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Use of Generative Design and Shape Optimization Tools for Advanced Engineering Design

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Abstract

The fast-paced development of high power computing hardware and user-friendly interfaces, along with increasing capabilities of commercial software, are leading to the earlier exposure of students to advanced levels of engineering graphics, design, and analysis tools in undergraduate curricula. Specifically, easy-use of computer aided design packages allow students to practice with engineering analysis aspects beyond solid modeling or engineering graphics. This paper will give details about shape optimization and Generative Design, which are revolutionary techniques for optimization of engineering parts for complex design scenarios and advanced engineering analysis. Surveying of students have indicated overwhelmingly positive feedback for the course and group projects, which appears to have increased their hands-on knowledge and skills with respect to advanced design and engineering analysis software.

Introduction

With the advancement of computer aided design (CAD) software and the user-friendly interfaces of engineering analysis packages for finite element analysis, computational fluid dynamics, and multiphysics solutions, engineering curricula are being revised to train industry-ready engineering graduates with up-to-date technological software and hardware. Implementation of advanced design tools allows students to learn rigorous hands-on tools and apply their knowledge to solving real-world design problems, with computational resources and cloud computing capabilities.

At Howard University, the Mechanical Engineering curriculum offers Introduction to CAD (Computer Aided Design) as a first-year course, along with Computer Aided Engineering, a third-year course that teaches advanced CAD with the inclusion of generative design and topology optimization - widely considered as advanced design techniques. These courses teach students how to use commercially available Computer Aided Engineering software for multidisciplinary system design and optimization [1-5]. With such acquired skills, students conceptualize complex engineering design problems in virtual spaces and solve those by using CAE software (i.e., Autodesk Fusion 360). Generative design and optimization, along with structural and thermal analysis, are covered in the course with real-world engineering examples. Some multiphysics analyses are also investigated in the latter class by coupling different types of analysis to tackle challenging engineering problems. Students learn how to work on a multiphysics design project in a team through offline meetings, synchronous, and asynchronous communication tools (i.e., Slack and Blackboard). The following sections describe generative design and shape optimization techniques, with examples of student projects which increased students' skills in upper level core/elective courses, such as capstone design courses or CAD/CAM and aid in preparing more competitive students for future industry and career engineering practice.

Generative Design

Generative design, available in Autodesk Fusion 360, is a novel design process for optimizing engineering parts. The design process requires a series of calculations and solutions based on material specifications, design objectives, and other user-defined parameters using a statistical method in conjunction with stress analysis [6]. Cloud-based calculations require extensive computational resources for the purpose of finding optimal solutions for the selected parameters.

As seen in Figure 1, the process starts with a partial, or rough, model of the anticipated design along with necessary boundary conditions including preserve/obstacle geometries, loads, materials, machining processes, and design objectives. Based on these parameters, a series of design solutions are provided. The final optimal design, chosen based on weight, cost, stiffness or other parameters, can be modified by defining additional constraints in the design problem.

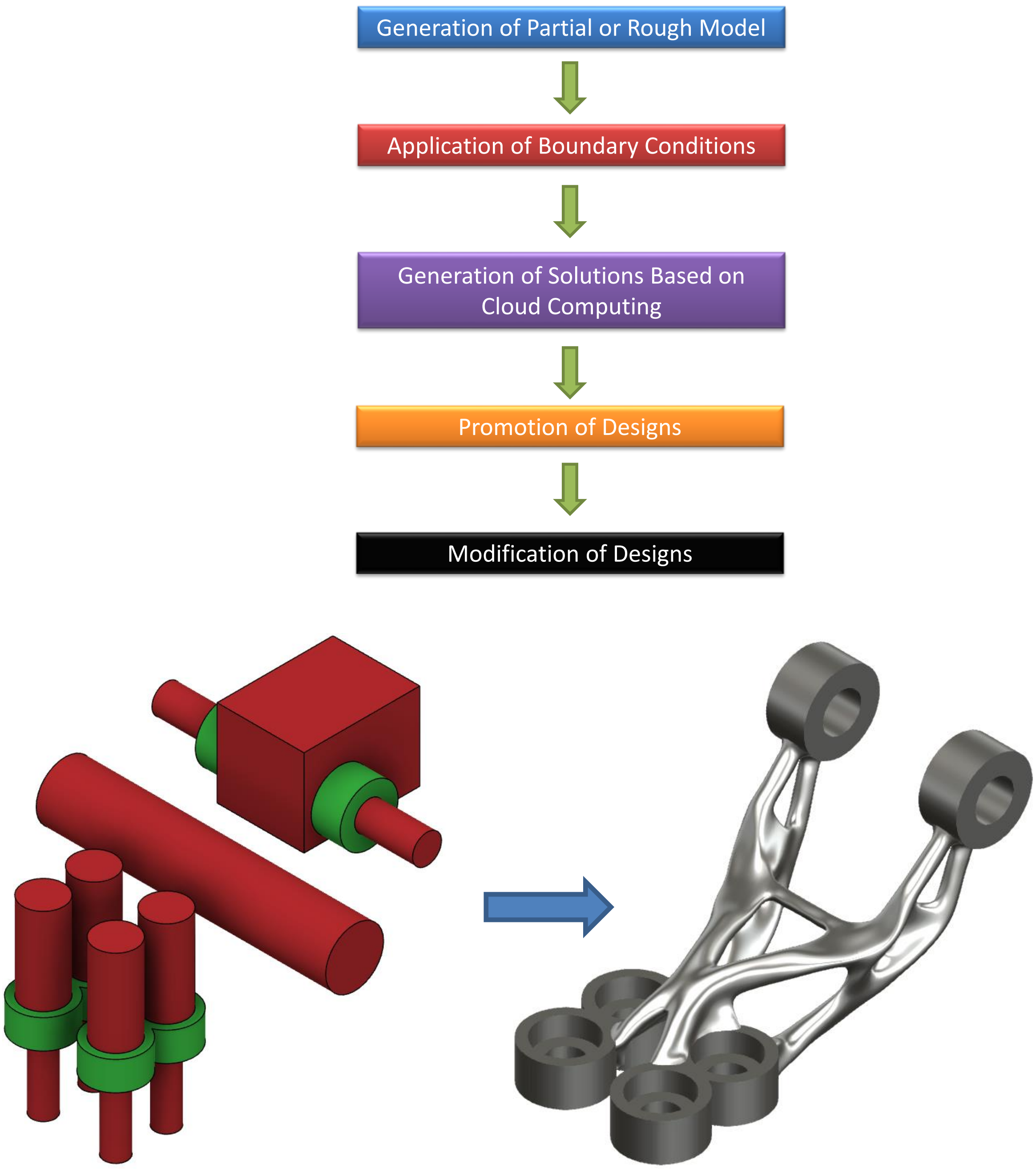

Figure 1. Generative Design Process

As compared to conventional methods used in CAD courses, the generative design approach teaches students an innovative and rigorous approach for faster, lighter, and cheaper design of products, which can be optimized based on strength, manufacturing processes, and cost. Surveys indicated that students were overwhelmingly satisfied with generative design (over 50% extremely satisfied and over 40 percent somewhat satisfied). The following describes a group project which required students design an armchair using generative design.

A Group Project: Generative Design of an Armchair

Students were assigned to a group project to redesign a basic chair and improve various factors such as weight, strength, price, and aesthetics to create a new and innovative product. The generative process, final design, and simple stress analysis are presented in Figure 2 and Figure 3.

Parameters

- Load based on 300 lb Person
- Materials: Aluminum AlSi10Mg, Stainless Steel AISI 304, Titanium 6Al-Av, HP 3D HR CB PA 12
- Minimum Safety Factor of 2.00
- Objective: Minimize Mass
- Manufacturing: Unrestrictive, Additive, Die Casting
- Dimensions: 17.7 x 17.7 x 45 in^3
- Seat Height: 20 in, Arm Height 29 in

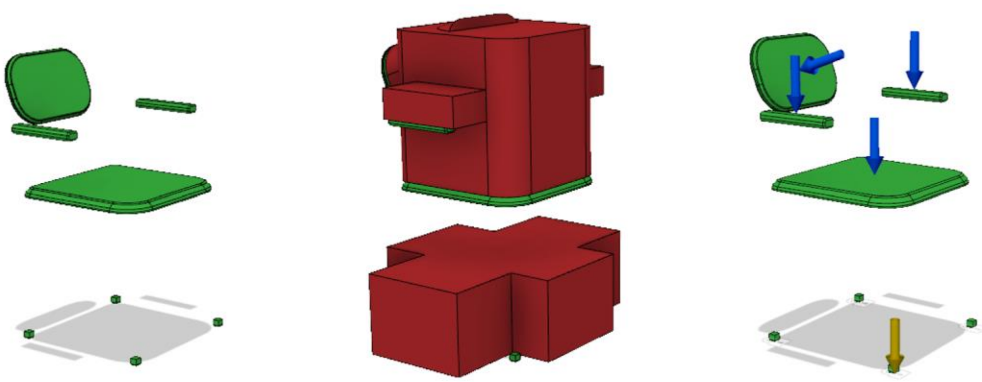

Figure 2. Generative Design of an Armchair

Figure 3. Final Design and Static Simulation

Shape Optimization

Shape or topology optimization is an algorithmic process which provides the most efficient design solution based on a set of shape constraints by removing materials from the design. Shape optimization typically occurs near the end of the design process when a final product needs weight and cost reductions due to material constraints [7]. Figure 4 shows the process for shape optimization, which uses simulation technology to predict the design performance, and automatically makes the changes to improve the design and accelerate product development processes. As seen in the figure, the optimization process starts with a rough design which is used to rebuild a mesh model in a CAD system. This is in contrary to generative design which requires constraints, loads, and manufacturing processes based on design specifications. Thus, shape optimization leads to one design solution, while generative design provides a set of iterative models based on cost, materials, and other design specifications.

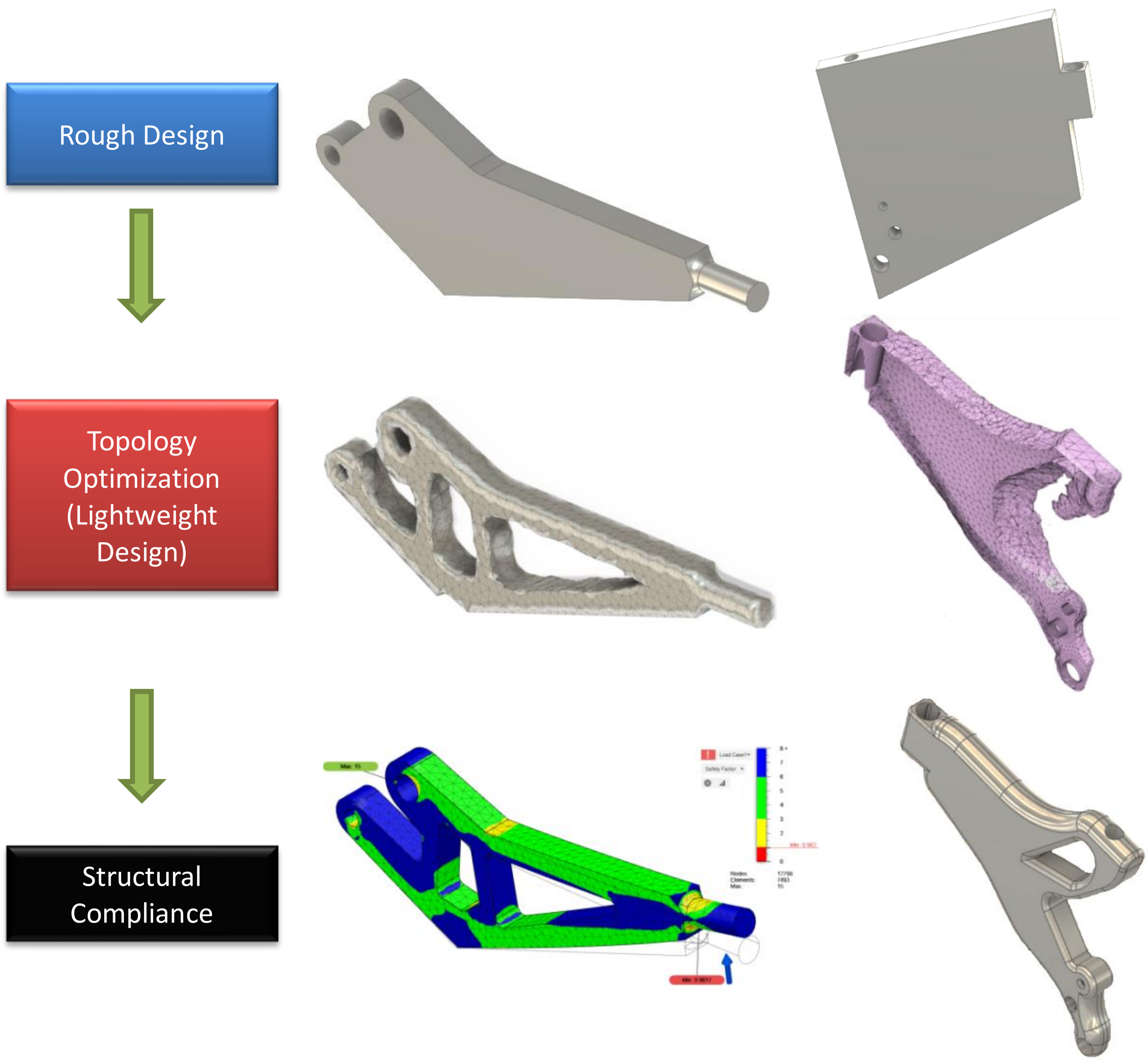

Figure 4. Shape Optimization Process

Surveys indicated that students were overwhelmingly satisfied with shape optimization approaches (over 80% extremely satisfied and over 15 percent somewhat satisfied). The following describes a group project which required students optimize a simple cube using shape optimization, for which survey results indicated 60% extremely satisfied and 40% somewhat satisfied.

A Group Project: Shape Optimization of a Cube

Students were assigned to a group project to optimize a 2x2x2 cube for maximum load bearing. Figure 5 shows the shape optimization process. Constraints included ABS plastic, 40% of volume and 1000 lbf load. In the end, each group was required to use PLA 3D printing to make the final product as shown in Figure 6.

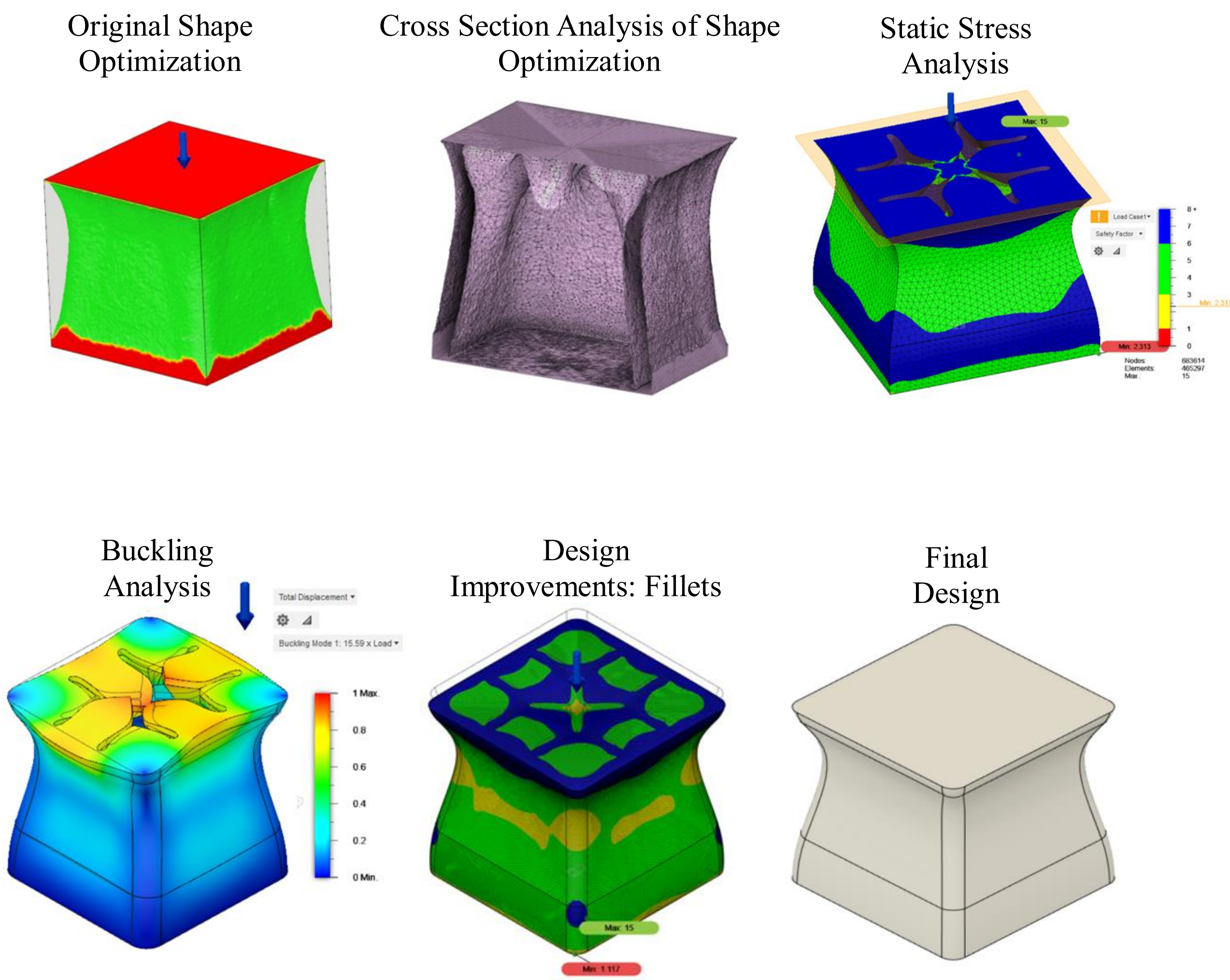

Figure 5. Shape Optimization of a Cube

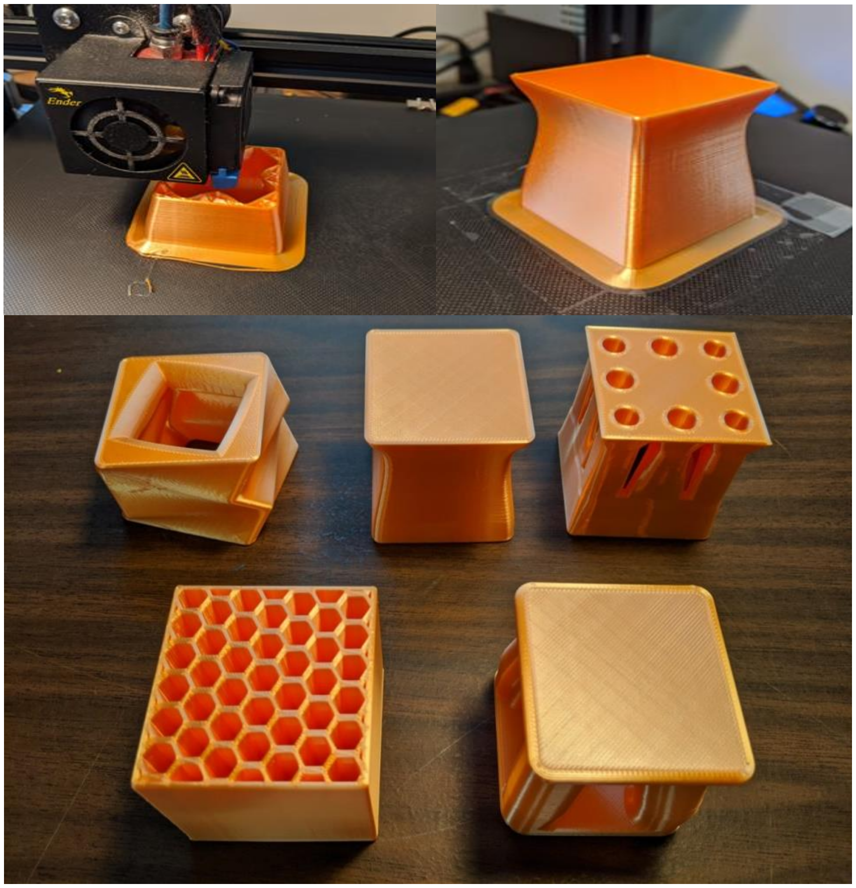

Figure 6. 3D printed models

Conclusions

Computer Aided Engineering has proven to be an effective course to train undergraduate students with advanced design, analysis, and optimization techniques using design software such as Autodesk Fusion 360, which includes generative design and shape optimization tools to revolutionize the engineering design process for cost-effective and light solutions. The course covers detailed theory and hands-on practice of the techniques for optimization of design products based on materials, machining processes, design objectives and other specifications. Surveying of students showed overwhelmingly positive results such that the course and group projects increased their hands-on knowledge and skills with respect to advanced design and engineering analysis software. Overall, this course allowed students to learn more about improving the design process and the final product via multiple exercises and group projects. Through group projects, students gained experience and skills about time-efficient design solutions and increasing performance for unique applications (e.g. satellite, passenger aircraft, high-performance vehicle, electric mobility scooter, etc.).

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