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Metallic Structural Origami: Manufacturing of a Folded Plate Lattice Bridge

Project Overview

This proposal is for the continuation of a spring UROP project motivated by the following:

Origami is the inspiration for using sheet stock material to create high load-bearing structures. Manufacturing-wise, the idea of using a 2-D single layer process with embedded 3 dimensional information shows significant potential. With rapid manufacturing, exploring structural origami as an architected cellular solid is achievable as well.

Industry and researchers' interest in low-density, yet high-specific stiffness materials has generated consistent work on architected cellular solids. It has been proven that discretely assembled cellular solids can perform as ultra light materials with record-setting density-stiffness ratios[1]. Many of these studies, however, only consider beam lattices.

Besides, beam lattices maintain a lower ratio of stiffness to strength than plate lattices at the same relative density. They also show inflexibilities in generating geometries out of a greater range of materials. A different approach is to consider the less-researched plate lattices. Plate lattices with the same relative density to beam lattices have an increased specific stiffness 2.5 times that of their beam lattice counterpart[2].

As a demonstration of the significance of the concepts mentioned above, we aim to design and build a bridge using discretely assembled plate lattices. I will be working under the guidance of graduate researcher Alfonso Parra Rubio and Professor Neil Gershenfeld.

Personal Responsibilities & Goals

This project can be broken down into three objectives:

1. Creating a parametric CAD representation of the cell array with variable fold angle and dimensions. Finding a solution to formulate irregular cells intersecting the surface
2. Creating an appropriate manufacturing technique and cell design for integration

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[1] *Reversibly Assembled Cellular Composite Materials*. http://cba.mit.edu/docs/papers/13.09.Science.pdf.

[2] Berger, J. B., et al. "Mechanical Metamaterials at the Theoretical Limit of Isotropic Elastic Stiffness." *Nature News*, Nature Publishing Group, 20 Feb. 2017, https://www.nature.com/articles/nature21075.

3. Testing and iterating with different parameters to optimize the performance

Previously, I focused on the first objective: creating a script that generates a 3D structure of plate lattices from an input target surface and to prepare it for manufacturing.

As of now, I created a script that can generate an array that fits a bounding box of the target surface, and then trims all the cells to be contained inside the surface. Since I had to learn grasshopper functionalities as well as develop and debug an implementation method, this took a month of gradual development.

As the next step, I moved on to recreate the same process using a single Python module and Rhino API to interface with Rhino. The idea is to create code that is exportable, give me finer control of the Rhino objects as well as develop my understanding of the implementation. Over the course of a few weeks, I have recreated all the vertices of a single cell and the folding constraints by manipulating the vertex coordinates and thoughtful use of geometry. I have also managed to generate the cell surfaces and points in Rhino using Rhino geometry functions, then generate an array of these cells to populate the bounding box of the target surface.

I am now working on creating a test array of points that will sort which cells will be included or bound to the target surface. This will hopefully improve the time complexity when generating cells subsequently. Before the end of the Spring semester, I plan to complete the creation of irregular boundary cells and move on to the next component of the project.

For this summer UROP, I aim to work on the manufacturing and potentially the testing part of the project. This involves a few possible pieces:

1. Writing a script to extract the 2D geometry from the parametric CAD model
2. Designing cells that can lock with each other instead of using large sheets of metal to connect each cell with many rivets
3. Creating or modifying manufacturing techniques in order to produce an entire cell by stamping sheet metal or eventually some other method

Personal Statement

While so many of the undergraduate student body seem to have a strong background in STEM fields, I have always found my inspiration and confidence through things related to design and complex origami. This UROP offers a way for me to develop new practical skills that allow me to further pursue design and engineering while also enabling me to make use of my expertise and passion. By attending weekly lab meetings, I have also been greatly inspired and motivated by the many incredible projects going on in the lab, and I would like to learn from and contribute to this environment for as long as I can.