Biodegradable bridges: Living structures that respond to the environment

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Living structures such as this traditional bridge in India made of vines provide a source of inspiration for entirely new materials. Credit: iStockphoto

Researchers are looking into new materials to lay the foundations for living structures that respond to their environment. They aim to create self-sustaining infrastructures that can monitor their condition and even repair themselves.

When Eleni Chatzi is not busy reading technical papers about vibrating bridges, smart infrastructures and data-driven engineering, she enjoys immersing herself in science fiction novels. "I like pondering unconventional ideas and imagining a world that is yet to come," says Chatzi, Professor of Structural Mechanics at ETH Zurich. Indeed, there is a ring of sci-fi to it when she talks about applications that her research could someday lead to. One such futurist vision is bridges that grow out of a handful of seeds and consist entirely of organic material.

This 38-year-old civil engineer, whose professorship has received funding from the Albert Lück-Stiftung since 2010, specializes in structural health monitoring. Chatzi diagnoses the health of dams, bridges, wind turbines, aircraft and vehicles using sensors, algorithms that convert and process signals, and machine learning. Currently, engineers have to either externally install the sensors needed to measure tension, deformation, acceleration, wind and strain, or incorporate these devices into the initial structural design. "However, this is usually an extra expense and a disruptive factor, especially on building sites," explains Chatzi. Crews have to install countless cables to transmit the measured data to a central computer for analysis. "That's why we'd like to develop infrastructures and machines with intrinsic intelligence that are aware of their condition even without externally mounted sensors," says Chatzi.

Conscious concrete

An unprecedented class of materials provides the underpinning for this kind of self-aware infrastructure—and researchers around the world have been busy exploring their mysteries for the past few years. One example is intrinsic self-sensing concrete. Mixed with carbon fibers, carbon nanotubes and nickel powder, this material monitors its condition autonomously to provide information about cracks, moisture or unusually heavy loads. This data is coaxed from the structure by applying voltage and constantly measuring the electrical resistance.

A second line of research into materials with self-healing properties points in a similar direction. Last year, in a project inspired by plant photosynthesis, US researchers presented a polymer that can repair itself by reacting with carbon dioxide in the surrounding air. Other groups are working with bacteria that form lime when exposed to rainwater and other moisture. Added to concrete, they can seal small cracks on their own. Experiments are underway with microvascular networks that release "healing" fluids when an injury occurs. Responding much like the human organism to a skin wound, they polymerize to fill the fractures.

Incorporating biological functions

"We're seeing a fusion of materials science and biology," says Mark Tibbitt, Professor at the Macromolecular Engineering Laboratory at ETH Zurich. He notes that in the past, chemical and other engineers had looked to nature primarily for inspiration for mimicking properties such as the lotus blossom's ability to repel water. "Today, we're trying to incorporate biological functions into materials." These efforts are fueled by breakthroughs in materials science and biotechnology. DNA engineering and new molecular biological methods such as CRISPR/Cas gene editing can now serve to introduce new biological functions into cells for very specific purposes. Additive manufacturing using 3-D printers enables high-resolution, data-based material design. Combining concepts from a number of fields—chemical engineering, polymer chemistry, materials science and systems biology—Tibbitt's research aims to develop soft, tissue-like polymers for biomedical applications.

"The fascinating thing about living organisms is that they perceive their environment, react to it and even heal themselves when injured. We want to instill these qualities in materials and infrastructures," says Tibbitt. He believes future applications could include houseplants that clean the air and change the color of their leaves to call attention to air quality, and buildings that change with the seasons to keep their interior climate comfortable.

Tibbitt met Eleni Chatzi a year ago at an event for exploring radically new avenues of research. Although the two work on very different scales, they often talk about the same concepts. Recurring topics include materials that can "heal" themselves. Recently, they began to foster dialog among researchers at ETH about living, self-sensing and self-healing materials and infrastructures. Materials scientists, chemical, civil and electrical engineers, biologists and computer scientists have all joined in to develop materials with the goal of working at different scales right from the start instead of scaling them at a later stage. "ETH Zurich is the perfect hub for this venture because it has so much expertise in all the key areas," says Tibbitt. An initial workshop and a symposium are scheduled to take place in spring 2020 for experts to discuss the matter. The idea is to define research questions and then launch the first transdisciplinary projects.

Living with animated environments

This is a fresh avenue of research that Chatzi and Tibbitt have embarked upon, and at this stage there are many more questions than answers. One big question is how to assure safety and stability when infrastructures develop a life of their own. Another is how humans and animals will react to an engineered environment consisting of living organisms. And what happens if a synthetic organism leaches from a new building material into surrounding waters? "We have to think about bioethical questions and safety concerns from day one," says Tibbitt.

Such risks also present great opportunities: concrete production accounts for around eight percent of today's global CO_2 emissions. Entire strips of sandy beaches are being sacrificed to the global construction boom. Many landfills are overflowing with rubble from demolished buildings.

Organic infrastructures with closed material cycles—such as bridges made of remarkably robust plant fiber—offer a sustainable alternative. If damaged, they could repair themselves. At the end of their service life, they could simply break down into individual compostable components.

Provided by ETH Zurich

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