

Snap-shaping soft origami sheets

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Abstract

Real origami structures are not rigid; plates and hinges may bend and stretch. Adding such compliance to rigid origami models enriches their behaviour, leading especially to the creation of mechanically bistable structures [Silverberg et al., Nat. Mater. 2015]. Compliance thus opens up a new design space for origami shapeability, with the potential to formulate design rules for controlling a structure's stable configurations.

We explore this new shape-design space using a compliant, corrugated origami sheet, consisting of thin, soft plates connected by parallel hinges (Fig. 1a, left). When point loads are applied to the edges of the sheet (Fig. 1a, middle), the structure can undergo a rapid, elastic snap-through instability into a new stable configuration with a distinct spiralling shape (Fig. 1a, right). This reshaping is purely a result of the introduction of compliance in the sheet's facets, which produces a geometry-mediated energetic competition between stretching and bending in the underlying material of the sheet.

We confirm that the geometric coupling between stretching and bending in the origami sheet leads to bistable behaviour via a simple computational model, illustrated in Fig. 1b. We further show that the reshaping capacity of the origami strip is contained in the snapping behaviour of its individual folds. A fold may snap through into a configuration with a stretch-defect (Fig. 2a, left). In a large origami sheet, adjacent local defects result in a geometrically incompatible structure- it is energetically costly to accommodate defect clusters. As a result, defects will interact and move to minimize geometric frustration (Fig. 2a, right). The interaction between defects depends on their mutual distance; our network model indicates that nearby defects will attract, while distant defects repel (Fig. 2b). A line of neighbouring defects in an origami sheet will therefore be stable, resulting in a characteristic spiralling shape.

In conclusion, we show that the introduction of compliance to origami leads to a rich design space of multistable structures. We show that the range of available multistable shapes of a corrugated origami sheet can be explored and understood with straightforward experimental tools and minimal numerical models.

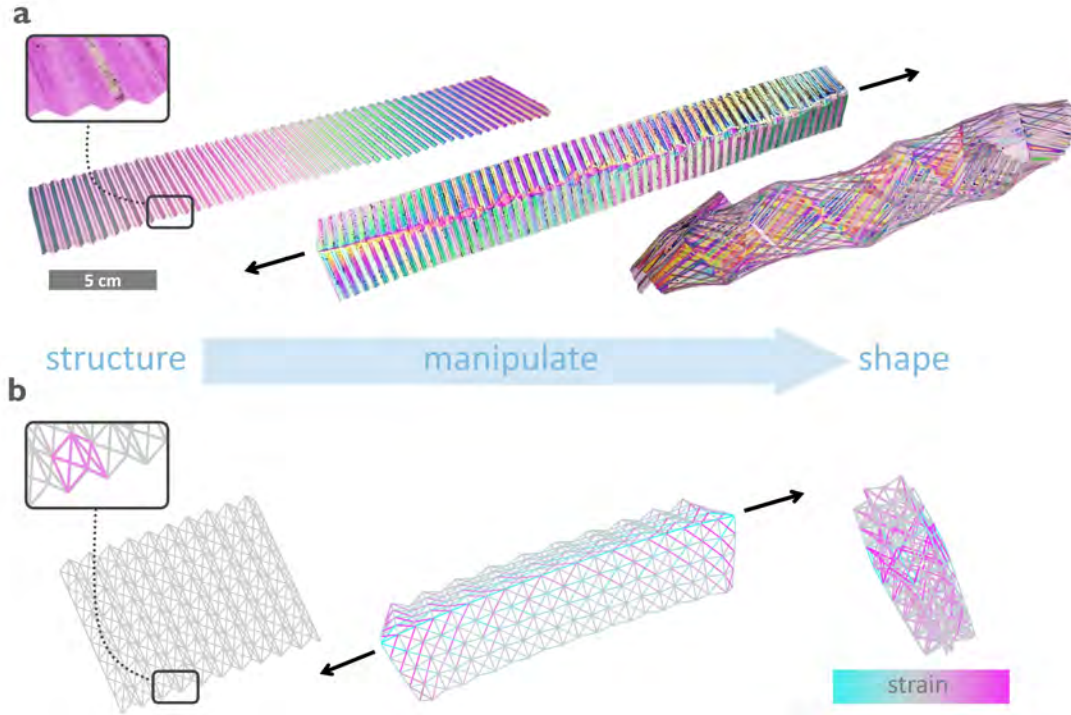


Figure 1: A compliant origami strip snaps through into a new, stable shape. a) An origami sheet made of $15\ \mu\text{m}$ thick PET film, consisting of soft plates and parallel hinges (inset) is shown. The coloring is obtained by photographing the strip between crossed polarizers. Under external point forces (dark arrows), the sheet snaps through into a new, stable, spiralling shape. **b)** The behaviour of the origami sheet is simulated using a simplified network model, consisting of stiff linear springs connected by soft torsional springs (inset). Under external loading, the simulated network finds a new stable configuration that reproduces the curling shape of the real sheet.

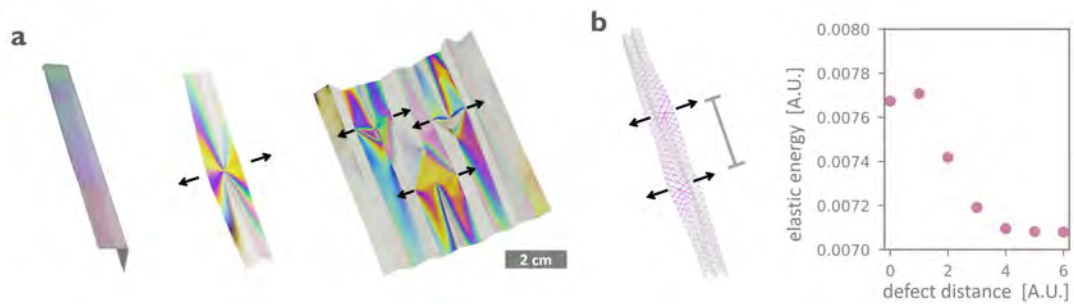


Figure 2: Individual snap-through defects in each origami fold are responsible for the re-shaping behaviour of the strip. a) A single PET film origami fold ($23\ \mu\text{m}$ thick) undergoes a snap-through instability into a new, stable state under external forcing. A stretch-defect is created at the snap-through location. In a large origami sheet, this local stretching leads to geometric interactions between defects. **b)** Defect interactions can be investigated using the discrete model shown in Fig. 1b, by calculating the network's elastic energy as a function of the distance between defects (indicated left). The results (shown right) indicate that defects created close together will stay that way to minimize their energy; conversely, defects created at a distance will repel.