

Kinematic and Kinetostatic Classification for Motion-Task-Oriented Synthesis of Folding Mechanisms

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Abstract

For the technical realisation of origami-based folding mechanisms and transformable folded structures respectively, ideal thin facets are replaced by thick rigid panels of given thickness and creases are substituted by revolute joints. This equivalent describes *thick rigid origami*. Whenever moving facets are essential for the overall function e.g. in optical or acoustical applications, the technical use of engineered folding is advantageous. No additional mechanisms or supporting devices are required. Herein the major benefits such as great variety and mobility of folding mechanisms, combined with a possible weight reduction and a compact design can be of optimal use. Amongst other examples, two successfully implemented realizations are the *Soundspheres* by the University of Michigan [Thün et al. 12] and the *Al Bahar Tower* facade shading system [Aedas 12].

Yet, the design of folding mechanisms is challenging because of complex kinematic dependencies and possible collisions during motion seem. These obstructions are not limited to folded structures, but occur comparably in spatial mechanisms and parallel robots. In contrast to these disciplines, however, motion-task-oriented synthesis methods, guidelines and key figures are missing, collections or catalogues are not focussed on kinematic properties and no classification similar to the parallel robotic theory is available. This seems to limit the broad usage of folding principles.

Therefore, this paper presents a first step towards guidelines for folding mechanisms – a special class of foldings with a limited number of facets, one or more degrees of freedom and possible non-symmetries. An approach for the selection of patterns meeting the requirements for defined motion tasks, simulation and visualisation of patterns is presented. Formerly, folds have been characterized by pattern affiliation or design characteristics [Barej et al. 13, Bowen et al. 13]. Here, a classification of folds with special consideration of kinematic properties is developed. As a result, existing categories are extended and the structural and dimensional synthesis are separated. A collection of folding patterns has been determined and a subdivision of the results is possible according to various criteria such as a structural representation, motion type, degree of freedom, possible syntheses or geometric constellation. Figure 1 (a) illustrates the developed classification with the Miura-Ori pattern as an example.

Another addition to the collection’s information sets contains key figures of stress properties obtained via finite element analysis (FEA). Therefore, this paper presents a FEA study and experimental analysis of the stresses in folding vertices depending on geometric sizes. Key figures support the design process already at an early stage and facilitate the selection of application-oriented fold structures. The diagram in figure 1 (b) shows the derivation of a key figure for the Miura-Ori pattern.

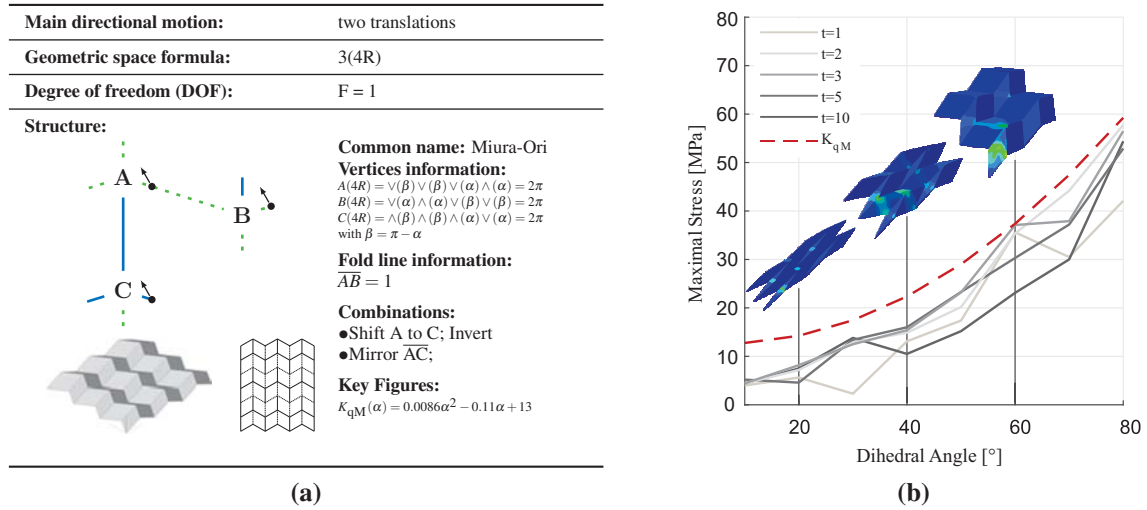


Figure 1: Collection entry for the Miura-Ori pattern (a) selection from the foldscheme collection containing kinematically-relevant information (b) key figure K_{qM} and FEA stress distribution for different dihedral angles and thicknesses

Furthermore, common definitions are extended by a distinction between the structure and the kinematics of folding mechanisms. These are used to organize the collection shown above. In order to validate the presented approaches, a modular *Simulink* Library for simulation and visualization has been implemented. As proof of concept a folding mechanism for an optical application has been synthesised and developed using the collection presented here. Design guidelines as used in various engineering fields assist scientists and engineers with the identification of innovative but feasible solutions. A comparable framework for folding mechanisms has been introduced here.

References

- [Aedas 12] Architect Team Aedas. “Al Bahar Towers Responsive Facade.” In *ArchDaily* by Karen Cilento, 2012. Available online (<https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas>).
- [Barej et al. 13] M. Barej, Y. Safi, B. Sköck-Hartmann, T. Gries, U. Steinseifer, B. Corves, and M. Trautz M. “Systematisierung gefalteter und faltbarer Strukturen in technischen Anwendungen.” *Konstruktion* 1/2 (2013), 69–74.
- [Bowen et al. 13] L. Bowen, C. Grames, S. Magleby, R. Lang, and L. Howell. “An Approach for Understanding Action Origami as Kinematic Mechanisms.” In *ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, edited by ASME, 2013.
- [Thün et al. 12] G. Thün, K. Velikov, C. Ripley, L. Sauv  , and W. McGee. “Soundspheres: Resonant Chamber.” *Leonardo* 45:4 (2012), 348–357.