A Bio-Informed Topology Optimization Algorithm Based on Leaf Venation Structures

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Abstract

Current trends in biomimetic design using branching systems tend to result in forms based on global morphologies that are predominantly aesthetic, often overlooking the potential of micro-structures in natural forms. One of nature's mysterious lightweight structures, leaf venation plays a crucial role in transporting essential resources to the leaf surface while simultaneously enhancing the mechanical properties of the leaf. The surface/volume ratio is thus maximized to increase surface area as efficiently as possible. This research studies the effects of leaf venation patterning to leaf stress and stiffness and develops a novel topology optimization algorithm inspired by the structural efficiency of venation patterns. It builds upon various precedent research that combines biology, algorithmic botany and architecture. Early work in generative botany was based on L-systems for computer graphics applications focused on creating believable growth of plant species for placement in virtual scenes. Recent approaches are inspired by biologically motivated theories of how branching morphology is achieved in nature, while others generate venation patterns based on perceived geometric rules to capture fundamental morphological characteristics. Gokmen [1] describes a process for generating venation patterns based on performance criteria using the distribution of auxin sources. However, the criteria used is non-structural. In this paper, we adapt Gokmen's approach to structural applications by basing performance criteria on the stress-distribution from a finite element analysis. Originating from both supports and loads branching occurs using a modified Gokmen algorithm, with each branch sized according to its internal forces. This yields a robust topology optimization algorithm that can apply structurally efficient branching patterns to a variety of shapes, support conditions, and applied loads. As a case study, the algorithm is applied to the design of nodes in an architectural assembly capable of responding to variable loading conditions.

References

[1] S. Gokmen. *A Morphogenetic Approach for Performative Building Envelope Systems Using Leaf Venetian Patterns,* eCAADe 31, pp.497-506.

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[3] A. Runions, M. Fuhrer, B. Lane, P. Federl, A. Rolland-Lagan P. Prusinkiewicz, "Modeling and Visualization of Leaf Venation Patterns," *ACM Transactions on Graphics*, 24(3), pp.702–711, 2012.

Fig. a. Venation growth patterns [3]. Fig. b. N. Frangos and A.Vasilyev, leaf scan venation
Fig. c. N. Frangos, Various shapes and configurations of bent steel members without joints.

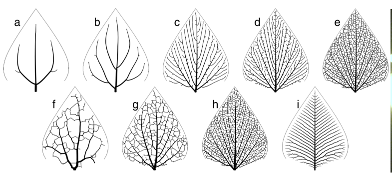

Fig.a

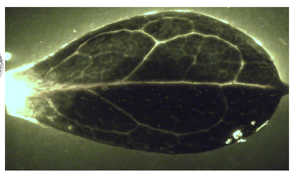

Fig.b

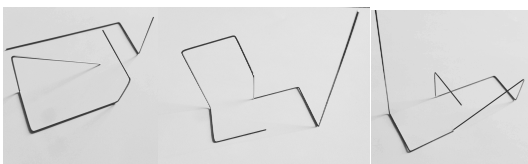

Fig.c