

Mind-blowing modular origami: the art of polyhedral paper folding, by Byriah Loper

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BOOK REVIEW

Mind-blowing modular origami: the art of polyhedral paper folding, by Byriah Loper, North Clarendon, VT, Tuttle Publishing, 2016, 96 pp., \$16.95 (softcover), ISBN-13: 978-4-80531-309-1

Mind-Blowing Modular Origami is not an exaggerated title for a book that presents truly spectacular origami designs far beyond most people's ability to create or replicate. The young author, Byriah Loper, is leading the field with new 'wire frame' designs of intricate complexity. Modular origami involves folding many individual sheets of paper which effectively become the parts of a construction kit – their tabs and pockets connect them together to build a larger object. Wire frames are a specialty within this genre in which each piece of paper is folded to become an edge of a polyhedron. The overall goal is not just one, but a cluster of symmetrically entangled polyhedra. This is a narrow specialization in which Loper (who is in his early 20s) has distinguished himself in just a few years.

Origami aficionados have been impressed when seeing some of Loper's highly creative output online and at the annual Origami USA conference exhibit in New York for the past few years [7]. Now he has documented a beautifully illustrated collection of his designs with detailed step-by-step instructions for their construction. [Figure 1](#) shows an elegant example in which each coloured component is a dipyrmaid assembled from nine paper struts (of two different lengths) so the complete assembly of 10 components involves 90 neatly folded rectangles in total, carefully interlinked and joined at their tips to form a symmetric stellar cluster.

This 96-page book is not just a showcase of designs and a how-to-fold manual. It contains a bit of origami history, some mathematical information and enough background material to prepare the folder for problem-solving as required. For the reader wishing to start replicating these designs, the introduction includes a page describing materials, including types of paper. Choosing between thicker or thinner paper involves a strength/flexibility trade-off. The size of the initial pieces is another crucial decision: too large and the overall model becomes a storage problem; too small and your klutzy fingers cannot manage the tiny little folds. The international notation for describing different types of origami folds is reviewed, so there is a self-contained reference for standard terminology such as the 'water-bomb base,' the 'sink fold,' a 'swivel-squash fold' and the many types of arrows, each indicating a particular fold or transformation. A 'Tips and Techniques' section explains underlying principles to help the reader solve the many assembly puzzles that will arise along the way.

On the mathematics side, the introduction includes a page summarizing the structure of the Platonic solids, giving the number of faces, edges and vertices of each and diagramming how they are connected. These provide the underlying architecture of the book's models. Their rotational symmetries are the foundational mathematics of the wire-frame designs. The locations of threefold, fourfold and/or fivefold axes are nicely illustrated in the assembly diagrams throughout the book. For someone who has internalized the polyhedral structures, these axes serve as landmarks that allow the builder to visualize larger neighbourhoods of the complete construction when it is only partly assembled, thereby guiding the placement of the next components.

On the too-much-detail side, I find it odd that the book gives a wordy paragraph of overly step-by-step instructions of what to divide by what to calculate length and width when a given rectangle is to be scaled to a desired size while keeping its proportions. I suspect that any



Figure 1. ‘Aurora,’ a wire-frame modular origami by Byriah Loper consisting of 10 interlocking triangular dipyramids. It is assembled from 90 thin rectangles of paper, carefully folded into struts with small tabs and pockets at each end, intricately interwoven, and joined at the corners by inserting the tabs into the pockets of neighbouring struts. (Cover photo, reprinted with permission.)

reader who needs those details is not prepared to make much headway into the heart of the book.

The bulk of *Mind-Blowing Modular Origami* is a description of how to make 19 original models that Loper designed. The first seven are kusudama models and the remaining 12 are wire frames. ‘Kusudama’ is the Japanese term for a style of decorative modular orb based on polyhedral symmetries. [Figure 2](#) shows an example. They are usually tightly closed (so no light can pass through), unlike wire frames, which are generally open so you can see inside and right through between the struts. The kusudamas each have a connected surface while the parts of a wire-frame weave in and out through each other to make a multilayered structure. But the two styles involve many similar mathematical and construction details, so the kusudamas serve as an excellent introduction to the wire frames.

The wire-frame models presented here contain from 90 to 650 components. Half of them consist of exactly 120 parts. Each part involves a series of folds as in [Figure 3](#) to produce the proper lengths, face angles and dihedral angles. My experience shows that with practice, each part may require roughly 3 minutes to fold individually. So you can do the math to see that a typical wire-frame design might require 6 hours just to create the parts. That is not including the time for cutting or ripping the paper to the proper length/width ratio and only sets the stage for the harder problem of figuring out how to interweave the parts and properly join their ends, which add hours to the overall task. These projects are not for the faint of heart!



Figure 2. This kusudama design, called 'Vortex Module,' is assembled from 30 folded paper squares. It is one of the simplest in the book. (Page 18 image modified by George Hart, reprinted with permission.)

In contrast, the kusudama models are much simpler geometrically and designed 'from more of an artistic perspective.' While there is usually freedom to choose their complexity and assemble a tetrahedral, octahedral or icosahedral variant, typically they look good when made with 30 components, corresponding to the edges of an icosahedron or dodecahedron. They require much less commitment than the wire frames, but still you should not expect to complete one in a single spare hour. While these kusudama designs are perfectly adequate for their introductory purpose, they do not stand out to me as surpassing the existing literature in the way the wire-frame models do, so the book would not have suffered if a few were omitted.

The unique strength of the book is that it illustrates the author's expertise in wire-frame models at three different levels: coming up with original overall structures, designing folding patterns to make individual struts with the proper lengths and angles and the expert technical execution of the models evidenced in the photographs. Another requirement for constructing these designs that the book makes clear is heroic patience. The reader is warned in two different places that 'folding the individual units may be tedious.' This is an understatement. While I have made a variety of moderately complex kusudamas in the past, I was not prepared for the good many hours required for these wire-frame designs.

My biggest problem in constructing these designs is that they would frequently fall apart. A tab is inserted into a pocket when you connect two pieces, but later when your attention is

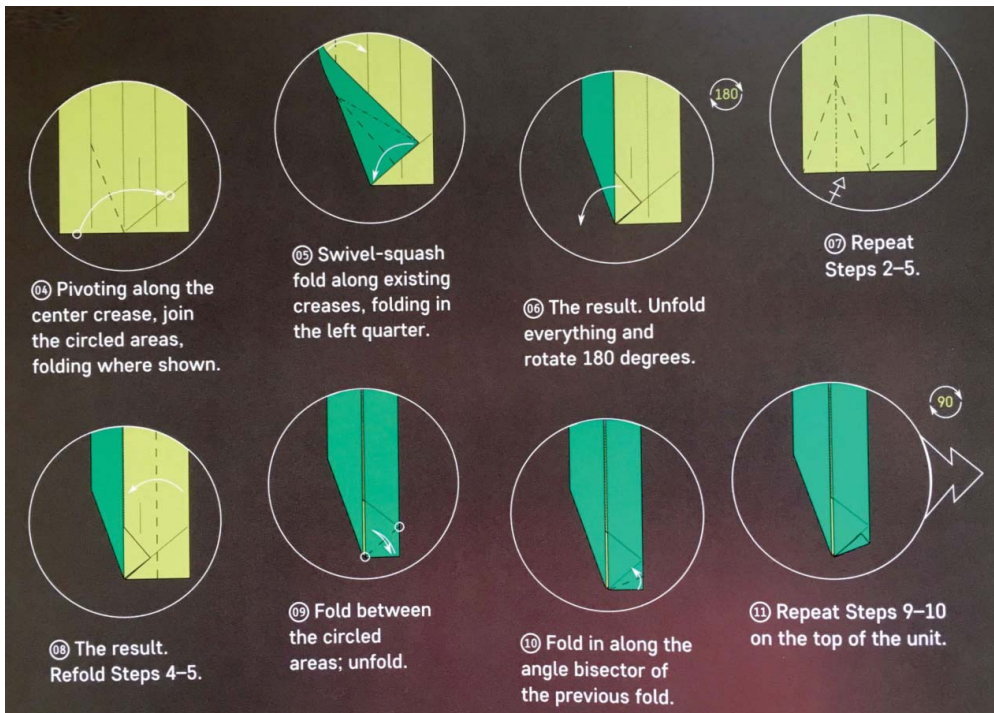


Figure 3. Some of the steps to create the small connecting tabs and pockets at each end of each strut of 'Aurora' (Figure 1). (Page 80 image, reprinted with permission.)

elsewhere, the tab nonchalantly slides itself out of the pocket. So unlike origami purists (who eschew scissors, tape and glue) I would find myself adding a small dot of glue to the tabs, so they cannot fall out of their home. This works so well for me that I must say I repeatedly found myself wondering if a forensic origamist might also find small traces of glue on Loper's models.

The spontaneous disassembly problem is just one aspect of the engineering side of these designs. As with all constructive sculpture, these are physical objects which must hold together, resisting gravity and other disturbing forces, not just after completion but also during the assembly process when they are especially fragile because there are many loose ends. The choice of materials can alleviate some problems. We are informed that 'elephant hide' paper is 'excellent for all Wire Frames, and good for most decorative modulars as well.' Loper uses the term 'frame holder' to refer to pieces of wire that can be used like twist ties during assembly to temporarily bind struts together where they cross. Many photographs illustrate their use. When complete, the sides of the struts of the individual polyhedral units rest against each other to hold each other in place, so the frame holders can be removed.

Other important technical details concern how best to make dozens or hundreds of identical components. Purists may want to follow the detailed folding instructions for each strut. Those with a more practical bent will look for time-saving shortcuts. This starts with the initial step of creating a paper rectangle of the proper aspect ratio. For some models, a multi-step process is given by which a purist can start with a square sheet and make a series of folds that lead to the construction of a point defining the shorter edge of the desired rectangle, after which a sharp crease and a careful rip release the rectangle from the square. This will seem overly fastidious to many, so for other models the author effectively throws his hands up in

the air and says to proportion your initial rectangle with a decimal aspect ratio, e.g. 1:3.375, knowing people like me will happily use a ruler and paper cutter. As a compromise, a hybrid method is also described in which one folds a template like a purist, then copies the template's rectangular shape for mass production.

Similarly, the tedious nature of component fabrication leads one to find steps that can be efficiently bypassed without significant loss of accuracy. For example, after being a purist for the first few modules, one learns to fold a corner to a line's midpoint as gauged by eye rather than first constructing the midpoint by halving. The author does not detail such shortcuts but notes generally that 'the folding process can be expedited by omitting the given reference steps and approximating the final folds.' I would be interested in seeing some detailed tricks of this nature that he has found to work.

In the end, to succeed in these projects, one must enjoy the process. For me, the assembly process is the exciting part. Visualizing where struts should go and weaving them into place is a fun puzzle because it presents ever-changing challenges. However, the tedium of folding all the struts by myself outweighs that pleasure. No doubt there are others who would have reversed preferences, so these wire-frame designs might be good group projects where the labour can be divided among many hands.

In the hours of wire-frame construction, there is plenty of time to reflect upon what one is doing. I found myself thinking 'art is long, life is short.' But in fact, it is not clear how long paper art may last. If your purely unglued construction does not spontaneously disassemble (perhaps accelerated by a bumpy transportation adventure) it risks being severely squished in an instant of carelessness or turned to mush in a moment by water damage. Over the years I have also lost paper art to chemical self-destruction 20 years after I made models from inexpensive stock that was not acid-free. In thinking that these models are not likely to last very long, I set myself up to avoid allocating the enormous time necessary for making them. Focusing on the 'life is short' half of the aphorism, I would pause and work on other projects instead. Perhaps others would have found a meditative flow in folding hundreds of parts and I have a Western bias in not appreciating the value of ephemeral art. However, my inability to complete the larger models just gives me more respect for Loper's work.

The book only briefly outlines the history of modular origami and wire frames, giving a nod in a couple of paragraphs to a dozen or so designers for their important contributions that this work extends. Mitsunobu Sonobe apparently created the fundamental 'Sonobe unit' in the 1960s, which sparked the field [6]. Tomoko Fuse [8] developed many kusudama variations. Tom Hull's Five Intersecting Tetrahedra (FIT) was the first interwoven polyhedral compound [5]. Robert Lang rigorously studied the mathematics of interlinked polyhedra [9]. And Daniel Kwan (another creative young designer) pushed the field forward in recent years with many impressive wire-frame models [4].

Teachers who see this book will wonder if it might be suitable for use in their classes. Mathematical art can serve as a hook for getting art-focused students to engage in math and can also provide inspiration that leads math-centred nerds to appreciate the humanities. Modular origami in particular has been put to these uses and teachers can easily find books and online lesson plans with activities that blend math and art via origami. Such hands-on activities present natural teaching opportunities to discuss many mathematical topics in a casual context, including symmetry, measurement, proportional scaling, angle bisectors, polyhedra, etc. Math lessons are most effective when they answer a question the student is interested in learning about. But my opinion is that *Mind-Blowing Modular Origami* would serve better as generic inspiration than as lesson plan. The book combines engaging images and mathy terminology. (Care to build 'Five interlocking wrinkled truncated tetrahedrally distorted skew rhombic hexahedra' anybody?) But the technical demands of the wire-frame projects are so advanced that they would engender more frustration than joy in most students.

For the benefit of teachers wanting to introduce the topic in their classes (or for general readers wanting to develop their folding skills up to the requisite level to construct these wire-frame designs), let me suggest the following syllabus, leaving the details to be found in many books and online resources. For excellent examples of the modular origami literature at a more introductory level, I recommend searching for books with ‘origami’ in the title, looking for authors such as Tomoko Fusè, Rona Gurkewitz, Meenakshi Mukerji, Ekaterina Lukasheva or Faye Goldman. An excellent initial modular origami construction is the octahedral frame made from six water-bomb bases [3]. This ‘starter drug’ introduces basic folds, the modularity concept and a cyclic structural logic (part A tucks inside B, which tucks inside C, which tucks inside A). Experience shows that students love making it and seeing how it holds together. After that, designs made with simple Sonobe units [2] are valuable for illustrating the bijection between module units and polyhedral edges, empowering students to start from their geometric knowledge and plan their own structures to build. You can have students make a series of small constructions individually, then disassemble them and have the class as a whole construct one larger design. Optionally, a variety of kusudamas can then be explored, giving a sense of the many types of folds and decorations possible. Next, you can introduce the elegant style of open faces by building a dodecahedron from 30 ‘penultimate modules’ [1]. Then, Thomas Hull’s FIT is the ideal introduction to the difficulties of weaving multiple polyhedra through each other [5]. While the FIT’s 30 modules may seem very manageable compared with the 90–650 used in this book’s designs, it is already a formidable challenge suitable just for the most tenacious students. Expecting a student to build any of the wire-frame designs would likely be counterproductive. But do show this book to your class. It is certainly educational and inspirational.

I should mention that the publisher, Tuttle, which generally focuses on Asian culture, especially origami, has done a nice job with the book’s design and production. It is filled with lucid colour images such as those shown in Figures 1 and 2. The folding diagrams are clear and easy to follow as evidenced by the example shown in Figure 3. The layout and editing are professional throughout except that someone was apparently sleeping at page 35 which contains both a hard-to-read section of text printed in green and blue ink on a greenish-blue background and a long paragraph about the symmetry of the designs which is repeated verbatim from page 15. Another quibble is that one might fault the book for saying nothing at all about the design process, e.g. how the strut widths are determined, but that is arguably a separate topic for a future book. It would be interesting to see some of the steps (partial models? computer renderings?) and failures (strut ratios too loose or too tight?) along the way to these successful designs.

The subtitle of the book is *The Art of Polyhedral Paper Folding*. So a disagreeable reader might fairly ask: ‘Is this art?’ One could argue that the market for how-to modular origami books proves that modular origami can be replicated by the masses, and so can be dismissed as just a craft, not fine art. My feeling is that this is indeed art, for a number of reasons. The first is that the category ‘art’ is a social construct and the math/art community has warmly welcomed modular origami as an artform, as evidenced by published papers in the Bridges Conference Proceedings and in this journal, and works in the art exhibitions at the Bridges Conference and the Joint Math Meetings. A second reason is that the wire-frame creations in this book, in fact, cannot be replicated by the masses. The level of patience, care and geometric insight required to fold the parts and properly interconnect them is beyond all but the highest level of origami experts. While written in the style of a how-to book for the masses, this is in fact a ‘master class’ for which only a small number of devoted folders are ready. Third, there is art in the creative act of designing these structures. No geometry text or web page includes an icosahedrally symmetric compound of 10 triangular dipyramids or any of the 11 other

geometric structures underlying these wire-frame designs. To conceive of it, to envision its proportions, to select it for reification, to engineer all the details of its fabrication and then to devote the time and care to physically build it as a visually engaging, colourful, aesthetic object is the process of an artist consumed with the need to create his visions. Byriah Loper is an artist. The world needs more such artists.



In summary, *Mind-Blowing Modular Origami* gives a sampling of the state of the art in geometric paper folding at a level many readers will not be ready for. But it provides inspiration which I hope will lead many to improve their polyhedral knowledge and develop more advanced skills. Far beyond cranes, it is a book explaining wire-frame designs for patient expert folders with many hours to dedicate to an intricate project. As is appropriate for objects of such mathematical and engineering complexity, there are many technical details that must be explained. But the art is never lost in the process. The vision, passion and creativity of the author are made evident through this well thought-out series of beautiful challenges at the forefront of the field.

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