'Origami' lattices with nano-scale surface ornaments

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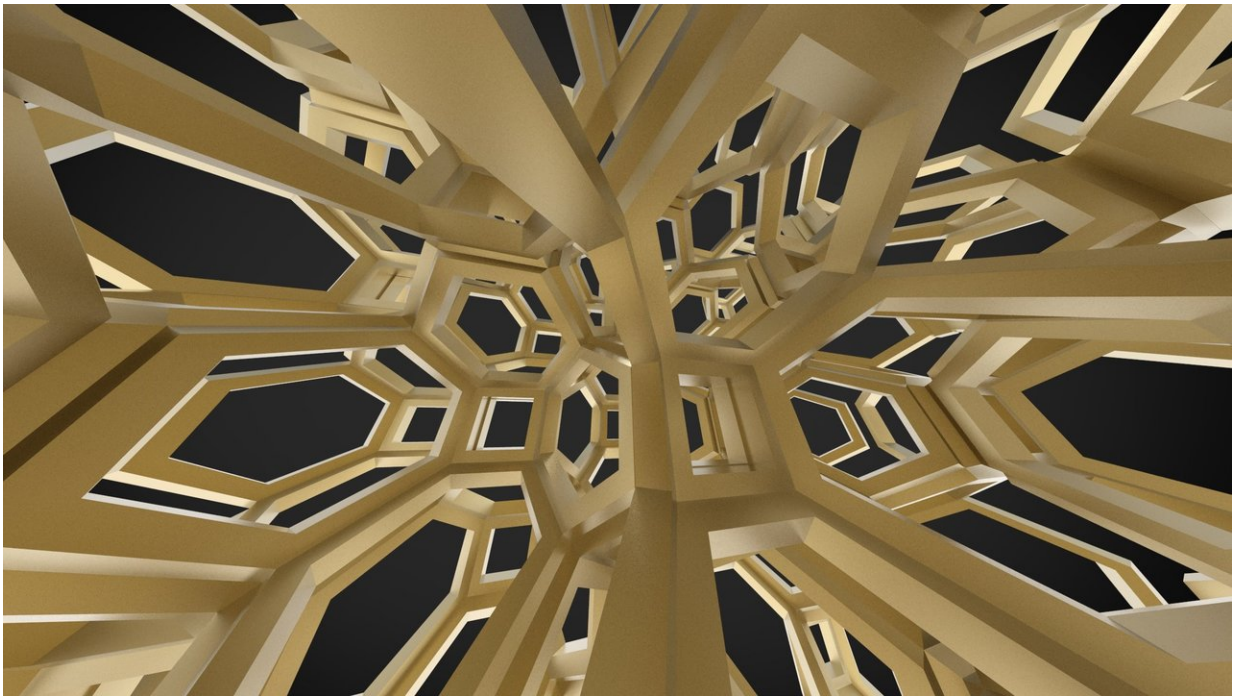

Credit: Delft University of Technology

Inspired by origami, the Japanese art of paper folding, researchers at TU Delft are developing an alternative to 3-D printing that gives the final products many more functionalities than what is possible with 3-D printing. Such functionalities could, for instance, be used in medical implants or devices incorporating flexible electronics. In their publication in *Science Advances* on Wednesday November 29th, the

scientists report successfully applying their technique to lattice structures.

Lattice structures are used in the design of so called metamaterials to achieve unusual physical, mechanical or biological properties. Examples are ultra-light, ultra-stiff materials, fluid-like solids and materials with ultrahigh energy absorption properties. These metamaterials derive their properties not from the properties of the base materials, but from the complex geometry of their lattice structures. Until now, lattice structures could be only made with 3-D printing processes, which limited their functionalities. The research group led by prof. Amir Zadpoor at TU Delft has shown for the first time how to use origami techniques to fold complex lattice structures from flat sheets.

Nano-scale surface ornaments and more

To incorporate advanced functionalities into metamaterials, the surfaces of the lattice structures may need to be ornamented with special features such as nano-patterns or electronic devices. The alternative approach of starting from a flat shape (instead of 3-D printing) allows for incorporation of those functionalities that generally could only be applied to flat shapes. Advanced micro- and nano-patterning techniques such as electron beam nanolithography allow for free-form patterning of surfaces. "However, they generally work only on flat surfaces," says prof. Zadpoor. "Moreover, our access to the internal surface areas of 3-D-printed lattice structures is very limited."

"Combining free-form surface ornaments with lattice forms seemed therefore impossible. But inspired by the Japanese art of paper folding (origami), we have found a way that allows for that combination. We have proposed the unusual approach of 'folding' lattice structures from initially flat states. That approach provides us with full access to the entire surface of what will eventually become our lattice structure. We

could then use the currently available techniques to ornament the surface. We have categorized lattices into three basic categories and, for each of those, have proposed a folding strategy. Self-folding mechanisms have been also incorporated into the flat material to allow for self-folding into the final lattice shape," says Zadpoor. The folding mechanism is activated (for instance by a change in temperature) to enable folding of the flat sheet and the formation of complex 3-D structures. The lattice structures could bear arbitrarily complex surface ornaments at different scales. "We show how free-form 3-D ornaments could be applied on the surface of flat sheets with a resolution of a few nanometers."

One possible application is the development of (meta-)biomaterials that stimulate tissue regeneration. Another application is integration of flexible electronics (for example, sensors and actuators) in the design of metamaterials.

More information: Shahram Janbaz et al. Origami lattices with free-form surface ornaments, *Science Advances* (2017). DOI: 10.1126/sciadv.aao1595

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