

TOPOLOGY OPTIMIZATION OF INDUSTRIAL ORIGAMI STRUCTURES: A SEQUENTIAL DESIGN APPROACH WITH PROTOTYPE FABRICATION AND TESTING

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Abstract

Industrial origami using advanced curve crease folding of sheet metal has recently emerged as a promising structural design and manufacturing approach that enables lightweight yet stiff three-dimensional structures to be created from flat sheet materials through folding processes. Because complex shell-like geometries can be produced using only sheet processing and folding without expensive molds, this technology offers a potential pathway toward low-cost manufacturing of high-performance structures.

Meanwhile, topology optimization is widely used to automatically determine optimal material distributions for lightweight structures under prescribed loading and boundary conditions. However, systematic design methodologies integrating industrial origami with topology optimization remain largely unexplored.

This study proposes a sequential design approach combining industrial origami and topology optimization. In the proposed framework, a platform unit designed using STILFOLD's proprietary industrial origami technology is first used as a base geometry, and topology optimization is subsequently applied to introduce perforation patterns that maximize structural stiffness under a prescribed weight reduction constraint.

The optimization is performed on the folded three-dimensional geometry using a shell-based finite element model. The design domain exploits the geometric symmetry of the platform unit to reduce computational cost, while representative vertical and horizontal loading conditions are considered. The material distribution is optimized using the SIMP method combined with a Helmholtz-type filter and a smooth Heaviside projection to obtain stable and manufacturable designs. To ensure foldability, crease regions are treated as non-design domains so that material removal near folding lines is avoided.

The optimized perforation patterns are mapped to the flat sheet through geometric nonlinear analysis for flattening, enabling a consistent design workflow from structural optimization on the folded geometry to manufacturable flat patterns.

To evaluate the practical feasibility of the proposed design approach, multiple prototype platform units with different perforation patterns were fabricated, including the original base design without perforations. These prototypes were subjected to simple loading tests to compare their structural responses and to assess the effect of optimized perforation patterns. The results demonstrate that the optimized designs maintain sufficient structural stiffness while achieving 20% weight reduction.

The present work demonstrates the feasibility of combining industrial origami with topology optimization through a sequential design strategy and prototype fabrication and testing. As future work, we aim to develop an integrated optimization framework that simultaneously designs curved crease patterns and perforation layouts, enabling a unified design methodology for high-performance and lightweight folded structures.