Journal of Zhejiang University-SCIENCE A

Cite this as: Bao-tong LI, Su-na YAN, Jun HONG, 2016. A growth-based topology optimizer for stiffness design of continuum structures under harmonic force excitation. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 17(12): 933-946. http://dx.doi.org/10.1631/jzus.A1500328

A growth-based topology optimizer for stiffness design of continuum structures under harmonic force excitation

Key words:

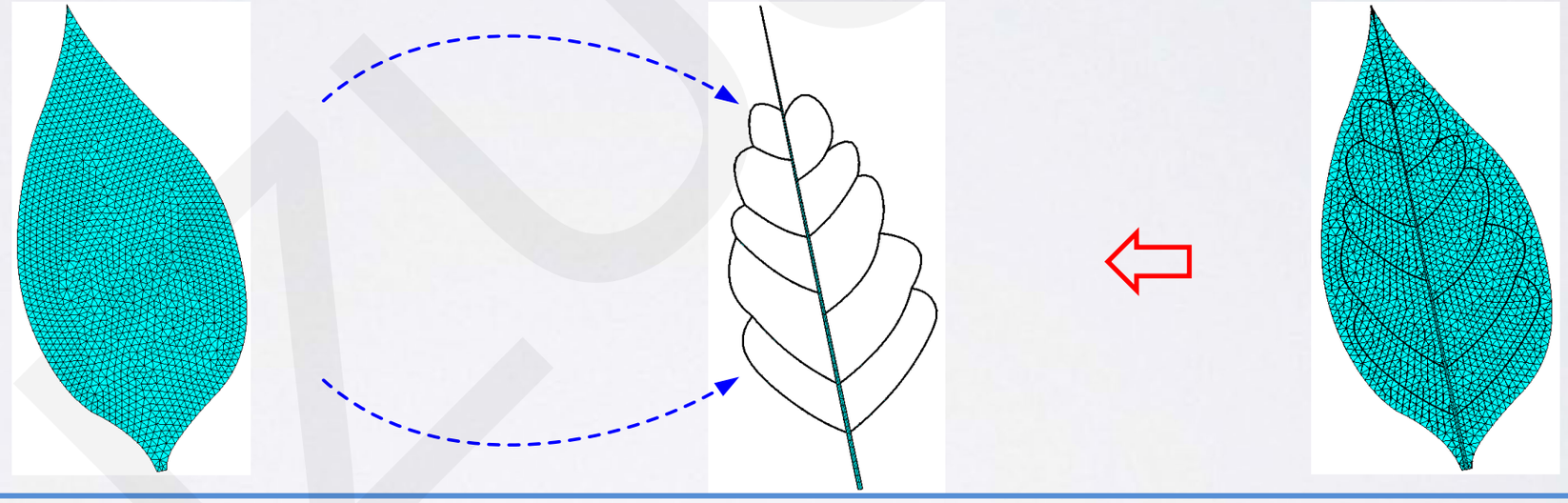
topology optimization, adaptive growth, stiffness design, stiffener layout, harmonic force excitation



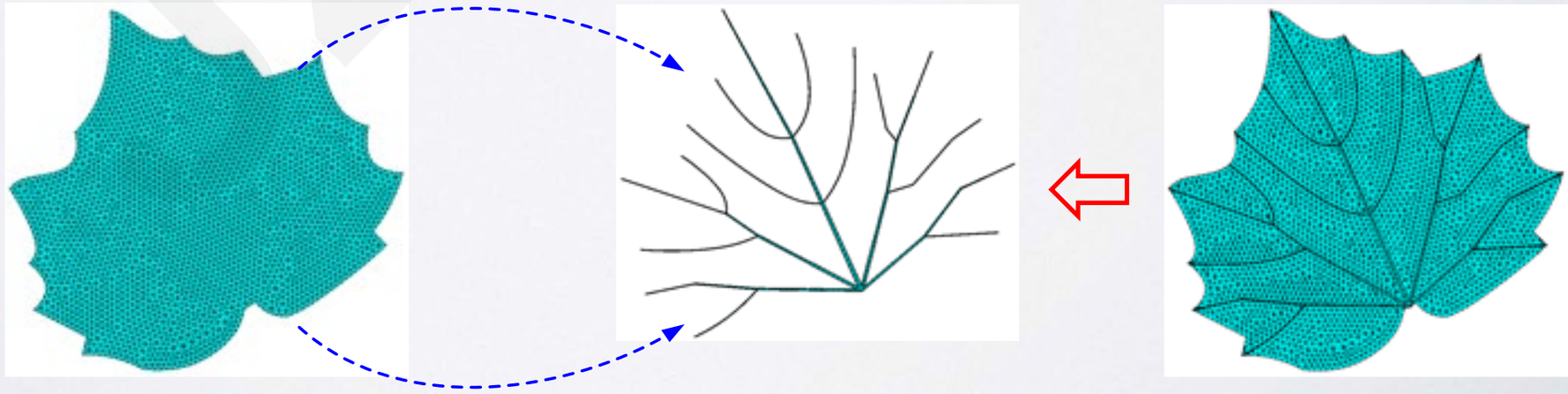
Background

Leaf venation is one type of compliance effective structure with branching pattern. Numerical tests find that it has geometrical and mechanical characteristics that are of interest for an innovative transfer into stiffness design of continuum structures under harmonic force excitation.

Plant leaf with pinnate venation



Plant leaf with palmate venation



Method

Leaf lamina is simulated by a plate structure aligned with candidate stiffeners of minimal cross-sectional areas. Base plate is divided by the 4-node quadrilateral shell elements, and the stiffeners formed by two adjacent nodes of the shell elements are divided by the 2-node beam elements.

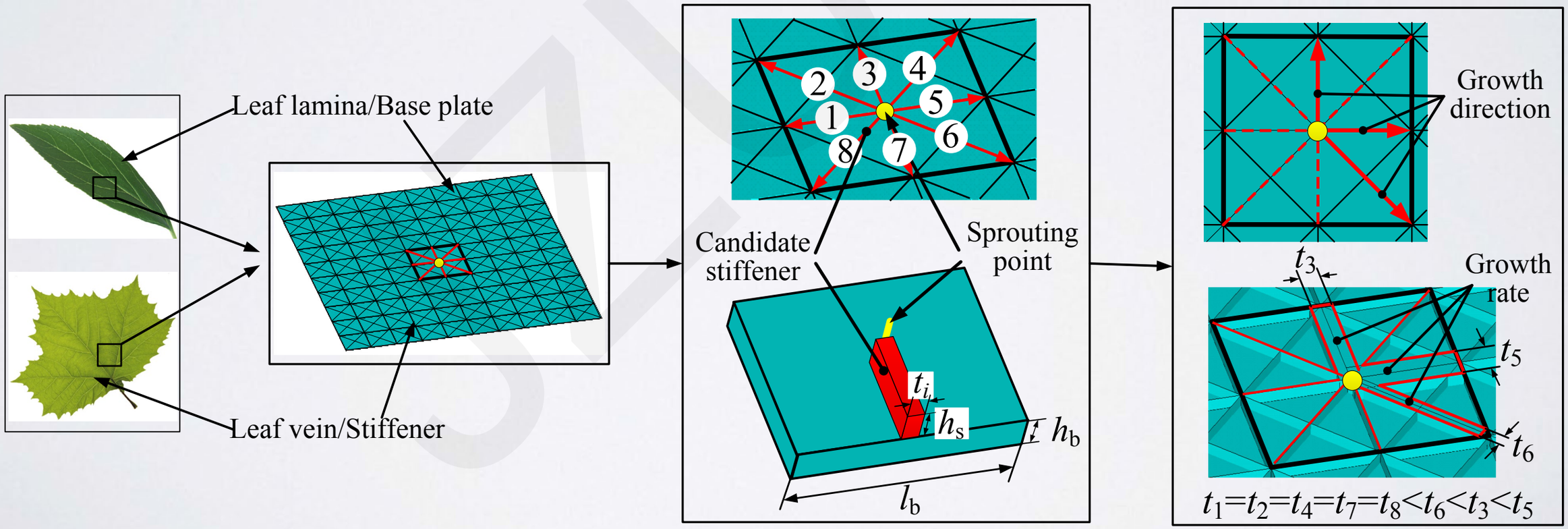
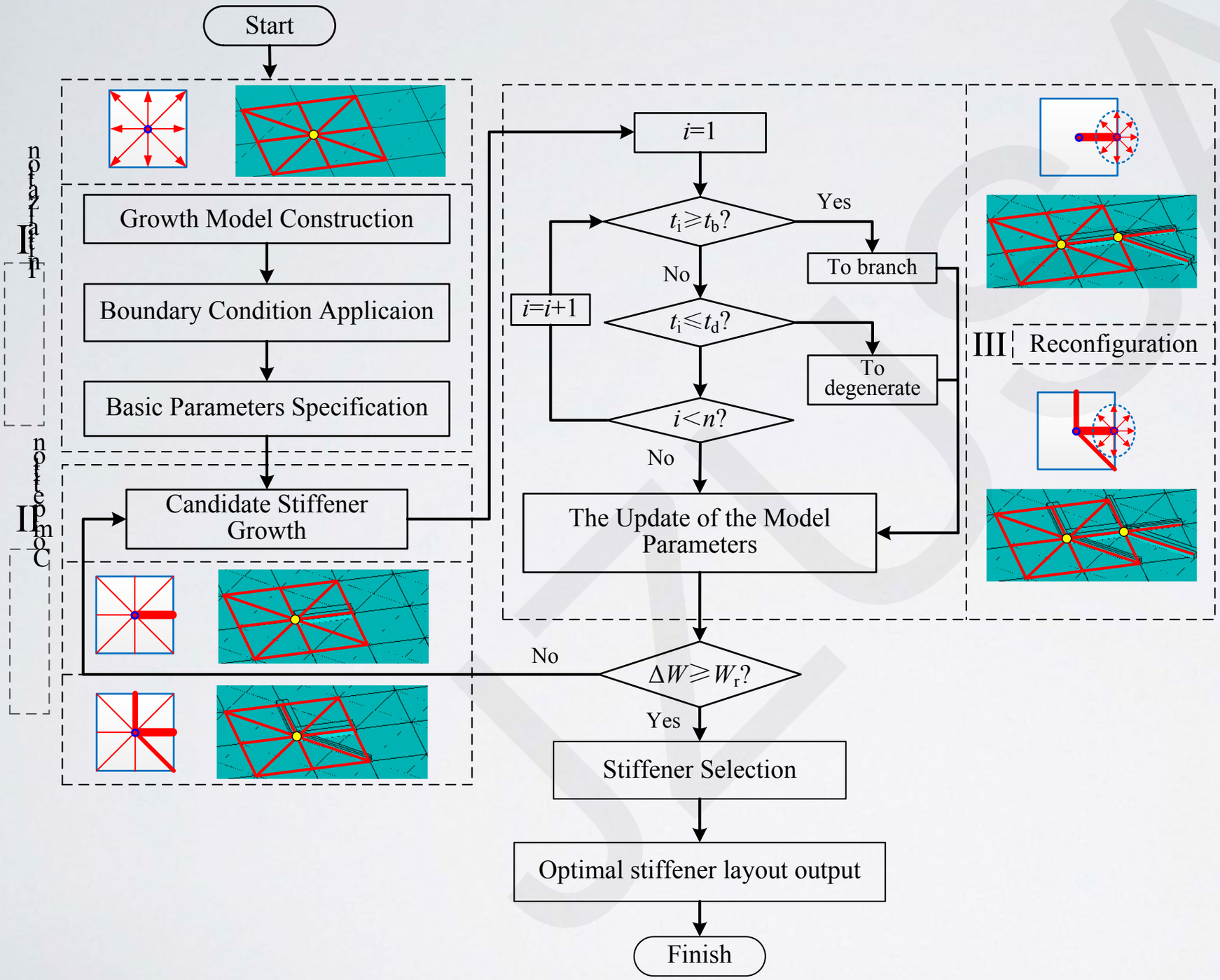


Figure: FE model for growth simulation of plant leaves

Method



STEP_1: Initialization

STEP_2: Competition

STEP_3: Reconfiguration

Figure: Flowchart of the growth algorithm

Result

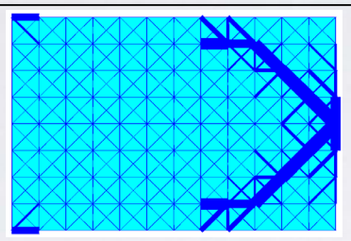
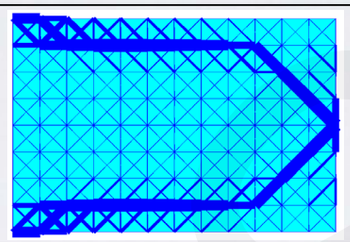
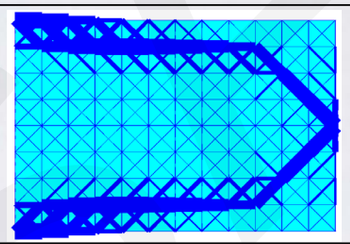
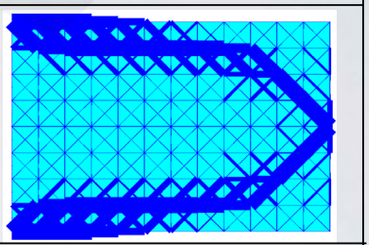
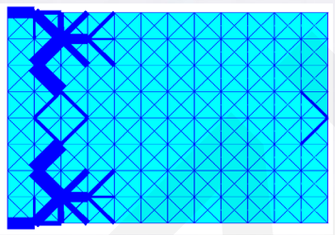
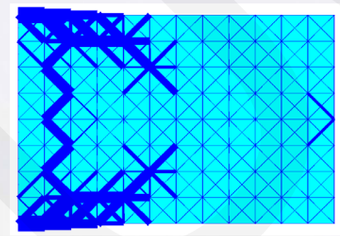
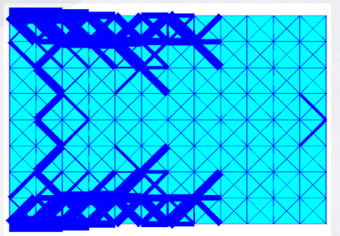
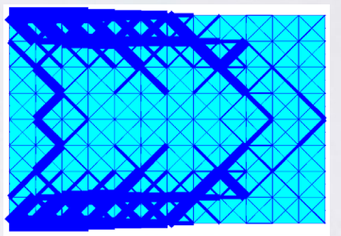
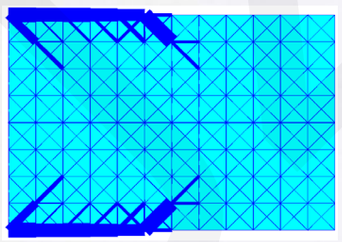
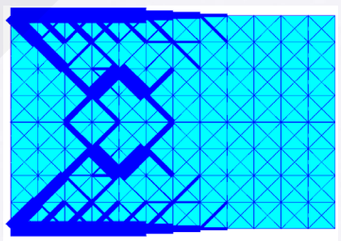
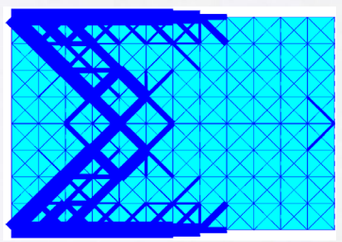
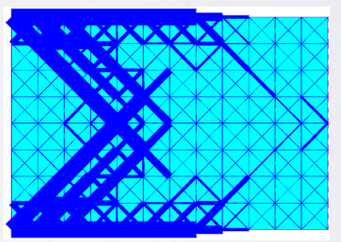
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0	Adaptive grow process				
	First order natural frequency	3541.1Hz	3544.2Hz	3807.1Hz	3841.5Hz
	Displacement amplitude	2.73×10^{-4}mm	1.78×10^{-4}mm	1.44×10^{-4}mm	1.26×10^{-4}mm
1.5	Adaptive grow process				
	First order natural frequency	4098.2Hz	4227.7Hz	4336.5Hz	4353.8Hz
	Displacement amplitude	2.92×10^{-4}mm	1.83×10^{-4}mm	1.62×10^{-4}mm	1.35×10^{-4}mm
3.0	Adaptive grow process				
	First order natural frequency	4563.1Hz	4815.5Hz	4898.4Hz	4933.6Hz
	Displacement amplitude	3.26×10^{-4}mm	2.22×10^{-4}mm	1.84×10^{-4}mm	1.64×10^{-4}mm

Figure: Stiffener growth processes under a vertical harmonic force

Result

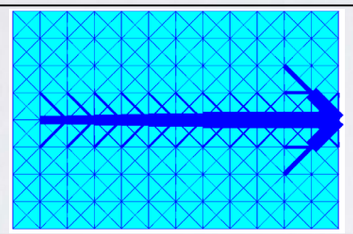
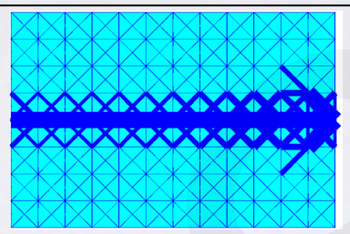
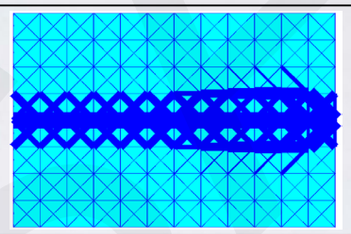
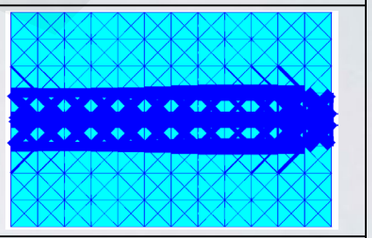
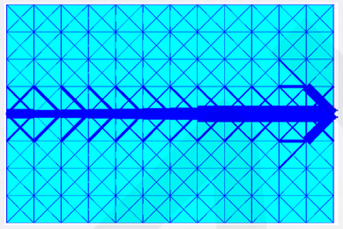
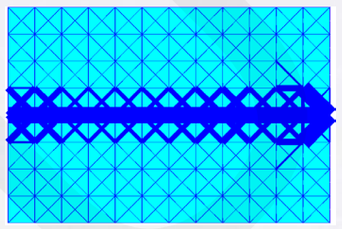
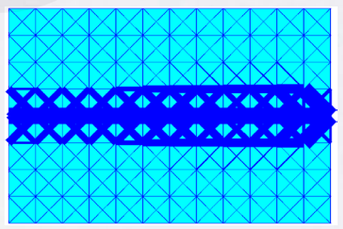
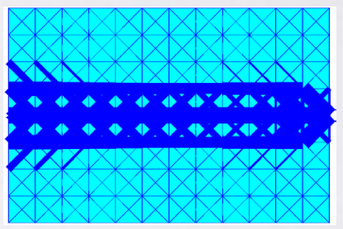
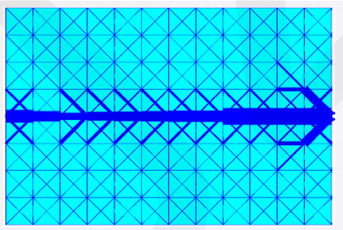
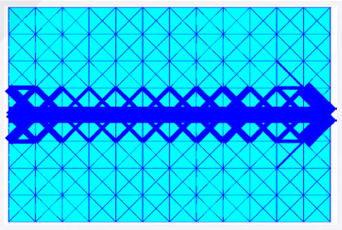
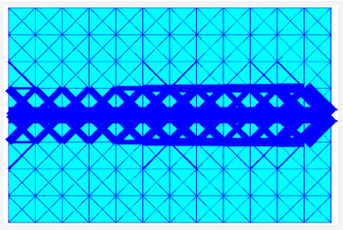
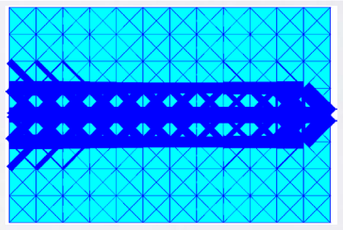
Excitation Frequency/KHz \ Material Consumption		$0.3W_p$	$0.6W_p$	$0.9W_p$	$1.2W_p$
0	Adaptive grow process				
	Second order natural frequency	9892.5Hz	10021.2Hz	10097.4Hz	10929.5Hz
	Displacement amplitude	2.87×10^{-5}mm	2.54×10^{-5}mm	2.27×10^{-5}mm	1.79×10^{-5}mm
1.5	Adaptive grow process				
	Second order natural frequency	9979.3Hz	10249.4Hz	10786.4Hz	11323.0Hz
	Displacement amplitude	2.99×10^{-5}mm	2.64×10^{-5}mm	2.33×10^{-5}mm	1.89×10^{-5}mm
3.0	Adaptive grow process				
	Second order natural frequency	10132.1Hz	10352.6Hz	11015.2Hz	11402.1Hz
	Displacement amplitude	3.18×10^{-5}mm	2.85×10^{-5}mm	2.50×10^{-5}mm	2.01×10^{-5}mm

Figure: Stiffener growth processes under a horizontal harmonic force

Conclusions

- A well-founded mathematical explanation for the optimality of plant morphogenesis is derived, which leads to a simple criterion for formulating the growth competition among candidate stiffeners.
- In designing a cantilever beam under harmonic excitation with the proposed approach, the growth of stiffeners shows great adaptiveness to the exciting force in terms of the direction and frequency of excitation.
- The proposed approach has the potential to facilitate vibration-proof design of stiffened plate/shell structures. Although the optimized beams have complex layouts, it could be conveniently manufactured by additive manufacturing technologies.

Acknowledgments

The work reported in this paper is supported by the National Natural Science Foundation of China (No. 51405377), and the National Science and Technology Major Project of China (No. 2015ZX04014021).