

# **Numerical model coupling rigid origami kinematics with an intermediate force flow**

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## **Abstract**

The paper will present a modeling approach combining energetic principles of mechanics with rigid folding kinematics. It provides a contribution to the current aims to incorporate physical environment into rigid origami models. The mathematical and numerical framework will be explained and demonstrated.

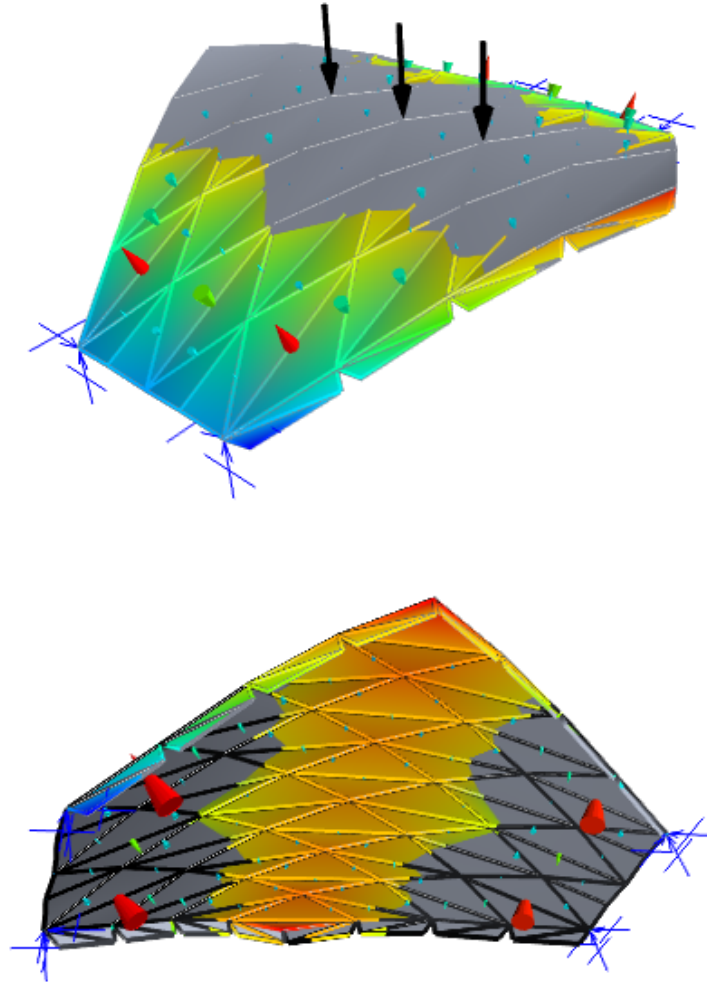
The model is formulated as an incremental optimization problem with the goal function given as the total potential energy including the work of external forces, potential energy of gravity, and stored deformation energy owing to bending, within the crease lines. Equality constraints are provided by conditions of rigid folding kinematics and by conditions defining supports. Inequality constraints are included for specification of mountain and valley crease lines.

Each component of the optimization problem is provided with explicitly implemented derivatives with respect to the vertex displacements so that gradient optimization methods can be used effectively. The examples presented in the paper will be solved using sequential least squares programming method. Goal functions, equality constraints and inequality constraints are provided as plug-in modules of a configurable optimization framework ORICREATE [1].

The present enhancement of the ORICREATE framework enables the analysis of intermediate force flow during the folding process of a plate with finite stiffness of fold lines. It can be used for simulation of manual or robotic folding accounting for the bending resistance of fold lines and self-weight of the structure. It can be used for crease pattern optimization with tuned structural performance.

The simulation approach has been used for coupled analysis of the folding process and of the structural performance. The modeling framework served as a design tool for doubly curved shell with an irregular distribution of fold angles. The shell was constructed by folding of an oricrete plate with an imprint of the Yoshimura crease pattern. Figure 1 shows the bending moments along fold lines and the deformed shape induced by the applied point loads..

[1] Chudoba R et al. ORICREATE: Modeling framework for design and manufacturing of folded plate structures. Origami6 - Part II: Technology, Art, Education. 2015; 523-536.



**Figure 1:** Deformation of the Yoshimura shell due to vertical loading with corresponding distribution of bending line moments along the fold lines.