

# Parametric Design of Origami Surfaces with Periodic Tessellations

M. Gardiner, R. Aigner, H. Ogawa, R. Hanlon

Ars Electronica Futurelab, Ars Electronica Strasse 1, Linz 4040.

keywords: parametric, origami, design

## Abstract

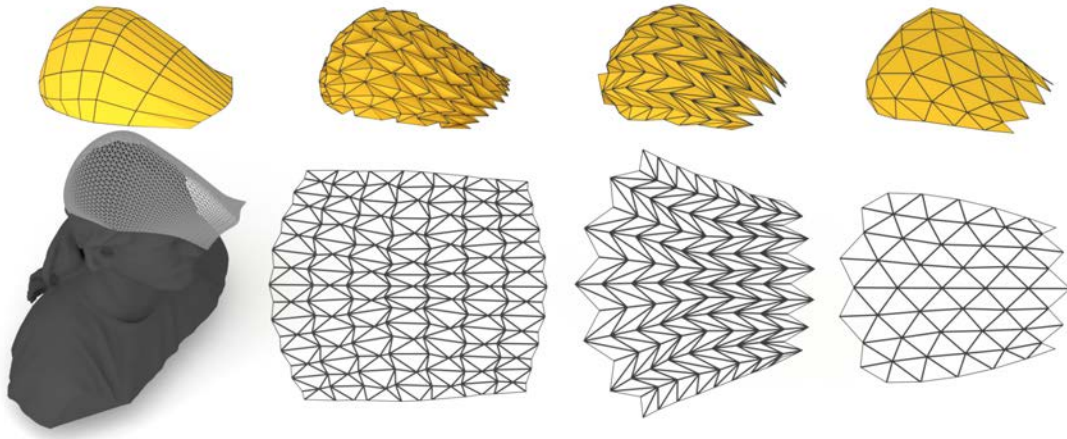


Figure 1. Proof-of-concept Parametric Designs for origami headwear with various periodic Tessellations. From left top to bottom: design-to-fit surfaces of target geometry and 3D scan data; waterbomb 3D mesh and crease pattern; Kresling pattern 3D mesh and crease pattern; low-resolution Yoshimura 3D mesh and crease pattern

Software for origami design is a highly specialised topic and the utility of existing tools tends towards solving specific categories of design problems. Examples of this intent can be as specific as Ronald Resch's software to solve configurations of the triangular Resch pattern [Resch and Christiansen 1970], towards more generalised tools like *Origamizer* by [Demaine and Tachi 2010; Tachi 2008] integrated into *FreeForm Origami* [Tachi 2010] to find crease patterns for any given mesh, or Tachi's earlier software *Rigid Origami* [Tachi 2009] intended to explore and evaluate the rigidity of a given geometry or crease pattern, or an algorithm by [Dudte et al. 2016] intended to solve geometric surfaces with detailed analysis and composition of the Miura-ori. Overall, algorithms are specialised and design processes vary from engineers to artists, and from engineering to aesthetic qualities.

In this paper we focus on a design method to approximate geometric surfaces with periodic tessellations—also known as open corrugations—with the intent to explore off-grid and irregular configurations and to compare a range of patterns for a particular design target. In addition to the aesthetic qualities of these patterns, we have particular interest in open corrugations due to their deployability and application to kinetic origami systems such as

*Oribotics* [Gardiner 2009; Gardiner 2015]. In folded-plate structures, design criteria such as rigid-foldability, developability, target shape, and unit pattern have emerged in released software packages such as *FreeForm Origami*, *oricreate* [Chudoba et al. 2015], and the *Rigid Origami Toolbox for Matlab* [Gattas 2013]. Dudte et al. include material properties to determine fold scale versus accuracy of the finished form.

Our key criteria is divergent from existing packages, we prioritised the following: 1) **Simple pattern definitions** to allow the end-user to virtually prototype one design with many tessellation patterns, add new ones, and to switch patterns at design-time; and 2) using a **Parametric CAD environment** to support end-to-end visualisation and parameterization of the process. This supports design-to-fit context specific design and customisation of the digital fabrication data. Further criteria form the basis of our investigation: we define a target geometry surface to define the approximate target folded surface, the periodic tessellation unit, and two-dimensional resolution of patterning used to generate the surface approximation. For generating a developable approximation from the initial input surface, we use a numeric solver, minimizing a multi-dimensional error function, ensuring requirements such as developability and planarity of individual origami segments. Our algorithm is also able to maintain overall object symmetry and to prioritize a selected subset of vertex positions. Our software then computes a flattened crease pattern ready for fabrication.

We present our method in detail alongside our resultant virtual and physical prototypes. To satisfy our design parameterisation criteria we selected Rhino/Grasshopper for our software prototype, as it affords visualisation of the complete process that are critical for design-time modification and its tools support digital fabrication. Our unit definitions are comprised of arrays of vertices that construct an idealised folded geometry that can be sketched on graph paper or designed in 3D software, and our algorithm is compiled as a Grasshopper Plugin. In our evaluation we compare patterns for a given design target, and discuss fundamental geometric properties of well-known tessellations such as Yoshimura, Mura-ori, Waterbomb, Kresling and Resch patterns. We examine cases of problematic geometries not solvable by the algorithm, and also compare our results to optimisations from other packages.

Our results support our case for simplified unit pattern definitions and parameterisation of the complete design process. We conducted workshops with design students and found visualisation and selection of patterns for functional and aesthetic reasons had a radical impact on design-to-fit problems. The ability to design target geometry at scale in context with other design criteria, such as in Figure 1. showing scan data and designs of an origami cap designed-to-fit with iterations in different tessellation patterns, illustrates the benefits of Parametric CAD and Computational Origami in a single environment. (Note: the waterbomb pattern version in Figure 1. was physically prototyped using a digital fabrication technique, see our other abstract *Fold Printing: Using Digital Fabrication of Multi-Materials for Advanced Origami Prototyping*). Finally, we discuss potential applications of the method from bespoke garments to designs for soft robotics actuators in advanced oribotic applications.

## References

- CHUDOBA, R., VAN DER WOERD, J., AND HEGGER, J. 2015. Oricreate: modeling framework for design and manufacturing of folded plate structures. *Origami* 6, 523–536.
- DEMAINE, E. AND TACHI, T. 2010. *Origamizer: A practical algorithm for folding any polyhedron*. Manuscript.
- DUDTE, L.H., VOUGA, E., TACHI, T., AND MAHADEVAN, L. 2016. Programming curvature using origami tessellations. *Nature materials*.
- GARDINER, M. 2009. A Brief History of Oribotics. *Origami* 4, AK Peters, 51–60.
- GARDINER, M. 2015. Folding and unfolding a million times over: Longevity, origami, robotics and biomimetics as material thinking in Oribotics. *Symmetrion* 26, 2, 189–202.
- GATTAS, J. 2013. Rigid Origami Toolbox. <http://joegattas.com/rigid-origami-toolbox/>
- RESCH, R.D. AND CHRISTIANSEN, H. 1970. The design and analysis of kinematic folded plate systems. *Proceedings of IASS Symposium on Folded Plates and Prismatic Structures*.
- TACHI, T. 2008. *Origamizer*. <http://tsg.ne.jp/TT/software/>
- TACHI, T. 2009. *Rigid Origami Simulator*. <http://tsg.ne.jp/TT/software/>
- TACHI, T. 2010. *Freeform origami*. <http://tsg.ne.jp/TT/software/>