Improved ways for designing big, complex structures

By Anne Kirsten Frederiksen and Lena Kristina Carlberg

A group of researchers from DTU Mechanical Engineering has recently obtained a new world record of giga scale resolution in the process of designing an aircraft wing. Now, the researchers want to go even further and develop a new paradigm for mechanical design of big, complex structures.

Giga scale resolution is a new world record

Professor Ole Sigmund and Associate Professor Niels Aage are the mainstay of the project NextTop that produced the giga scale resolution results.

They have worked with topology optimization for a long time. The technique is by now well-known and used all over the world in a variety of disciplines including mechanics and thermodynamics. Topology optimization is a mathematical method that optimizes material layout within a given design domain.

“Over the past years we have developed, as part of the project NextTop, a new model for calculating the optimal design of complex structures made by different kinds of materials. To demonstrate the model, we chose to design a wing structure for a Boeing 777, which contains more than 1 billion elements”, says Professor Ole Sigmund.

Lower weight and environmental impact

The researchers were offered the opportunity to test their new calculation method on a European super computer through a grant provided by PRACE, Partnership for Advanced Computing in Europe. The resolution of the Danish researchers’ new model is about 200 times higher than current state-of the art techniques – and the 8,000 involved computer cores needed several days to calculate a new design for the wing. When the calculations were finished, the result revealed a brand new design with unconventional curved details and a world record giga resolution.

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“Our approach is described in a paper recently published in Nature, one of the world’s leading scientific journals. The method makes it possible to take a look at the design of the wing as a whole and at the same time see the smallest details of the many tiny elements of the wing. You can compare it with the experience of moving from the big and clumsy LEGO DUPLO bricks to the finer and more intricate detailed standard LEGO bricks. This made a world of difference regarding accuracy and the possibility of working at different scales,” says Niels Aage.

The method revealed an optimized design of an aircraft wing with curved ribs instead of the straight ribs known from present wings. At the same time, the model found an advantage in adding fine supporting struts. The new design led to a wing of less weight and consequently a reduction of fuel consumption and carbon emissions during flights.

Screen shot from the TopOpt 3d App downloadable from the App Store.

Next step is a new design process

The two researchers are of course proud of their new world class resolution, but they are already in charge of a new project, InnoTop, which they hope will make it possible to go even further.

“Our vision is to develop a new paradigm for design processes. We want the giga resolution to work real time. This will make it possible for experts from different areas to be part of the same process and profit from the possibility of changing the design regarding the consequences of different expert inputs. It will make the design process more efficient and avoid decisions that have to be changed later, when new experts get involved and add new requirements,” explains Ole Sigmund.

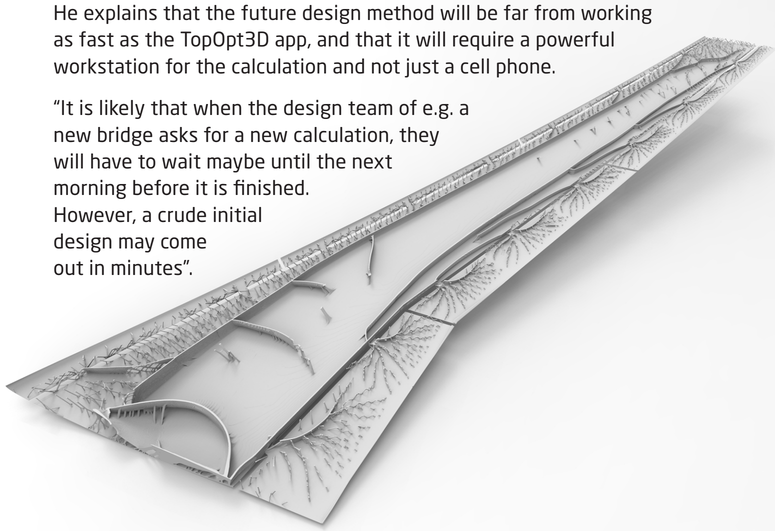
Combination of two existing techniques

The very ambitious project will be based on the combination of two different techniques, which are both developed by the researchers themselves or colleagues at DTU. It is the TopOpt3D app and the first model for topology-optimization developed 30 years ago.

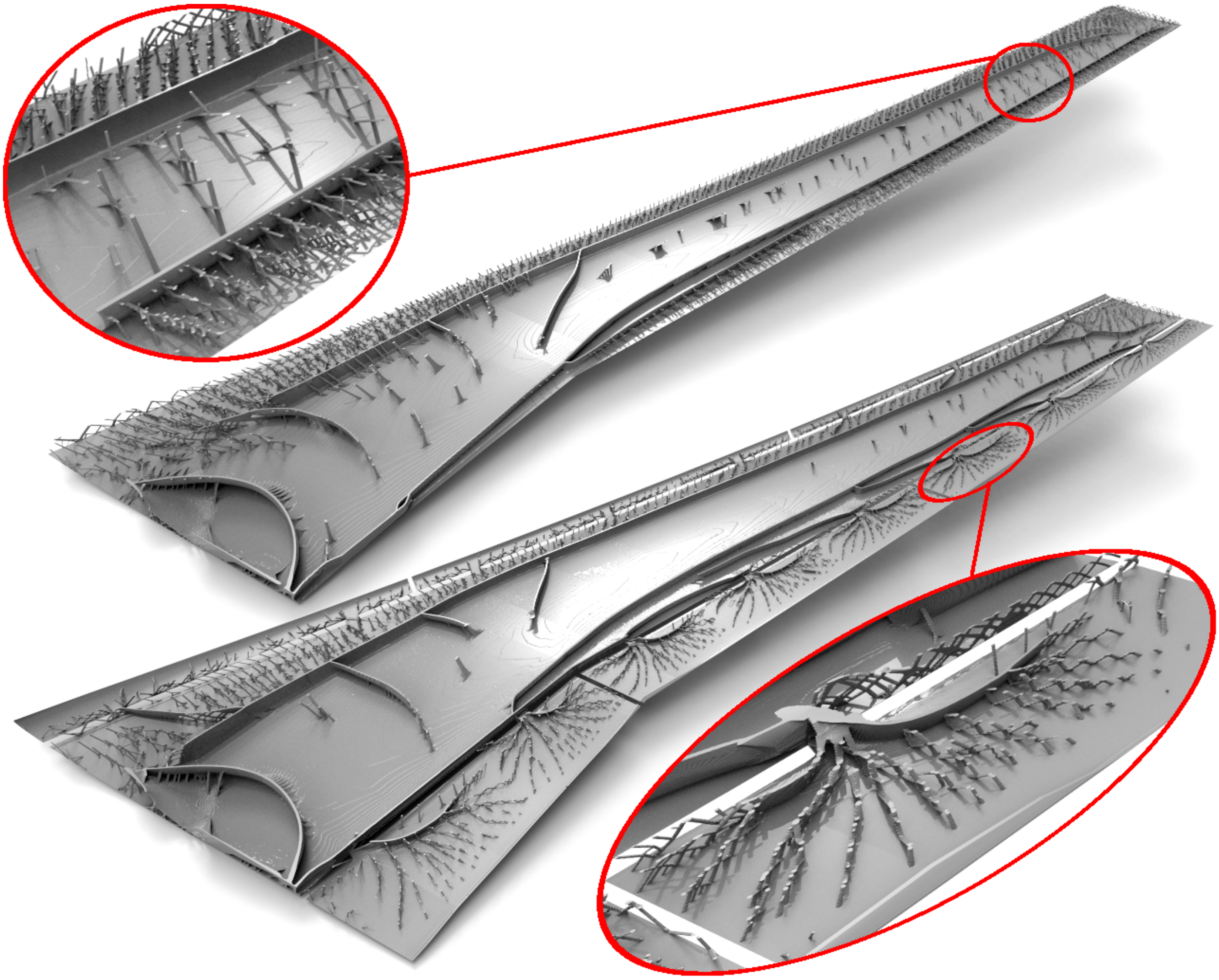
“Ole and I are part of the team that developed the TopOpt3D app. The app is an interactive topology optimization tool in 3D. The app allows the user to change loads, supports and the volume fraction interactively and watch the design evolve to a new optimum in real time. At the moment, the app can only illustrate rather simple structures and changes, but we want to develop it to handle bigger and more complex structures,” says Niels Aage.

He explains that the future design method will be far from working as fast as the TopOpt3D app, and that it will require a powerful workstation for the calculation and not just a cell phone.

“It is likely that when the design team of e.g. a new bridge asks for a new calculation, they will have to wait maybe until the next morning before it is finished. However, a crude initial design may come out in minutes”.



Aerial view of the optimized load carrying structure of a Boing 777 wing.



Different views of the optimized B777 wing structure obtained with a giga resolution topology optimization frame work developed at DTU Mechanical Engineering.

See changes real time without a super computer

The focus of the new InnoTop project is to find out how to make a new design process that can be handled without a super computer, which was necessary in order to obtain the first giga resolution result. The goal is therefore to find methods that reduce the amount of calculation times by 4-5 orders of magnitude in order for regular computers to handle it.

The reduction of calculations will partly be obtained by revitalizing the first topology optimization method developed by Bendsøe from DTU and Kikuchi from the University of Michigan back in 1988. The original method was since then abandoned, but offers a multiscale approach, which Ole Sigmund and Niels Aage find promising.

Revitalization of an old method for topology optimization

The original method contains multiscale information about density distribution. The way of working with information in the 30-year-old method has so far inspired to reduce computing times by almost two orders of magnitude in 2D and more is expected in 3D.

"We are collaborating with international and local colleagues to transform the multiscale information of the old method into 3D structures by computer graphics methodologies, which can be used in CAD systems. CAD systems will make it possible to implement our new method in companies and organizations that already use CAD for design processes. Our aim is that the new method will be able to deliver a quality just as good as the giga resolution we obtained with the super computer when we developed the new Boing 777 wing design", says Ole Sigmund.

"My vision is to be able to give industry the tools for a new process before the InnoTop project ends in six years,"

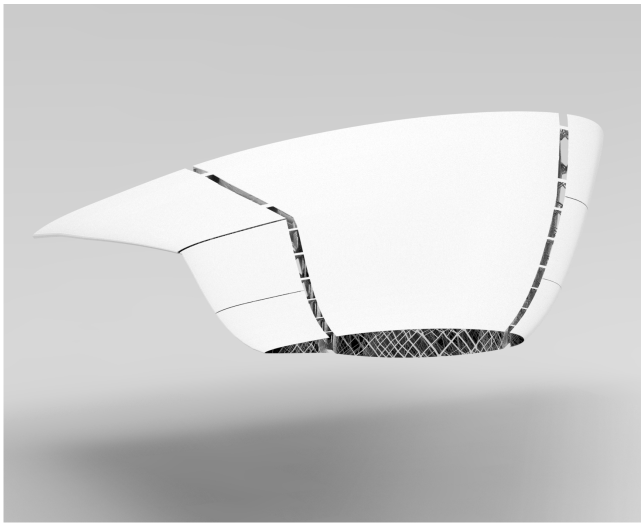
New kind of design process

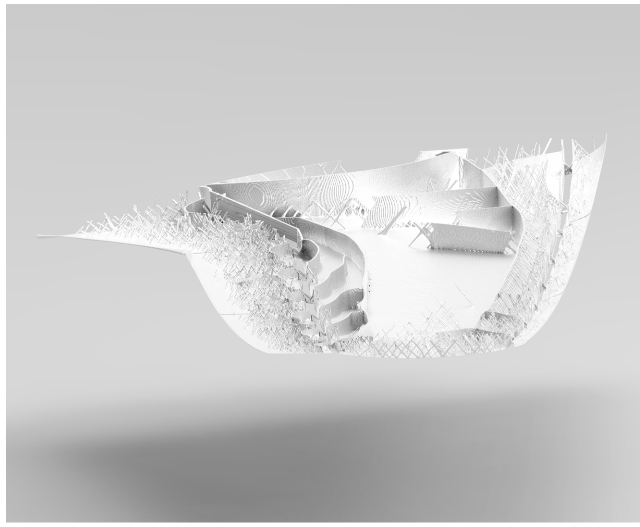
When all information on multiscale and microscale structures is gathered in a CAD system for example, it will be possible to show the design evolve in real time. Different technical experts can work together and simultaneously give their inputs and restrictions to the design of an aircraft wing for example, no matter whether it concerns energy optimization, passenger experience, weight, material composition or another parameter. It will all be mixed in the new method and give the involved experts the possibility to see how the design evolves when they change one of the parameters. Exactly as you are able to see the design change in real time in the TopOpt apps today.

"In that way, we are able to create a much more efficient design process, which will be a game changer. Many different industries will benefit from a new process – not only when designing complicated structures as bridges or aircrafts, but also when designing new materials, new products, buildings, etc. My vision is to be able to give the industry the tools for a new process before the InnoTop project ends in six years," says Ole Sigmund.

The researchers do not only want to make a new design paradigm possible. They also want to extend the possibilities for design with their new model.

"It is interesting to be able to design an optimal construction of a new wing of an aircraft. But we want our new design method to go further and be able also to calculate the best shape of a wing in proportion to its purpose. No one says that an aeroplane needs two traditional wings and a tail plane; the model can probably design a much better layout of a plane for transportation of people and goods," says Niels Aage.





B777 wing structure viewed from the tip. Left: with upper skin layer and right: with upper skin removed.

Facts about NextTop

The NextTop project: Topology Optimization - the Next Generation, ran from 2011-2016 and was funded by VILLUM FONDEN with DKK 12.1 million. Professor Ole Sigmund coordinated the project.

Project outcome
Amongst others, topology optimizations methods that focus on novel possibilities and constraints associated with additive manufacturing methods.

Paper in Nature
Aage, Niels; Andreassen, Erik; Lazarov, Boyan Stefanov; Sigmund, Ole. Giga-voxel computational morphogenesis for structural design. In: Nature, Vol. 550, No. 7674, 2017, p. 84-86.

See the TopOpt groups webpage: www.topopt.dtu.dk for more information.

VILLUM FONDEN

Facts about the Villum Investigator project InnoTop

The InnoTop project: Interactive, Non-Linear, High-Resolution Topology Optimization is funded by VILLUM FONDEN through a VILLUM Investigator Project awarded to Ole Sigmund. VILLUM FONDEN (a part of THE VELUX FOUNDATIONS) is a non-profit, private charitable foundation that supports technical and scientific research as well as environmental, social and cultural projects in Denmark and internationally. The 6 year project was initiated on September 1st, 2017. The total budget is 36.2 million; 31.1 million is funded by VILLUM FONDEN.

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