

Structural performance of foldable surfaces based on Miura-ori textures

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Abstract

In this study kinematic and static behavior of plate and shell structures based on origami patterns is investigated in view of their potential applications as adaptive surfaces in architecture [1]. In particular, the study focuses on tracking the mechanical behaviour of Miura-ori tessellated surfaces throughout the entire folding process.

The broad, multi-disciplinary and rapidly evolving scientific contexts addressing origami designs range from mathematics, physics, engineering and architecture. Restricting ourselves to architectural applications, we focus on the analysis of plate and shell structural solutions able to change their configurations in reaction to users' needs or environmental inputs.

The structural and geometric potentialities of adaptive folded surfaces stem from their unique capability of combining efficient resisting mechanisms, due to their corrugation, in statically constrained configurations, with the ease of varying their global geometry, due to rigid body motions, throughout the folding phase [2]. Thus, starting from planar states, depending on the underlying folding pattern design, folding surfaces may take a variety of prescribed form-resistant spatial configurations.

Aiming to design mobile flat and curved structural systems, a systematic investigation of adaptive surfaces generated according to parametric laws shows that origami patterns provide a wide spectrum of geometrical possibilities enabling to exploit both, bidirectional corrugation in a static configuration and one degree-of freedom deployable structure. In this realm, we consider "rigid-origami", in which large global deformations are achieved only as a result of the opening and closing of the folds. In particular, the Miura-ori pattern chosen tessellation includes planar and spatially modulated (generalized) textures [3].

The geometric construction phase is carried out by implementing the origami pattern geometric features through the definition of digital visual algorithms. More specifically, the basic geometries of the Miura-ori pattern are generated according to a parametric-geometrical method, both in the classical form, suitable to realize planar configurations, and in the generalized version, suitable for approximating barrel vaults.

From a kinematic point of view, the advantages of the Miura-ori tessellation in terms of covered area for a given corrugation amplitude were shown through parametric investigations concerning with planar and curved geometries.

The mechanical investigations pertaining to the designed origami-based adaptive planar and curved structures aims to identify the static performance and the geometry during the whole folding motion. Both aspects are tackled by relying on different models: numerical finite element models and simplified analytical models consisting of 3D spatial truss structures.

In the static analysis, different boundary conditions and load configurations, applied to different spatial configurations of the chosen pattern, are considered through FEM simulations. The reduced Miura-ori analytical models are composed by rigid bars located along the folds directions, spherical hinges in place of the vertices and additional bars dividing the quadrangular facets into triangles; the latter assure the facet bending rigidity during both the loading and folding phases (Fig. 1).

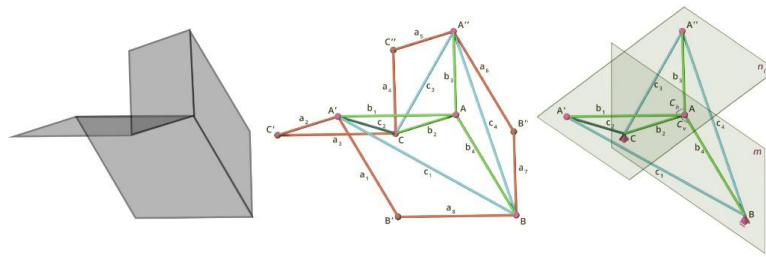


Figure 1: Simplified Miura-ori analytical model.

The large displacement kinematics is studied in order to describe and predict the rigid folding movement of the origami assemblies. An equivalent von-Mises truss analytical model is derived in order to describe finite motions of both, single Miura-ori modules and global assemblies characterized by rigid and flat-foldable panels. In particular, the behavior of classic and generalized Miura-ori tessellated surfaces is analysed during the entire folding phase, gathering empirical curves describing the dependence of the variable dimensions of the overall covered area and the sides' length with respect to the pattern height and folding angles. The kinematic investigations involve parametric comparisons between the same flat and curved configurations considered in the static analysis.

From the static viewpoint, it is found that the influence of the type of boundary conditions decays rapidly with the distance from the origami edges. As far as planar systems, under all the considered loading conditions with fixed (or hinged) corners, the Miura-ori tessellated surfaces show an efficient form-resistant behaviour. The latter takes also advantage of the favourable moment of inertia associated to the corrugation along two orthogonal directions.

References

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