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Synthesis of Frame Field-Aligned Multi-Laminar Structures.

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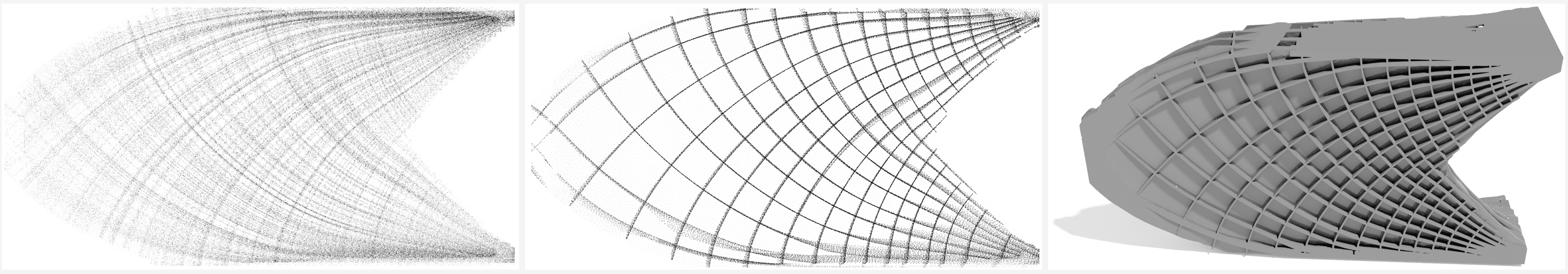

Figure 1: Cut through view of different stages of the process. To the left the full superset of surfaces, the centre is the selected set of surfaces and the the right we have the volumetric structure.

Introduction

We propose a method for generating multi-laminar structures from frame fields. Rather than relying on integrative approaches that find a parametrization based on the frame field, we find stream surfaces, represented as point clouds, aligned with frame vectors, and we solve an optimization problem to find well-spaced collections of such stream surfaces.

In addition to stream surface tracing and selection, we provide a method for generating structures from stream surface collections. This method produces a volumetric solid from a signed distance field associated with each surface and combines these to form the output structure for the collection. We demonstrate our methods on several frame fields produced by the homogenization approach for topology optimization yielding single-scale structures from optimal multi-scale designs.

Homogenization - Our Input data

In the field of topology optimization, the homogenization approach has been revived as an important alternative to the established, density-based methods. It can represent the microstructural design at a much finer length-scale than the computational grid.

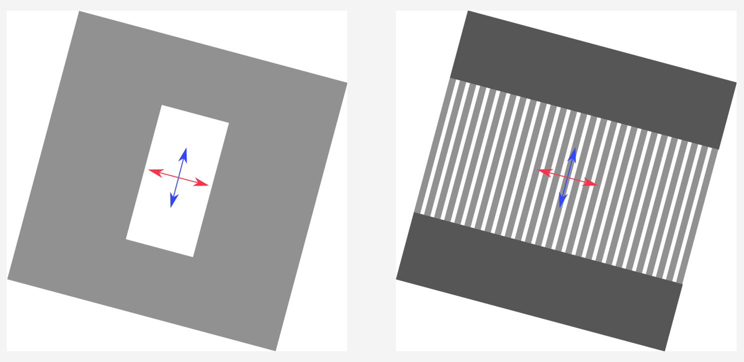

Figure 2: Example of a rank-1 and rank-2 microstructure, where the rank-2 structure have orthogonal layers.

In a 3D problem with a single loading case the rank-3 microstructure with orthogonal layers have been shown to be the optimal solution Avellaneda 1987. These rank-2 microstructures can be described by a frame field and a local material thickness associated with each direction of the frame.

The frame fields we work with are unsigned and unordered direction fields, where the directions are orthogonal to each other. Figure 4 show an example frame field in 3D separated into the 3 families. However, this separation is not possible in general due to singularities.

Singularities

Singularities are always a challenge when they arise. Singularities are primarily a problem when a surface is constructed with the edge colliding with the singular curve.

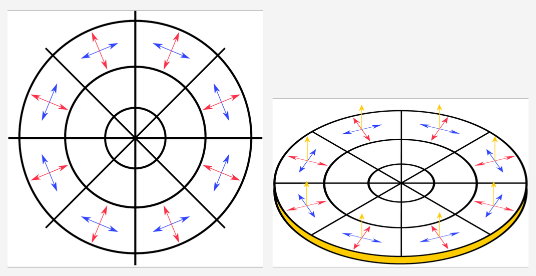

Figure 3: Zoom in of the center singularity of the cylindrical field from Figure 4.

However, we work with a mechanically optimal solution. Meaning in 3D singularities show up when the direction of material does not matter. This observation essentially highlight the regions of local isotropy. So isotropy can happen when all directions matter equally (Solid regions), none matter (Void) and only a single of the 3 directions matter (Plate). These 3 situations mean our method are not affected by these singularities at all since surfaces are not constructed in void and solid regions and plates will have no material asigned to the 2 isotropic directions.

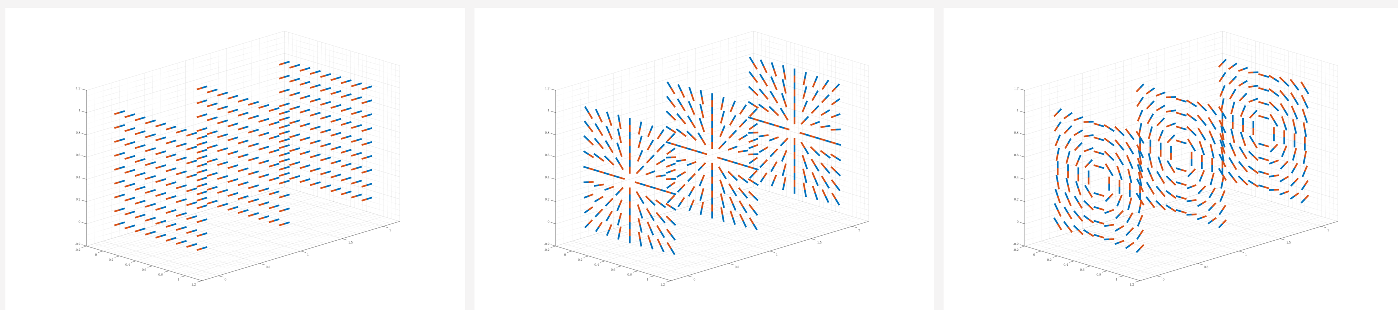

Figure 4: The 3 different directions separated into the 3 different families. Please note we have no guarantee that this separation is possible.

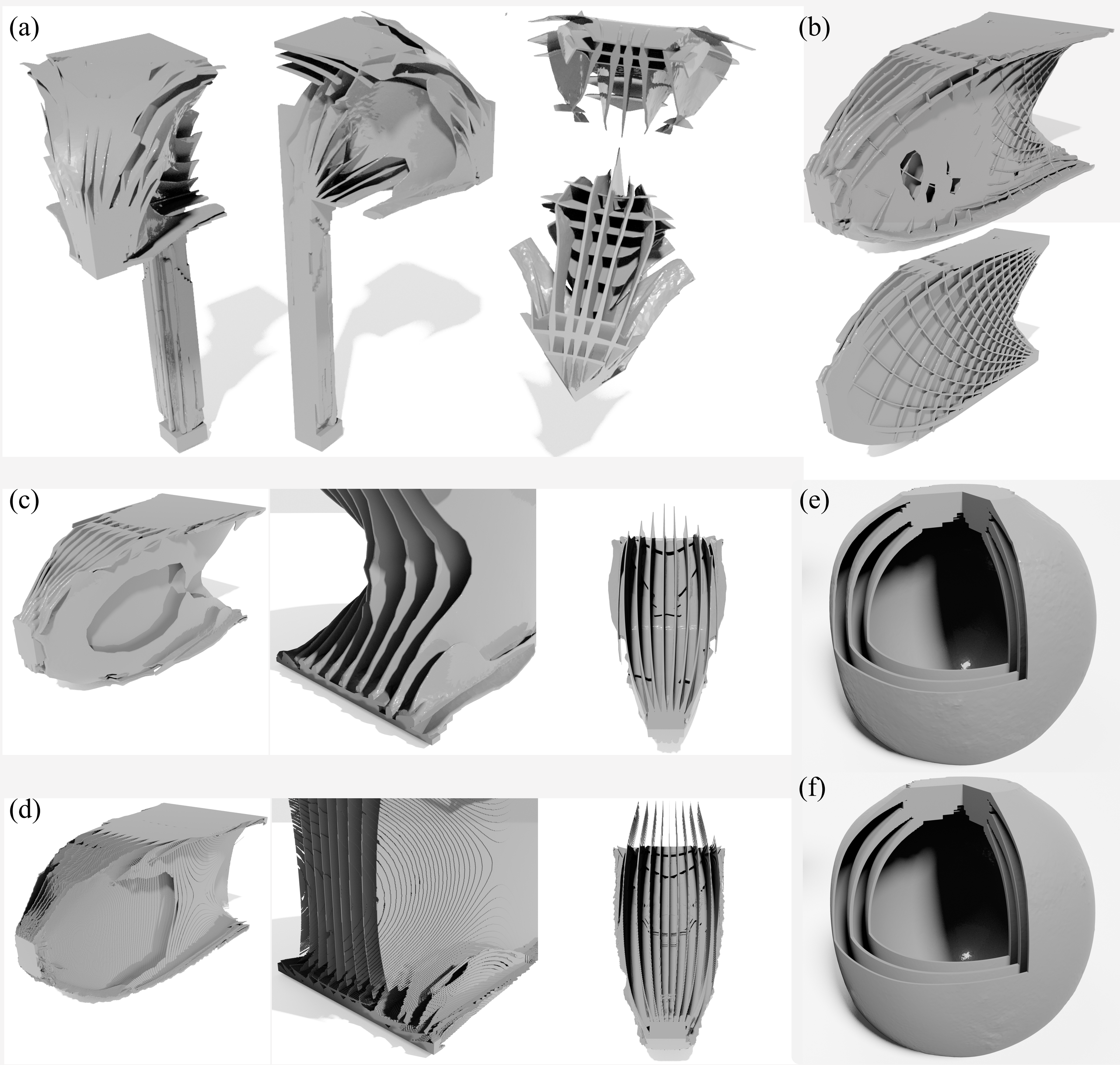

Figure 5: These renderings show our final results. (a) depicts the results for the Electrical Mast example defined by Geoffroy-Donders et al. 2020. It is shown from 2 different angles and a cut open through the top. (b) is a rendered version of a Michell cantilever where 3 layers have been enforced. (c) and (d) depict the classical Michell cantilever, (c) is our results and (d) is the state of the art by Groen et al. 2020.

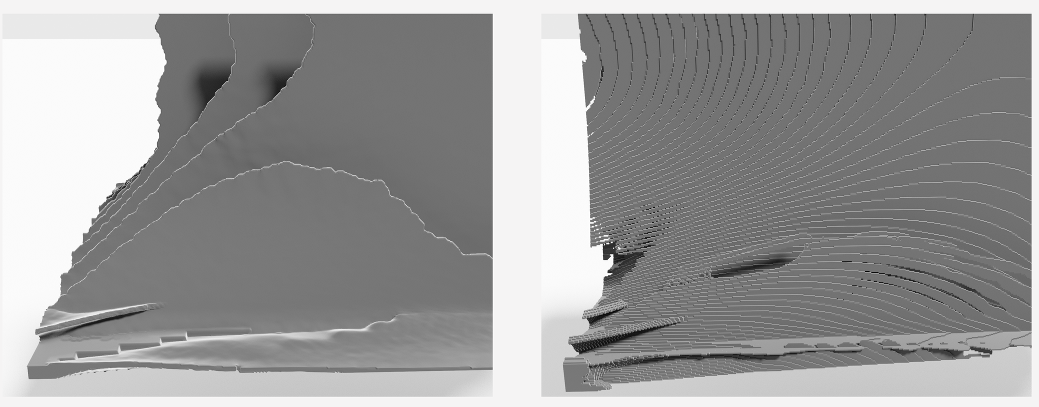

Figure 6: Close up comparison of the Cantilever example. Right is the previous state of the art by Groen et al. 2020, left is ours. Note the staircasing in the results of Groen et al. 2020.

Generating surfaces

Each surface is expanded from a single starting point using ideas from Poisson Disk Sampling [Bridson 2007]. This sampling technique allow us to populate the domain with points no closer to each-other than a specified value. Point positions are estimated through an iterative Runge-Kutta method started locally from established points.

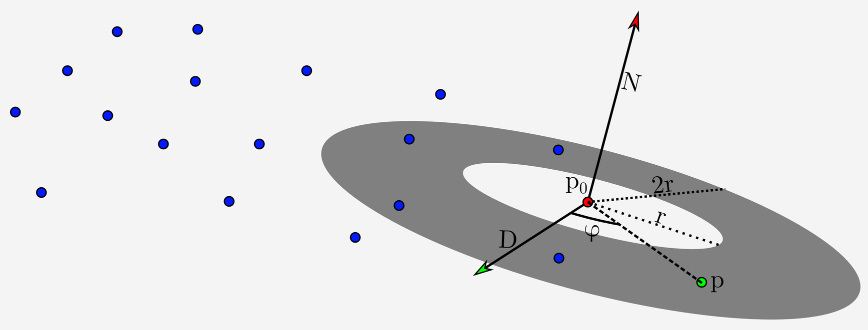

Figure 7: Points are generated by two randomly sampled values, the rotation φ of D around the surfaces normal N and distance from the centre point p_0.

Sub-selection

We setup a covering problem using a grid of probe points. This covering problem is NP-hard, however, a relaxation can reduce the size of the surface set significantly. In order to compute the selection for each frame direction, we assign an index to the probe points based in which frame corresponds to the surface normal close by. The frames are unordered, but as it can be seen in Figure 8 the total number of activated probe points does not depend on the ordering.

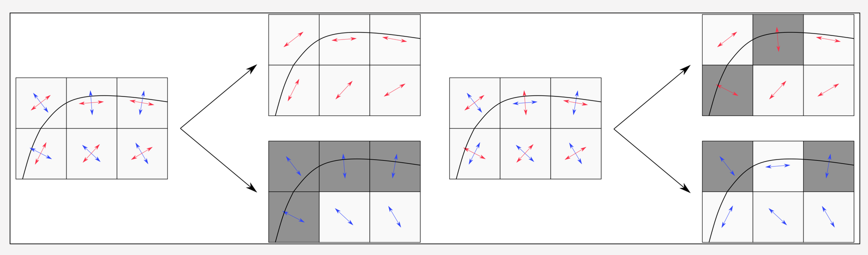

Figure 8: Activation of probes in an ordered (left) and unordered (right) frame field. Note, the number of activated probe points is unaffected by the ordering.

Results

In conclusion our method provide a efficient system for extracting mechanical structures. Groen et al. 2020 have previously shown an integrative approach to compute a similar result. Our method perform mechanically on par with Groen et al. 2020 mechanically, however, we have achieved a $10x$ speedup.

The results in Figure 5 show the results of our system on multiple datasets, and it inculdes a direct comparison with Groen et al. 2020 ((c) and (d)). Figure 6 highlight that our method produce smooth structures, where Groen et al. 2020 see staircasing.

References

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