From 3D Tessellations to Lightweight Filling Materials for Additive Manufactured Structures: Concept, Simulation and Testing

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ABSTRACT

Additive manufacturing is a technology that produces three-dimensional parts layer by layer from a variety of materials [1-3]. Thanks to recent strides in raw material development, deepening of the physics groundwork and widespread availability of up-to-date equipment, this technology is rapidly evolving from a mere prototyping commodity into a true manufacturing process. In the additive manufacturing workflow, a digital data file is transmitted to a production machine, which ultimately translates an engineering design into a 3D-printed part with virtually any conceivable shape. The majority of parts produced by additive technologies are not printed solid. Printing solid parts requires high amounts of material and long print time resulting in high costs and structural inefficiency. To optimise the printing process and improve the design, most parts are printed with solid shells and filled with a lightweight cellular structure. The infill behaves basically as the core material in a sandwich construction with the main aims of providing distributed support to the load-carrying outer shells (Figure 1) and resisting diffused shear action. This paper proposes a simple two-step method to design periodic filling materials based on the combination of two well-established sciences. In the first step, the 3D space is tessellated with repetitive solids belonging the major classes of space-filling polyhedra. In the second step, a trabecular lattice structure is formed by placing one-dimensional beams along the edges and across the faces of the original polyhedra [4-6] so as to generate kinematically rigid truss-like grids. This simple procedure generates entire families of easily manufactured porous metamaterials that are intrinsically lightweight, strong and stiff. Examples originating in the tessellation of regular volumes using triangular, square and hexagonal prisms are supplied in Figure 2. Examples suitable for filling irregular shapes using rhombic dodecahedra, truncated octahedra and Weaire–Phelan cells are displayed in Figure 3. Figure 4 shows sandwich panels printed from ABS polymer by Fused Deposition Modelling (FDM) technology using the unit cells in Figure 2. The paper has three aims: 1) to illustrate the geometric design and the enforcement of structural efficiency of these architectures; 2) to characterize the materials through FE analyses based on scaling and homogenization techniques; 3) to validate the numerical results against experimental tests on a selection of prototype structures.

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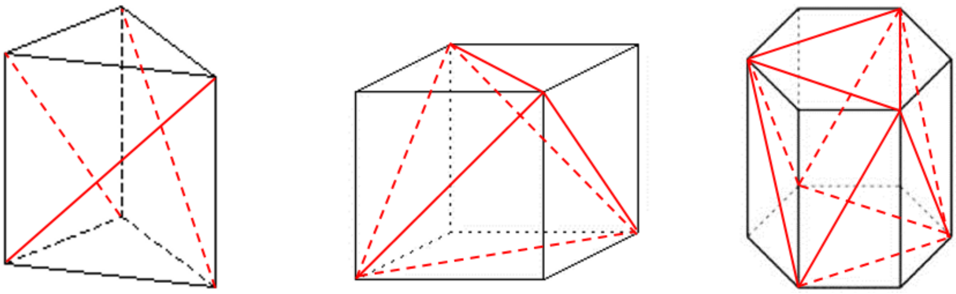
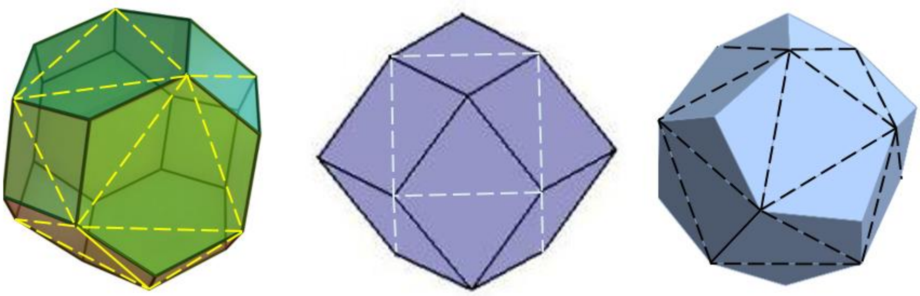
(a) (b)

Figure 1 Monolithic sandwich-like parts with porous cores: (a) regular shape and (b) irregular shape.



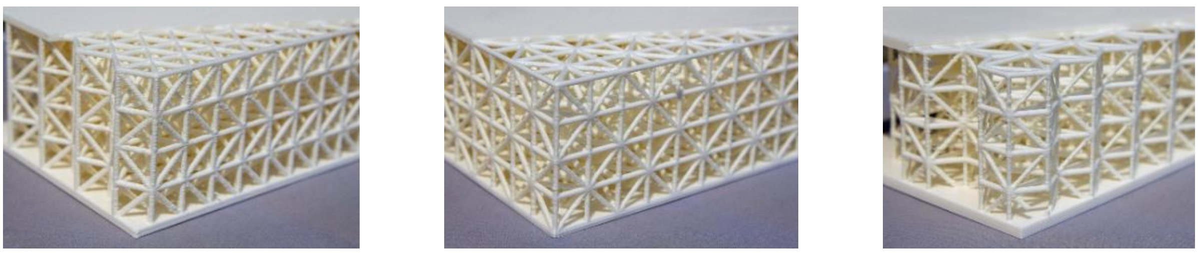
(a) (b) (c)

Figure 2 Unit cells suitable for tessellation of regular volumes: (a) pentahedron, (b) hexahedron, (c) hexagonal prism (red lines show added beams needed to achieve kinematic rigidity).



(a) (b) (c)

Figure 3 Examples of elemental cells suitable for tessellation of irregular volumes: (a) truncated octahedron, (b) rhombic dodecahedron, (c) Weaire-Phelan cell (dashed lines across faces show added beams needed to achieve self-rigidity).



(a) (b) (c)

Figure 4 Examples of sandwich panels printed by Fused Deposition Modelling techniques: (a) pentahedron, (b) hexahedron, (c) hexagonal prism.