Project Year

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Project Title

Top Opt It: Visualizing Civil Engineering Concepts

Project Team

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Audience

The targeted audience for this project is students enrolled in the following three Civil Engineering undergraduate courses: (1) 560.141 *Perspectives on the Evolution of Structures* (Freshman), (2) 560.206 *Solid Mechanics and Theory of Structures* (Sophomores), and (3) 560.325 *Concrete Structures* (Juniors). Longer term, the proposed topology optimization visualization tool has the potential to be extended more deeply into the CE Curriculum from courses in fundamental programming (560.220 *Civil Engineering Analysis*) to design (560.320 *Steel Structures*) and analysis (560.445 *Advanced Structural Analysis*, 560.440 *Applied Finite Element Methods*). There are also opportunities to incorporate into CE student Groups (Steel Bridge Design Team, Seismic Challenge), as well as other engineering disciplines (e.g., the ME Baja Team, BME Design Teams).

Pedagogical Challenge

One-dimensional representations of structures still dominate Civil Engineering textbooks. When 'zooming in' to examine the stress state at a point in these structures, two dimensional, black and white images are used, at best with contour lines. These figures are not only difficult to interpret, but also are limited to a very few examples, keeping students in the standard 'benchmark' box. Comprehension can be significantly enhanced by exploring the bounds of that box by allowing students to create their own structures for analysis and/or by solving the inverse problem (what structure/load will give us this stress state). For example, students are told that materials with negative Poisson's ratio exist in theory but are not provided any visualization of the mechanisms. Ultimately the challenge is that analysis tools capable of solving the forward problem require significant training and tools for solving the inverse problem have not been commercialized.

Solution

We propose developing an interactive topology optimization program that will allow undergraduates to explore fundamental civil engineering concepts. Topology optimization is a free-form approach to design where a structure seemingly organically grows out of air to take on a structurally efficient form. While primarily used in engineering design, we see significant opportunities for it in general engineering education. Based on minimum energy principles, it highlights load paths, stress concentrations, efficient forms, etc. By making the program interactive students will be able to enter their own design and analysis problems for structures they are curious about. The primary challenge is making the program user-friendly through a GUI interface. We anticipate coding in MATLAB and using MATLAB GUIs, ideally creating a version that can be run interactively through our web server.

Faculty Statement

The fundamental challenge faced is that structural analysis software requires training, and user-friendly visualization tools, such as Google Sketchup, do not enable structural analysis. This makes it extremely difficult for students to explore structural forms and their behavior beyond what is prescribed as standard in textbooks. Our goal is to create a highly interactive program that allows students to input their own design and problems and watch the solutions develop on the fly. Done this way, students can enter problems that they are personally curious about – my experience is that students are far more motivated and learning is enhanced in such situations. For example, we have similar course projects in my graduate level *Structural Optimization* course, and students have ended up designing CD holders for their dorm rooms, bicycle frames, and concrete shell structures.

A particularly interesting aspect of the proposal is that we are using a design optimization tool to enhance understanding of structural analysis and behavior. What we have learned from topology optimization is that the most efficient structures mimic their stress states. For example, the structure in a topology optimized beam exactly mimics the trends of the stress trajectories in a solid body (stress trajectories are an elusive concept for sophomores). Similarly, the flow of tension and compression forces in a concrete beam can be visualized by optimizing the steel reinforcement in that beam with topology optimization. An arch structure forms when optimizing the stiffness of a body under a pressure load. The effect of inertial forces in fluids can be visualized by examining topology optimized fluidic diodes – devices that allow flow in one direction but not the other due to inertia of the fluid.

The fellows will assist in all aspects of coding the user interfaces and graphics. The methodologies and code are largely developed in a (non-user friendly) research version of the code.