Appendix

Current status of development: At the moment, we have a functional web app prototype of the product: http://www.ai-gs.com/frontend/DFW-GH.html

The technology developed by Masoud Akbarzadeh et al. enables a novel design technique for aerodynamic structures such as airplane wings or wind turbine blades. The technique incorporates graphic statics and Maxwell form and force diagrams, which are widely used in structural design. For example, the computer-aided design (CAD) software Rhinoceros 3D contains many downloadable plugins for 2D and 3D graphic statics design.

Graphic statics design involves the use of form and force diagrams. Form diagrams encode the geometry of the structure, with load bearing elements (skeleton of structure) and load bearing points drawn and labeled (resembles the actual structure visible to the naked eye). Force diagrams encode the internal force network of the structure, with force vectors drawn to scale as lines. The length of the lines are proportional to force magnitude, so that in order to guarantee a stable structure (sum of forces equal to zero), the force diagram must consist of closed polygons. Mathematically, force and form diagrams are 'topologically dual'; that is, reciprocals of each other. In practice, this means that we have an algorithm that can generate one type of diagram from the other. Combined, both diagrams map out a complete structural form for how a desired structure should be built.

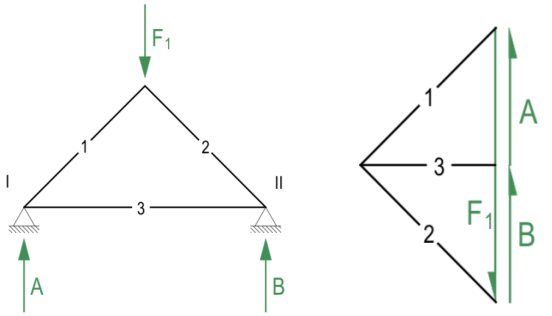

Figure 1: 2D force (right) and form (left) diagrams for a very simple structure (source: ETH Zurich). More complicated structures such as those in airplane wing design are different only in added complexity; the algorithms are all the same no matter how large the structure is or how many nodes there are.

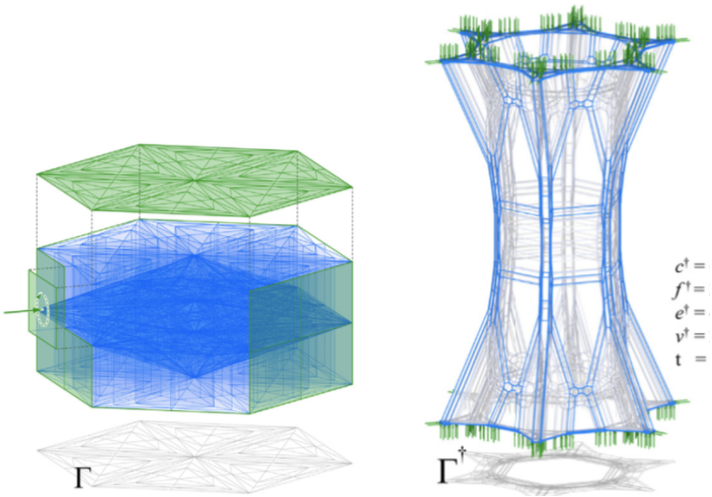

Figure 2: 3D force (right) and form (left) diagrams for a more complicated structure (source: Nejur, Akbarzadeh).

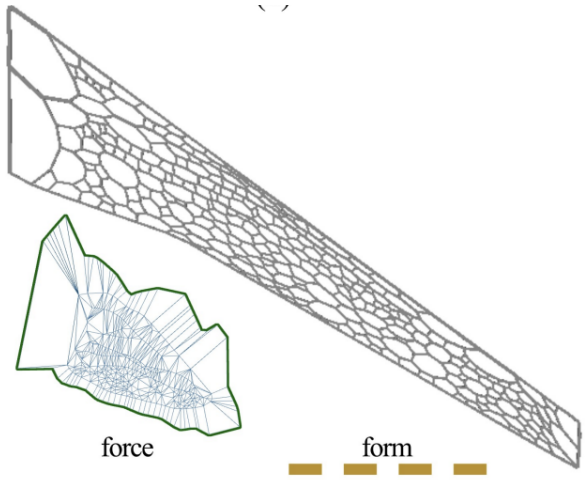

Figure 2: 2D force (lower left) and form (upper) diagrams for a bio-inspired AnisoWing design.

The key innovation developed by Prof. Akbarzadeh is to facilitate the design process of wings via machine learning techniques. After selecting appropriate materials, the typical design process involves a human designer who proposes a structure based on rigorous design rules and applied mechanics. Graphic statics is an example of such a design rule. Designers want to balance multiple variables, for example maximizing the beauty of the structure, and minimizing material cost. This traditional process involves a significant amount of highly-skilled labor, and is limited by the current understanding of design principles.

A new type of design process, facilitated by this technology, can both reduce the hours of labor required of the highly-skilled designer and also unlock new design principles, for example ones inspired by dragonfly wing design, that were previously unavailable to human designers.

The technology process workflow, learned from a dataset of twenty-one dragonfly wings, is as follows:

1. The human designer specifies the boundary of a form diagram of a wing or turbine blade
2. A trained General Adversarial Network (GAN), a machine learning algorithm that specializes in image generation, generates the boundary of the force diagram reciprocal to the form diagram
    a. This image bounds the external force network as well
3. A second trained GAN generates an intermediate geometry of the internal network of the force diagram, called the force main path, before the final force diagram
4. * A third trained GAN finally generates the force diagram from the force main path *
5. The graphic statics algorithm generates the form diagram from the force diagram
6. A trained Artificial Neural Network (ANN), an inflexible yet robust vector-based machine learning algorithm that specializes in one-to-one mappings, predicts the lengths of the edges in the form diagram from the force diagram generated by steps 3 & 4

*This step currently contains a manual input that needs to be automated. This automation has a straightforward solution that Anisoptera plans to implement as soon as possible.