JEAN-CHARLES TREBBI

CHLOÉ GENEVAUX

GUILLAUME BOUNOURE

# THE ART OF FOLDING VOL. 2

## DESIGN WITHOUT BOUNDARIES

NEW TRENDS, TECHNIQUES and MATERIALS

INCLUDES **10 free** TEMPLATES

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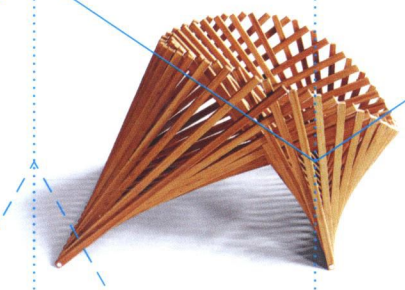

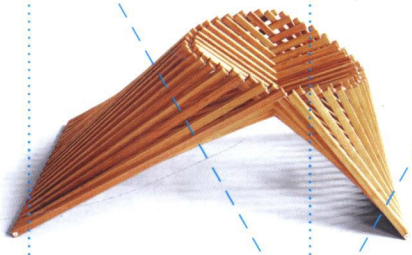

Volume I of *the Art of Folding* presented a great panorama of creators who are inspired by origami and whose work with various materials draws on this traditional technique. The vast and fertile word of folding plays host to so many exciting innovations in various fields that their multiple variations naturally demanded a follow up. Drawing on examples from nature, this second volume focuses on folders' know-how. Through the many reference points that it touches on and a comparative approach, it sheds light on original techniques and their applications in design, decoration and architecture. This new study of the art of folding is a source of inspiration for inquisitive minds and those who explore or create in all artistic genres. It gives readers the opportunity to discover and put into practice an art form that is both traditional and forward looking.

Born in Paris, Jean-Charles Trebbi is an urban architect, designer, artist and writer. A Renaissance man who specializes in the infinite possibilities of folding, cutting and assembling using paper, cardboard, textiles and even wood and metal, and influenced by Bruno Munari, Katsumi Komagata and Masahiro Chatani, he creates his own art books, which are often inspired by urban spaces and architecture, and produces completely original structures with pop-up and cutting elements. He is the author of several books on near-natural architecture and on cutting, folding and pop-up techniques for all sorts of materials.

Chloé Genevaux and Guillaume Bounoure live and work in Montpellier, France. This duo of architects cofounded the Archiwaste collective, which has been creating experimental and ephemeral constructions since 2006. Their research aims to enhance the value of new or underestimated materials such as cardboard. They specialize in three-dimensional modelling of nonconventional forms based principally on folding. Having worked on architectural projects aimed at improving environmental quality from 2007 to 2014, the couple now focuses on parametric design as part of the BOUGE workshop, which they founded in 2015.

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# THE ART OF FOLDING VOL. 2

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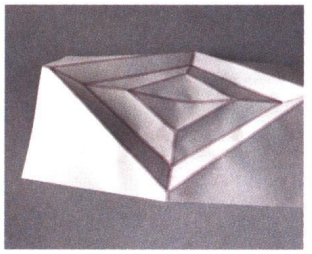
# FOLDING TECHNOLOGIES

## Paper



• *Christophe Guberan (p. 150)*

**DIRECT FOLDING**
Without scoring (tools: hands, folder used by printers making rolled, simple, double, parallel, zigzag folds etc.).

**MANUAL SCORING**
(Tools: folding tool, scorer).

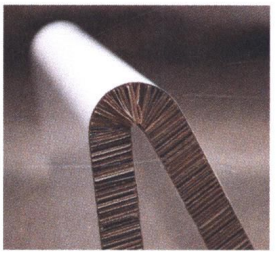
**COMPUTER-CONTROLLED SCORING**
(CNC tools: Cameo or Roland cutting plotter for paper).

**MICROPERFORATION**
(Tools: microperforator to create round holes or manual or CNC cutter to create dashes).

**MOISTENING**
Of the entire surface of the paper for crimping techniques, or moistening of the edge of the fold only.

**CASTING OR WEAVING**
Of paper with insertion of metal rods. The fold is formed by shrinkage of the paper during the drying process, or manually, with the metal causing the given form to remain.

## Cardboard



• *Studio Nuy van Noort (p. 99)*

**MANUAL SCORING**
(Cutter, rounded tip, folding tool etc.).

**COMPUTER-CONTROLLED SCORING**
(Cutting plotter with specific point).

**SCORING WITH PRESSES**
And cutting forms (tools for shaping cardboard used in the packaging industry).

**V MILLING**
Of multiple-layer corrugated cardboard or of honeycomb cardboard, with double-blade cutter for foam board.

## Plastic

• *Polly Verity (p. 36)*

**SCORING**
For certain plastics that can be folded cold (full and alveolar polypropylene).

**V MILLING**
For certain plastics that can be folded cold (cutter with 90° or 60° V angle on manual or CNC milling machine).

**FOLDING WITH A FOLDING MACHINE**
For certain plastics that can be folded cold (polycarbonate, polypropylene).

**INJECTION MOULDING**
Process that involves softening a plastic material in the form of granules or powder and injecting it into a mould to shape and cool it.

**THERMOFORMING**
Shaping technique for a material in slab form that involves heating it to soften and shape it with a negative or positive mould.

## Metal

• *Normal Studio (p. 96)*

**FOLDING WITH A FOLDING MACHINE**
Manual or automatic (constraints: straight folds, limits on angles and distances).

**STAMPING**
Deformation of a sheet of flat and thin plate with a high-power press equipped with special tools, to obtain in particular a non-developable form.

**ROBOTIC ARMS**
For curved folds: two computer-controlled arms take hold of a piece of sheet metal on either side of the fold to be made, and they then move in space, mimicking the movement of a person's hands, but with more power and precision.

**MOULDING**
(Eg: moulds of folds in paper and a counter-mould).

**PERFORATION**
Of sheet metal along the folds (using a CNC milling machine or stamping) and manual folding without tools.

**HINGES**
(Assembled or made in the piece of metal itself).

## Textiles

• *HOID (p. 76)*

**FOLDING THROUGH SEWING**
Pattern in one or several pieces, folded and sewn.

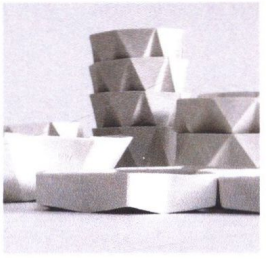
**NEEDLE PLEATING**
Passing of a needle above and below the accordion-pleated fabric.

**PLEATING WITH A PLEATING FRAMEWORK**
A process that involves manually inserting a piece of cloth between two sheets of folded Kraft cardboard that produce a male-female mould. This configuration is sometimes wrapped around a metal cylinder and placed into a gas-powered steamer.

**PRINTING**
Of patterns with inflatable ink.

**MOUNTING**
Of rigid parts forming the faces (thin pieces of cut wood veneer, for example).

## Concrete / Plaster / Earth



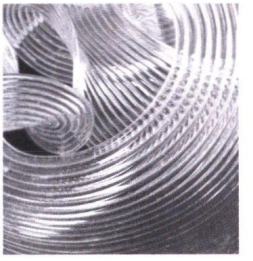
• *Charlène Fétiveau (p. 56)*

**PROJECTED**
Requires fibres and various frames that give shape to the folds. This type of working of thin layers can be carried out by hand or with machines (Tyrolean style to project coatings). This requires a good mastery of repetition over a multistage production process. Climatic conditions during production influence the final result.

**CAST**
Requires a formwork (lost or otherwise) and a release operation. The formwork is a (negative) mould of the folded form. It must be sufficiently strong relative to the surge of the liquid, and have a surface that is easy to remove from the mould and that is usually oiled. It also requires fibres (straw, glass fibre, metal fibres, etc.) and frames (metal, wood, reeds, brambles, etc.).
High-performance concretes and plasters allow very thin folded surfaces.

**COMPOSITE TEXTILE**
Textiles soaked in plaster or concrete then shaped for drying. Composite textile, thin panels of concrete.

## Glass



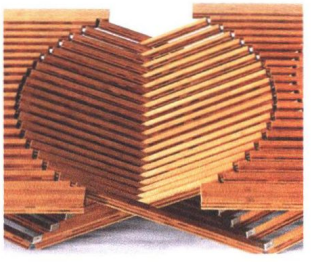
• *Erik and Martin Demaine (p. 34)*

**HOT FORMED**
Sticks or tubes worked over a flame with regular movement.

**CAST**
Liquid glass is pressed between two rollers.

**BLOWN**
The glass is blown at the end of a hollow steel rod.

## Wood



• *Robert van Embricqs (p. 109)*

**BENDING**
Process that involves softening the wood using heat or steam so that it becomes flexible enough to be curved. It is set on a mould to the desired shape and stabilizes during drying.

**MOULDING**
Process that involves gluing and positioning sheets of wood on a form and then hot pressing.

**ASSEMBLING**
Of panels along fold edges (gluing, screwing etc.).

**HINGES**
Assembly of two panels with metal hinges or those of another material, in order to maintain the fold's possibility of movement.

**MOUNTING**
On a foldable material (paper, textiles, etc.).

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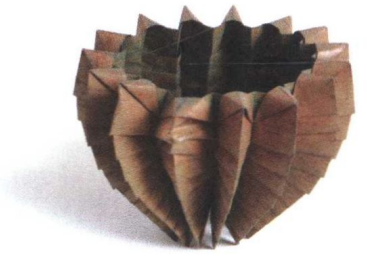
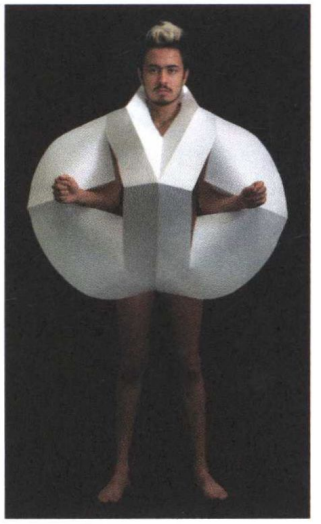
• *Éric Joisel.*



• *Paul Jackson.*



• Géomorphos, *Andres Gallego, Prof. Mauricio Velásquez Posada, Prof. Claudia Fernández Silva.*

• *FFIL*

# Contents

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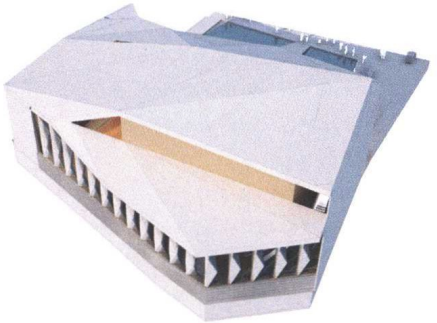
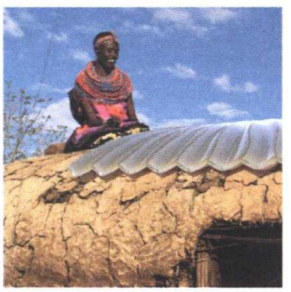
• Flux Furniture.



• Broissin Architects.



• Eric Olsen.

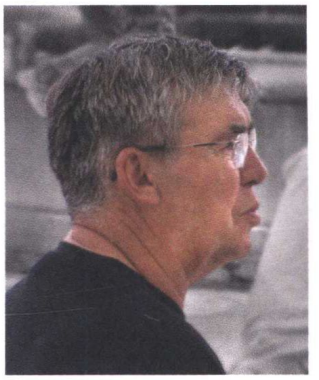
## FURNITURE AND LIGHTING



## ARCHITECTURE



## INNOVATION



*In memory of our friend and teacher Thierry Berthomier (1944-2010), who introduced us to the world of folding.*

*Chloé & Guillaume*

A whole host of creators reveal their passions in this volume, from Éric Joisel with his *commedia dell'arte* characters to Polly Verity with her magnificent creations and Bernard Girault with the sensitive perspectives of his theatrical folds. And it taps into local traditions such as Anjou's cap pleating and into the potential of approaches and research involving our robotic origami-folding friends.

My coauthors Guillaume and Chloé are architects who have placed folding at the heart of their research activities. They created the company BOU-GE (www.bou-ge.com), which works on innovative products based on folding for the architecture and design sectors. In developing more technical aspects of folding, we have pooled our knowledge, and we thought it essential and useful to draw up an overview of folding techniques and types, which you will find on page 172 as well as on the inside of this volume's jacket.

We hope that you enjoy reading this book and that this new crop of quality creations proves to be a source of inspiration.

*Jean-Charles Trebbi*

## WHY FOLD?

In a world made up of interacting elements—a world that is a theatre of evolutions of all kinds—metamorphoses will take place. Through a combined interplay of material strengths, spatial expanses and temporal omnipresence, which is governed by a few principles of order and minimums (concepts that are potentially synonymous with economy), transformations that are global or local and continuous or discontinuous are fostered at all levels. As a result of this interplay, within the two-dimensionality of surfaces (the favoured mediums for linear one-dimensionality, as well as the outer layer for three-dimensionality and its volumes), the fold—that remarkable singularity and site of exceptional behaviour—can come about.

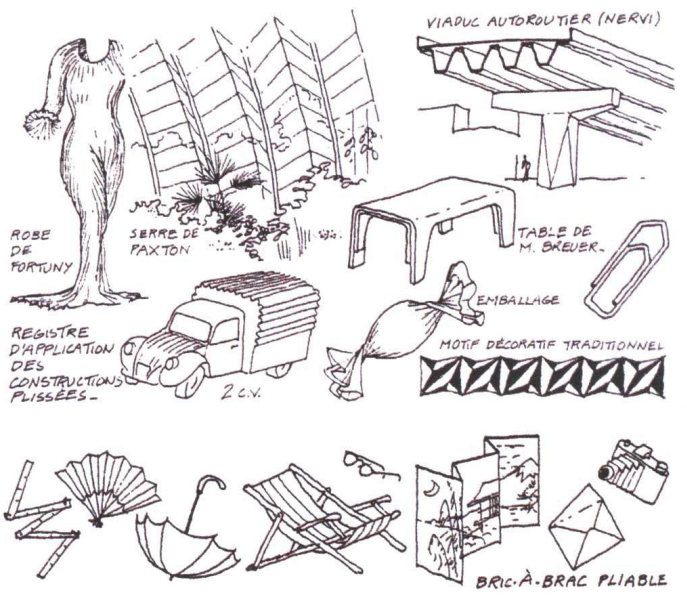
Everything that exists is touched in this way, from the inert mineral kingdom to the living worlds of the plant and animal kingdoms, in which folding is a fundamental morphogenetic process that stamps its mark on the many structures whose birth and life it contributes to. By virtue of the balance between form and function, the characteristics of the generated forms correspond to capacities for preferred actions, though the protean may be accompanied by a certain versatility. Via the broad categories of primary properties (the inherent roles performed by basic folding: protective capacity, resistance through form, joint mobility), there is opportunity for many other potentially useful secondary effects to be produced.

Everything produced by man—for whom the exemplary nature of what nature has produced offers a lesson—for his own use corresponds to a similar rationale. But the aspirations particular to the human mind—the search for harmony and meaning—now must also be added to purely utilitarian demands. Folding is in its essence able to satisfy such purposes. In its multiple variables that humans are sensitive to, it possesses all of the sculptural qualities conducive to formative expressiveness (classic aesthetic contrasts of protruding or receding relief, shadows and lights, straightness and curvature, direction, texture, and so forth).

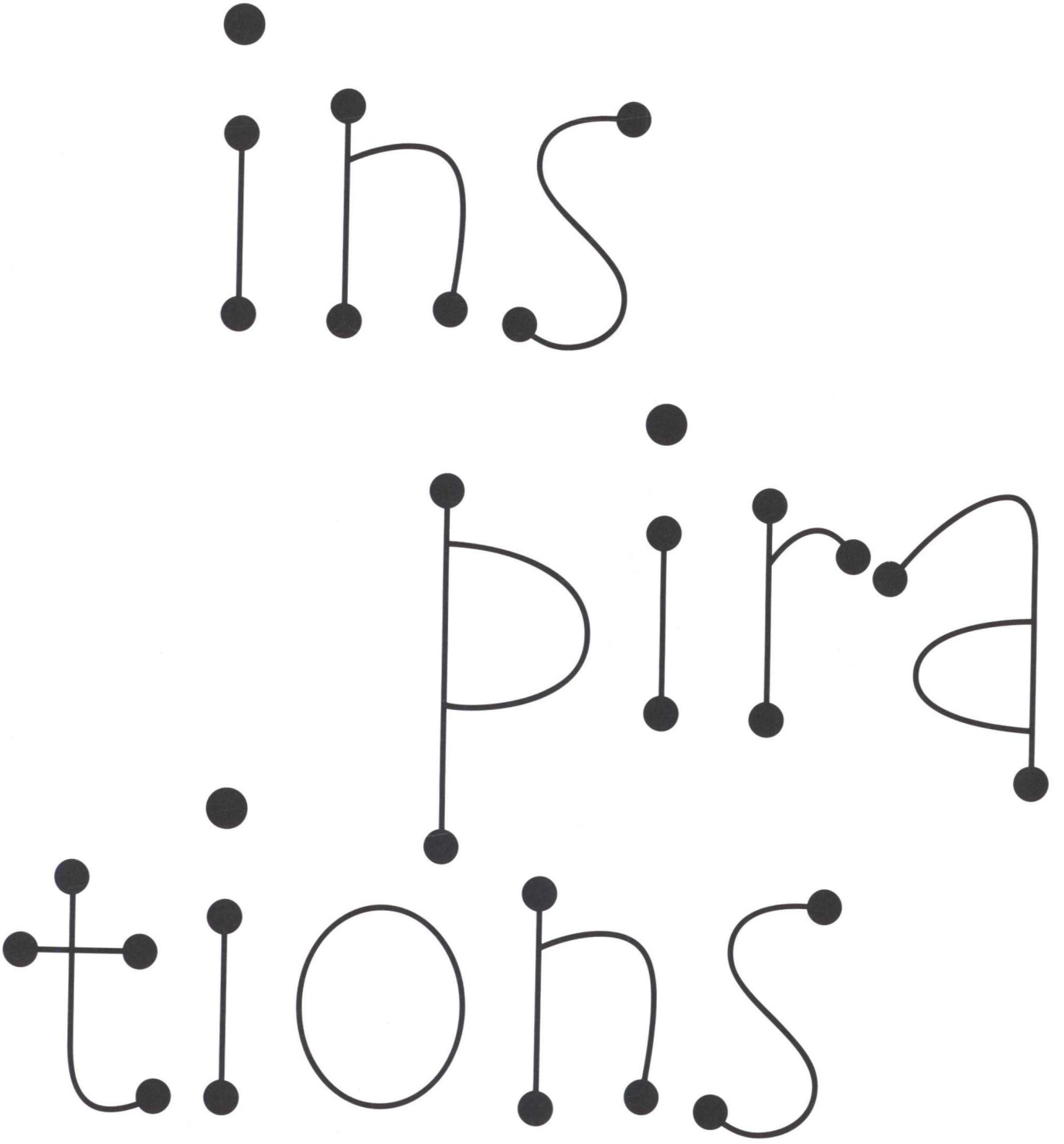
As for meaning, the law-like determinism of cause and effect that requires that a given configuration consistently results in a given role is such that each form can speak to us (such as the receptive invitation offered by concavity). And it is possible to understand in words like simplicity, complexity and explanation what certain configurations of folds are able to express as etymological truth.

An abundance of resources—which are occasionally playful, possibly magic and always spectacular—give folding eminently pedagogical virtues. Folding therefore offers the designer who seeks to format space and material for human use a real language to express tangible ideas. Through direct application to materials in activities ranging from basic and universally accessible artisanal practices to sophisticated techniques, folding is a permanent source of creativity. This activity, which is enriched with the cultural values of all eras and places, has offered countless gems in many fields—and it still produces new ones, as it will continue to do so long into the future. The creations presented here illustrate just this.

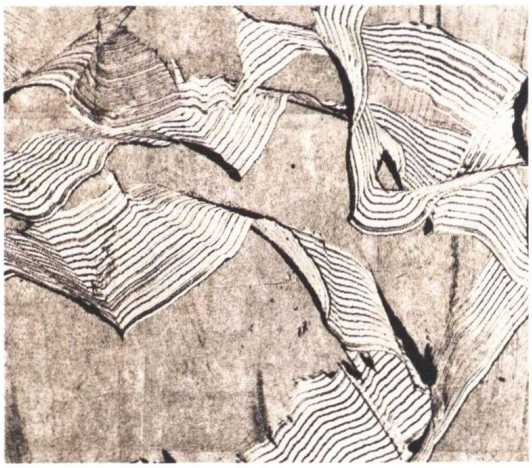
*Jean-Marie Delarue, 2015.*




• *Jean-Marie Delarue, sketch illustrating the fields of application for folding as a result of its structural, technical, functional and expressive features, taken from the book* Plis, Règles géométriques et Principes structurants, *École d'architecture Paris-Villemin, 1997.*




• *Vincent Floderer, leaves, crimping technique:*
Ailettes - Algues vertes, *display case*
*26 x 39 x 5,5 cm (10 1/4 x 15 3/8 x 2 3/16 in),*
*exhibited at the Freising Gallery, Munich, Germany, 2008.*



• *Richard Sweeney,* Monotype, *detail.*
• *Kunsulu Jilkishiyeva,* Anatolian orchid, *2012.*

## INTRODUCTION

"But before explaining the organization of the world of forms any further, it seems important to me to stress that, in my opinion, the folding process opens up new avenues for understanding a whole universe of configurations for materials."
*J-M Delarue, in Il 27* Natural building, *1980.*

Folds have many functions in the organization of beings and things. According to Jean-Marie Delarue, folds entail a universal process of morphogenesis that governs the mineral, plant and animal kingdoms.
Everywhere in nature, folded forms emerge harmoniously, and they are the outcome of many interacting factors. The same configuration of folds can satisfy several functions. Folds' structuring role—that is, giving rigidity through form to a small amount of material—is only one function among others. Without creating an exhaustive list, one might think of folds as a processes for bringing about growth or increasing complexity, or as a hatching mechanism. "The metamorphoses that the embryo undergoes—for example, the generation of defined organs—take place through folds that give rise to multiple interfaces for energy exchanges, compactions of proliferating expanses, consolidating nervurations, hatching mechanisms and moving and articular folds (...). Later, these folds also give rise to shrivelling and its wrinkles." Folds are also characterized by their ability to contain owing to the manner in which they give form to matter and encompass and envelop. But folding is also unfolding. At the moment that they are made and owing to the endogenous or exogenous forces that they involve, folds also become movement.

In geological terms, for example, the folds of the Earth's crust are the visible trace of thrusts caused by the continents' drifting. These folds are the result of a compression of matter and constitute the Earth's relief. They are in certain respects the marks of time.
Whether on an infinitely small or infinitely large scale, folds structure material, carry genetic information and are perhaps even part of the morphology of the universe. In *L'Univers chiffonné***, Jean-Pierre Luminet describes a topologically crimped space that nevertheless has no edges or corners, calling to mind a flexible fabric.

Who never glimpsed or hoped for, through the fabulous progress of twentieth-century humanity, the beginnings of a new world? Each of us folds and unfolds our existence like paper tissue: memory, time and space as we conceive of them seem to be shaped by conceptual deployments and folds that are true jumps of intelligence toward infinity. What is the key for interpreting this mysterious alphabet? Folds may in essence be the shortest path towards what is distant in terms of ideas and facts.

* Research report entitled *Constructions plissées, figuration graphique et recherche structurale*. Research under the scientific supervision of J.-M. Delarue with the collaboration of J.-F. Brossin. 1981-87. Ministère de l'Equipement, du Logement, de l'Aménagement du Territoire et des Transports, direction de l'architecture et de l'urbanisme, sous-direction de l'architecture et de la recherche. ADRI, École d'architecture Paris-Villemin.

** Luminet Jean-Pierre, *L'Univers chiffonné*, Folio, 2005.

## THE PLANT WORLD

The great diversity of the plant kingdom presents a complete and exhaustive panoply of the fold's main functions. Man's many efforts and accomplishments were not invented from scratch. The plant kingdom is a special field of study, and if we look at it from the original perspective of folding, it allows us to understand many things. In his research report *Constructions plissées**, Jean-Marie Delarue studies the main roles played by folds in nature. "Folding occurs at each stage of plant development (blooming, growth, wilting), and it is involved in each type of organ (in a particularly evident way in external and relatively extended two-dimensional elements such as leaf blades and flower petals)."

The kinetic dimension of folds is very important in nature. It is a process of adaptation and change that is based on both needs and growth. We might consider, for example, a leaf's development process. It first grows in the limited space of the bud or germ. This is vernation. The leaf is arranged in the bud based on folds that allow it to take up a minimum of space until it becomes ready and unfolds in the open air.

Unfolding is a key principle in the process of growth and blooming, but some leaves or flowers can also fold themselves back up. This is part of a process of adaptation to weather conditions, or one that governs, for example, the different phases of reproduction.

## ANATOMY

Because they are present on both the outside and inside of our body, folds are familiar to us and are a part of our identity. As with animals, they are found where our joints are located, allowing mobility (think, for example, of the elbows, neck and hands, that mobile and agile tool par excellence).

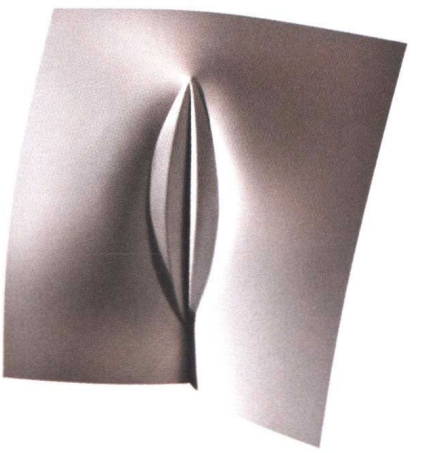
Similar to our fingerprints, they are specific to each individual. Folds are also engraved into our skin. These reliefs create a nonslip surface that improves the sensitivity of our touch.

They are also one of the elements of our expressiveness. Expressions of joy, sadness and pain differ in each of us, and they are marked by a particular number of folds located in different places (around the eyes, mouth, forehead and so on). In the long run, they create an imprint of a person's character on the face, and they increase gradually in number as we age and our skin sags.

The inside of our body makes great use of folds, which perform different functions. From the moment we are formed, during the phase of cell differentiation, cell proliferation generates folds that become the site for the various organs. In addition, in order to increase the surface for exchange between two distinct volumes, the membrane that separates them consists of multiple folds. This allows an increase in the exchange surface within a minimum of space.

We might liken this principle to the design of a finned radiator, which through its folds has a large exchange surface, thus improving the radiator's performance. Folds are also found in the places through which nutrients pass, a process that is momentaneous and repetitive and that to a greater or lesser extent involves volumes. This requires conduits that can open and close as well as fill and empty, depending on the given needs.

Present in the deepest parts of ourselves, the fold is intimate in nature, and sometimes it gives us the sensation of a harmonious organization of matter.



- *Stefan Weber, mask.*
- *Victor Cœurjoly, studies of curves.*

• *Éric Joisel*, coq.
• *Robert Lang*, Fiddler crab.
• *Victor Cœurjoly*, Vaca y buey de Belén.

## THE ANIMAL WORLD

Among other things, animals use folds because of their kinematic properties, particularly in order to adapt to different situations. The wings of the bat, for example, occupy a significant area when they are unfolded, which provides the lift necessary for flight. They fold back into a small volume at rest.
Shellfish are interesting to observe owing to the structural characteristics of their shells. Their protective outer skeleton is through its natural constitution an adapted response to development conditions and to the crustacean's environment. These natural shells are distinguished by three components: their microscopic (stratified, crystalline and multidirectional) structure, the distribution of the general curves of the shell, and the presence of secondary folds or many waves.

The carapaces of insects, which are sometimes genuine ribbed shields, illustrate folds' structuring and motor functions, thanks to a natural composite material called chitin. This "resin" can be flexible, rigid or even sharp within the same expanse of material. The thin and light wings of flying insects are stiffened by folds, which allow better resistance to bending and an economy of material that is essential for these living beings with an ephemeral existence.
Folds are also a component of the internal anatomy of most animals. Within a small volume, they allow a great length of "piping" to be arranged, as well as large exchange surfaces between different organs.
When they allow several entities to be articulated, folds can take on a motor function. One example of this can be seen in the way in which caterpillars move.

At the level of joints, a significant stretch of membrane is required to be able to freely evolve in many directions of space. We may observe in this respect that the very hard skin of elephants is particularly creased at spots that movement places especially heavy demands on. The presence of folds provides the flexibility necessary for living beings and therefore for their mobility.

## LIGHTS AND SHADOWS

Through the different superpositions and changes to planes that they create, folds bring about a stark or subtle play of shadows and lights.
The shadow's qualities are particularly relevant in Japanese culture, a subject that Junichirô Tanizaki talks about in his book *In Praise of Shadows**: "Such is our way of thinking—we find beauty not in the thing itself but in the patterns of shadows, the light and the darkness, that one thing against another creates. A phosphorescent jewel gives off its glow and colour in the dark and loses its beauty in the light of day. Were it not for shadows, there would be no beauty."
The sense of beauty that we obtain from properly ordered folds comes directly from the interplay of light and shadow that enlivens a surface and makes it change. Shadow slips an element of mystery into each fold, giving birth to a poetic dimension in places that by themselves are meaningless.

## VISUAL EXPRESSION

The way in which things hang often creates the body's equivalent expression to facial wrinkles. It betrays emotion or tiny tensions of the soul that artworks try to mirror. It is perhaps through such hanging that the painter projects on the canvas a reflection on painting itself, in a kind of painting of painting. As they are revealed by the effects of chiaroscuro, folds becomes volume, animating the canvas and revealing a depth. Folds have the particularity of being associated with continuity and discontinuity, a feature described by Leibniz's metaphor that "the division of the continuum must not be considered to be like that of sand into grains, but like that of a folded sheet of paper or tunic, such that there may be an infinity of folds."**

• *Andres Diaz Arboleda, as part of* Geomorphos, *course led by Mauricio Velásquez Posada and Claudia Fernández Silva at the School of Architecture and Design, Universidad pontificia Bolivariana, Medellin, Colombia, 2008-2012.*
• *Paul Jackson,* Fourplanes.

* Junichirô Tanizaki, *In Praise of Shadows*, Leete's Island Books, 1977.

** Leibniz, Pacidius Philalethi (C, p.614-615), in *Le Pli, Leibniz et le baroque*, p 9, "Critique" collection, Les éditions de minuit, 1988.

• *Metal folding,*
*Pioes Sia company, Latvia.*
• *Andrey Ermakov, Egg box.*

## THE FOLD'S KINETICS: "FOLD, UNFOLD."

Many everyday objects that are manufactured to meet various specific human needs make use of the fold's transformational ability. We use it to save space and increase mobility.

## THE FOLD AS STRUCTURING PRINCIPLE

The principle of strength through form rather than through the amount of material used is what characterizes the structuring role of the fold. The starting point is a two-dimensional surface, which through folding takes on volume and organizes space in three dimensions. The fold can be seen as a means of organizing the void that it encompasses. Responding to a natural need for material and energy savings, it brings toughness to a surface that otherwise would remain flexible and unable to hold.

## FOLDING TECHNOLOGY

In general, all materials lend themselves to being given folds through moulding or assembly processes, but this is not the case for forming or folding. Concrete, for example, is impossible to fold, but some of the moulding techniques for it have been inspired by folding.*
Folding is a permanent plastic deformation—that is, the fold does not disappear when the effort applied comes to an end.
When they are folded, materials undergo a stretching (tension) in the outer convex part and a pushing back (compression) in the concave inner part. The surface shared between these two zones is called "neutral fibre"; it retains its original length.
The structure of the material (plasticity), the property of resilience and the section (thickness and diameter) will determine the boundaries of the fold.
The thickness of folded materials varies from very small dimensions (a few microns in the case of the aluminium foil used in the partitions of planes, or in nano-origami in the field of nanotechnologies), to dimensions limited by machines, the curvature radius and stretchability limits –10 cm (4 in) for plastics, 5 cm (2 in) for metals–.
Nowadays, many products, objects and buildings are created according to principles of folding. In a research report entitled *Technologie du pliage*,** Jean-François Brossin describes the main techniques for folding materials.
According to Brossin, "We can distinguish three distinct folding processes for materials:
– forming consists of folding or bending a semifinished product such as a tube, a sheet or a bar by force;
– moulding, in which the material in its plastic state occupies a cavity and solidifies.
– assembly, which involves fastening parts together through different techniques.
It is interesting to note that the structural properties of folds also apply to materials that cannot be folded in the strict sense of the term, like a corrugated brick wall or a folded concrete structure produced through formwork (moulding)."

* See Trebbi Jean-Charles, *L'Art du pli, v1*, p.110. éditions Alternatives, Paris, 2008.

** Jean-François Brossin, "Technologie du pliage," in *Constructions plissées*, research report, MELATT, Paris, 1981, op. cit.