Product Design Revolutionized by Programmable Materials

Research gives materials new extraordinary capabilities. The Fraunhofer Cluster of Excellence Programmable Materials CPM has been ensuring this since 2018. A team of seven around PD Dr. Heiko Andrä, Deputy Head of the Department "Flow and Material Simulation", provides the appropriate mathematics, simulation and optimization expertise from Fraunhofer ITWM.

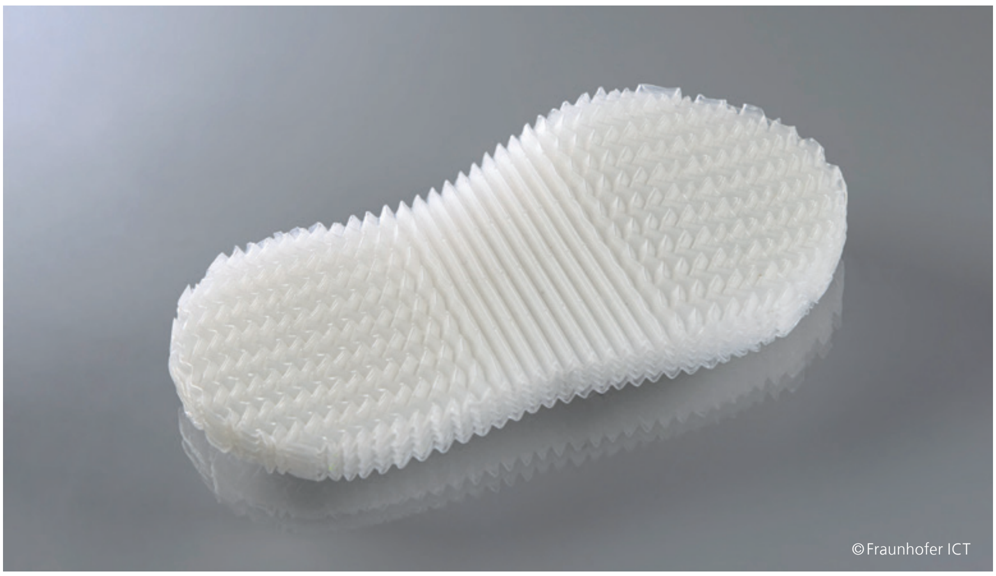
Running shoes with built-in cushioning that automatically adapts to the surface – whether forest floor or asphalt. Car seats that adapt to body tension or exterior components that quickly soften when they crash into pedestrians. Sound like dreams of the future? The cluster is about nothing less than the future of new materials.

In the Fraunhofer CPM, the competencies of various Fraunhofer institutes are bundled and work is carried out on various projects on the topic of "programmable materials". After four years, the first funding phase has ended. Since then, a lot has happened, also in the ITWM team.

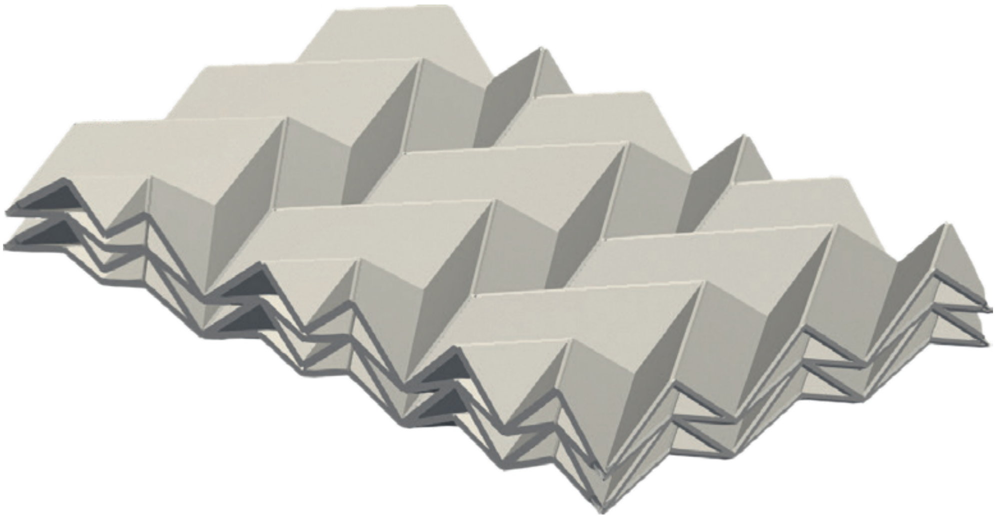
The Inner Values Count

New manufacturing processes such as 3D printing make it possible to produce targeted programmable structures in the micrometer range that have previously been developed on a computer.

In the case of "programmable materials", it is the internal structure that is important; through it, properties can be specifically controlled and the material behavior can change reversibly. Internally, they consist of a three-dimensional arrangement of many small individual cells. These serve as basic elements, are also called unit cells, and assemble them to



The Future of Materials: Product Design of a Plastic Sole Made of Programmable Material



Origami mathematics: The individual cells are folded elements made of plastic foils.

form two- or three-dimensional lattices. In their development, the researchers are taking their inspiration from nature. Because just like there, each cell not only has its own structure, but also properties and functions that make up the material as a whole. The arrangement of thousands of cells offers options for designing novel materials with local behavior that adapts to external conditions. What makes the materials so special is that they respond to specific triggers from outside. Such switching triggers include temperature, load or humidity. But what do companies gain from this development?

Software Tools Make Developments Ready for Industry

"In our ideal scenario, an engineer comes to us with certain desired functions of the product, and our tools help to find a combination of unit cells so that the material composed of these specific unit cells performs the desired function," Andrä explains. "For this purpose, the ProgMatDesign and ProgMatSim software tools have been created in the CPM, which enable virtual experimentation by selecting and arranging the cells."

With the help of optimization methods, each individual location in the component is given different parameters. The researchers from Fraunhofer IGD, Fraunhofer IWU and Fraunhofer ITWM are providing a web-based graphical user interface (ProgMatDesign) for designing the unit cells and programmable materials – it's easier to use than usual CAD software. "We are also building a database, where all the information on unit cells can be found, effectively the blanks for building the material. Using our in-house developed tool ProgMatSim, structures with optimal design are computed and used directly as input for 3D printing." A team then prints and tests the finished material, and it is recomputed if necessary. "Because it's not quite as ideal as in the digital twins yet realizable in practice on the 3D printer. The material sometimes warps or there are other interference aspects that don't show up in the virtual twin," Andrä says. But the mathematician is confident.

Mathematical Origami Art

Fraunhofer CPM is currently working on the scientific foundations and identifying potential applications of programmable metamaterials. In the process, cross-institute teams are also creating shape-morphing materials, which look like art, such as the origami materials that take on a desired shape when you pull on them. The individual cells are folded elements made of plastic films. In his doctoral thesis, Tobias Lichti, with the support of the Fraunhofer ICT and IWM, is computing the optimum size of the fold for each cell so that the origami material finally takes on the desired shape. This would not be possible without mathematics – in the end, the folded structures are hopefully at least as useful as they are beautifully shaped.

www.itwm.fraunhofer.de/programmable_materials

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