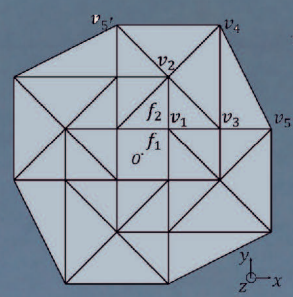
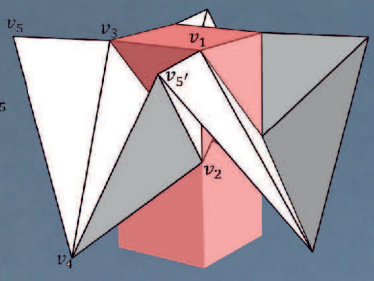
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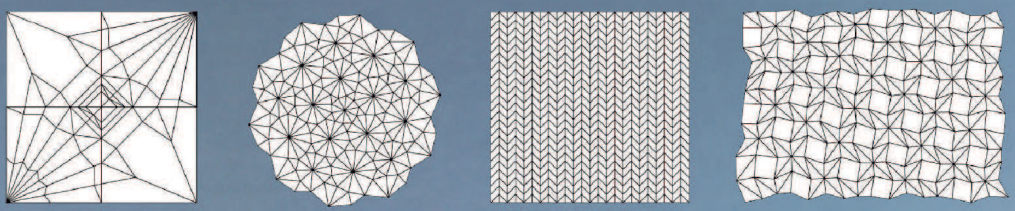
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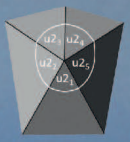
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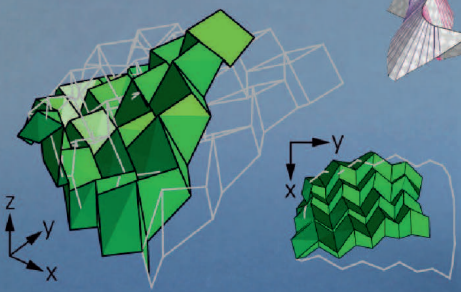


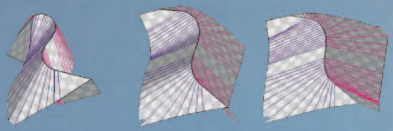














Edited by Robert J. Lang, Mark Bolitho and Zhong You

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Engineering Two

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Origami[7] General Preface

Origami[7] is a collection of papers published for the **7th International Meeting on Origami in Science, Mathematics and Education (7OSME),** held at Oxford University in the United Kingdom from September 4–7, 2018. 7OSME is the seventh conference in a series dedicated to research in the applications of origami and folding in the conference title fields, as well as in technology, design and history.

The First International Meeting of Origami Science and Technology, December 6 –7, 1989, was organised by Professor Humiaki Huzita at the Casa di Ludovico Ariosto, in Ferrara, Italy. This conference brought together people interested in the mathematics and application of origami. Five years later the Second International Meeting of Origami Science and Technology, November 29–December 2, 1994, was held at Seian University of Art and Design, in Shiga, Japan. Organised by Professor Koryo Miura, the meeting grew to include presentations in origami design, education and history.

The third meeting, March 19–11, 2001, was organised by Professor Thomas Hull, at Asilomar, Pacific Grove, California, USA. The meeting adopted the title, the Third International Meeting of Origami Science, Mathematics, and Education. The acronym OSME was adopted for the series and the meeting became known as 3OSME. Subsequent meetings have followed this convention.

The fourth meeting, 4OSME, September 6–10, 2006, was organised by Robert J. Lang, at the California Institute of Technology, Pasadena, California. The fifth, 5OSME, July 13–17, 2010, was organised by Eileen Tan, Benjamin Tan, and Patsy Wang-Iverson and was held at the Singapore Management University, Singapore. 6OSME, August 10–13, 2014, was organised by Ichiro Hagiwara, Koryo Miura and Toshikazu Kawasaki, and was held at the University of Tokyo, Japan.

7OSME, 4–7 September 2018, was held at Oxford University, Oxford, United Kingdom. The conference was organised by a team led by Professor Zhong You, Oxford University, that included Mark Bolitho, former Chairman of the British Origami Society; Professor Yan Chen, Tianjin University; Professor Simon Guest, Cambridge University; Professor Chris Budd, Bath University; and Mark Schenk, University of Bristol. 7OSME marked a return of the OSME conference to Europe, the first since the inaugural meeting in 1989.

Selected papers presented and published for 7OSME comprise the volume that you are now reading.

Both presentations and published papers for 7OSME were reviewed by a dedicated committee chaired by Robert J Lang. The committee comprised 17 members: Norma Boakes, Mark Bolitho, Chris Budd, Yan Chen, Mary Frecker, Simon Guest, Tom Hull, Yves Klett, Jun Mitani, Jorge Pardo, Glaucio Paulino, Mark Schenk, Tomohiro Tachi, Ryuhei Uehara, Patsy Wang-Iverson and Zhong You. The committee coordinated a peer review process through a group of more than 130 reviewers.

During the review process, 207 two-page abstracts were received for consideration. The authors of 166 abstracts were invited to submit full papers. Of these 110 full paper submissions were received, resulting in the selection of 96 papers that were selected for publication.

Papers published in Origami[7] were spread across six categories: 11 papers in art and design, 5 papers in education, 2 papers in history, 5 papers in other science applications, 23 papers in mathematics, and 50 papers in engineering.

In the nearly 30 years since the first OSME conference was held, the scientific and technical aspects of origami have exploded in interest across the fields represented in this work. The connections between folding and diverse fields have proven to be subtle, deep, and rich; origami research may now be found at mainstream technical conferences ranging from materials research to mechanical engineering, robotics, and computer science. Despite the expansion of venues where origami research may be found, the OSME series of conferences continues to grow, a testament to the vibrancy and potential in origami and its affiliated fields. Each OSME conference has grown in size as new applications of folding are explored and developed. Engineering has seen particular interest; half of the published papers in this work came from this area of research. The expansion of origami as an academic field of study has been driven in part by dedicated university research centres at major universities around the world, including postgraduate programmes in Oxford University in the UK, Tianjin University in China, and nationally funded programs in applications of origami at numerous universities in the USA.

Beyond engineering, other folding fields are still well represented. In this work, Volume One includes papers on art and design, education, and science. Papers published range from the exploration of folding in architecture, to presenting folding sculpture as contemporary art. There are also studies of new creative

folding processes and methods. The papers categorised as Science include research into new and emerging research areas.

Volume Two includes papers on the mathematics of folding. Papers range from exploration of the mathematics inherent in folded structures, to the use of folding techniques to explore and illustrate mathematical concepts. Several papers look into the mathematics connected with specific folding structures, including the Miura-ori pattern and origami tessellations.

Volumes Three and Four include papers on engineering. Papers published include research into diverse folding applications and products, adding strength to defensive shields, reinforcing tube strength, development of space sails, and the applications of folding processes to robotics. Some papers also explore the mechanical properties of the Miura fold, curved folding, and tessellations.

Origami[7] contains a unique collection of papers. Thanks to the efforts of the review team and the authors, who wrote, re-wrote and responded to reviews, the collection represents the leading edge of applied origami research.

The OSME conference brings together practitioners from different disciplines, connected by their common interest in folding and its application. The sharing of these ideas through published papers will lead to further collaboration and inspiration. The papers presented give an idea of the current state of applied origami. They also give some indication of new and emerging trends that we will see explored in the years ahead.

We hope that you enjoy Origami[7].

Mark Bolitho, Zhong You, and Robert J. Lang,

On behalf of The Editors of Origami[7]

September 2018

Origami^7 Volume Four Preface

Origami, the ancient art of creating unique patterns and shapes through paper folding, is inspiring engineers to design multi-functional materials and structures that bend, stretch and curve, overcoming various traditional design constraints. While mathematicians are interested in the geometric aspects of origami objects, such as the foldability of origami patterns, engineers, are more focused on developing novel application-oriented structures and materials with deployable features.

In the recent years, origami has been applied to various high-end engineering applications at varying scales. These range from shape-changing materials and surfaces with enhanced and interesting properties, to medical devices and the construction of space satellites.

The third and fourth volume of Origami^7 includes papers that relate to the application of origami and folding in Engineering. Volume three includes papers relating to, Deployable structures inspired by origami, Structural design using origami, Fabrication, and Modular origami and metamaterials.

- *Deployable structures inspired by origami*: Origami and folding mechanisms can be applied to structural systems to create transformable objects. The papers in this section explore the application of origami to specific designs. These include the paper the "Design of an Origami-Inspired Deployable Aerodynamic Locomotive Fairing" (authored by Tolman et al.), "Deployable Sub-module for Space Solar Power Station Based on Origami", (authored by Tang et al.). The construction of a "Rigidly Foldable Rotational Erection System (RES)" (authored by Miyamoto). The application of a light weight defensive shield is explored in the paper "Origami-Based Deployable Ballistic Barrier" (authored by Seymour et al.).

- *Structural design using origami*: Origami can be applied to an object's structural designs to develop new inherent mechanical properties and behaviours. "A Generative Shape Grammar for Piecewise Cylindrical Surfaces and Curved-Crease Origami" looks at a general design approach to curved folding (authored by Gattas) and the paper "Curved-Crease Origami with Multiple States" explores the structural designs made with curved folds as opposed to straight line creases (authored by Lee et. al.). "Programmable 3-D surfaces using origami tessellations" (authored by Yuan et. al.) and "Designing Self-Blocking Systems with Non-Flat-Foldable Degree-4 vertices" (authored by Foschi and Tachi), look at how folding can change structural properties of a surface. The paper "Multiphysics Origami: Achieving Tunable Frequency Selective Surfaces

from Origami Principles", (authored by Novelino et al.), explores how folding can change the tuneable frequency of selective surfaces

- *Fabrication*: Advances in fabrication techniques such as 3D printing, has opened up the potential for industrial-scale production of origami-based objects. As a result, this area of research has is now receiving greater attention from the scientific community. However, the fabrication of origami-based materials and structures can be challenging. Specifically, the replication of complicated creases and facets required to create the desired physical properties and behaviour of an object. This section of Origami[7] covers various aspects of fabrication relating to origami objects such as "Folding Fabrication of Curved-Crease Origami Spindle Beams" (authored by Cui et al.), "Fold Printing: Using Digital Fabrication of Multi-Materials for Advanced Origami Prototyping", (authored by Gardiner et al.) and "Kirigami fabrication of shaped, flat-foldable cellular materials based on the Tachi-Miura polyhedron" (authored by Calisch and Gershenfeld).

- *Modular origami and metamaterials*: Modular origami is a technique of paper folding involving more than one sheet of paper to create larger and more complicated structure. With this technique, each of the sheets of papers is folded to form a specifically designed module. The modules are assembled in two or three dimensions. These modular constructions (and conventional origami tessellations) can be used to create metamaterials with unique properties. This section of Origami[7] comprises two interesting studies on the mechanical behaviour and interactive designs of such modular origami objects, "A Modular Origami-inspired Mechanical Metamaterial" (authored by Yang and You) and "An Interactive Design System for Deltahedron-based Modular Origami" (authored by Tsuruta).

Zhong You

September 2018