

# Folding Shells

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## Abstract

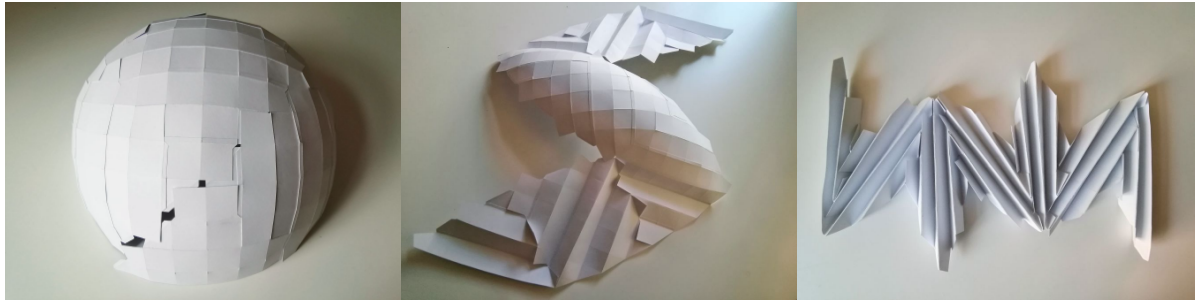
Usually, a structural shell having a smooth surface such as the hemispherical one of a dome can't be folded for transport. This is possible only if its final surface shows a relief of zigzag folds counteracting the advantage of domes: a small surface-area-to-volume ratio, suited to save material and energy. However, a substantially double-curved surface subdivided into quadrilateral facets offers a folding solution. The result is a flat oblong fanfold object - without providing numerous cuts into the cohering unfolded undevelopable shell surface..

For this, the borders of adjacent, initially plane strips each comprising one row of facets on one blank of sheet material have to be congruent. By reasons of symmetry, the quadrilaterals are trapezoids forming a faceted rotational surface such as a globe defined by intersecting meridians and. parallels of latitude. Regular, diagonally outlined portions of such a rotational surface can be combined as modular shell portions to result in a continuous shell surface of a multipolar dome or, of an anticlastically curved space labyrinth's fragment or, of combinations of both options – shapes as shown in US Patent 7,591,108, Figs. 50 – 61. Hereby, coplanar triangles each being the rest of a cut-off trapezoid are combined in pairs along the common sides of adjoining shell-portions to result into kite-shaped facets.

Each of said quadrilateral, especially lozenge-shaped shell portions can change into a fanfold object after intentionally making it buckle locally, e. g. by making it snap or switch gradually, vertex by vertex along each second series of folds, to an inverse or opposite state, that is, to switch a convex vertex pyramid into a concave one when the shell's curvature is synclastic.

At first, fan-like folding seemed to me to be possible only if the borders of the shell portions are free, that is, if each shell portion is neither adjoined to another one nor fixed on a rigid plane. But by folding the kite-shaped facets along their symmetry axis alternatingly into sloping ridges or sloping valleys, interconnected shell portions can be folded interdependently together in a Miura-like manner.

The shell portions of the presented dome designs are arranged along a s-shaped path. So, the emerging dome has only two gaps to be closed during unfolding. The two gaps are bridged by kite-shaped facets being attached alternatingly inside and outside along one side of the gap in order to encompass the border of the other side. In an equal configuration, each of the diagonal fold lines between gapless interconnected, cohering shell portions is covered by additional kite-shaped, facets being attached at one of their triangular facet halves, Hereby, the intentionally flattened fold doesn't sag to become a destabilising valley traversing diagonally more than two facets because each shell portion tends to convolve per se.



**Figures 1 to 3:** Folding process proved in a paper model of a 4 frequency dome



**Figures 4 to 6:** Unfolding process of a 5 frequency dome

Before making a 5 frequency 10 ft dome (Figs. 4 to 6), a 1:5 paper model (Figs. 1 to 3) with only 4 frequency was made. N frequency means the number of facets at each of all shell portion's four sides. To prevent unintentional buckling, N shouldn't be too large because the dihedral angles between facets shouldn't be too close to 180°.

The paper rows of facets are glued together by tabs. The overlap is mastered by placing each second row of a shell portion in the same surface layer. The paper model is easy to handle. However, the sheet material of the 10 ft dome has to be more resilient than normal cardboard in order to master the scale effect. It must be able to be warped without remaining deformations, thus be flexible, but still semi-rigid to avoid unintended buckling too. So, PP-coated paperboard, 300g/m<sup>2</sup>, was applied. Abutting rows of facets are joint by PP packing tape inside and outside. But before, all edges of the blank's cuts have been coated with adhesive tape to prevent both: splicing of paperboard under in-plane pressure across the joint lines in the unfolded state as well as delamination of the PP-skins from the paperboard core under out-of-plane shear forces occurring between facets temporarily bent during deploying.

So, not a single seam was broken even when a wind gust grabbed a still exposed, movable larger region of the rising shell and, thus wrinkled small regions across provided folds and originally flat facets in a transition to the already more rigid shell region during unfolding.

If the ground is plane, the structure can withstand vertical loads but it has to be fixed all around on the ground against wind also deforming the loose base if the ground is not smooth.

Further work: The dome will be enlarged after replacing synclastic shell regions by anticlastic ones being able to be folded equally. Free borders of openings or transitions have to be stiffened additionally. In an even larger scale, the unfolded shell of thin material could be covered at both sides by thick rigid panels, e. g. sandwich panels. So, it could act as one single continuous inner layer to interconnect a plurality of abutting doubled panels.