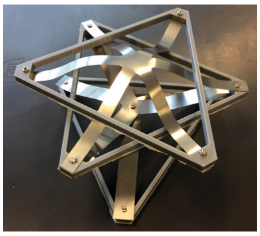
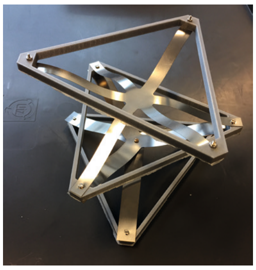
Optimizing complex designs, one calculation at a time

Prof.dr. Fred van Keulen of the Structural Optimization and Mechanics research section (Department of Precision and Microsystems Engineering, TU Delft) develops ways to enhance and automate the conventional design process using computational modelling and optimization techniques. These techniques allow designers to confidently predict the performance of a complex design. Given a set of boundary conditions, whether geometrical or in terms of structural properties or material usage, they can even automatically design structures through a sequence of calculations, each one getting closer to an optimal design. To demonstrate this, Van Keulen shows how a simple design task slowly produces a curvy, extra-terrestrial-like design, which can only be manufactured using a 3D printer. "With increasing computer power and smarter algorithms, we can perform ever more complex design tasks."





Mock-up of a multi-stable structure. Ultimately we target active components based on multi-stable structures.

Finite elements

At the heart of Van Keulen's computational approach is the finite element method, a numerical method widely used for solving problems in engineering and computational physics, particularly those that are too complex to obtain an analytical solution. To create or analyze a complex design, the space that contains the design is divided into a grid. "In mathematical terms, the complex problem is subdivided into smaller, simpler parts that are called finite elements. The latter are linked together and form so-called finite element models, which can be solved using computers. Moreover, these finite element models may provide extremely efficient information on the effectiveness of potential design changes."

Optimization

The key concept is optimization, Van Keulen explains. "Over the years, the focus of this optimization has shifted. Initially, the field revolved around optimization of simple dimensions. Next, the field moved on to finding the optimal shape of the structure. The current focus is on layout or topology optimization. Here, the entire layout of the design is optimized within a given design space, for a given set of loads, boundary conditions and constraints, with the goal of maximizing the performance of the system. In contrast with shape and sizing optimization, the design can now take on any shape and layout within the design space, not just a predefined configuration."

Increasingly complex

The continual increase in computer power offers the opportunity of numerical calculations making a difference in increasingly complex design challenges. "Consider an optical instrument, used in various research and industrial environments to steer laser beams. Mirrors are key components of such an instrument. They need to be aligned with the utmost precision and stability. A tiny offset in the position of a mirror could send the laser beam way off target. A current design challenge deals with the alignment stages and their integration

Professor Fred van Keulen
a.vankeulen@tudelft.nl
+31 15 27 86 515

TU Delft

into the optical instrument as a whole. They need to be insensitive for thermal fluctuations and be accessible for manual operation. In the future, the design of the instrument including all mirrors could be optimized as whole. Industry can't wait for us to learn how to do that."

Ultimate precision

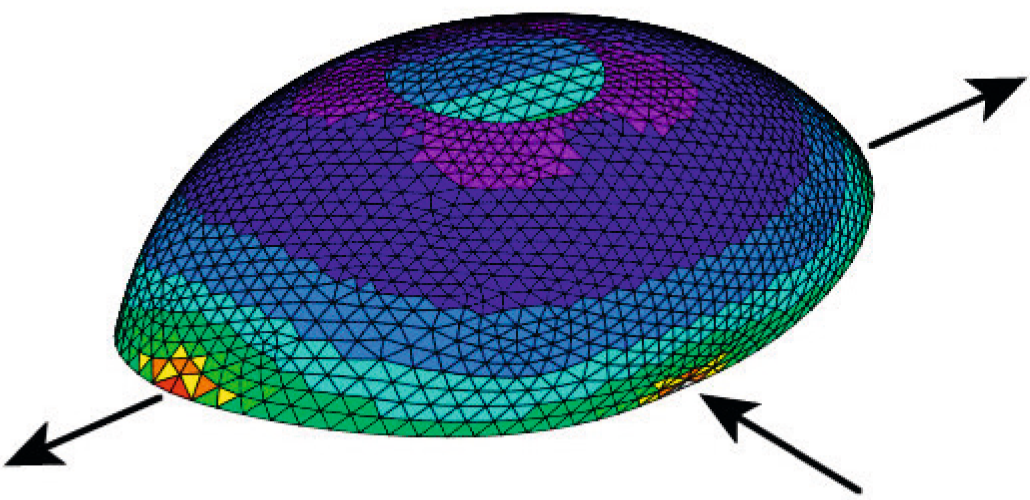
"We're ultimately dealing with precision. We're designing structures that need to arrive at or maintain their exact position or motion while coping with disturbances, vibrations, thermal loads, cooling effects, et cetera. In looking for the ultimate precision, we naturally arrive at the nanoscale: we are very interested in designing structures on the nanoscale, and creating the tools needed to build and handle them, like wafer scanners and optical instruments." "The nanoscale introduces an additional level of complexity, since moving from the scale of the micrometre to that of the nanometre (a thousand times smaller) involves changes in the physics involved." This is where TU Delft's Nano Engineering Research Initiative (NERI) comes in.

1+1=3

As one of the driving forces behind NERI, Van Keulen explains how it has already proven to be an accelerator of developments. "Within NERI, we're formulating common, faraway goals. By sharing, discussing and adjusting these goals, they become the basis for long-term partnerships." There are many visions for future capabilities or products, for which Van Keulen is sure there will be major demand. "NERI is based on the question, how can 1 plus 1 be 3?" In establishing the first NERI plans and partnerships, lots of talking and drinking coffee was involved, he explains. Talking to various companies, what started off as "That sounds like a nice pet topic for academics" eventually changed into "We need it! When can you deliver?" "After lots of preparation, we're finally ready to start doing what we like doing most: engaging in exciting and useful research projects." Van Keulen concludes: "What we have with NERI is pretty unique, even in an international perspective."

Game changer

An interesting challenge, on the nanometre and larger scales, is the use of structural elements that exhibit highly nonlinear behaviour. A typical example is a bistable structure, i.e. a structure that has two stable configurations between which it can switch. Combining two of such elements results in a structure with four possible configurations. "If you extrapolate, you can appreciate that building with bistable elements is a route to structures that can be used to align or move with the greatest accuracy." However, the transitions between configurations do introduce an additional complexity in the calculations and, in particular, the optimization. "This is stuff for the future. As an example, automatically designing the layout of complex multistable structures is something we can only dream of yet." When asked where the field of structural optimization will be in this future, Van Keulen is very frank: "I don't know. After sizing, shape, material and topology optimization, there isn't a game changer waiting in the wings yet. In the meanwhile, the challenges faced in topology optimization are still huge!"



Non-linear modelling tools are key ingredients of our research.