# The Aesthetics of Resource Efficiency
## ... or: how to build beautiful sustainable structures with less material

**Five years ago, Daria Kovaleva made the trip from Russia to Baden-Württemberg to experience the particularly successful collaboration between architects and civil engineers in Stuttgart. Her first major project immediately became a showcase for this collaboration. Together with her colleagues at the Institute of Lightweight Structures and Conceptual Design (ILEK), she planned the Rosenstein Pavilion, which was intended to demonstrate how interdisciplinary research can sweep away the design limits of previous architectural and construction styles.**

Using resources efficiently is one of the prerequisites for sustainability in the construction sector. This is particularly relevant to the work of architects and engineers, as a building's ecological footprint is already defined in the design phase. That’s why, when it comes to the development of material-saving architectural solutions, the experts are taking inspiration from nature and are studying, for example, cases where biological organisms apply various construction principles to fulfil their vital functions using minimum resources. One of the ways in which biological tissues react to the demands of the external environment is by only using material where it is functionally necessary.

A pavilion built for a special exhibition of construction bionics at the natural history museum in Rosenstein Palace, Stuttgart, shows how such insights can be applied to architecture and construction. The pavilion was designed and planned by Daria Kovaleva, a research associate at the ILEK and one of many researchers at the collaborative research centre “Transregio (TRR) 141: design and construction principles in biology and architecture. Analysis, simulation and implementation”. Since 2014, architects, construction engineers, mechanical engineers and structural engineers from the University of Stuttgart have been collaborating at the TRR 141 with biologists and physicists from the University of Freiburg as well as geoscientist and evolutionary biologists from the University of Tübingen. Their common goal is to analyse the operating principles of biological systems and replicate them in architecture and construction. To this end, the researchers are studying such things as the skeletal structure of sea anemones and the mechanism by which the crane flower (Strelitzia reginae) opens.

### Fusion of Form, Structure and Material

The Rosenstein Pavilion was modelled on natural tissues that serve a load-transference function. As Kovaleva explains: “human bones dynamically adapt their structure over the course of life to meet the external demands placed on them”. Bodies build more bone mass in areas of the body that are subject to higher load stresses and save material and weight in those areas where the bones have less to support. The young architect's objective was to apply these construction principles to her experimental structure and to use fewer resources by distributing materials differentially to meet the specific load requirements at each point. Just as in nature, the 31-year-old explains, one should not consider an object’s structure and material separately in this context, but rather one has to view them as a single entity. Because architects and construction engineers traditionally work closely together at the IKEK, the pavilion was developed in the context of an integrated planning process, in which the team took a holistic approach to the architectural, structural and production engineering requirements at the very early design stage.

For planning purposes, Kovaleva also referred to studies relating to functionally graded structures, which the ILEK team and its director Professor Werner Sobek have been carrying out since the 1990s. The work in question involves modifying the internal structures of structural elements, to utilise less material, whilst leaving their external geometry unchanged. In the case of so-called gradient concrete, for example, different concrete mixtures are poured at different points of a building to meet the specific local structural requirements.

### Light Work through Internal Finesse

With her contribution, Kovaleva is now introducing this concept to the broader public. “For the first time ever”, she says, “we want to implement the principal of functional grading at the architectural scale. We decided to opt for an open porosity to make it visible to the observer. Just as in biological, direction-dependent structures, the density and orientation of the porosity correspond to the magnitude and direction of the area of tension”. This resulted in the creation

Photo: University of Stuttgart / Uli Regenscheit

of a “scientific-artistic vision” of how resource-saving construction could work in the future.

The team worked on the Rosenstein Pavilion for one and a half years. Also involved were researchers from the Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW) and Institute of Textile Technology and Process Engineering Denkendorf (ITFT). To fabricate the 69 individual construction elements, the geometry of each individual segment was produced on the computer, then exported as a negative form (mould) so that the formwork could then be milled on a CNC machine. The forms were lined with carbon fibres to reinforce the concrete and then poured out. Once the concrete hardened, the experts removed the formwork, which was reused to cast other segments. Finally, the structure was assembled on a frame and fastened into place before an external metal cable then ensured that the structure took on its intended geometry.

By this means, Kovaleva achieved a 40 per cent material saving compared with a continuous concrete shell with a comparable load rating. At 3.5 metres high and with a surface area of almost six by six metres, the shell is only three centimetres thick and weighs just 1.7 tonnes. Daria Kovaleva designed her structure to fit exactly into the space allocated for the pavilion, the former breakfast room in Rosenstein Palace with its columns and pilasters. The structure rests on four extremely delicate-looking supports that precisely fit within the pattern of the marble floor and – via an ascending funnel form – terminate under the coffered ceiling. The original room is visible through the pores, which accentuates the aesthetic effect and the impression of unity of form, structure and material.

### Interdisciplinarity is The Future of Construction

The ILEK's particular approach and that of other institutes at the University of Stuttgart was what drew

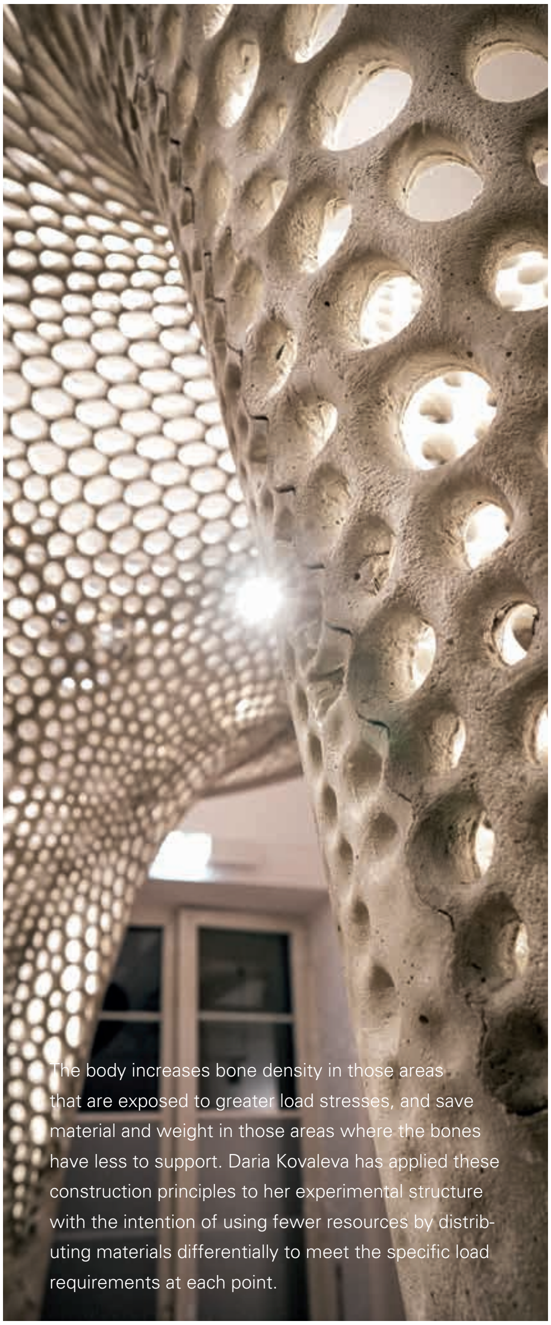

Photo: University of Stuttgart/ILEK

The body increases bone density in those areas that are exposed to greater load stresses, and save material and weight in those areas where the bones have less to support. Daria Kovaleva has applied these construction principles to her experimental structure with the intention of using fewer resources by distributing materials differentially to meet the specific load requirements at each point.

Kovaleva to Germany five years ago. Having gained her master's degree in Russia, she worked with various firms as an architect and was also employed as a site manager for the renovation of an historic residential block. At the same time, she began designing experimental architecture and installations to explore the form-giving and spatial delineation potential of materials, such as textiles and plaster, in which context, she drew inspiration from the works of Werner Sobek and his predecessor, the visionary architect and Pritzker-Prize-winner Frei Otto. Otto was already drawing upon nature for inspiration and aspired to minimise material wastage back in the 1960s – principles still espoused by TRR 141 today.

Kovaleva joined the Moscow offices of the Werner Sobek Group in 2012, which is where she first encountered the Stuttgart school, which emphasises a close collaboration between construction engineers and architects. A year later, she relocated to Stuttgart, the capital of Baden-Württemberg, to underpin her practical experience, garnered in the Werner Sobek office, with the research being carried out at the ILEK. “Germany”, she says, explaining her motivation, “is extremely forward looking with a thriving culture of fundamental research”.

To concentrate on research, she then transferred to the institute, where she is currently working on her doctoral thesis. Her work is focused on gaining “a better understanding of the structural aspects of architectural design” and consolidating her knowledge of construction engineering. The architect feels she is in the right place to do this: “The Stuttgart school of architecture is very specific to Germany and Europe”. That’s another reason why she wants to develop the theoretical basis for her work here. “The structural demands are one of the most important aspects of the design process”, she says: “Only a close collaboration between architects and the engineers results in projects, that are planned on an integrated basis right from the start and which generate new theoretical insights. Material-saving and energy-efficient construction – that's what Stuttgart stands for”.

Plans for the second funding period for TRR 141 are currently being prepared. The first already provided some ten million euro of support for the German research community. Daria Kovaleva and her project colleagues now want to do more analysis at the material level to develop novel $CO_2$-neutral, more creative ways of building using fewer materials. Given the burgeoning global population, simply continuing the traditional approach to construction is not an option. “We need to find a way to better exploit the properties of construction materials”, says Kovaleva, “and of producing holistic structures by taking account of these during the design process”. In precisely the manner, in fact, that she succeeded in doing with the Rosenstein Pavilion.

*Daniel Völpel*

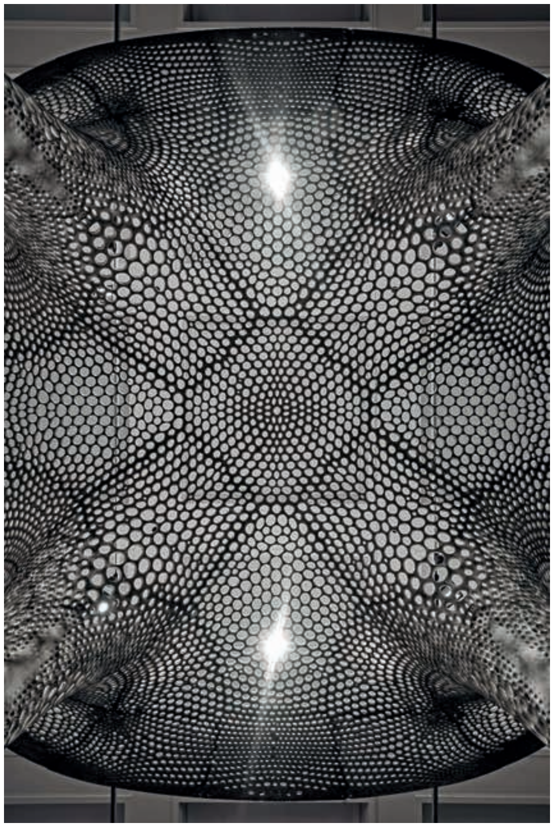

Photo: University of Stuttgart/ILEK

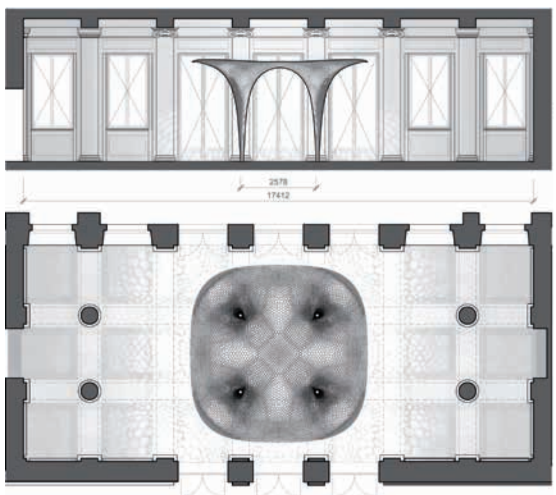

Figure: University of Stuttgart/ILEK

Inspired by nature: Architects and building engineers are taking inspiration from the skeleton of a sea anemone to design the “roof” of the pavilion.