Claims

1. A method of additively manufacturing a minimal surface structure (61, 62, 63) of a three-dimensional article (100, 200), the method comprising a computer (10) executing the steps of:

recording in the computer (10) an envelope (11, 12) of the three-dimensional article (100, 200);

generating a density field (2) across a volume (121) enclosed by the envelope (12) with densities of the density field (2) corresponding to local requirement values of at least one physical parameter at respective positions of the three-dimensional article (100, 200);

generating an adaptive Voronoi tessellation (VO) of the volume (121) using the density field (2);

generating a first skeleton graph (A) associated with the adaptive Voronoi tessellation (VO);

generating a second skeleton graph (B) associated with the first skeleton graph (A);

generating a digital minimal surface model (5) from the first and second skeleton graphs (A; B);

wherein the method further comprises a 3D printer (30) additively manufacturing the minimal surface structure (61, 62, 63) according to the digital

minimal surface model (5), wherein generating the adaptive Voronoi tessellation (VO) comprises:

generating a set of scatter points (21) corresponding to a distribution of the densities of the density field (2);

randomly distributing the scatter points (21) across the volume (121) enclosed by the envelope (12);

generating a plurality of Voronoi cells of the adaptive Voronoi tessellation (VO) using the randomly distributed scatter points (21) as generating points of the Voronoi cells,

wherein the first skeleton graph (A) is formed by edges of Voronoi cells of the adaptive Voronoi tessellation (VO),

wherein generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B) comprises:

generating a minimal surface precursor (3) from the first and second skeleton graphs;

generating a minimal surface shape (4) by smoothening the minimal surface precursor (3);

assigning a wall width to the minimal surface shape (4);

generating the digital minimal surface model (5) according to the minimal surface shape (4) and the assigned wall width.

2. The method according to claim 1, characterized in that generating the adaptive Voronoi tessellation (VO) using the density field (2) comprises iteratively generating a plurality of Voronoi cells of the adaptive Voronoi tessellation (VO) by weighted stippling using the density field (2).

3. The method according to claim 2, characterized in that iteratively generating the plurality of Voronoi cells comprises iterating the steps of:

a) calculating the weighted centroid (C) of each Voronoi cell using the density field (2) and shifting generating points of the Voronoi cells to the respective centroids (C);

b) generating new Voronoi cells of the adaptive Voronoi tessellation (VO) using the shifted generating points and replacing the Voronoi cells of step a) by the new Voronoi cells;

until the calculated centroids (C) conform with the generating points of the Voronoi cells in step a).

4. The method according to claim 3, characterized in that iteratively generating the plurality of Voronoi cells comprises executing the steps of:

c) calculating for each Voronoi cell a cell weight by integrating the density field (2) over the respective Voronoi cell;

d) recording in the computer a first weight threshold and a second weight threshold, wherein the first weight threshold is larger than the second weight threshold;

e) splitting Voronoi cells with a cell weight above the first weight threshold and deleting Voronoi cells with a cell weight below the second weight threshold;

after step b) of claim 3.

5. The method according to claim 4, characterized in that the steps c)-e) are executed for the first 10-30%, preferably 20%, of the iterations of steps a)-b) of claim 3.

6. The method according to one of the preceding claims, characterized in that generating the density field (2) comprises:

dividing the volume (121) enclosed by the envelope (12) into a plurality of, preferably tetrahedral, voxels (122) and generating at least one local requirement value for each voxel (122).

7. The method according to one of the preceding claims, characterized in that the second skeleton graph (B) is generated by Delaunay tetrahedralization of generating points of the adaptive Voronoi tessellation (VO).

8. The method according to one of the preceding claims, characterized in that from a segment of the first and/or second skeleton graph (A; B) which traverses

the envelope of the three-dimensional article, a first segment part lying outside the volume (121) enclosed by the envelope (12) is removed and replaced by a segment part which is obtained by mirror-imaging about the envelope (12) at the position where the segment of the first and/or second skeleton graph traverses the envelope (12) a second segment part lying inside the volume and adjoining the first segment part.

9. The method according to one of the preceding claims, characterized in that Voronoi cells which extend beyond the envelope (12) of the three-dimensional article (100, 200) are trimmed at the envelope and the centroids of the trimmed Voronoi cells are recalculated using the density field.

10. The method according to claim 1, characterized in that generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B) comprises:

assigning a first electrical charge to the first skeleton graph (A);

assigning a second electrical charge to the second skeleton graph (B), the second electrical charge being equal in absolute value, but opposite in sign to the first electrical charge;

generating the minimal surface precursor (4) as an equipotential surface between the first and second skeleton graph (A; B) using a Coulomb force field

calculated based on the first and second skeleton graphs (A; B) and their electrical charges.

11. The method according to one of the preceding claims, characterized in that the at least one physical parameter is selected from at least one of: mechanical load, stiffness, amount of storable fluid, fluid flow, heat transport.

12. A non-transitory computer-readable medium (101) having stored thereon computer-executable instructions adapted to cause a 3D printer (30) to additively manufacture a minimal surface structure (61, 62, 63) of a three-dimensional article (100, 200) according to a digital minimal surface model (5), the computer-executable instructions comprising a computer (10) executing the steps of:

recording in the computer (10) an envelope (11, 12) of the three-dimensional article (100, 200);

generating a density field (2) across a volume (121) enclosed by the envelope (12) with densities of the density field (2) corresponding to local requirement values of at least one physical parameter at respective positions of the three-dimensional article (100, 200);

generating an adaptive Voronoi tessellation (VO) of the volume (121) using the density field (2);

generating a first skeleton graph (A) associated with the adaptive Voronoi tessellation (VO);

generating a second skeleton graph (B) associated with the first skeleton graph (A);

generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B),

wherein generating the adaptive Voronoi tessellation (VO) comprises:

generating a set of scatter points (21) corresponding to a distribution of the densities of the density field (2);

randomly distributing the scatter points (21) across the volume (121) enclosed by the envelope (12);

generating a plurality of Voronoi cells of the adaptive Voronoi tessellation (VO) using the randomly distributed scatter points (21) as generating points of the Voronoi cells,

wherein the first skeleton graph (A) is formed by edges of Voronoi cells of the adaptive Voronoi tessellation (VO),

wherein generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B) comprises:

generating a minimal surface precursor (3) from the first and second skeleton graphs;

generating a minimal surface shape (4) by smoothening the minimal surface precursor (3);

assigning a wall width to the minimal surface shape (4);

generating the digital minimal surface model (5) according to the minimal surface shape (4) and the assigned wall width.

13. A computer-implemented method of generating a digital minimal surface model (5) adapted for additively manufacturing a minimal surface structure (61, 62, 63) of a three-dimensional article (100, 200) according to the digital minimal surface model (5) by a 3D printer (30), the computer-implemented method comprising a computer (10) executing the steps of:

recording in the computer (10) an envelope (11, 12) of the three-dimensional article (100, 200);

generating a density field (2) across a volume (121) enclosed by the envelope (12) with densities of the density field (2) corresponding to local requirement values of at least one physical parameter at respective positions of the three-dimensional article (100, 200);

generating an adaptive Voronoi tessellation (VO) of the volume (121) using the density field (2);

generating a first skeleton graph (A) associated with the adaptive Voronoi tessellation (VO);

generating a second skeleton graph (B) associated with the first skeleton graph (A);

generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B);

storing the digital minimal surface model (5) on a computer-readable medium (20),

wherein generating the adaptive Voronoi tessellation (VO) comprises:

generating a set of scatter points (21) corresponding to a distribution of the densities of the density field (2);

randomly distributing the scatter points (21) across the volume (121) enclosed by the envelope (12);

generating a plurality of Voronoi cells of the adaptive Voronoi tessellation (VO) using the randomly distributed scatter points (21) as generating points of the Voronoi cells,

wherein the first skeleton graph (A) is formed by edges of Voronoi cells of the adaptive Voronoi tessellation (VO),

wherein generating the digital minimal surface model (5) from the first and second skeleton graphs (A; B) comprises:

generating a minimal surface precursor (3) from the first and second skeleton graphs;

generating a minimal surface shape (4) by smoothening the minimal surface precursor (3);

assigning a wall width to the minimal surface shape (4);

generating the digital minimal surface model (5) according to the minimal surface shape (4) and the assigned wall width.

14. A computer program product comprising computer program code configured to control a computer (10) such that the computer (10) executes the steps of the method according to claim 13.