

A Generative Shape Grammar for Foldable Piecewise Cylindrical Surfaces

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Abstract

Parametric design systems are widely used in origami-inspired engineering design as they explicitly relate various useful elements of a folded geometry, for example unfolded crease pattern parameters and folded volumetric parameters. Generative design systems do not explicitly relate geometric elements but rather specify a set of computational rules for assembly and interaction of these elements. Generative design is thus suitable for conceptual design problems where constraints are poorly defined and key performance indicators are as-yet undefined or not computable.

Of the various generative design methods available, a shape grammar is one approach that is well suited for transformation and combination of geometric primitives. Shape grammars consist of a finite set of *shapes*, a finite set of shape transformations or *shape rules*, and an initial shape. Shapes are typically static or parametric geometric primitives, for example lines or cuboids. Shape rules are some defined spatial relations between the available shapes, for example a Boolean operation or Euclidean transformation, which transform a specified shape into a new shape. Recursive application of a shape grammar to an initial shape can thus generate all manner of different complex geometries which have a strong style conformity with the defined shape grammar.

This paper seeks to develop a generative shape grammar for a foldable and developable surface formed through piecewise assembly of cylindrical segments. This is an analogous problem to the assembly of piecewise arcs, a classical field of study in computational geometry. Existing piecewise arc algorithms are primarily concerned with approximation of a known target curve, whereas the shape grammar developed in this paper allows designers to rapidly synthesise stylistic variations of assembled cylindrical surfaces. Section 2 first introduces the basic elements of the shape grammar: a shape consisting of a ‘foldable’ arc segment primitive (Figure 1) and a set of shape rules which allow sequential arcs to be joined with G1 continuity (Figure 2). Section 3 then considers complex grammars which arise through combinations of the basic grammar, including loop closure and hierarchical segment substitution. Finally, Section 4 considers several design examples of the new shape grammar, including a generative wall panel design and a curved-crease origami lounge chair design (Figure 3).

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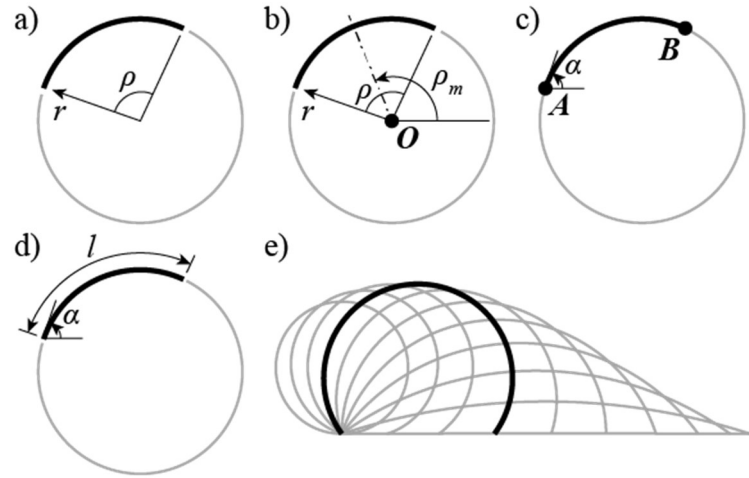


Figure 1: Typical arc segment parametrisations including a) polar form, b) polar form in \mathbf{R}^2 , and c) end tangent form in \mathbf{R}^2 . Foldable arc shape including d) parametrisation and e) folding.

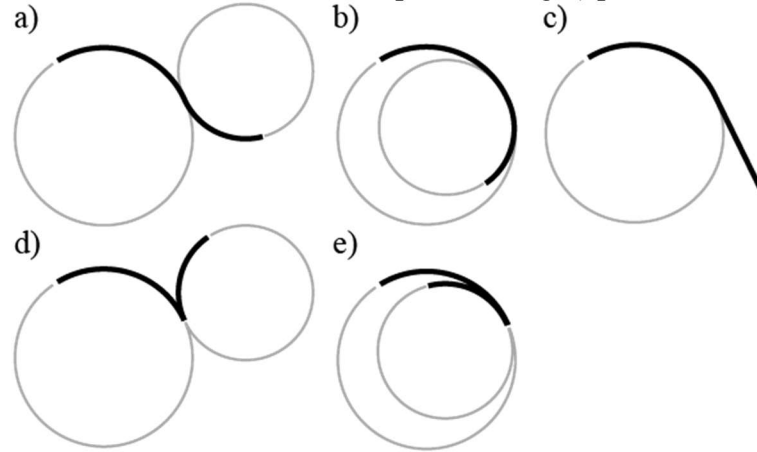


Figure 2: Shape rules from combination of arc segments with G1 continuity. Permissible combinations with a) external combination, b) internal combination, and c) degenerative case of straight-line combination. Non-permissible combinations with d) external and e) internal cusps.

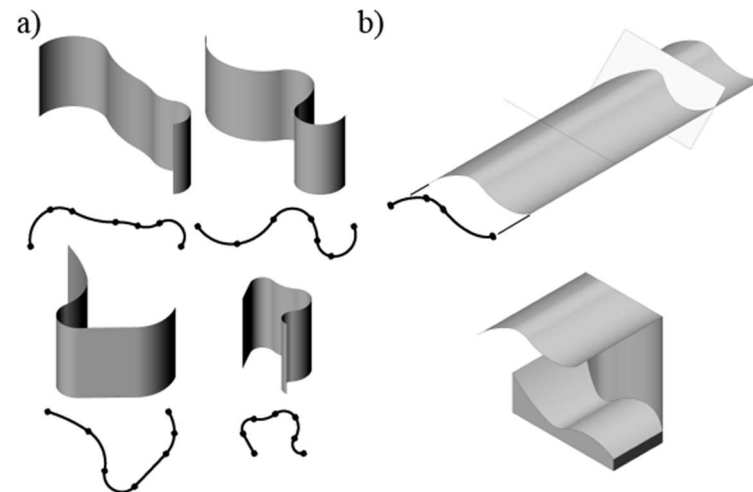


Figure 3: Designs generated from the shape grammar. a) 6-segment wall panels with random parameters. b) Mirror reflection of piecewise cylindrical surface for curved-crease origami chair.