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A material interpolation technique using the simplex polytope

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The Discrete Material Optimization (DMO) [1] and the Shape Function with Penalization (SFP) [2] constitute the state-of-the-art material interpolation techniques employed in structural optimization problems for identifying from a list of predefined candidate materials the most suitable ones for the given domain. The candidate materials are represented in this list by their mechanical properties, and per element/patch that discretizes the domain, these material properties are assigned a specific weight. Goal of the material optimization problem (MOP) is to solve for these weights and conclude for each element/patch on a unique material from that list. This work extends the concept of the SFP technique, which employs the shape functions of the 2^k-noded quadrangular element as the weights assigned to the candidate materials, by considering the shape functions of the $k-$dimensional tetrahedral element. This generalized tetrahedron constitutes what is defined as a *simplex* (simplest possible polytope defined in any given space), and similar to the SFP technique each of its vertices is tied to a candidate material. Given that the number of vertices forming the simplex is always one unit greater than the dimension of the space it is defined within, the dimension of the resulting MOP drops by one per element/patch of the domain. This is a direct cause of this definition since the -to be solved for- coordinates of the "optimal" vertex are defined in a dimensional space of one unit lower than the number of candidate materials. Contributing further to the computational efficiency of the method, the self-complementary property of the shape functions, holding within the domain of the simplex, automatically satisfies the constraint that the weights must add up to unity. The proposed material interpolation technique for MOP is integrated into the concurrent discrete fiber orientation and topology optimization problem (DFOTOP), and the corresponding compliance minimization problem is posed. The paper concludes with demonstrating the DFOTOP for compliance minimization on the benchmark academic case studies of the 3D cantilever and the 3D Messerchmitt-Bölkow-Blohm (MBB) beams for the cases of three, four, and eight candidate fiber orientations considered.

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