DTU Compute
Department of Applied Mathematics and Computer Science

Interactive 3D Topology Optimization

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Motivation: Topology Optimization is an engineering tool for optimizing material layout within a design space. To give students of the field an intuition of the topic an interactive application is created where the problem is solved in real-time and the users can see how the algorithm works.

1. Topology Optimization

The application solves the minimum compliance problem where the goal is to maximize stiffness on a structure subject to a constraint on the amount of available material.

A topology optimization problem contains information about where loads are applied and where supports are located. Loads are forces applied to a region, such as the deck of a bridge. Supports are fixed regions where material can attach in order to prevent the displacement of the loads.

The problem can be stated in a discrete form as:

$$
\begin{aligned}
\min_{\rho\in\mathbb{R}^n} \quad & \phi(\boldsymbol{u}(\boldsymbol{\rho}),\boldsymbol{\rho}) = \boldsymbol{F}^T\boldsymbol{u} \\
\text{s.t.} \quad & \boldsymbol{K}(\boldsymbol{\rho})\boldsymbol{u} = \boldsymbol{F} \\
& V(\boldsymbol{\rho})/V^* - 1 \le 0 \\
& 0 < \rho^{\min} \le \rho_i \le 1 \,, i = 1, \ldots, n
\end{aligned}
$$

, where φ = **$F^T u$** is compliance, **ρ** is a vector of *n* densities (design variables), **u** and **F** are nodal displacement and force vectors respectively, **$K(\rho)$** is the global stiffness matrix, and **$V(\rho)/V^* -1 <= 0$** is the volume constraint. Finally **p^{min}** is a lower bound of the design variables as described.

2. User interaction

The user can rotate the view around the object using the view cube.

The user models the problem by inserting 3D objects, such as cubes and spheres, which are then labelled as a load region or a support region.

Objects can be selected using click-selection or lasso selection. Selected objects can be moved, rotated or scaled using 3D widgets.

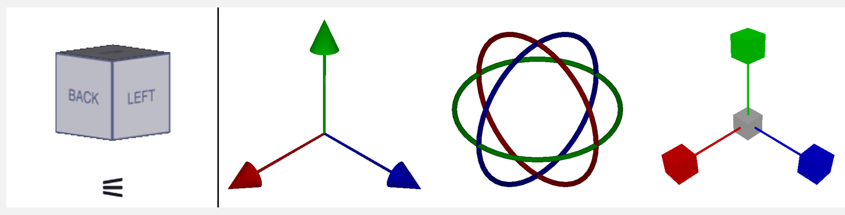

Fig. 1. (Left) View cube and (right) 3D transformation widgets, translate, rotate and scale

As soon the user has modelled a valid problem then the optimizer will start running and the optimized shape will appear and evolve while the problem is being refined by the user.

3. Optimization and visualization

The problem modeling takes place in continuous space, but the optimization is performed in discrete space. The mapping of the problem to discrete space is performed semi transparent to the user; The user will be able to see the actual nodes influenced by a given region using small loads and support widgets.

We have three different ways of visualizing the result; Marching Cubes using either Lambert shading or by highlighting boundaries using additive blend shading. Alternative the raw element densities can be visualized as voxels.

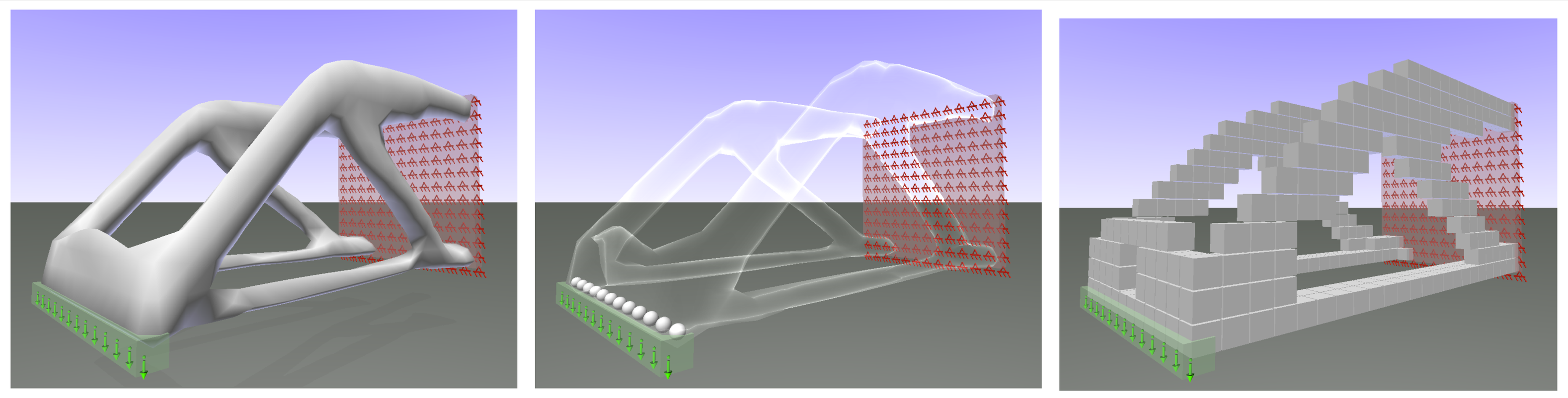

Fig. 2. Visualization using Marching Cubes (left), transparent (middle), voxel (right)

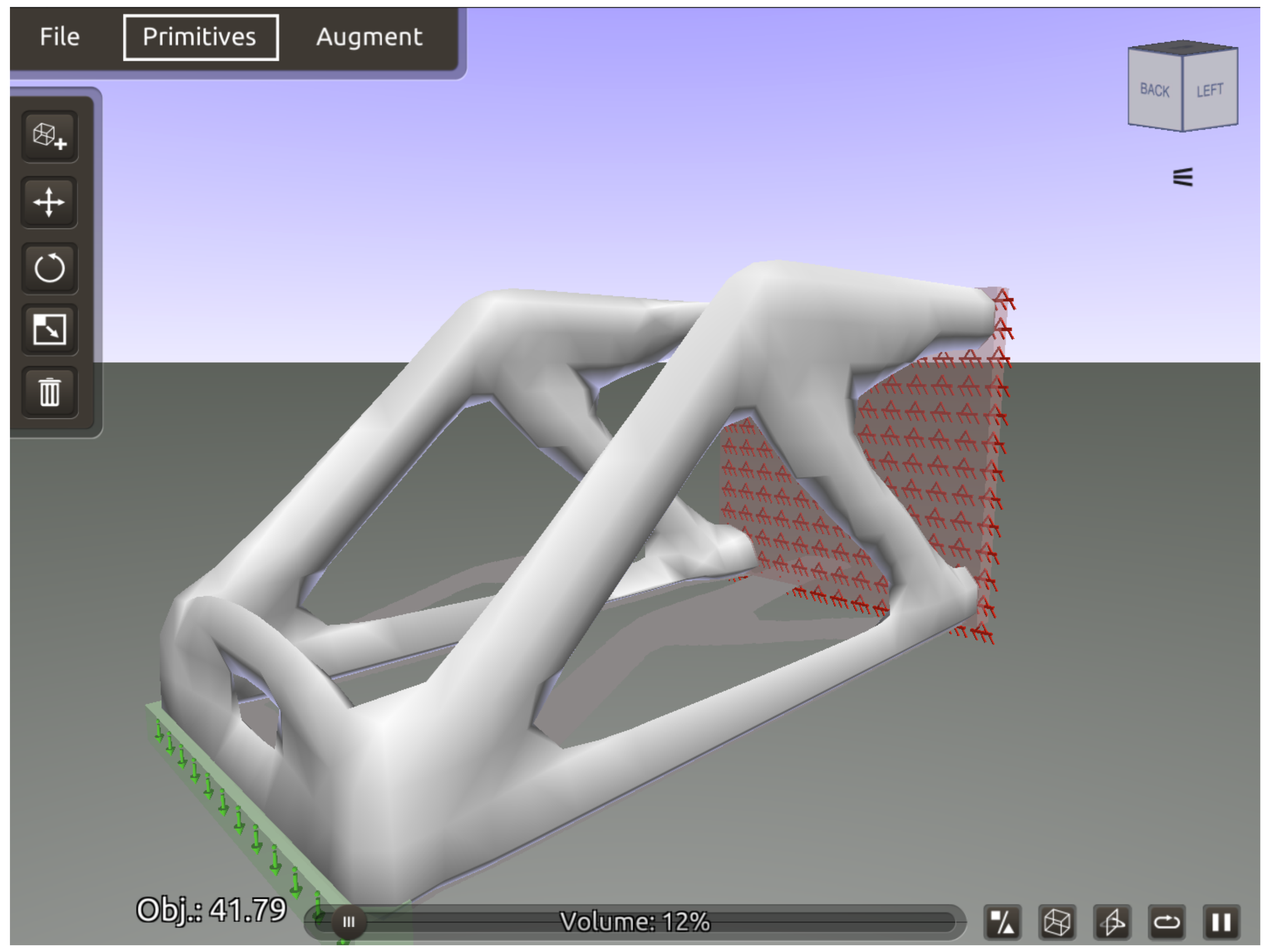

Fig. 3. TopOpt 3D App running on an iPad.

4. Results

The application can be used to model simple problems and to find good solutions for these problems.

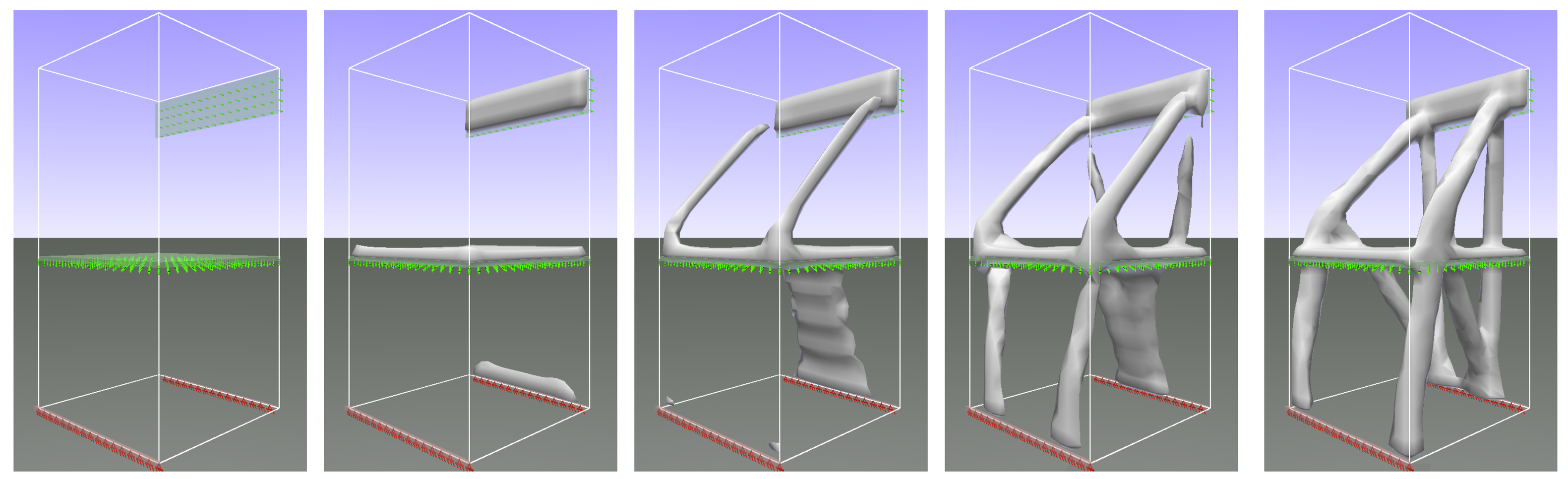

Fig. 3. Modelling a chair and finding the optimized shape. The screenshots shows the optimization after 0, 4, 7, 11 and 150 iterations

TopOpt 3D is available on
www.topopt.dtu.dk (desktop)
and on AppStore (for iOS devices)

iOS