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Structural optimization and geometric modeling of lattice structures for Additive Manufacturing

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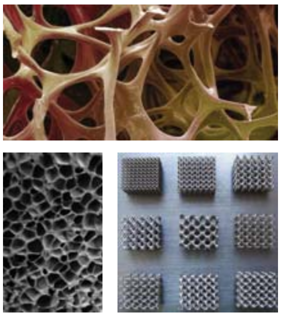
Abstract

Additive manufacturing technologies enable the fabrication of innovative components not achievable by other technologies, such as cellular structures, characterized by lightness and good mechanical properties. In this work a new structural optimization and geometric modelling approach is proposed to design regular cellular structures as a function of material, loads and constraint conditions. Several cell types were studied and a classification as a function of relative density and compliance was proposed. The method aids the design process of cellular structures for additive manufacturing and the results drive the choice of the best cell type as a function of the boundary conditions. In this way many advantages are achieved such as lightness and less expensive components.



Method

The proposed design method is based on the substitution of a solid model with cellular structures, obtaining a wire model computed repeating a unit cell inside a part. Based on diameters of the beams, material, loads and constraints, a finite element (FE) model is built. Then the FE analysis is performed, obtaining for each beam a value of utilization. This index identifies the level of usage of the material for each element and is similar to the ratio between the actual Von Mises stress and the maximum admissible stress. When the utilization of each beam is inside an established range, the optimal solution is found. In other cases, based on the actual radius and utilization of each beam, new radii are computed and the FE model is re-built and re-analyzed (*Fig. 1*).

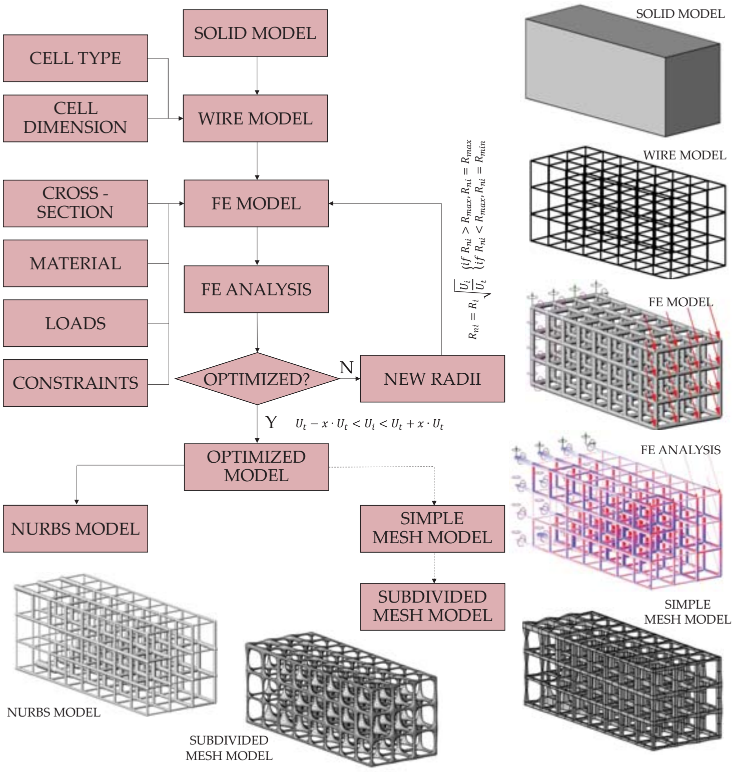


Fig. 1 Framework of the proposed design method.

As a result of the optimization process a radius for each beam is found. Then around of each wire of the model a cylinder with spherical caps is drawn and finally a boolean union was carried out among all the elements obtaining a NURBS model. This approach highlights some limits related to boolean operations (which often fails and demands high computational resources), sharp edges (inducing stress concentration), NURBS high complexity (inducing difficulties in model visualization and determining extremely large file dimension). To overcome these limits a specific modelling procedure was developed for cubic cell (*Fig. 2,4*), consisting in:

- the definition of a simple and consistent mesh model, approximating each beam element (cylinder) by 8 planar mesh faces (the cylinder assumes a double truncated pyramidal shape as in *Figure 2*);
- the application of subdivision surface schemes (Catmull-Clark) to create fillets and round off the beam sections, obtaining a mesh suitable for data exchange in Additive Manufacturing.

The whole approach was integrated in the same CAD environment (Rhinoceros® 5 by Robert McNeel & Associates) adopting IronPython as programming language, Karamba as FE solver, Grasshopper as graphical algorithm editor and Weaverbird for subdivision surface.

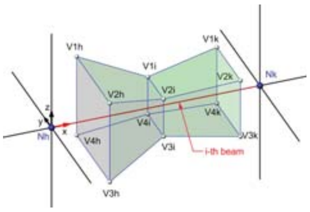


Fig. 2 Modeling a mesh around a beam.

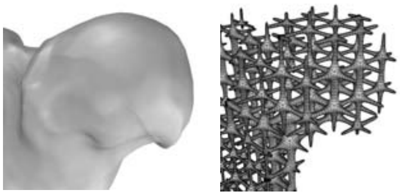
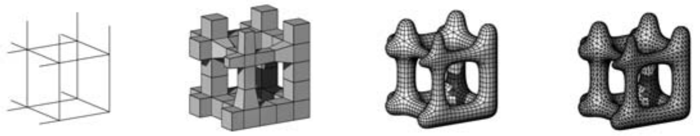


Fig. 3 Example of the proposed method.



WIRE MODEL | MESH MODEL | SUBDIVISION | TRIANGULATION

Fig. 4 Framework of the proposed approach: from a wire model and optimized diameters, a mesh was built. Then a subdivision scheme is applied. Halving each face, a triangular mesh in computed.

Test cases and results

A cantilever beam with dimension 30x30x80 mm was adopted as solid model to optimize. The cantilever beam was filled with 6 type of cells having dimension equal to 10 mm (*Fig. 5a*). Two cantilever beam load conditions were applied: 50 N vertical force and 50 N axial compressive force. The load force was distributed in the nodes lying in the free end of the cantilever. The nodes of the beams lying in the opposite face of the cantilever were adopted as fixed supports. The material used in the design and optimization process is polyamide 12. *Figure 5b,c,d,e* show the compliance index D (max displacement/force) and relative density ρ (volume fraction) behaviour for the two load cases. Other test cases were carried out adopting different shapes, materials and boundary conditions. *Figure 6* shows a visual comparison between the proposed method and topology optimization.

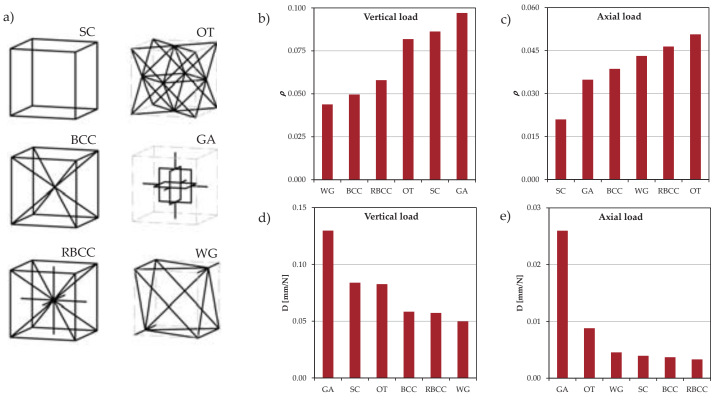


Fig. 5 Results: a) Cell types investigated; relative density ρ b) under vertical load and c) under compression; compliance index D of the structures d) under vertical load and e) under compression.

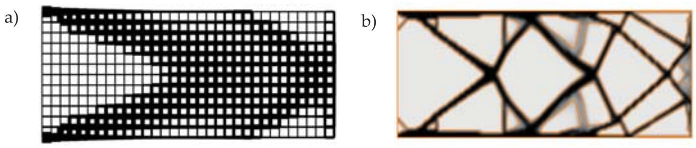


Fig. 6 Proposed method on a cubic cell (a), vs topology optimization (b).

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