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CORRECTION

Correction to: Simple, accurate surrogate models of the elastic response of three-dimensional open truss micro-architectures with applications to multiscale topology design

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Correction to: Struct Multidisc Optim
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The original version of this paper unfortunately contains three errors in the topology optimization code that was used to generate the examples. Line numbers refer to the code as it appears in Appendix D of the original paper.

The first error is in integrating the modeled elasticity tensor $\mathbb{C}^h$ to form the finite element stiffness matrix. We hard-coded a Jacobian determinant appropriate for 2D elements rather than 3D elements, such that the elements are too stiff by a factor of two. The final command on line 142,

```
KE=KE+G'*CE*G/4;
```

should be corrected to read

```
KE=KE+G'*CE*G/8;
```

Since this error scales the compliance values and sensitivities uniformly, it does not change the final design obtained, nor does it change the relative performance between the models.

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The second error is in evaluating the sensitivity Dc of the compliance c with respect to the relative density ρ of the lattice in a given finite element. One term in the expression of Dc is the derivative DC^h_{1122} in terms of the modeled quantities E^h, ν^h, and G^h, and their derivatives DE^h, $D\nu^h$, and DG^h with respect to ρ. The value of DC^h_{1122} implemented in the topology optimization code contains an error. Line 160, which originally appears as

```
C1122 =  ((DE*v+E*Dv)*(1-v-2*v^2)
         -E*(1-v)*(-Dv-4*v*Dv)) /
         (1-v-2*v^2)^2;
```

should be corrected to read

```
C1122 =  ((DE*v+E*Dv)*(1-v-2*v^2)
         -E*v*(-Dv-4*v*Dv)) /
         (1-v-2*v^2)^2;
```

This error results in slightly incorrect values of DC^h_{1122} for the three truss lattices and the Hashin-Shtrikman material, although not for the SIMP material, since in this latter case $D\nu^h = 0$. Since the optimality criterion update to the design depends on the value of Dc, the final designs obtained in the paper are therefore incorrect, although after fixing this error, we see that it creates only small differences in the final solutions. The main impact is that with the correct value of Dc, the fixed-point iteration scheme used in the optimality criterion converges far sooner for some trusses than we observed in the original paper.

The third error is in implementing the surrogate models for E^h and G^h for the truss lattices. The surrogate models for both these moduli are normalized by the corresponding moduli E_S and G_S for the solid material that comprises the lattice, that is, the surrogate model are of E^h/E_S and G^h/G_S, respectively. The topology optimization code incorrectly evaluates

$$E^h = E_S\alpha_1 v_1 + \alpha_2 v_2 + \cdots + \alpha_N v_N$$

rather than

$$E^h = E_S(\alpha_1 v_1 + \alpha_2 v_2 + \cdots + \alpha_N v_N)$$

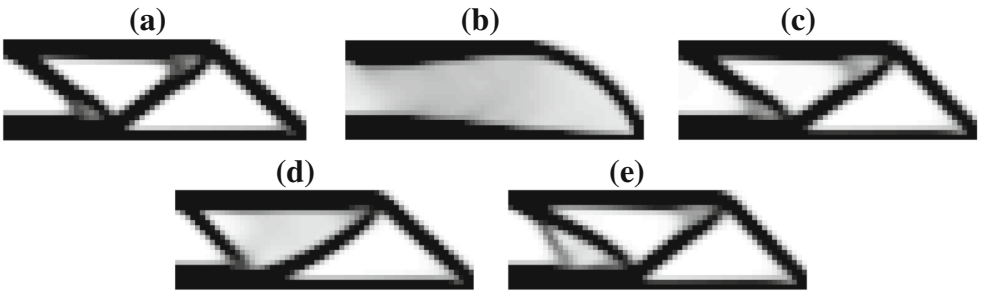

Figure 14 Designs which minimize the compliance of the MBB beam, assuming the **a** SIMP, **b** Hashin-Shtrikman, **c** isotruss, **d** octet truss, and **e** ORC truss material models. The design domain is shown; the full MBB beam is symmetric about the left edge. Darker regions indicate higher relative density ρ

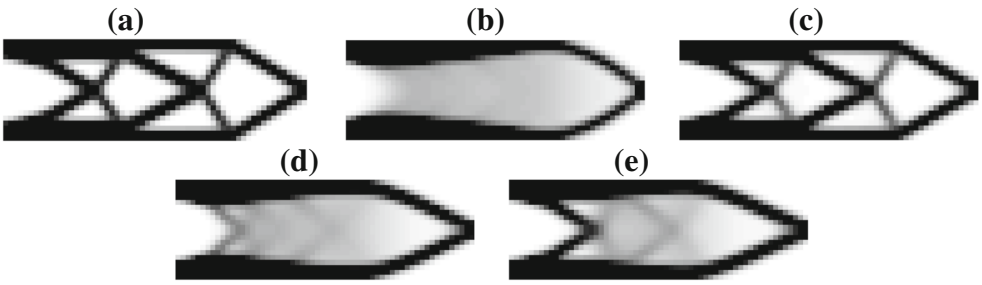

Figure 15 Designs which minimize the compliance of the cantilever beam, assuming the **a** SIMP, **b** Hashin-Shtrikman, **c** isotruss, **d** octet truss, and **e** ORC truss material models. Darker regions indicate higher relative density ρ

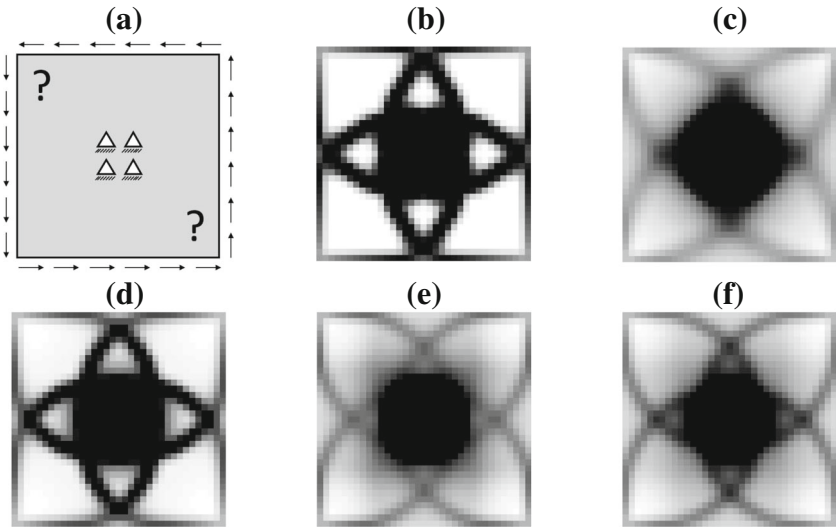

Figure 16 Designs which minimize the compliance of the torque load case depicted in **a**, assuming the **b** SIMP, **c** Hashin-Shtrikman, **d** isotruss, **e** octet truss, and **f** ORC truss material models. Darker regions indicate higher relative density ρ

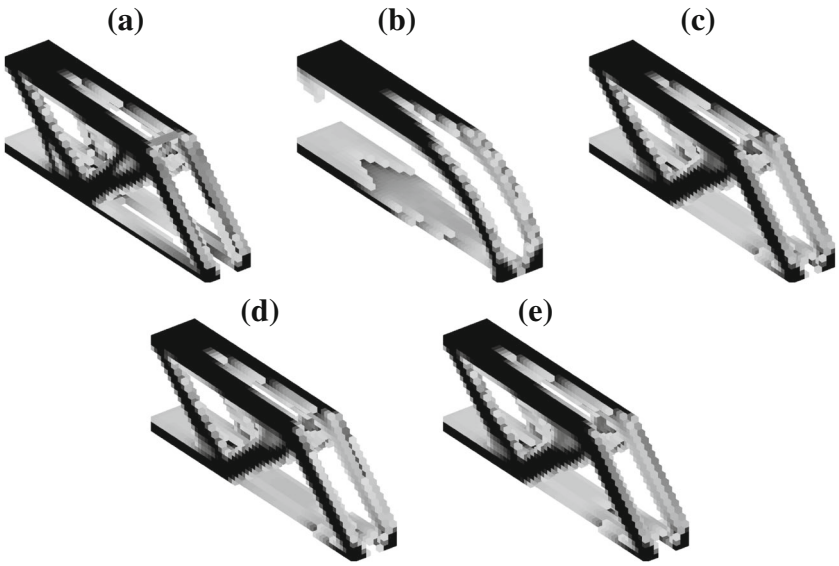

Figure 17 Designs which minimize the compliance of the three-dimensional MBB beam, assuming the **a** SIMP, **b** Hashin-Shtrikman, **c** isotruss, **d** octet truss, and **e** ORC truss material models. Darker regions indicate higher relative density ρ. Regions of $\rho < 20\%$ are not rendered

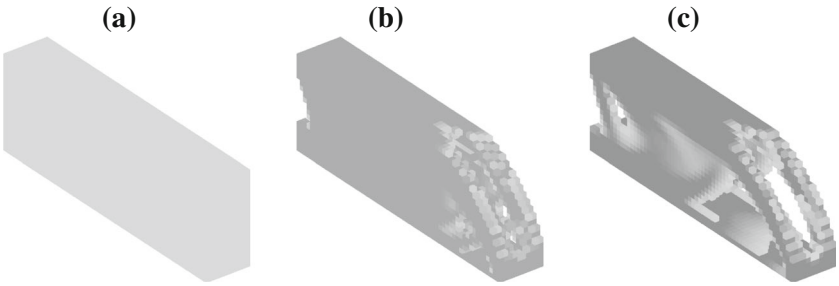

Figure 19 Additional designs of the three-dimensional MBB beam, each assuming an ORC truss microstructure: **a** uniform density, **b** multiscale SIMP design with void and lattice material; and **c** a spatially-varying relative density within a limited range. Each design has the same 20% total relative density limit as the previous example shown in Fig. 17 and uses the same color axis wherein darker regions indicate higher relative density ρ. Regions of $\rho < 20\%$ are not rendered

Table 4 Results of compliance design for the MBB beam

Material	SIMP	H-S	Isotruss	Octet truss	ORC truss
Final compliance	203.1052	185.1466	213.3568	206.1350	190.7214
Total relative density	0.500	0.500	0.500	0.500	0.500
Improvement vs. SIMP	–	8.8%	–5.0%	–1.5%	6.1%
Iteration count	95	71	96	150*	150*

Each truss lattice material has compliance comparable to the SIMP design within the error inherent in the surrogate models. An asterisk on the iteration count indicates that the iteration was terminated manually

Table 5 Results of compliance design for the cantilever beam

Material	SIMP	H-S	Isotruss	Octet truss	ORC truss
Final compliance	189.0800	171.9042	195.7026	196.8662	179.9794
Total relative density	0.500	0.500	0.500	0.500	0.500
Improvement vs. SIMP	–	9.1%	–3.5%	–4.1%	4.8%
Iteration count	60	57	108	107	113

Each truss lattice material has compliance comparable to the SIMP design within the error inherent in the surrogate models

Table 6 Results of compliance design for the torque load case

Material	SIMP	H-S	Isotruss	Octet truss	ORC truss
Final compliance	2214.6014	2192.8346	2342.3880	2245.9916	2175.5964
Total relative density	0.500	0.500	0.500	0.500	0.500
Improvement vs. SIMP	–	1.0%	–5.8%	–1.4%	1.8%
Iteration count	38	9	86	17	16

Each truss lattice material has compliance comparable to the SIMP design within the error inherent in the surrogate models

Table 7 Results of compliance design for the three-dimensional MBB beam

Material	SIMP	H-S	Isotruss	Octet truss	ORC truss
Final compliance	50.6308	43.5106	50.6104	49.6954	45.5630
Total relative density	0.200	0.200	0.200	0.200	0.200
Improvement vs. SIMP	–	14.1%	0.0%	1.9%	10.0%
Iteration count	104	134	158	181	198

The Isotruss and octet truss lattice materials have compliance comparable to the SIMP design within the error inherent in the surrogate models; the compliance improvement for the ORC model slightly exceeds the error of the surrogate models

Table 8 Results of compliance design for the three-dimensional MBB beam

Material	Single scale SIMP	Full spatial variation	Uniform density	Multiscale SIMP	Limited spatial variation
Final compliance	50.6308	45.5630	263.4428	117.7222	90.8974
Total relative density	0.200	0.200	0.200	0.200	0.200
Improvement vs. SIMP	–	10.0%	–420%	–132%	–79.5%
Iteration count	104	198	–	76	75

The first two columns of results duplicate the SIMP and ORC data from Table 7. The three remaining columns correspond to the ORC truss designs of Fig. 19. All three alternatives have higher compliance than either the SIMP or ORC designs of Example 6.4

and analogously for G^h, where the sum of $\alpha_i v_i$ terms represents the surrogate model as the sum of scaled basis functions. Lines 174, 185, and 196, which began as

```
E = Es * (  ...
```

should be corrected to read

```
E = Es *((  ...
```

Lines 181, 192, and 203, which began as

```
G = Gs * (  ...
```

should be corrected to read

```
 G = Gs *((  ...
```

Lines 176, 183, 187, 194, 198, and 205, which ended as

```
... (1+2*deriv);
```

should be corrected to read

```
... (1+2*deriv));
```

In the general case, this can be a very large error, depending on the magnitudes of E_S and G_S. In the case of our paper, we used $E_S = 1.0$, so in fact the value of E^h was correct; but $G_S = 0.38$, and so the value of G^h was too high by a factor of approximately 2.5. That is, as implemented in the topology optimization code, the truss lattices have artificially high shear stiffness at all relative densities. This error does not affect the SIMP or Hashin-Shtrikman designs.

We have corrected these errors in our topology optimization code and re-generated the examples from the original paper. Corrected versions of Figs. 14, 15, 16, 17 and 19 and Tables 4, 5, 6, 7 and 8 appear below. In general, the results show faster convergence and higher (worse) compliance than originally, as expected. Our observation that the ORC truss out-performs the isotruss and octet truss remains true for each example; however, with the corrected results it is no longer the case that any of the truss lattices out-perform the Hashin-Shtrikman material, and indeed they also compare less favorably to the single-scale SIMP designs than we observed in the original paper. The ORC truss has lower (better) compliance than the SIMP design in each example we considered, but in three of the four cases, the improvement was within the margin of accuracy of the surrogate model, suggesting that the improvement may be illusory. In the 3D example, however, the improvement does exceed the margin of accuracy, although it is still lower than we originally reported.

It remains the case that even though the performance of the lattice designs is now comparable with the SIMP design, such designs retain the advantage of being immediately manufacturable since we know precisely what microstructure gives the interpolated response, in contrast to the SIMP design which uses a fictitious penalized material. It is also interesting to note that with the corrected code the converged designs obtained with the lattice materials are much more similar to those obtained for the SIMP material; large regions of intermediate relative density are not efficient in the presence of the mass constraint once the artificially high shear stiffness is corrected.

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Compliance with ethical standards

Conflict of interests The authors declare that they have no conflict of interest.