



Creased Logic: A Review of Origami's Role in Mathematics and Beyond

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Abstract: Mathematics has profoundly impacted the discipline of origami, facilitating the emergence of sophisticated design methodologies. Origami constitutes the art of meticulously folding paper into various sculptures without the necessity of cutting the material or employing adhesives for assembly. This traditional Japanese craft of paper folding unveils complex geometric patterns manifested through its crease lines. We highlight the dynamic relationship between artistic ingenuity and mathematical principles in the realm of advanced origami design, as well as the role of origami as a practical pedagogical instrument for the instruction of geometric concepts, delving into its mathematical intricacies. In this review, we will examine the process by which the construction of a representational origami figure is accomplished through the application of mathematical algorithms. Furthermore, it investigates the techniques that have broadened the creative horizons within the field of origami and its different applications.

Keywords: Crease patterns, Miura fold, Collaborative learning, Deployable structures, Foldscope, Airbag folding, Waterbomb bases, Bento boxes, Collapsible furniture Symmetry, Mathematical origami, Visualization, Geometric folding, Modular origami.

1) Introduction: Origami, the venerable Japanese art of paper manipulation, has transcended its cultural and aesthetic origins to become a significant instrument for mathematical exploration and education. Through a multitude of studies, researchers have demonstrated how the humble art of paper folding can reveal deep geometric principles, promote experiential learning, and represent complex phenomena encountered in the empirical world. The dynamic interplay between creativity and mathematics that is inherent in origami serves as a pathway that connects abstract theoretical frameworks with tangible experiences, particularly in educational environments where it enhances spatial reasoning, improves problem-solving skills, and cultivates student involvement. The versatility of origami underscores its significance as both an educational strategy and a field of scholarly inquiry, thereby enriching the spheres of mathematics, pedagogy, and scientific exploration.

2) Important Definitions:

1. Crease Pattern:

A *crease pattern* is like a blueprint of an origami model. It shows how a square piece of paper is divided into different flat sections using straight lines, called *creases*.

These lines represent where the paper will be folded. The spaces between the creases

— the flat areas — are called *facets*. Each facet is a polygon (a shape with straight sides), and together they make up the full pattern on the paper.

2. Base:

Think of a *base* as the first stage of an origami model. It's what you get when you

fold a square piece of paper into a 3D shape without stretching or tearing it. The paper only bends along set fold lines (creases), and each section stays flat in between.

3. Flap:

A *flap* is like a part of the model that sticks out — for example, what might become a leg, wing, or arm. It's made up of several connected flat parts that all fold together toward the same edge of the paper. If any other piece connects to this group and folds in the same direction, it becomes part of the flap too. The edges of the flap usually connect back to one or two key points on the paper.

4. Flat Fold:

A *flat fold* means that after all the folding is done, the whole thing can be pressed completely flat — like closing a book — with all the layers lying neatly in one plane[16].

3) Fundamentals of Origami:

Before diving into the deeper mathematical ideas behind origami, it's helpful to understand some of the basic terms and symbols commonly used in the field. Over the years, these terms have been standardized by several leading figures in origami research and design, such as Robert Lang, David Huffman, Clowes, Waltz, Takeo Kanade, and Akira Yoshizawa [1][2].

Basic Terminology in Origami

Here are a few essential folding terms you'll often encounter:

- **Mountain Fold:** This is when the paper is folded away from you, forming a peak (like a mountain).
- **Valley Fold:** This is the opposite — folding the paper toward you, creating a dip (like a valley).
- **Crease:** The visible line left on the paper after a fold is made and then unfolded.
- **Crease Pattern:** The full map of all folds and creases in a model, visible after it has been completely unfolded.

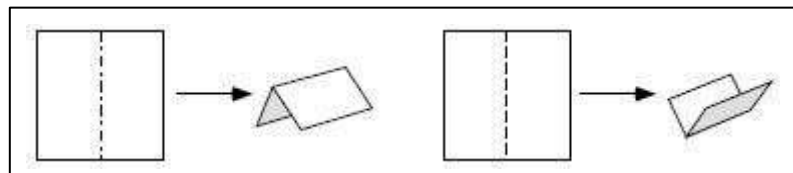


Fig. 1 Crease lines, Left: Mountain crease, Right: Valley crease (adopted from [2])

The Huzita-Hatori axioms, initially articulated by Jacques Justin in 1989, consist of seven axioms that were subsequently refined by Humiaki Huzita in 1991 and ultimately consolidated by Koshiro Hatori, Justin, and Robert Lang in 2001 [8]. —The axioms are:

1. Given two points P_1 and P_2 , there is a unique fold that passes through both of them.
2. Given two points P_1 and P_2 , there is a unique fold that places P_1 onto P_2 .
3. Given two lines l_1 and l_2 , there is a fold that places l_1 onto l_2 .
4. Given a point P_1 and a line l_1 , there is a fold that places P_1 onto l_1 .
5. Given two points P_1 and P_2 and a line l_1 , there is a fold that places P_1 onto l_1 and passes through P_2 .

6. Given two points P_1 and P_2 , and two lines l_1 and l_2 , there is a fold that places P_1 onto l_1 and P_2 onto l_2 .
7. Given one point P_1 and two lines l_1 and l_2 , there is a fold that places P_1 onto l_1 and is perpendicular to l_2 .

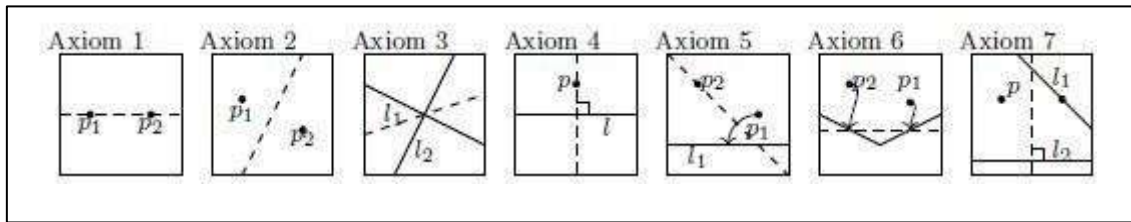


Fig.2 Representing the axioms on a sheet of paper (figure adopted from [6])

4) Different aspects of Origami:

4.1. Origami Design via Mathematical Algorithms:

The combination of mathematical theory and computational techniques facilitates the creation of highly intricate origami models that would be exceedingly challenging to construct manually. Using graph theory, origami can be redefined as a mathematical process to model designs as tree graphs where edges represent paper flaps. This algorithmic approach enables precise planning of complex origami structures [16].

Mathematics in Origami

Origami isn't just an art — it's also deeply mathematical. Researchers have used several branches of math to analyze and design folds, especially:

- **Geometry:** Helps in analyzing angles, distances, and the structure of folds.
- **Topology:** As discussed by Thomas Hull [2], this branch helps understand how surfaces can bend and connect without tearing.
- **Lang's Tree Theorem:** A method developed by Robert Lang [5] to describe how paper can be folded into shapes with multiple flaps.
- **Maekawa's String-to-Beads Technique:** A conceptual method to represent folding sequences [3].

Origami constructions may be represented algebraically and how specific geometric challenges—such as trisecting an angle or duplicating a cube—become resolvable via origami techniques, in contrast to traditional straightedge and compass methods[10].

4.2. Folding Math into the Curriculum as a Tool for Teaching

Origami offers a multifaceted approach to mathematics education, combining hands-on learning with deep conceptual engagement. Both theoretical perspectives and empirical research affirm its value as a powerful teaching tool. Origami has the potential to foster mathematical thinking through spatial reasoning, problem-solving, and collaborative learning. Origami naturally integrates core mathematical ideas such as symmetry, transformation, measurement, and geometric reasoning. The student-centered nature of

origami—where learners teach models to peers and create their own instructional materials— encourages active participation and aligns with constructivist educational theory [3].

Origami-based instruction significantly improves student retention of geometry concepts compared to traditional methods. Their study found that students who learned geometry through origami retained more content over time, with no significant difference in performance between male and female students. They advocate for integrating origami across all educational levels and recommend teacher training to facilitate its effective use in classrooms[11].

Origami can function as a potent educational medium for comprehending geometric concepts such as the Pythagorean theorem, angle trisection, and area calculations through experiential paper folding[6].

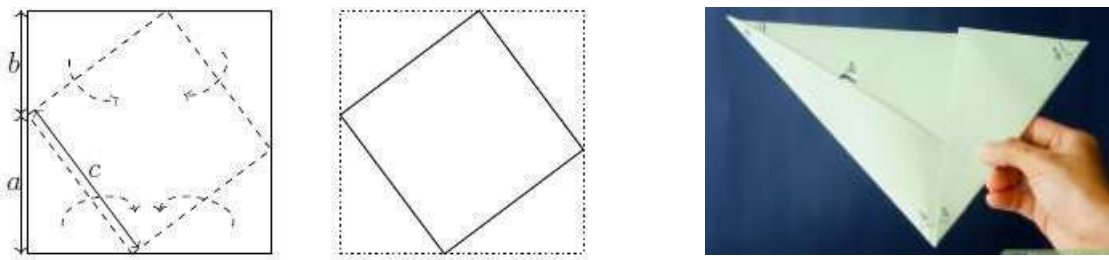


Fig. 3 Left: Demonstration of Pythagorus Theorem (adopted from [6]) , Right: Paper Protractor.

Together, these instructional strategies and supporting research demonstrate that origami not only boosts immediate comprehension and engagement, but also significantly enhances long- term retention. It is an inclusive, effective, and highly adaptable pedagogical tool that meets the goals of modern mathematics education.

4.3. Origami-Inspired Deployable Structures for Aerospace Applications

The intersection of origami and aerospace engineering has fostered a novel domain of lightweight, compact, and deployable structural designs. Nishiyama (2012) presents the Miura fold as a foundational example, describing its mathematical elegance, space-saving design and practical efficiency in compactly folding surfaces such as solar panels for spacecraft[14].

Expanding on this, Morgan, Magleby, and Howell (2016) proposed a structured framework for **origami-adapted design**, aiming to transition fold patterns from concept to functional aerospace mechanisms. Their methodology is validated through applications like origami bellows for Mars Rovers, expandable habitats, and parabolic antennas. These designs demonstrate key advantages such as stowability, rigidity, and high compressibility, offering practical insights into translating flat-fold origami into 3D mechanical solutions[20].

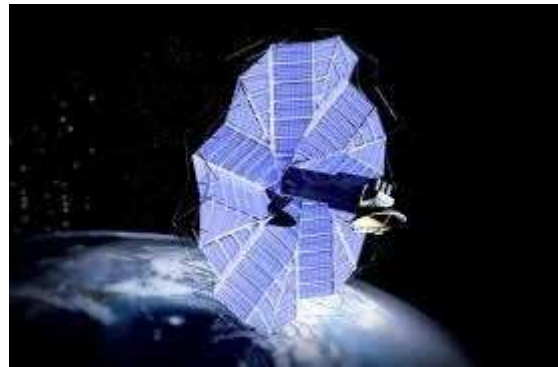
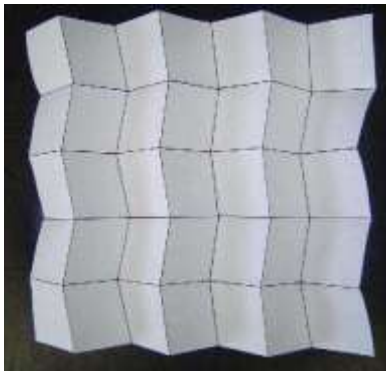


Fig. 4 Origami in Space Exploration, Left: Miura Fold (adopted from [14]), Right: Computer-generated Model of Flasher Solar Panel (adopted from [15])

Yue (2023) complements this discussion with a comprehensive review of origami-based deployable structures, focusing on geometric principles, rigid-foldability, and engineering applications. Highlighting folding patterns such as Miura-ori, flasher, and waterbomb, Yue outlines how they are implemented in solar sails, antennas, and robotic systems[15].

Overall, these works reflect a growing synergy between traditional folding techniques and modern engineering, illustrating how origami principles are driving innovation in deployable aerospace technologies.

4.4. Origami-Inspired Engineering Solutions

Origami has emerged as a transformative design principle in engineering, enabling the creation of compact, foldable, and functional structures. Rus and Tolley (2018) highlight how origami robots leverage folding mechanics to integrate actuation, sensing, and control in a single planar sheet, allowing rapid, low-cost fabrication with built-in compliance and morphing capabilities[19].

This approach is applied in diverse fields—from Turner et al.'s (2015) review of mechanical engineering applications, where origami enables efficient design of mechanisms and deployable systems, to Prakash's Foldscope, an origami-based microscope offering robust, affordable imaging for field science and education[18]. Mroz and Pipkorn (LS-DYNA study) further apply origami theory to simulate airbag folding and deployment, improving realism and safety in automotive design[7].

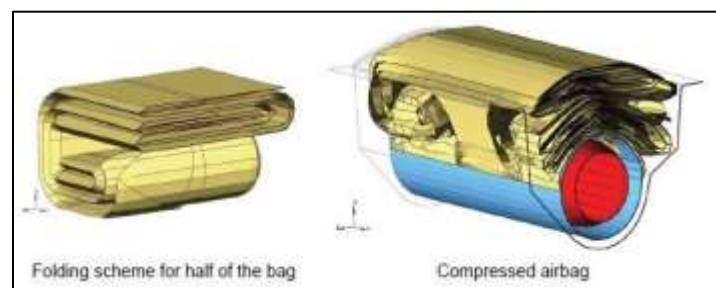
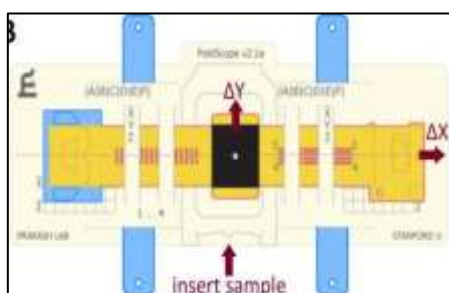


Fig. 5 Origami inspired mechanical innovations, Left: Foldable microscope (adopted from [18]), Right: Final airbag model after folding and compression inside the housing module (adopted from [7])

All these works underscore origami's power in simplifying design, reducing cost, and enhancing functionality across mechanical, biomedical, and robotics engineering.

4.5. Origami-inspired Architecture

Origami-inspired design offers novel approaches to creating reconfigurable and deployable structures across engineering disciplines. Dureisseix (2012) provides a comprehensive overview of the geometric, mechanical, and structural principles underlying origami mechanisms, highlighting their relevance in fields ranging from architecture to biomedical devices. Key patterns like Miura-ori and waterbomb bases are explored for their foldability, structural rigidity, and ability to form complex 3D shapes[17].

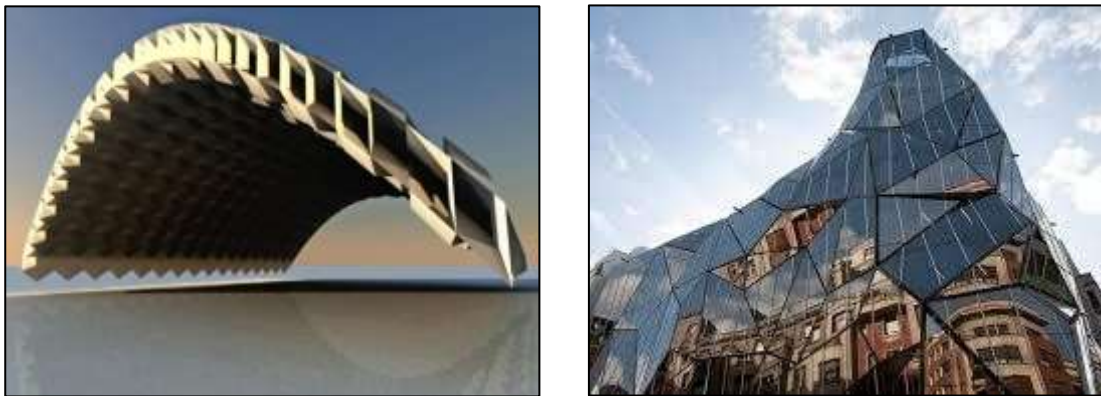


Fig. 6 Computer –generated architectural canopy (adopted from [22])

Reis et al. (2015) emphasize the architectural potential of origami through structures that combine aesthetic form with mechanical functionality. Their commentary on Filipov et al.'s work illustrates how modular —zipper! Miura-ori tubes enable strong, load-bearing yet deployable systems, bridging a gap between traditional origami and structural engineering. This synergy unlocks new possibilities for adaptive buildings and lightweight infrastructures[22].

4.6. Applications of Origami in the Food Industry

Origami-inspired principles have found increasing relevance in the food industry, particularly in packaging, automation, and food presentation. Folding-based design is employed to create compact, material-efficient packaging solutions such as takeout containers, folding cartons, and bento boxes, which can be shipped flat and easily assembled on-site. This approach not only reduces packaging waste but also enhances structural integrity and functionality. In food automation, origami has influenced the development of soft robotic grippers and compliant manipulators capable of handling delicate or irregularly shaped food items without causing damage—an essential feature in high-throughput food processing lines[21].

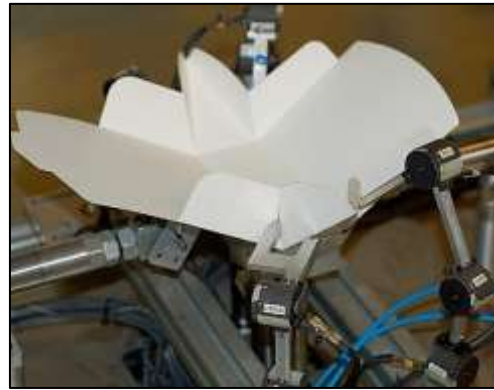


Fig. 7 Origami inspired food packaging (adopted from [21])

Furthermore, origami mechanisms have been incorporated into functional packaging, enabling self-opening seals, portion-control systems, and smart structures for steam venting or reconfiguration during cooking. Recent advances also include the use of edible materials formed into origami-like structures, allowing flavour or nutrient delivery systems to unfold during preparation. Finally, in the domain of culinary artistry, chefs and designers utilize origami techniques for the aesthetic arrangement of food, contributing to the growing trend of edible architecture in gastronomy. Collectively, these innovations highlight the versatility of origami as a tool for both practical and creative enhancement in food systems.

4.7. Origami-Inspired Innovations in Modern Home Furnishing

The art of origami has increasingly influenced modern home furnishing by providing innovative solutions for space-saving, multifunctional, and aesthetically dynamic interior designs. As urban living spaces become more compact, origami principles offer practical advantages in creating furniture that is foldable, transformable, and modular. These designs allow a single piece to serve multiple functions—such as seating that converts into storage, or tables that collapse into compact forms—maximizing utility without sacrificing style [13].



Fig. 8 Foldable furniture inspired by origami

Beyond functionality, origami brings a geometric elegance to interior aesthetics, allowing designers to merge form and function with visual intrigue. Through the integration of modern materials and digital fabrication techniques, origami-inspired furnishings represent a convergence of tradition and technology, offering sustainable and adaptable solutions for contemporary living.

4.8. Origami in Nature

The greatest inspiration for origami comes from nature itself. Most of the physicists and mathematicians working with origami often find inspiration from nature. If we closely observe the world around us we can find that folding is everywhere. Whether it be the flowers which unfold when it's time to bloom or the wings of birds and insects which unfold when it's time to fly. The crease patterns on the Hornbeam leaves are clearly visible; see Fig. 9 (Left) [17]. These patterns from the natural world have been studied by origami artists and various applications to the real world are made possible. In particular, the wings of insects such as most of the species of beetles and ladybugs show the Miura-ori pattern; where the wings are folded under the hard cover known as elytra. The venations in the wings show the crease patterns[23].

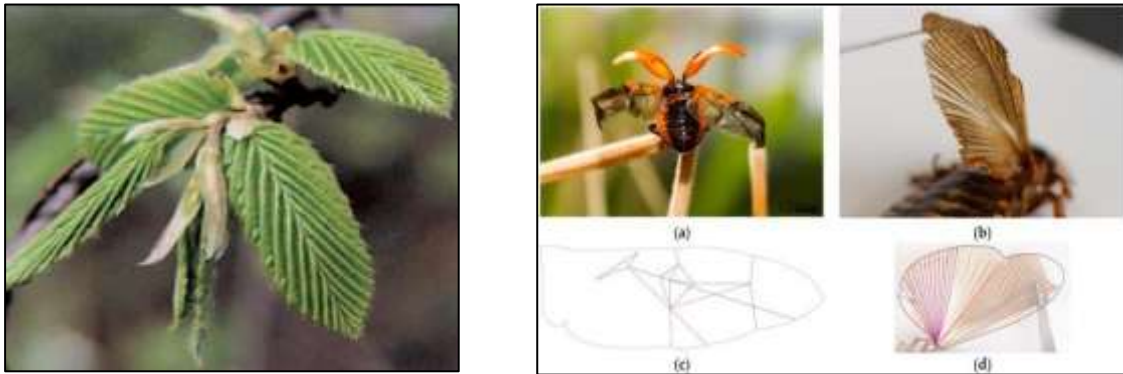


Fig. 9 Origami in Nature, Left: The Hornbeam leaves (adopted from [17]), Right: Crease patterns on the wings of a ladybug (adopted from [23])

Conclusion:

Origami transcends mere artistic expression; it serves as a dynamic modality through which intricate mathematical concepts can be examined, visualized, and imparted. From addressing ancient geometric conundrums to engaging learners within educational environments and simulating biological phenomena, the confluence of origami and mathematics perpetuates the stimulation of innovation and comprehension. Each of the examined scholarly articles contributes distinctively to this complex interplay, illustrating that the domains of folding and mathematical formulas share a fundamental similarity.

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