

Computational Design for Performance, Manufacturability and System Integration

“The focus of my research is computational design techniques,” says Dr Matthijs Langelaar, Associate Professor of at the Department of Precision and Microsystems Engineering (PME). “In other words, how to use the power of computers to enhance and perhaps even fully automate the design process.”

Topology Optimisation and Unexpected Designs

Much of Langelaar’s research makes use of an advanced computational design technique called Topology Optimisation (T.O.). Based on the mathematical notion of topology, which describes the way different components of an object are interrelated or arranged, Topology Optimisation is a very powerful mathematical way to optimise the layout of an object within a given design space, in effect suggesting the most efficient design concept. “If you think of a design e.g. a chair, then there’s a certain amount of material that’s connected in a certain way to form a certain shape,” explains Langelaar. “Well that’s what you also do in Topology Optimisation but then in a computer simulation – you allow parts of the material in certain locations to connect with each other so that in one combination, they form a particular shape like a chair, but in another combination, they form different shape, perhaps like a table. So a shape can be modified by rearranging the material layout, and you can see that as a design process, shifting from one shape to another.” This computational design technique also involves a numerical simulation allowing the design performance of that object to be evaluated, showing for example how stiff or how heavy the chair shape is as opposed to the table shape. This enables optimisation of the design with respect to that particular property - by optimising the layout of the material. “What’s particularly nice about

Topology Optimisation, and why I really like working on it, is that it’s a technique that’s able to generate concepts. You don’t have to start with an actual concept proposed by a designer; the concepts are really generated by these computational processes. That means that surprises can happen, and unexpected innovative designs can emerge.”

Microchip manufacture

Topology Optimisation is a relatively recent design technique, which has evolved considerably since its introduction 30 years ago. Now with greater computer speeds and capacities, researchers can use T.O. to help solve design problems that, using traditional designs methods, were previously unsolvable. Within the Nano Engineering research Initiative, Langelaar is facing one such challenge: “One of the projects that we’re working on is to design a platform used in a process in the semiconductor industry, to position wafers in order to make computer chips and microchips that are used in phones, computers, smart cars and all kinds of devices. It has to be done very precisely and the platform should not vibrate otherwise there will be errors. So we’re adapting the T.O. process to find the optimal shape for that platform with the best dynamic performance.” Moreover, the project is not only about the design of an isolated mechanical component, it’s also about designing

Dr.ir. M. Langelaar
M.Langelaar@tudelft.nl
+31 15 27 86 506



that component as part of the system. “This platform is connected to sensors and actuators, and it’s also part of a control loop,” says Langelaar, “meaning that we don’t just consider the individual part in isolation, we also include the whole system surrounding it in the optimisation. Here we are on the forefront of research as there are no established T.O. methods for doing this.”

Topology Optimisation & Manufacturing

Right now, Topology Optimisation is mostly used at the conceptual phase of a design process and as such, it is applied to a wide range of industries e.g. aerospace, mechanical, bio-chemical and civil engineering. But the very fact that the T.O. technique often creates unexpected and non-traditional designs causes difficulties for the manufacturing process. “For a long time in T.O., we didn’t care too much about whether a design was easy to manufacture,” admits Langelaar. “We used the technique to generate a rough optimised shape, which was then used as inspiration for designers who would work out what the important features of the design were, and then ask how can we make it. In effect, the designers would have to translate the computer-generated shape into something that could be manufactured practically, which wasn’t a very efficient process. But now that computers have become faster, we can actually do this whole topology optimisation in 3-D, at a good resolution and get high quality design concepts. We therefore aim to generate designs that are fully manufacturable to make the best use of these capabilities.”

Currently, Langelaar and his team are intensively involved in the worldwide research effort to combine Topology Optimisation and Additive Manufacturing, or 3-D printing, with specific consideration of any manufacturing restrictions. “There’s a lot of interest in Additive Manufacturing within the Precision Industry right now – what sort of gains it can enable us to achieve and how can it best be exploited. The design freedom Additive Manufacturing offers is unprecedented, so you definitely need these kinds of advanced design techniques. But at the same time, I also think it’s good not to forget the more conventional,

existing manufacturing techniques because, although 3-D printing is here to stay and will expand further, for many processes and many geometries, you can use cheaper processes - so we’re also looking at those and how to integrate those into this design tool.”

PME – a Multidisciplinary Department for Multifunctional Devices

Langelaar’s other research interests within Nano Engineering Research Initiative (NERI) include work on projects involving nonlinear and functional materials, and large deformations, e.g. shape memory alloys, viscoelastic materials and compliant mechanisms; functional microstructures and -devices, e.g. micro-actuators and micro-reactors; and solving multidisciplinary design problems, combining e.g. heat transfer, electrostatics, solid mechanics, fluid mechanics, and control. “What’s special about the NERI setting is that we have a very multidisciplinary orientation. For instance, the micro-nano-engineering group works a lot on bio-applications, organ-on-a-chip type of micro-fluidic systems, and these systems typically consist of a set of channels, where some cells may be placed, and there need to be fluids to transport nutrients or drugs to these cells as part of an experiment perhaps. There is a need to have more functionality, to be able to alter the flows or to stop delivery of certain drugs or nutrients to particular cells but start providing them to yet another cell on that chip. In other words there’s a need to be able to interact with and control such biological organ-on-a-chip type systems. So to create that functionality by making more of these multifunctional devices, we’ve been looking at whether we could combine the ideas of Topology Optimisation with these microfluidic control concepts in order to generate extremely small structures and in a manufacturable way. Our first designs for valves are promising and definitely different from our intuitive solutions. We’ve verified their functionality with macroscale prototypes and the challenge now is to scale them down to micrometre range and integrate them into a system.”

“Conventional topology optimization approaches lead to optimized parts that cannot be printed without additional support material. This is necessary when part surfaces exceed a certain critical angle. To avoid the added cost and labor caused by support material, Langelaar has developed a modified topology optimization process, that always produces fully printable geometries. The algorithm has meanwhile become available through commercial design software offered by Simulia.”

