte, professor of architecture at Penn State, and doctoral student Elena Vazquez adjust panels on the prototype shading system that Vazquez designed. Middle left, A dragon tree, whose branching structure and load-bearing strength make it a good model for tree-like pillars like those in Stuttgart's international airport, at bottom right. At bottom left, element for a fiber-and-concrete pillar being developed for architectural use at the University of Freiburg.

The façade or building envelope—what Duarte calls “the membrane that permeates between the interior of the building and the outside” —is a primary focus of adaptive architecture.

Patrick Mansell

Duarte’s work focuses on customized buildings that fit into their environmental contexts to create sustainable and affordable housing options. But conventional approaches to customization have their limits. “Once it’s built, it’s static,” he says. So he and his students began to explore the possibilities for buildings that continue to adapt in response to changing conditions.

For her Ph.D., Vazquez designed a shading system that could be added to the façade of an existing building, made up of panels that open or close in response to sunlight, controlling the amount of light and heat entering the building. Because a mechanical system would be expensive and difficult to maintain, Duarte and Vazquez were looking for a materials solution for her design.

“My research interest, broadly defined, is to find new engineered materials and figure out ways of incorporating them into architectural design,” Vazquez says. They turned to Ounaies, aware of her work with electroactive polymers. Vazquez spent time training in Ounaies’s lab, and eventually they settled on bistable materials as a possible solution. With just a little bit of energy, Ounaies explains, a bistable material can be nudged from one stable shape to another—snapping from open to closed, for instance.

Vazquez’s subsequent design incorporates just such a material, actuated by a polymer-based smart material, to open and close its shade panels. The system works in response to sunlight, without human intervention. A small protoype is mounted in the Stuckeman building at University Park and a grant awarded by the American Institute of Architects will allow the collaborators to build a full-scale model.

BEYOND THE FAÇADE

Not surprisingly, the façade or building envelope—what Duarte calls “the membrane that permeates between the interior of the building and the outside”—is a primary focus of adaptive architecture. “Anything you do there has a huge impact on performance, on energy consumption, on environmental conditions inside,” Duarte says.

At Freiburg, Speck and his colleagues are developing their own sun-shading systems, combining the opening and closing movements of a pair of plant models: the Bird-of-paradise and the waterwheel plant. Botanist Linnea Hesse, however, is more interested in a building’s structural elements. During a summer webinar event introducing Penn State and Freiburg researchers to one another, she presented a keynote talk on biomimetic structural design.

Hesse, a group leader in plant biomechanics at Freiburg’s Botanic Garden, noted that the branching structures of trees have already been incorporated into architecture—in the spectacular designs of buildings like Barcelona’s Sagrada Familia basilica and Stuttgart’s international airport, for example. In addition to their beauty, the tree-like pillars in these designs function to spread load-bearing requirements and allow for more interior space.

Courtesy: Linnea Hesse

With the goal of optimizing the load-bearing strength of such components, she is studying the dragon tree, a member of the Monocotyledon family that includes palm trees and bamboo. Monocots have a particularly pronounced fiber-reinforced inner structure, Hesse explains, achieving strength without excess weight and making them a good biological role model.

To better understand how a dragon tree’s inner structure adapts to a load, she turned to medical colleague Jochen Leupold, who trained her in the use of magnetic resonance imaging (MRI). Her time-lapsed scans of living trees, both under load and not, show localized changes in fibrous tissue due to weight-bearing, data that have already been used to improve the design of a fiber-and-concrete pillar being developed for architectural use.

Hesse is also using MRI and CT imaging to study branching mechanisms, how water is transported through monocot tissue, and the growth process itself. Understanding the inner workings of the plant, she says, is only the first step. Her vision is one day to help design houses that can adapt and grow over time, altering their structure to meet changing needs the way plants do. “It’s a bold idea,” she says. “But I think it’s possible. This is where I want to go.”

RE-THINKING CONCRETE

Juan Pablo Gevaudan, in contrast, wants to know how things break down. Gevaudan, an assistant professor of architectural engineering at Penn State, calls himself a modern cement chemist. He is focused on the problem of concrete degradation.

Patrick Mansell (2)

Rebecca Napolitano and Wesley Reinhart. Below them, detail of the interior of Axemann Brewery, Bellefonte, PA, an example of adaptive re-use. The microbrewery was formerly a metal factory. Design and construction focused on repurposing existing metal works and features, paying respect to the site's heritage.

Concrete is the most widely used construction material on Earth. Deployed in the harshest conditions, exposed to relentless attack by environmental acids and salts, concrete degrades over time. Erosion and rusting of embedded reinforcement bars cause eventual weakening and failure. Sometimes that failure is catastrophic, as in the Surfside, Florida condominium collapse of June 2021.

The first step to addressing concrete corrosion, Gevaudan says, is understanding exactly how it occurs. Once that chemistry is better known, researchers will be able to predict degradation before it happens, and to design more durable cements from materials that can respond and adapt to environmental conditions.

Alkali-activated materials are one possible alternative. “These have drawn global attention because they can be produced from the byproducts of industrial processes—steelmaking and coal-burning,” Gevaudan says. “They can also be made from clay, the most abundant material in the world. And they can be produced at ambient temperatures, so they are both local and environmentally friendly.”

Ideally, he says, the materials he develops will not only resist corrosion, they'll have the ability to repair themselves. Some researchers have even shown that certain types of bacteria embedded and living within concrete can perform this self-healing. But the longevity of these biological solutions is an open question, so Gevaudan and chemical modeler Michael Moseler of Freiburg are pursuing a different route. The two were awarded a LiMC^2 seed grant to develop a cement material that alters the surface chemistry of the embedded reinforcement bar within a concrete matrix, creating a barrier of ferrous mineral that halts and potentially reverses corrosion. The chemical process, Gevaudan says, mimics the formation of one of the toughest substances in nature: a mussel's teeth.

ADAPTING EXISTING STRUCTURES

Rebecca Napolitano's design inspiration comes more from history than from nature. As an undergraduate majoring in physics and classical languages, Napolitano, now an assistant professor of architectural engineering at Penn State, spent several summers in Italy, where she fell in love with historic structures and learning how they could comingle with modern ones. “It really opened my eyes to the importance of historic structures and how we can keep them as vital parts of communities,” she says.

But it isn't only monuments that Napolitano wants to preserve. “Over fifty percent of New York City is over 50 years old,” she says. “What are we going to do, tear it all down and start over?” Instead, she wants to design adaptivity into existing structures. By preserving and finding new uses for what already exists, she says, communities can reduce their carbon costs, decrease the amount of solid waste they send off to landfills, and save on new construction materials.

Preservation poses its own challenges, and Napolitano is developing digital technologies to address them. She is making innovative use of eye-tracking software and machine learning to help with detecting existing damage and simulations to aid in diagnosing and predicting problems.

“The way we inspect our infrastructure is really limited,” she explains. “Say it's a bridge. Right now we send an inspector every two years, and they might have to climb up on scaffolding to look at the underside, or dive to get at the underwater portion. It's difficult to be really thorough, and it requires a ton of expert knowledge.

Ideally, Gevaudan says, the cementitious materials he develops will not only resist corrosion, they'll have the ability to repair themselves.

Juan Pablo Gevaudan

Patrick Mansell

Right, the *liv*MatS Pavilion at Freiburg's Botanic Garden. A collaboration between the University of Freiburg and the University of Stuttgart, the cottage-sized structure is made of wound flax fiber bundles (detail at left), covered with a waterproof polycarbonate.

"With eye-tracking, we're trying to figure out how to capture the knowledge of that human expert, then apply machine learning to teach a drone, say, where to look, and have it fly in for a close inspection." She imagines a future where a single inspector could be aided by a team of autonomous drones, lightening currently heavy workloads.

Another major challenge is the ongoing monitoring of a building's structural health. Electronic sensors in older buildings may be too few or inadequately networked to provide critical information. They require an external power source and centralized processing. "Plus, embedded electronic sensors eventually stop working," Napolitano says.

She is working with Wes Reinhart, an assistant professor of materials science and engineering and Institute for Computational and Data Sciences co-hire, who uses artificial intelligence to design so-called metamaterials that could be used in next-generation sensors to eliminate these problems. In one example, a sensor made of photonic material could be designed with an interior microstructure that scatters light passing through it according to prescribed mathematical equations.

"Then you can measure that response," Reinhart says, creating what is essentially a passive computing technology. "Instead of a sensor that has to send data elsewhere to be processed, the sensor itself is doing the processing. It's a way that you can compute with very low power—hundreds or thousands of times less power than electronic computing."

That kind of capability, Napolitano adds, could be invaluable "not just in a city like New York, but in places around the world where electricity is not as easily accessible."

BUILDING THE FUTURE

"Architecture and building construction are key to our limiting climate change," says Thomas Speck. According to most estimates, building materials and operations account for over 30 percent of global carbon emissions.

The *liv*MatS Pavilion recently erected at Freiburg's Botanic Garden points toward one possible alternative. A collaboration between Freiburg and the University of Stuttgart, the cottage-sized structure is made of wound flax fiber bundles, covered with a recyclable (and waterproof) polycarbonate. Its light but strong load-bearing structure, Speck says, was inspired by the reticulate wood structure of the saguaro cactus. In addition to being a renewable resource, flax costs far less energy to produce than concrete and steel and can be harvested every year.

At Penn State, Benay Gursoy, assistant professor of architecture in the College of Arts and Architecture, is exploring in a similar vein, experimenting with mushroom-based composites as sustainable building materials that respond to temperature and humidity.

Engineered systems like passive-computing metamaterials or self-healing concrete would be sustainable in other ways, as well. Imbued with the capacity to sense changes in themselves and their environments and communicate with nearby structures, these materials would save the energy cost of transmitting data, and spread out the burden of decision-making. Instead of overwhelming a central processing center with oceans of data collected from thousands or millions of electronic sensors, a living material set in place could sense and respond on its own. Localizing decision-making in this way could in turn help to address another looming challenge for the hyperconnected smart cities of the future: cybersecurity.

We're still a long way from the vision of adaptive architecture using living materials, Ounaies concedes. It will require many different types of expertise, working together, to get there. "That's exactly what we're putting in place with this partnership," she says. "And that's what makes it so exciting."

"If we can design systems which can adapt, harvest energy, are robust and are sustainable," says Freiburg's Jurgen Ruhe, "this will be a truly new paradigm in materials research."

ESTHER OBONYO

on building sustainable, safe global communities

Getty Images/ bagotaj

In 2015, all United Nations member states adopted the 2030 Agenda for Sustainable Development—a blueprint outlining 17 Sustainable Development Goals focused on peace and prosperity around the world.

Esther Obonyo, associate professor of engineering design and architectural engineering, leads the Global Building Network, an initiative of Penn State and the UN Economic Commission for Europe aimed at advancing building science, construction, and management to accomplish Sustainable Development Goal 11: Sustainable Cities and Communities. Obonyo also serves as the lead for a $1.1 million Belmont Forum-supported consortium working to improve resilient and sustainable housing in low-income communities impacted by climate change.

WHAT DREW YOU TO THE BUILT ENVIRONMENT?

I was born and brought up in Nairobi, Kenya. Even though I'm from a middle-income family, I have lots of relatives who are in the lower social-economic status. From an early age, one of the things I was painfully aware of was the inadequate supply of quality housing for the masses. In these situations, you are not only looking at issues of building performance and technology, but also issues of economy. The transdisciplinary effort required to address this complex challenge of affordable, adequate housing drew me into feeling like this is a profession that can help me contribute.

HOW DOES YOUR JOINT APPOINTMENT IN ENGINEERING DESIGN AND ARCHITECTURAL ENGINEERING EMBODY THIS CROSS-DISCIPLINARY EFFORT?

To address the challenge of affordable, adequate housing holistically and comprehensively, you need transdisciplinary efforts. Coming to Penn State gave me an opportunity to explore synergies across multiple disciplines. I can maintain a grounding in engineering design and look at food insecurity as an aspect of adequate housing without losing credibility in the professional circles I move in, while concurrently exploring building performance aspects through my architectural engineering appointment.

WHAT IS THE GLOBAL BUILDING NETWORK UNDERTAKING IN SUPPORT OF SUSTAINABLE, SAFE BUILDINGS AROUND THE WORLD?

The Global Building Network's design allows synergies with universities and organizations to happen organically. It's not competitive. It's about being humble and saying, 'we are great at what we do, but what we do is not going to get us there,' in terms of supplying affordable, adequate, resilient, low-income housing and decarbonizing the building sector. Translating potential solutions into scalable impact requires several institutions working collaboratively. That's what the Global Building Network is all about.

We have an opportunity to avoid potential problems through knowledge transfer. It is established fact that the bulk of new buildings will be constructed in the global south. We are worried that if the global south follows the trends of the global north, we will not achieve our targets for healthy, resilient, sustainable, low-income housing. We can also translate the lessons and experiences of the global south into strategies to use at scale in the global north, such as the use of locally resourced, low-carbon materials to inform material-related decarbonization efforts.

The final piece of the puzzle is related to human dignity and respect. Housing is a basic human right. We've seen during the current pandemic that it's at the center of our health, well-being, and performance.

HOW WILL YOU AND YOUR COLLABORATORS USE THE BELMONT FUNDING TO IMPROVE LOW-INCOME COMMUNITIES?

A priority activity for me, at a personal level, is trying to engage with governmental and non-academic stakeholders. For me, step number one is making sure all stakeholders understand the value we create as academics. We've also prioritized gathering input from community members. The lived experiences of communities should inform every phase of the research process. Understanding and addressing the unique concerns and priorities for these different stakeholders requires input from multiple disciplines.

The question we are really trying to answer is 'what causes vulnerability?' We have failed community members by proposing one-dimensional solutions—we show up, we provide the walls, roof, windows, doors. Being adequately housed is more than the physical structure. In our research, we are redefining this with the help of social scientists, trying to find ways to connect with what the household members are asking for. Is it access to food, water, energy? All these still require a physical building. We can connect these needs to bankable projects policymakers can move and influence.

WHAT'S NEXT?

At the workshops and research presentations I've attended over the years, we usually end up with this statement: '…but the government." I would like the projects we are working on to have a different end, one where we say, '…and the government.' That's what's next for me—getting to the point where our research moves policy making.

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Garth Cripps, Morombe Archaeological Project

Surviving In Place

An environmental archeology project in Madagascar yields lessons in resilience – and connectedness

SEE STORY, PAGE 18