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Origami engineering: from deployable structures to configurational metamaterials

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ABSTRACT:

We explore origami stiffness properties, and in particular, we study how geometry affects origami behavior and characteristics. Understanding origami from a structural standpoint can allow for conceptualizing and designing feasible applications across scales and disciplines of engineering. We present an improved bar-and-hinge model that can analyze the elastic stiffness, and estimate deformed shapes of origami. The model simulates three distinct behaviors: stretching and shearing of thin sheet panels; bending of flat panels; and bending along prescribed fold lines. We explore the stiffness of tubular origami and kirigami structures based on the Miura-ori folding pattern. A unique orientation for zipper coupling of rigidly foldable origami tubes substantially increases stiffness in higher order modes and permits only one flexible motion through which the structure can deploy. Deployment is permitted by localized bending along folds lines; however, other deformations are over-constrained (and engage the origami sheets in tension and compression). Furthermore, we couple compatible origami tubes into a variety of cellular assemblages including configurational metamaterials. We introduce origami tubes with polygonal cross-sections that can reconfigure into numerous geometries. The tubular structures satisfy the mathematical definitions for flat and rigid foldability, meaning that they can fully unfold from a flattened state with deformations occurring only at the fold lines. From a global viewpoint, the tubes do not need to be straight, and can be constructed to follow a non-linear curved line when deployed. From a local viewpoint, their cross-sections and kinematics can be reprogrammed by changing the direction of folding at some folds. The presentation concludes with a vision toward the field of origami engineering.

BIOGRAPHY:

Professor Paulino is the Raymond Allen Jones Chair at the Georgia Institute of Technology. Prior to joining Georgia Tech in January 2015, he was the Donald and Elizabeth Willett Professor of Engineering at the University of Illinois at Urbana-Champaign (UIUC). His seminal contributions in the area of computational mechanics include the development of methodologies to characterize the deformation and fracture behavior of existing and emerging materials and structural systems; topology optimization for large-scale multiscale/multiphysics problems; and origami engineering. He received the Walter L. Huber Civil Engineering Research Prize from ASCE (2004) and he is a fellow of the USACM (2011), IACM (2012), and AAM (2015). He received the 2014 Ted Belytschko Applied Mechanics Award from ASME; and the 2015 Cozzarelli Prize from the National Academy of Sciences, "which recognizes recently published PNAS papers of outstanding scientific excellence and originality." He is associate editor of the Journal of Optimization Theory & Applications, ASCE J. of Eng. Mechanics, and Mechanics Research Communications, and a regional editor of the International Journal of Fracture. His contributions to the permanent scientific literature include more than 200 scholarly publications in peer-refereed international journals, and a book on The Symmetric Galerkin Boundary Element Method (Springer-Verlag, 2008). He is presently vice-President of the Society of Eng. Science (SES) and a member of the Board of Directors of EMI (Engineering Mechanics Institute). More information about his research and professional activities can be found at the following url: http://www.ghpaulino.com