Curved
ORIGAMI

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Thanks to all the people who helped me make, test fold, proofread and illustrate this book. Namely:

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Even to my opponents for motivating me to prove what I am capable of accomplishing.

Photo and media credits
Ekaterina Kim: my portrait,
Dáša Ševerová: all diagrams except "Water Drop".

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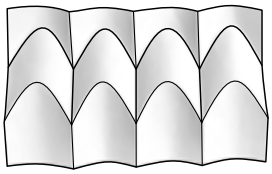

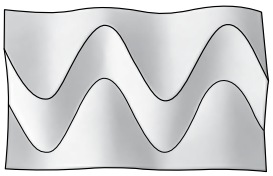

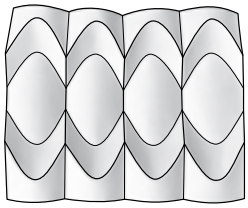

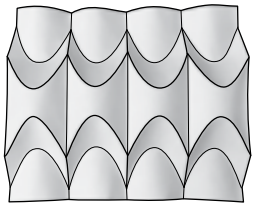

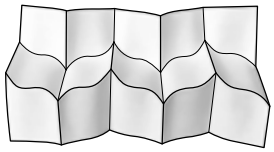

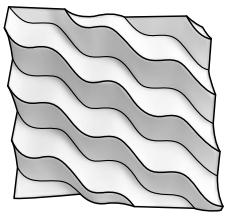

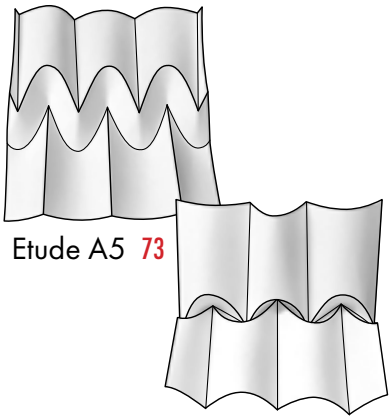

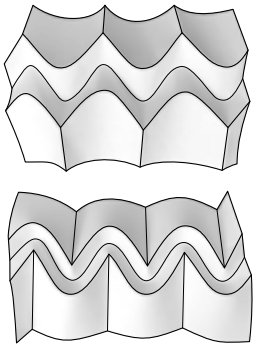

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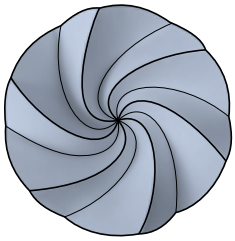

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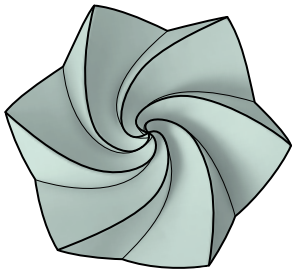

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Introduction

How can you learn curved folding? The answer to this question is not easy. "Learn" is a broad term. Learning one model does not entail mastering the whole topic. Knowing letters does not mean speaking the language. What I define as "learn" is being able to understand the structure of a model, being able to experiment and create on your own.

Some published knowledge on curved folding is unfortunately too mathy for a non-technical audience. And it creates a false perception of heavy mathematics and software being a requirement for curved folding design. I am going to prove this wrong!

During my ten years of researching curved-crease origami I figured out some easy tricks that work without lengthy and mathy explanations. There surely exist some scientific explanations for these tricks, but they are not necessary for intuitive understanding of curved folding. I won't be doing that myself as a hobby if it required too much thinking. It is fun and relaxing! I want to share the joy of experimenting with curved folds. It is not as complex as you might think. It is easy and fun! And I am going to prove it with this book.

Do you need a laser for curved folding? No, you don't! This is another popular misconception. While modern tools for origami exist, they are not required to begin. I aimed to create a book that is very practical, with instructions repeatable at home with a minimal set of tools. So a lot of attention is given to practical methods for creating your own hand-made tool set for curved folding.

I tried to create book that is good not only for beginners, but also for people who possess some knowledge already. For this reason some of the diagrams in Chapter 1 are presented as regular diagrams. But some variations are given in the form of crease patterns or hints. This should teach you to understand how to do variations and how to read crease patterns. In Chapter 2 you will learn how to create some origami tessellations. I did not want to teach some very particular designs though. I wanted to give you tools for creating your own tessellations instead! You learn the methods (words) and how they can work together, but the tessellations (sentences) you create will be yours! I really encourage you to experiment a lot with the designs. It's not only fun, but it broadens your understanding!

Paper

Curved folding technique requires paper to have slightly different qualities than standard origami paper. The common origami paper, *kami*, is usually thin, the thinner the better, to allow for multiple layers of paper to be still thin enough when folded together. Curved folding, on the other hand, often has one-layer areas exposed. We are also going to score paper with various scoring tools, which means our ideal paper should be tear resistant.

If you aren't yet into origami, plain printer paper might be your first choice, since it is thicker than kami. Printer paper is the most affordable and available option. I even challenged myself to fold the most of the models from "Parallel Tessellations" chapter from basic white printer paper. It works!

Tant paper is my personal favorite for curved folded models. Tant is a Japanese brand of bookbinding paper. It is also packaged specifically for origami and can be found in many origami shops or at Amazon in an abundance of vibrant colors and soft shades. It is tear resistant, has very nice texture and is a pleasure to fold. It is thinner and easier to work with than the other suitable papers. It is also solid core, which means that it has the same color throughout the paper, not only printed on the surface. No matter how deep you score this paper, it won't show you any white middle. The last property is especially important if you go for machine cutting (see page 15), as it exposes the middle. It is also less expensive than the other quality paper options.

My second favorite paper is *Stardream*. It is a metallic/pearlized paper that contains shimmer in it and hence has a distinctive sheen. This sheen adds a nice accent to curved surfaces. There's an example of Stardream paper on page 71. Other brands of pearlized paper produce very similar paper under different names. Local brands can be easier and less expensive to get in your area. So if you find text weight, around 110gsm, pearlized or metallic paper, give it a try!

Elephant Hide (EH, as people usually call it for short) paper is a German bookbinding paper. While some people believe it to be the best paper out there, I don't share that affection. It is certainly a high quality and very resistant paper, but it is more

Figure 1. Blue shades variety of Tant paper.

expensive and harder to get than the other options. It also only comes in earth shades. Colored Elephant Hide is considered a rarity, since it is not produced anymore. It has one more major drawback in my opinion: the color is printed on the surface of the paper, the inside is white. So if you opt for machine scoring with a blade, it becomes quite visible.

Another paper worth mentioning is *Skytone*. It has lighter shades than Elephant Hide, but is generally a good quality and weight paper. It is also more affordable than EH.

How do you find all these special kinds of paper? Online stores are certainly an option, although they rarely carry big sheets sold separately at a reasonable price. Instead you can take note of the common properties shared by these types of paper. They are either bookbinding papers or the papers for printing certificates, invitations etc. Look for specialty typography paper retailers in your area or ask local businesses who offer these specialty printing options. If they carry similar weight bookbinding papers, try them! They can suggest to you some affordable local brands to try.

Weight	Paper
50–70 gsm	Kami/Origami paper
80 gsm	Standard printer paper
80 gsm	Tant
90 gsm	Skytone
110 gsm	Stardream
110 gsm	Elephant Hide

Painting Paper

Acrylic paint

Paining paper is not only a great way to create a custom colored sheet, it can also improve the paper quality and texture. I discovered that a thin layer of acrylic paint adds strength to paper. It creates a plastic-like layer, that adds thickness, reduces tearing and repels moisture. Even standard printer paper can completely transform, when painted with acrylic paints.

Acrylic paints are widely available and quite affordable in craft stores. I discovered that cheaper brands sometimes have a nicer texture than the expensive artist-grade paints.

I prefer metallic or pearlized colors; they can soften bright paper colors. They also look great even when applied in very thin layers. I recommend having several similar colors and mixing them to create an artistic-looking pattern. You can also try making gradients on paper.

There are many ways you can apply acrylic paints on paper. While a brush may be your first choice when it comes to paint, I recommend using either a sponge or a palette knife. Plastic cards or similar tools also work well. A brush usually gives you a thicker layer of paint compared to a sponge.

The main secret to paper painting is: never add water. Water warps paper. You may get some warping from acrylic paint itself, but it is minor and it won't really damage your paper much. Lay it dry on a flat surface. It usually happens within a couple of minutes.

Use a palette or a piece of cardboard to prepare and mix several drops of paint for your sheet. Dip a sponge in your paint and apply to paper. Act quickly. You can choose different techniques of application. Don't worry if you don't get uniform coloring. Slight color irregularities add character to your origami models. I would only avoid high contrast strokes, as those strokes can draw the attention from the model's shape to the paper coloring.

Below are some of my acrylic-painted papers. You can see an example of a folded model on page 116. You can read more about the process in [10].

Spray paint

You can use spray paint to add an accent to your finished models. Several indirect sprays from a far distance or from the side can give a tessellation some visual volume. I don't recommend using spray paint before you folded a model, as it stains fingers and may come off in certain areas while you are folding. It also does not add any benefit to paper, as compared to acrylic paint.

Another very important use case for spray paint is stabilizing your model against humidity. Water-shaping technique only works if your models stay in a dry environment. If your tessellation is exposed to high humidity, it may slowly unfold. To prevent that, I sometimes spray paint my tessellations from the back, covering the entire surface. After they dry they are no longer flexible and they won't unfold by themselves.

The models on page 44 were slightly touched with golden spray paint.

Curved Folding Process

Unlike traditional origami that uses straight lines, curved fold origami has slightly different rules. The typical process consists of the following steps:

1. Scoring
2. Enforcing
3. Collapsing
4. Post-collapse cleaning
5. Shaping

Lets look at each step in detail.

Scoring

What happens to paper as you crease? The sharp fold you make disrupts paper fibers at that line. If you unfold and try to fold it one more time at the same line, your fold will go easy and become sharp immediately. It happens because you already broke the resistance at that line. What if instead of creasing the line we score it with a ruler and with some sharp tool? The tool disrupts the fibers at that line, making the future fold easier. The same happens if you use a dull knife on a piece of cardstock and add a partial cut to your paper. As you attempt to fold that cardstock, the fold will likely go where the structure has been weakened.

If you score a curve instead of a straight line, your fold will likely follow that curve. Unlike a straight-line fold, the curved fold will rarely reach a full 180˚angle fold. A full fold is the one that results in two layers of paper completely touching each other after the fold. A curved fold usually produces a 3-dimensional shape instead of flat one.

Since free folding of curves is not easy, scoring the curves becomes a crucial part of the process. Straight lines can be either folded as usual or scored using a ruler, but curves require scoring.

Scoring should be done with a relatively sharp instrument with a comfortable handle. Think of an equivalent to 0.5 mm gel pen tip in sharpness. This is ideal for a beginner. Sharper objects like sharp needles will require very gentle touch. Some clay modelling tools have comfortable grip and a long metal tip that is blunter than a needle, but sharper than the majority of pens.

Figure 2. Various scoring and folding tools

Tip: If you are using an old gel pen, you can completely get rid of the remaining ink. Gel ink is water-soluble, so you can remove the tip, wash it thoroughly and put back to enjoy clean scores.

Figure 3. Scoring: hold a tool at an angle to prevent tearing; score from the middle outwards in a single motion, trying to maintain equal pressure as you go. If you score with a two-needle compass, try to hold the needle at an angle, as you score.

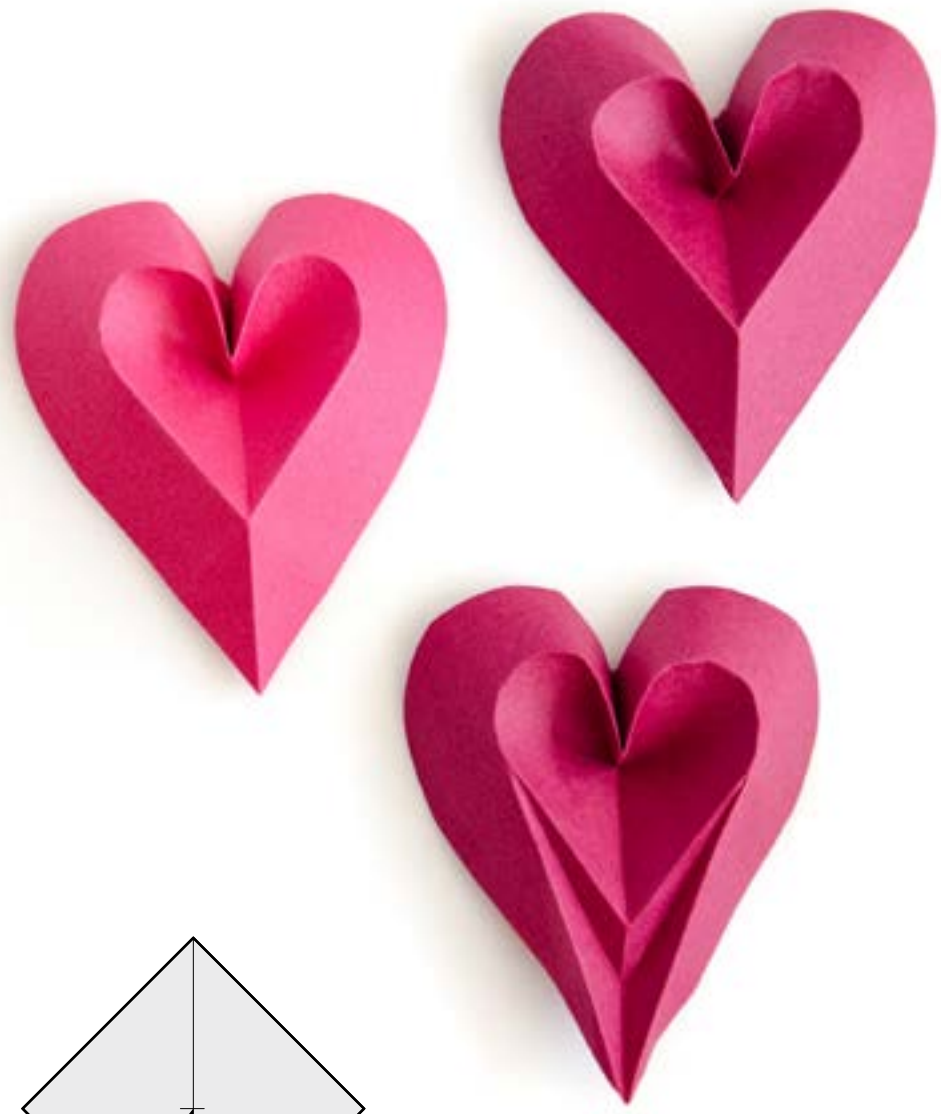
Curved Models

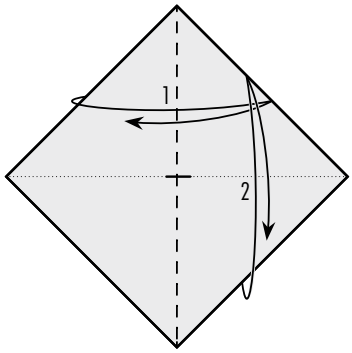
Heart

☆

7.5 cm (3″) square

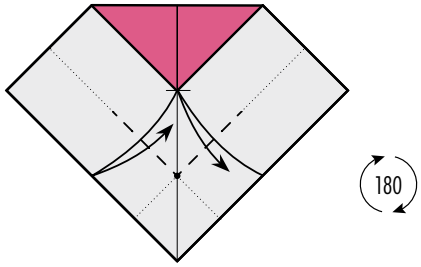
The best present for your loved ones. An easy to fold and versatile model with multiple variations for experimenting on your own.



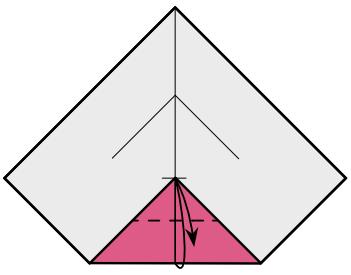


1

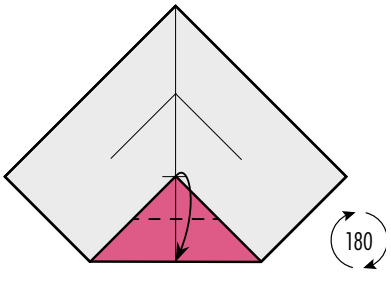
2



3 Crease the raw edges to the point, folding only part way across.



4 Crease through both layers only where shown.



5 Unfold the upper layer.

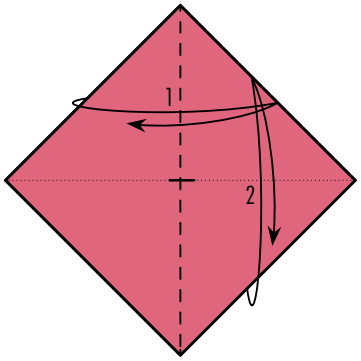
Double Heart

☆☆

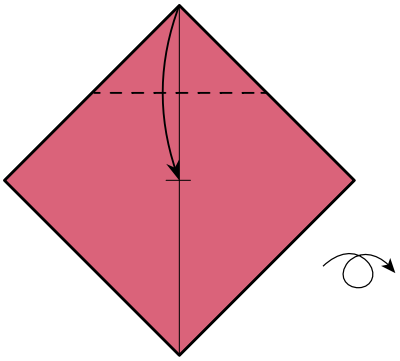
7.5 cm (3″) square

The best present for your loved ones. An easy to fold and versatile model with multiple variations for experimenting on your own.

This is a more elaborate heart.



1



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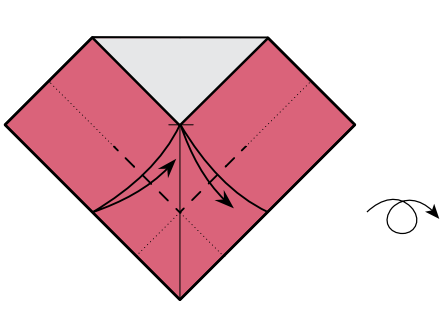
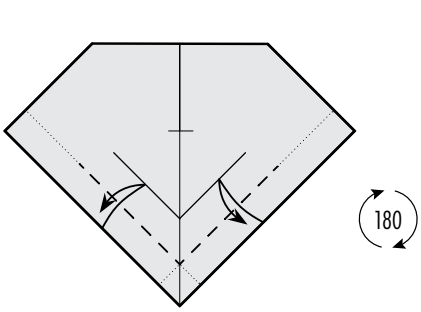
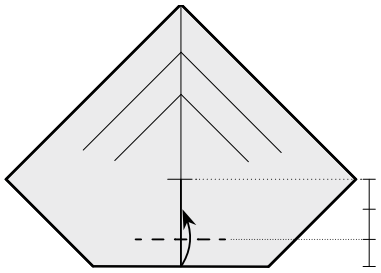


3 Crease the raw edges to the point, folding only part way across.



4 Crease only about the length from center to the pinch.



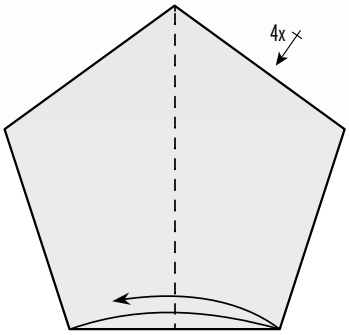
5 Make a crease one third from the midpoint through both layers.

Endless Love,
see page 26

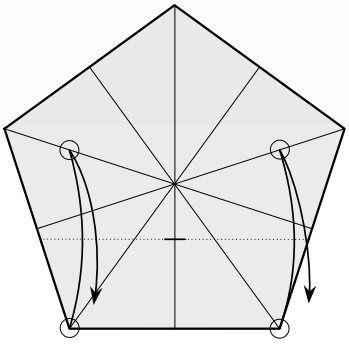
Jasmine

☆☆☆

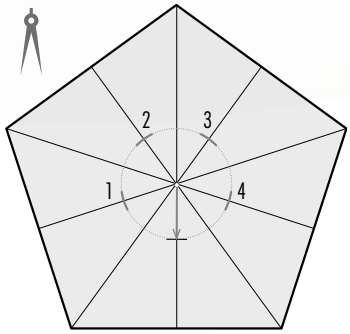
10–15cm (4″–6″) diameter pentagon
Requires a two-needle compass



1 Start with a pentagon. Refer to page 17 for cutting instructions.



2 Pinch by aligning the border to the points as shown.



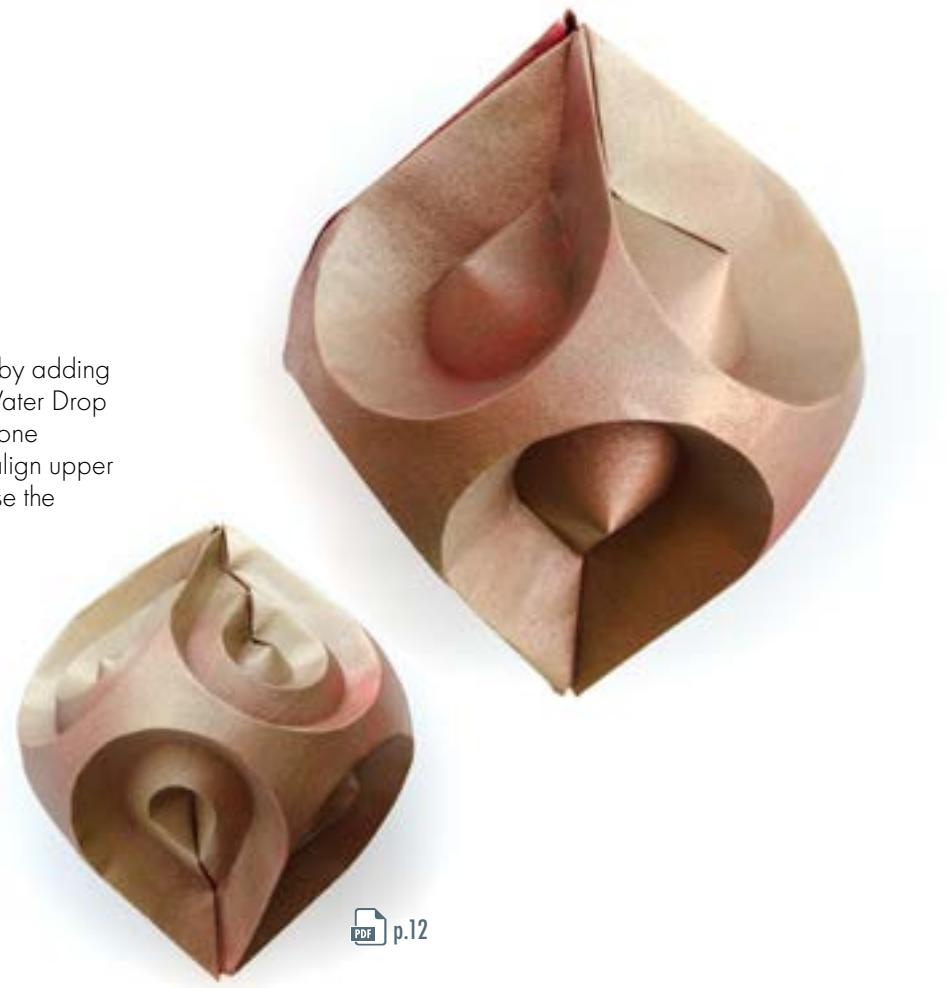
3 Use compass to copy the pinch mark 4 times.

Symbol

★★★★

Paper: 10 × 25cm (4″×10″)

This model allows multiple variations by adding curves the way we added them to Water Drop on page 26. You can add curves to one drop or to all of them. You can also align upper drops with the lower drops or increase the height of the model.



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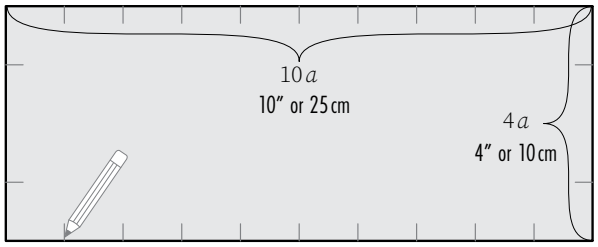
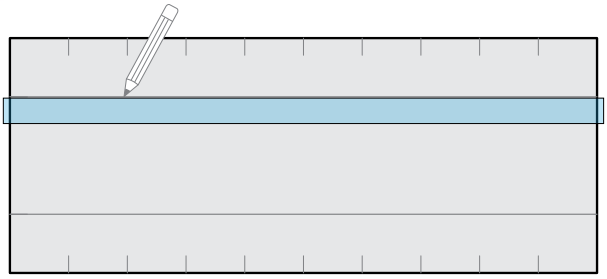
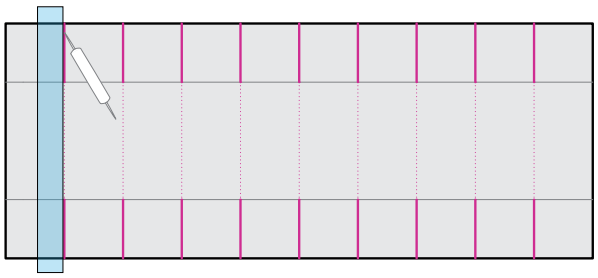


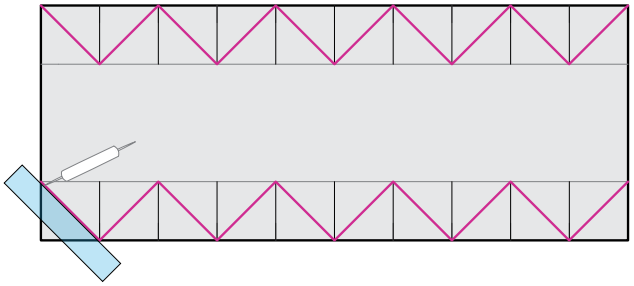
1 Start with 4:10 rectangle. Mark the tenths and fourths with a pencil



2 Draw quarter lines on the upper and lower sides.



3 Score the vertical lines from the sides to the quarter lines using a ruler.



4 Score the diagonals as shown.

Parallel Tessellations

p.24

What is an origami tessellation?

A tessellation, also referred to as tiling, can generally be defined as the covering of a plane using one or more geometric shapes, called tiles, with no overlaps or gaps.

An origami tessellation is not much different, in that it is the covering of a plane with one or more folded geometric shapes, called molecules, without the use of glue or cuts.

Origami tessellations can be flat or three-dimensional. In the latter case, we can define a tessellation as a shape of constant width, that can cover the plane infinitely.

There are a variety of ways you can compose a non-origami tessellation [2]. The same rules generally apply to origami tessellations. Studying regular polygon tilings or wallpaper groups can broaden your understanding of origami tessellations at their core and give you many new ideas on how to create new fascinating origami tessellations.

The tessellations in this chapter are based on parallel or mirrored molecules and curves. The tessellations in the next chapter are based on regular polygon tilings.

General Tessellation Tips

Protect your boundaries

When folding a tessellation, it is wise to leave some excess paper along the edges. This border will help account for any measurement errors you might make in the process of scoring. Don't rush to cut this paper away as soon as you have finished folding. You can use it to reinforce the sides of your tessellation, which tend to be weaker than the middle, by folding them to the back side. Alternatively, you could cut them away after you've finished shaping your tessellation, as sometimes the shaping process can warp the borders.

Use help

Every time I fold a tessellation, I wish I had more hands or fingers to assist me. During the process of collapsing, some parts of a tessellation may try to unfold or flatten. You can use small clothespins or paper clips to help you keep those pieces under control.

Not all the spots on a tessellation are suitable for placing a clothespin, so choose the areas that have paper layers that collapse flat or are close together. Stabilizing the edges is always a good idea. The borders lend themselves well to clothespin placement, and if you follow the boundary advice above, you can do so without risk of damaging the tessellation itself.

Shape it

The tessellations in this book are highly flexible and can vary in size depending on how much you decide to collapse them. Some tessellations tend to unfold or curl as soon as you remove any supporting clips. To control the final size and shape of your tessellation, use the water-shaping techniques outlined on page 13.

Be patient and gentle

While this advice would be useful when folding any type of origami, in the realm of origami tessellations, it is key. Trying to force folds too quickly or too strongly usually results in a warped piece that you'll likely want to throw directly into the trash.

For each step in the template-making process, there are certain angles, distances or curves you will have to choose. You can take the values suggested in the etudes or printable PDF file, but you are also encouraged to try your own values or combinations, which can work as well as the suggested ones. No matter which path you choose, try to ask yourself this simple question: "What changes if I alter this parameter?". The habit of asking this question might well become your key for understanding origami design in general. It can also greatly improve your origami intuition.

Difficulty

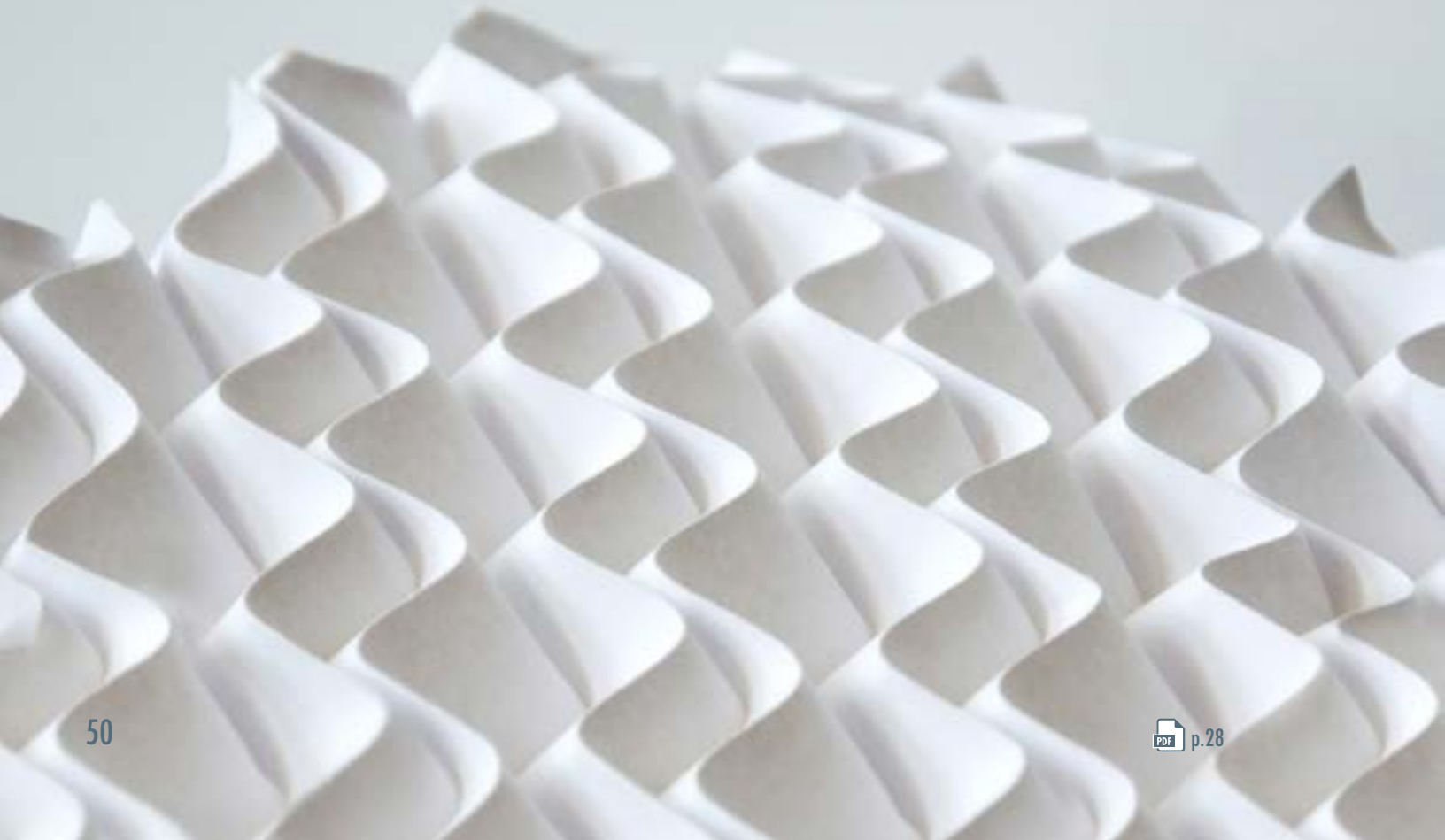
Etudes have difficulty between ☆ and ☆☆ associated with them. The difficulty of the final tessellation depends on the paper used, combined with the size and number of repeating molecules that comprise the full tessellation. The more elements there are, the more complex it is to fold. The size of the molecules used for a tessellation also plays a role in the overall difficulty of a piece, as the smaller the building blocks are, the trickier it is to fold.

If you are a beginner, I would recommend starting with larger building blocks and fewer repetitions.

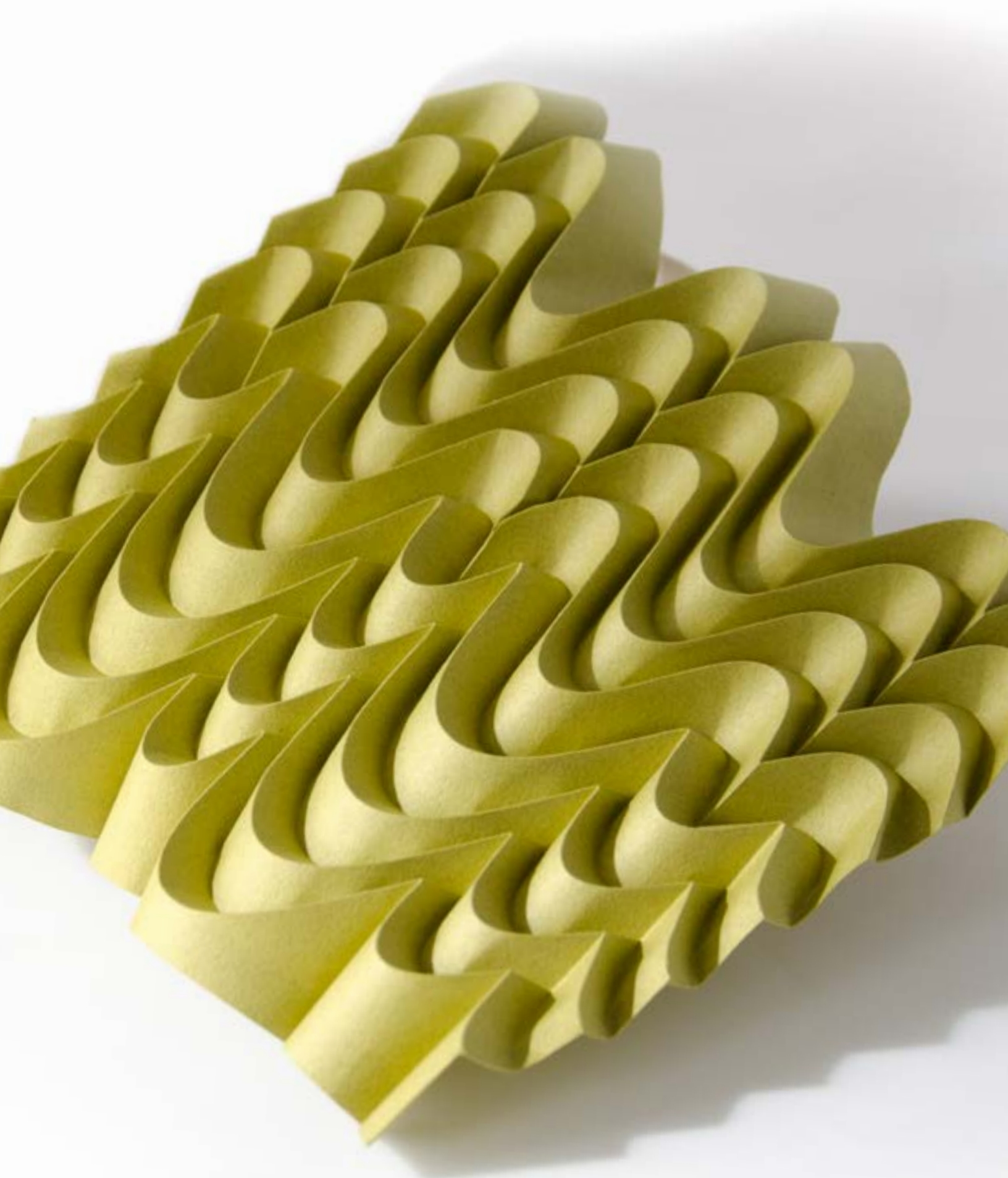
The plain white etudes in this chapter are predominantly made with standard printer paper. This is purposely done to demonstrate that even affordable, plain paper can produce spectacular results. If you have access to better paper, like Tant, I recommend using it. Higher quality paper is not only easier to fold and shape but is also more pleasurable to fold.

Credits and acknowledgement

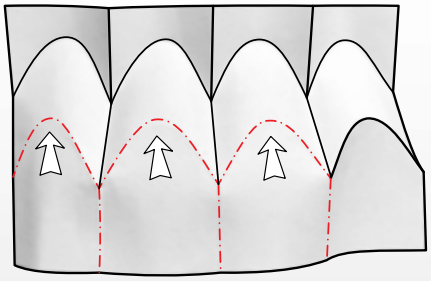
Many tessellations or elements of tessellations in this chapter are fairly easy and have been discovered by many people throughout the modern history of origami. And while different authors have used different angles and curves for their work, I think it is worth mentioning that Dr. David Huffman (1925–1999) is probably be the first person to have discovered most of the curve combinations, described in the etudes of this chapter [3]. Some of the elements were later rediscovered by Alessandro Beber, Christine Edison, Jun Mitani [6],[7], Jeannine Mosely and Polly Verity. Smooth curve B and multiple variations of the tessellations containing it should probably win first place for being the most rediscovered model throughout the realm of curved-crease origami.



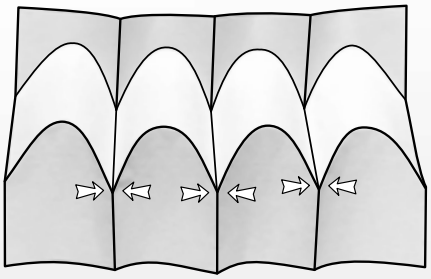
PDF p.28



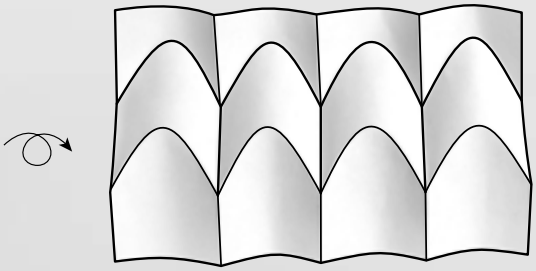
p.32



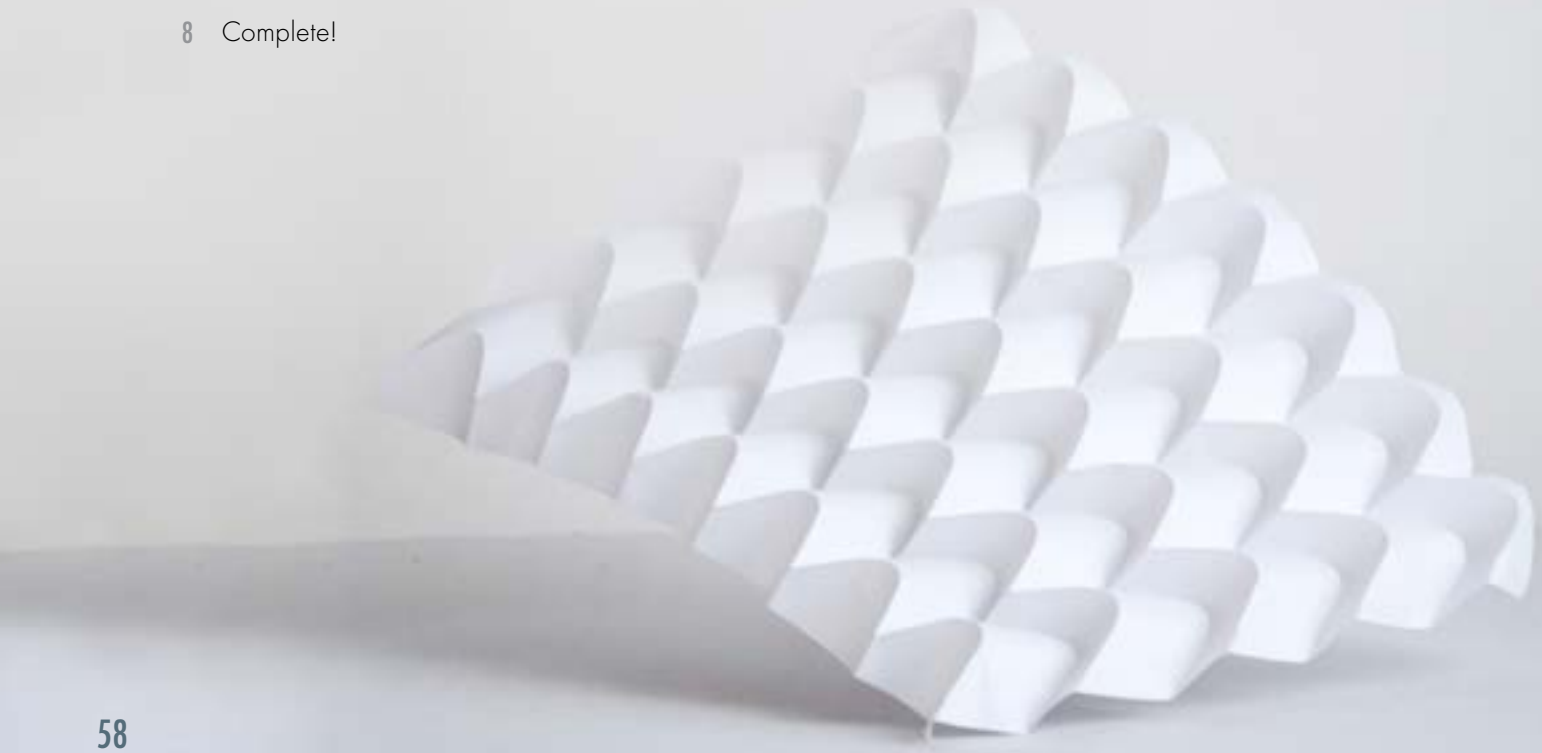
7 Continue reversing all the segments. The lowest portion of the vertical lines change orientation from valley to mountain folds.

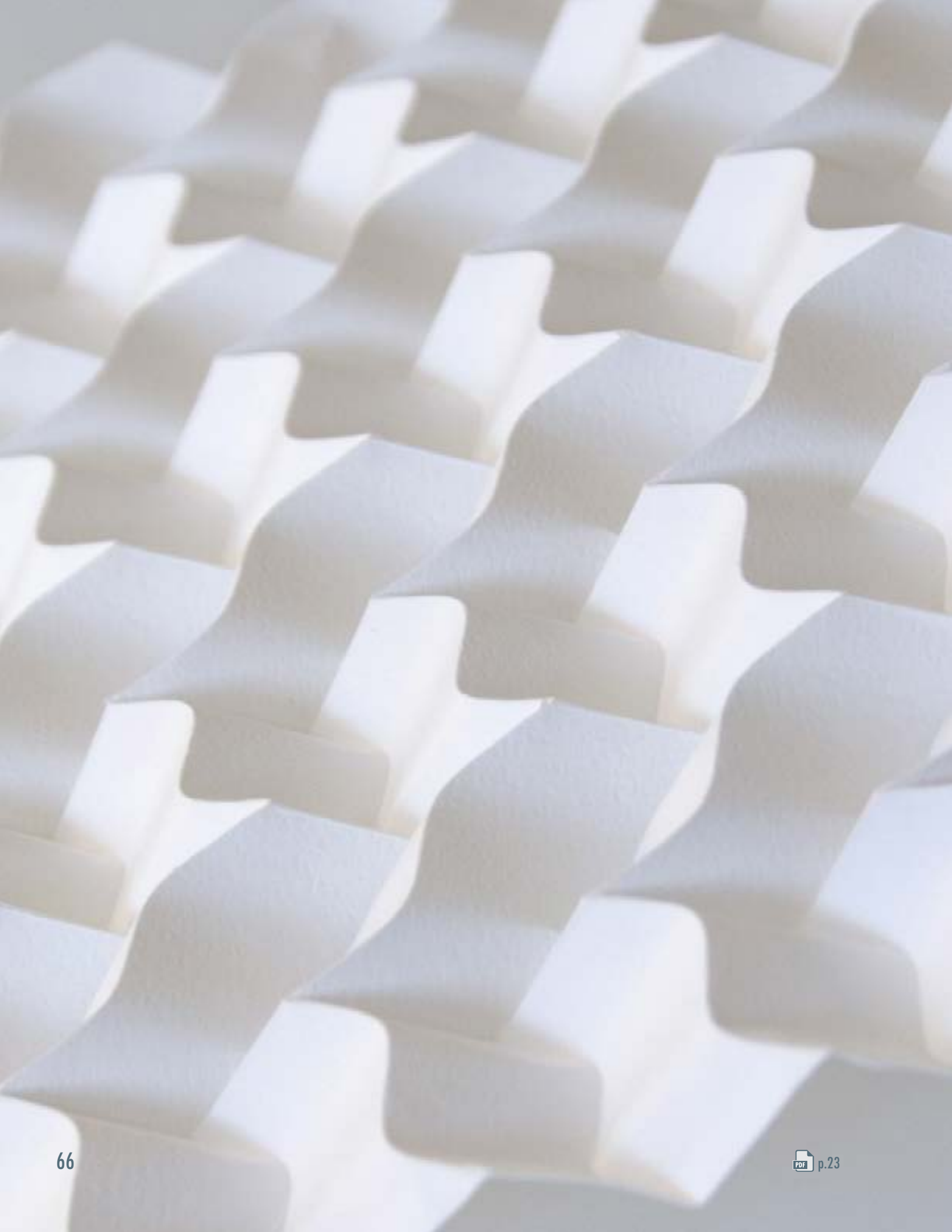


8 You can shape the intersection points by pressing them with two fingers one by one. This usually greatly improves the appearance.

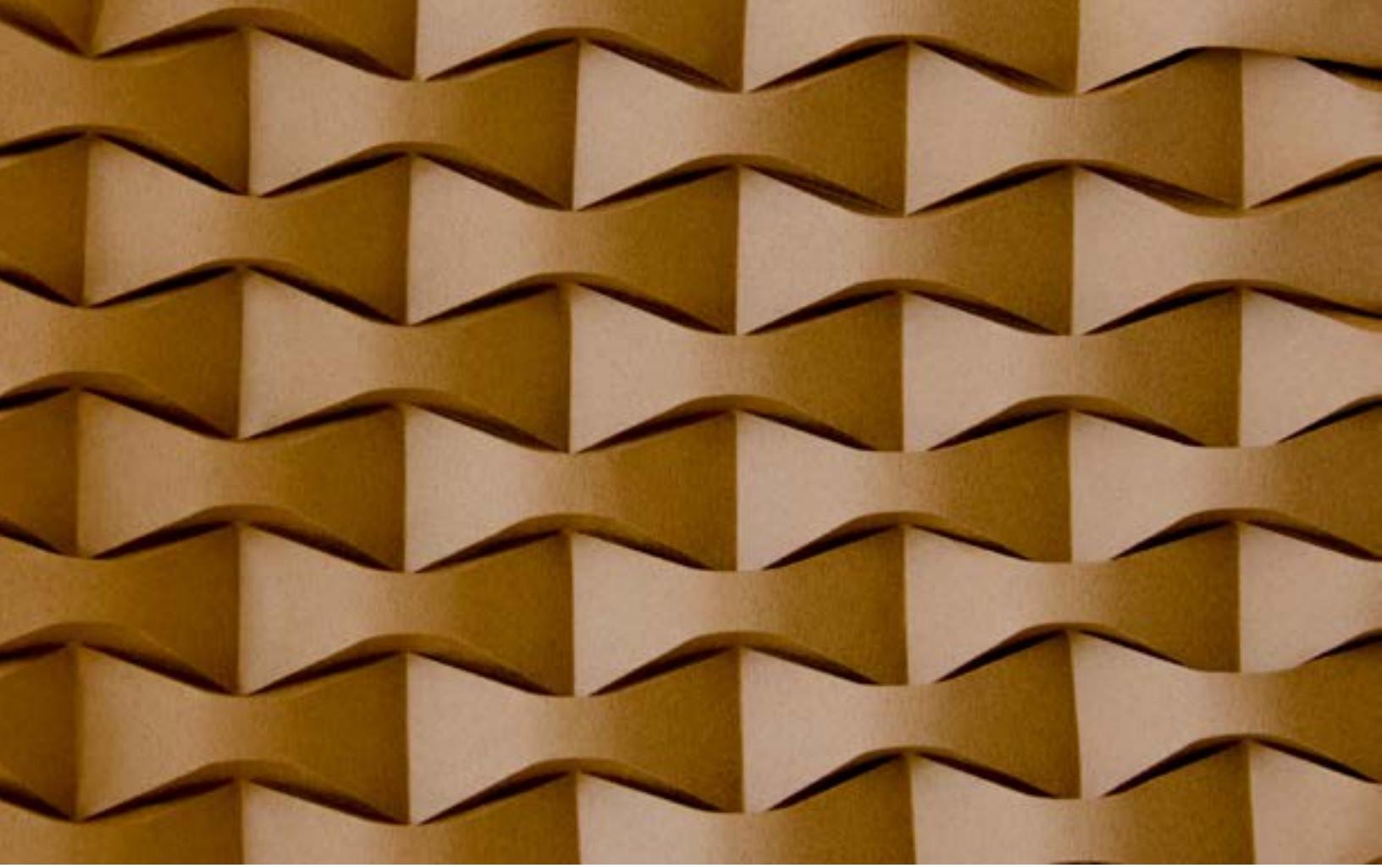


8 Complete!





p.23



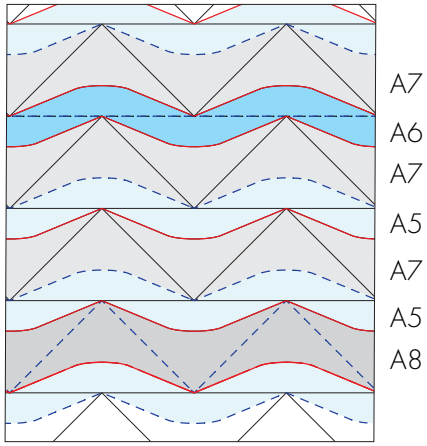
p.33

This is Etude A6 repeated all over the place (the top picture). And after you've made it, you can play a fun game: if you wish you can reverse one or several rows, which means you are making a shift from the element A6 to A5. To do so I gently flattened the middle row and then reversed the direction of the curves, ignoring the straight lines. They won't be very visible. And voilà! We just added some diversity to this otherwise too repetitive tessellation. This is a fun technique to play with and to make your tessellations even more unique!

p.36

Organic

Let's play with some tessellation elements! Take the crease pattern from p.34 and score all the lines. Reinforce them in both directions. Note that there are no valleys and mountains marked on that crease pattern. This is on purpose! Start collapsing it, assigning mountains and valleys as you go as you please and skipping some of the lines. This exercise will give you a deeper understanding of which elements and folds work together and which do not. There are plenty of different combinations you can derive from that unassigned crease pattern. Some of them pictured on this page.



The picture below shows the different elements working together in a crease pattern.

p.37

p.38

Leafy

This model is a demonstration of how you can use the template method for something that does not really look like it can be scored that way. This tessellation is seemingly different from the other ones in this chapter, but you can use the same methods to score it cleanly.

Smarter grid

There are two ways you can approach this tessellation. The first way is common in many tessellation books: start with a square grid and then add folds to that grid. Let's do it in a cleaner way! We can prepare a grid using a ruler and a pencil, then score only the lines and curves we actually need. Continue by reinforcing them in the direction we need and then fold. The ruler, pencil and scoring tool method avoids unnecessary creases and will make our tessellation very clean.

Smoothing as a design method

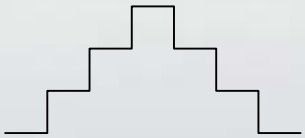
If you wonder how I could envision this design, look at the next tessellation, the Leaf Pattern on page 84. It has some very similar properties to its curved sibling, but all of its folds are straight. If you go back and examine how the Flat Curve A template was made (see page 53), you will see that the angles of the straight-fold tessellation are almost the same as the guiding angles of the curved template! This way if you have a nice straight-fold tessellation, you can try smoothing some of the angles into curves. This is a very powerful design method you can try.

So if you have some angle on a straight tessellation, you can use that angle to inscribe the curve in it. Note that some straight folds will have to disappear, like the folds that go perpendicular to a leaf shape that exist in a straight fold tessellation, but are missing from the curved version.

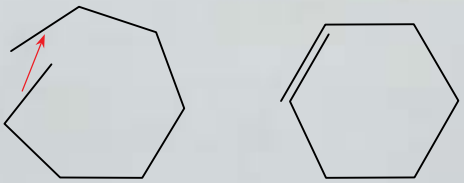
PDF p.40

Cylinders

When experimenting with curves in the previous section, you could easily find yourself in a situation where your tessellation cups into the section of a cylinder, rather than staying flat. Think back to earlier, when we discussed spacings and where the paper goes, whether up or down.



If your design goes up too much before going down, you'll wind up in a similar but slightly different situation. The schematic tessellation in the picture is technically flat, but may get too thick in the middle.



Similarly, if you use too many mountain folds in your tessellation, it is almost certain to curl into a cylinder, as the profile becomes more round than flat.

Now that we know what precipitates them, let us fold some cylinders on purpose!

The origin of this type of cylinder dates to about the 60s. I found an old Russian geometry book [8] that discussed an engineering problem involving thin, cylindrical shells collapsing under vertical pressure. If you have a paper cylinder and apply uniform force to the top of it, the paper should collapse into an attractive origami piece. If you try this and don't get an aesthetically pleasing shape from dropping a hefty book like "Origami Design Secrets" [4] onto your cylinder, you need to practice more.

All jokes aside, in the Russian geometry book they went on to prove that for any good function, you can create a cylinder using its curve. I am oversimplifying this mathematical concept right now, but theoretically you could take any a graph of any function and create a cylinder by following an algorithm!

p.43, p.42, p.44, p.45

Cylinder troubleshooting

It may happen for some curves that your cylinder does not close without warping. Try adding more sides to your cylinder or changing the curve to a less curvy one, if you'd like to keep the number of sides unchanged.

If ornate parts take too much space in the middle of your cylinder, it may be impossible to close. In that case reduce length z and increase lengths x and y to get more volume.

Invisible seam

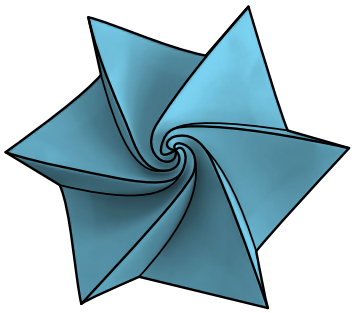
If you cut out paper at a valley fold of an ornate part. This way the paper edge gets hidden inside the ornate part, your seam won't be visible.

PDF p.50, p.57, p.46

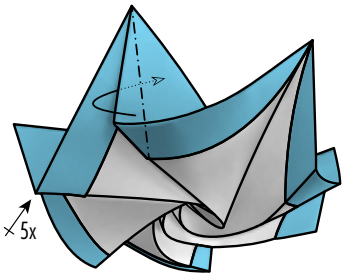
Easy Spirals

PDF p.111

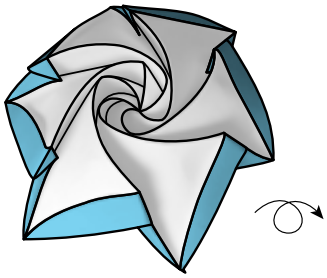
Side view of square and hexagonal spirals for different curves. All spirals shown are folded from the same size polygons and are collapsed close to their minimal shape. All of them can be relaxed back if needed.



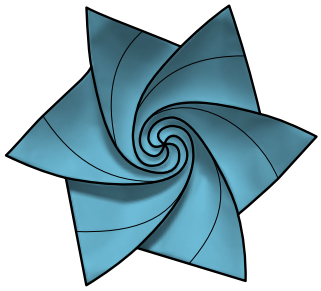
7 In the process.



8 Side view: fold the paper back to lock. Repeat 6 times total.



9 The result



Complete!

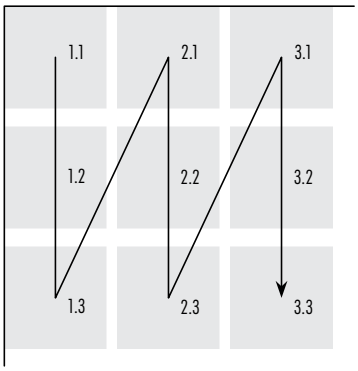
log 36°

Spiral A

log 45°

You can perform this kind of lock with almost any spiral in this book and with the various numbers of petals. The previous page photo shows the use of Spiral E. On this page there are (clockwise from the top) Spiral A with 5 and 6 petals, logarithmic spiral 45° with 5 petals and logarithmic spiral 36° with 6 petals.

Spiral Tessellations



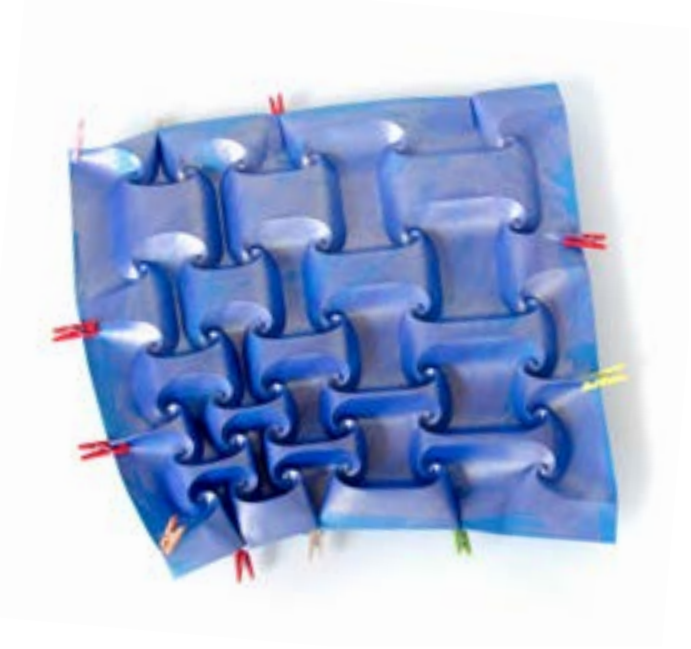
When all the lines are in place and are oriented correctly, you can apply pressure from all sides of the tessellation, collapsing it further. It sounds easy, but it is not.

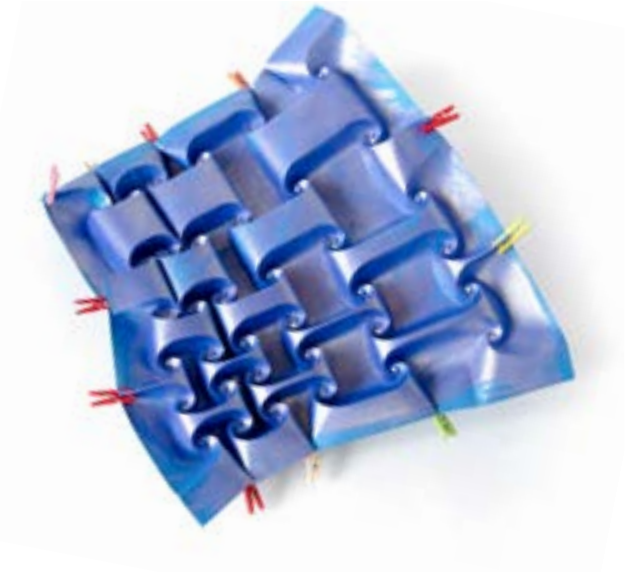
After collapsing your tessellation, you can find a suitable size box and put it there to free your hands. As the tessellation is elastic, you can use a wide range of different-sized boxes. You can also always use a larger box and put something inside, to make it smaller. I have a stash of different boxes and also keep some polystyrene blocks to adjust the size from inside.

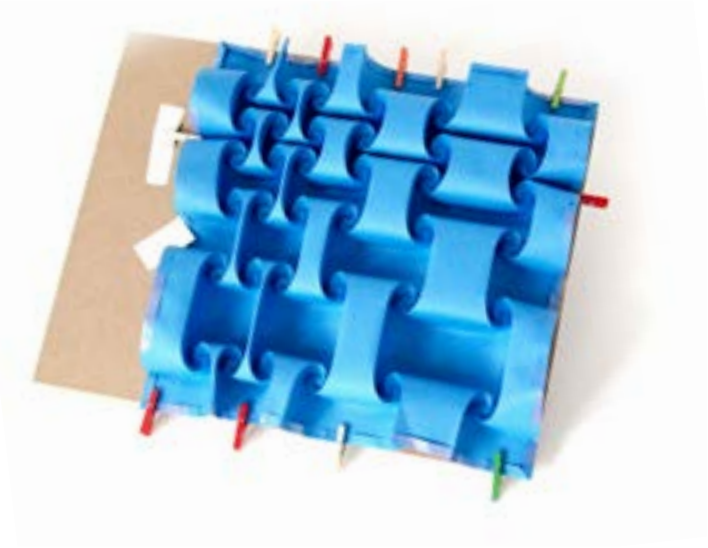
If you don't have a box, you can try using a piece of thick cardboard instead as pictured and affix your tessellation with clothespins to the cardboard of desired size. This method won't work with every tessellation, but having bigger borders around the tessellation can help.

At this point you can put all the missed creases back in place and smoothen all the curves. I usually use my wooden or rubber spatulas to go along each curve and make sure that it is smooth and nice. Having longer nails also helps. I prefer shaping mountain folds, so if I need to fix a valley fold, I would flip the tessellation over and shape the mountain fold from the other side. Use tools gently, as if you were getting some butter onto a butter knife. Try to use tools or nails, so that you don't bring excessive moisture from your fingers. Trying to shape curves with your fingertips is not the best idea.

The smoothing process is a very important step. It may easily take about the same amount of time that you spent pre-creasing and folding. But this step is exactly what turns something a bit crumpled into a flawless piece. Even my pieces don't look ideal initially. I always spend time with every single curve.







Quadra-A

☆☆☆☆☆+

6 cm (2.5") square for each molecule

If you've ever visited my website *www.kusudama.me*, you may have observed that I use capital letters after the names. This model is called Quadra-A. What does the "A" part stand for? "A" represents the curve name; this is one of the first curves I started to use for spiral tessellations. Later I discovered that many other different curves work as well, so I started adding the names of the curves after the name of the tessellation. "Quadra" takes its name from "square" in Latin. And this tessellation uses square molecules.

Energy-E

Many different curves can work to create the Energy model. If a particular curve gives you a nice hexagonal spiral, chances are the same curve can be successfully used for a tessellation.

Here is Energy-E. It tends to curl a bit if the spiral centers are pointing up (as shown). Pointing the centers down will result in a more flat tessellation.

Many logarithmic curves work for Energy models as well. You can refer to the section "Logarithmic Spirals" on page 101 for tips on how to choose good angle for a logarithmic spiral tessellation.

PDF p.65

About the Authors

Ekaterina Lukasheva is a contemporary origami artist. She first became acquainted with origami as a young student, quickly adopting it as her hobby. Her interest continued to grow as she began her studies at Lomonosov Moscow State University as a student of mathematics and cybernetics. It was then that she began inventing her own unique, modular origami models. After a successful launch of her website, kusudama.me, she unwittingly developed a fan base from around the world. In the recent years her area of interest was focused around the curved folding origami and tessellations. Years of her experience in this field resulted in this book.

Ekaterina published four books on modular origami before this book on curved-crease origami.

Kusudama Origami (2014)
Modern Kusudama Origami (2015)
Modular Origami Kaleidoscope (2016)
Floral Origami (2018)
Curved Origami (2021)

Ekaterina Lukasheva was born in Moscow, Russia. She graduated from Lomonosov MSU, receiving her Ph.D. in mathematics four years later. She currently lives in California with her husband Boris and their cats Eva and Blue. She is a frequent guest of honor at many origami conventions.

www.kusudama.me — personal website contains free diagrams, videos, and a lot of colorful inspiration.
instagram.com/ekaterina.lukasheva — latest pictures and fun short videos.
art@kusudama.me

Dáša Ševerová comes from Slovakia and currently lives in Switzerland. She worked as a high school teacher of math, biology, and informatics. Around 20 years ago she found a passion for folding paper and it never really stopped. She loves to fold and create geometrical origami of different types, ranging from modular origami to tessellations. Besides origami, she loves to make jewelry, drawing diagrams, and learn more about graphic design. Three years ago she published her first book *Origami Journey*, later she helped to create more origami books: *Shaping Paper* by David Gachepapier and *Origami Modulars for Everyone* by Ilan Garibi.

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