TISSUE ARCHITECTURE:
PROGRAMMABLE FOLDING IN DIGITAL RESPONSIVE SKINS

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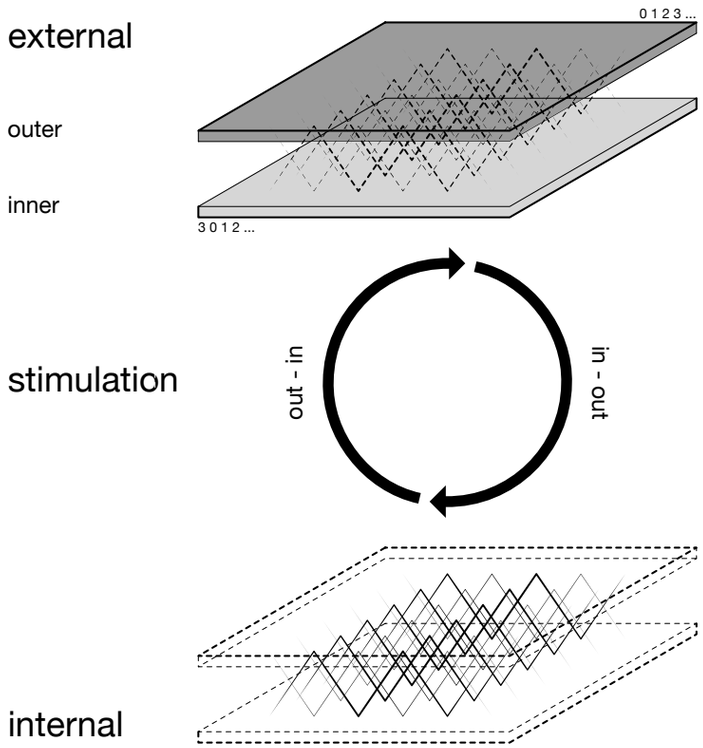

1 Programmable folding in digital responsive skins

INTRODUCTION: CONVERGENCE OF BIOPHYSICS, MORPHOGENESIS AND TISSUE ARCHITECTURE

Construction of soft "skin" at the architectural scale is challenging due to structural instability inherent to soft materials. Inspired by how cells interact with their microenvironments (Discher et al. 2009; Ingber 2006) upon folding of the embryo (Sasai 2013), basic physical properties of soft matter in living systems are parameterized as design units for programmable manufacturing to create new soft skin-like forms for potential architectural applications.

BIOLOGY AS SOFT MATTER: FOLDING OF LIVING MATERIALS

We propose a biologically inspired folding design system consisting of three components: (a) external matrix (outer and inner); (b) internal skeleton; and (c) stimulation (Figure 1). Biology uses folding to sculpt tissues in early embryogenesis from a hollow sphere ("blastula") via invagination ("gastrulation") (Figure 2a). The difference in material properties between outer and inner matrices drives polarized force generation, which leads to global folding (Davidson et al. 1995) (Figure 2b) of the embryo (Figure 2c). Therefore, careful arrangement of different materials around a contractile layer will enable one to design morphogenesis.

SYSTEMS FOR PROGRAMMABLE DIGITAL FOLDING SKINS WITH RESPONSIVE ENVIRONMENT

A generative folding skin design system was created by abstracting components into a spring-damper model (Kiss et al. 2004) (Figure 3a) using customized computational scripts in Rhinoceros (with Grasshopper and Kangaroo) consisting of three components as follows:

(a) External digital matrix codes – Four types of materials are designated as digital codes (Figure 3b): "0" Stiff Elastic; "1" Stiff Viscoelastic; "2" Soft Elastic; "3" Soft Viscoelastic.

(b) Internal skeleton – The cytoskeleton is generally characterized as viscoelastic material with a defined damper constant (Storm et al. 2005).

(c) Stimulation and propagation – The center of the system is pulled instantaneously (Figure 3c).

INVESTIGATIONS INTO PROGRAMMABLE DIGITAL RESPONSIVE SKINST

We demonstrate that a specific external matrix sequence not only encodes for a unique final shape, but also generates a reproducible set of morphogenetic sequences that lead to a final form, reminiscent of folding in biology. A matrix of outputs were generated from a base set of sequences to explore the range and overall iterative morphology of a new soft skin form in terms of time-lapse folding and material properties.

CONCLUSIONS AND FUTURE DIRECTIONS

This work lays the foundation to design new skin forms based on material properties of soft matter observed in living systems. The results presented here show that a seemingly complex folding process of soft matter can be deconstructed in terms of simple material parameters. Future directions include fabrication of new skin forms with discrete units of programmable soft materials at the scale of meters and also micro-scale engineering of tissue architecture.

ACKNOWLEDGMENTS

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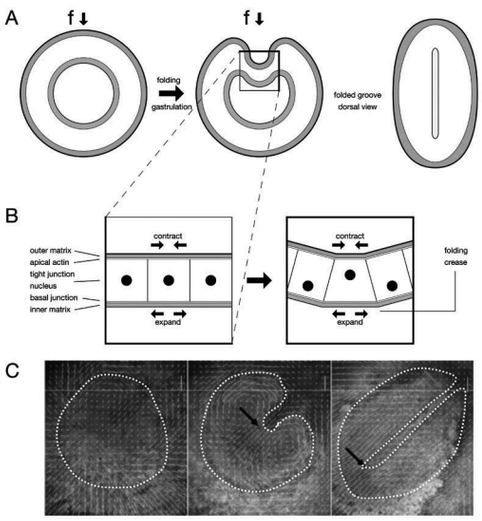

2 Folding of living tissues - (a) Folding at a millimeter-centimeter scale (b) Folding at a micron scale (c) Folding of the chick embryo during developmentt

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JAE-WON SHIN's work explores the construction of biological and artificial architectural systems from nano to macro scales. He is a Postdoctoral Fellow in the School of Engineering and Applied Sciences and the Wyss Institute at Harvard University. He completed his Ph.D. at the University of Pennsylvania Perelman School of Medicine. He is currently working on biomaterial-based strategies to fabricate functional tissues. He has also worked on collaborative design projects via the LabStudio and the Smart Geometry Group to develop architectural structures inspired by biology. His work was featured in the Collegiate Inventors Competition at the National Inventors Hall of Fame.

JENNY SABIN's work is at the forefront of a new direction for 21st century architectural practice—one that investigates the intersections of architecture and science, and applies insights and theories from biology and mathematics to the design of material structures. Sabin is an assistant professor in Design and Emerging Technologies in Architecture at Cornell University. She is principal of Sabin Studio, an experimental design studio based in Philadelphia, and director of the Sabin Design Lab at Cornell AAP, a hybrid research and design unit. In 2011, Sabin was named a USA Knight Fellow in Architecture, one of fifty artists awarded nationally by US Artists.