Estimation of Geometric Tortuosity for Bulk Acoustic Absorbers using the Heat Method

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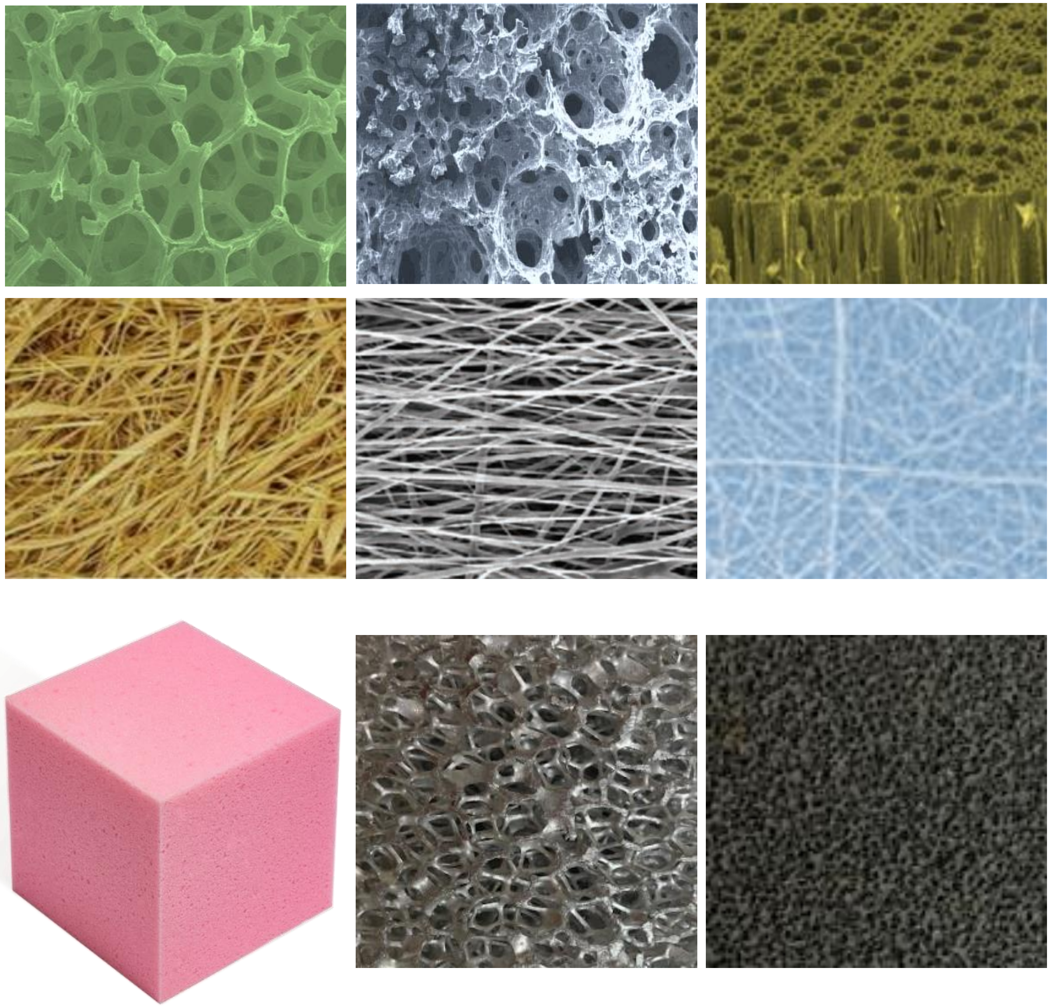
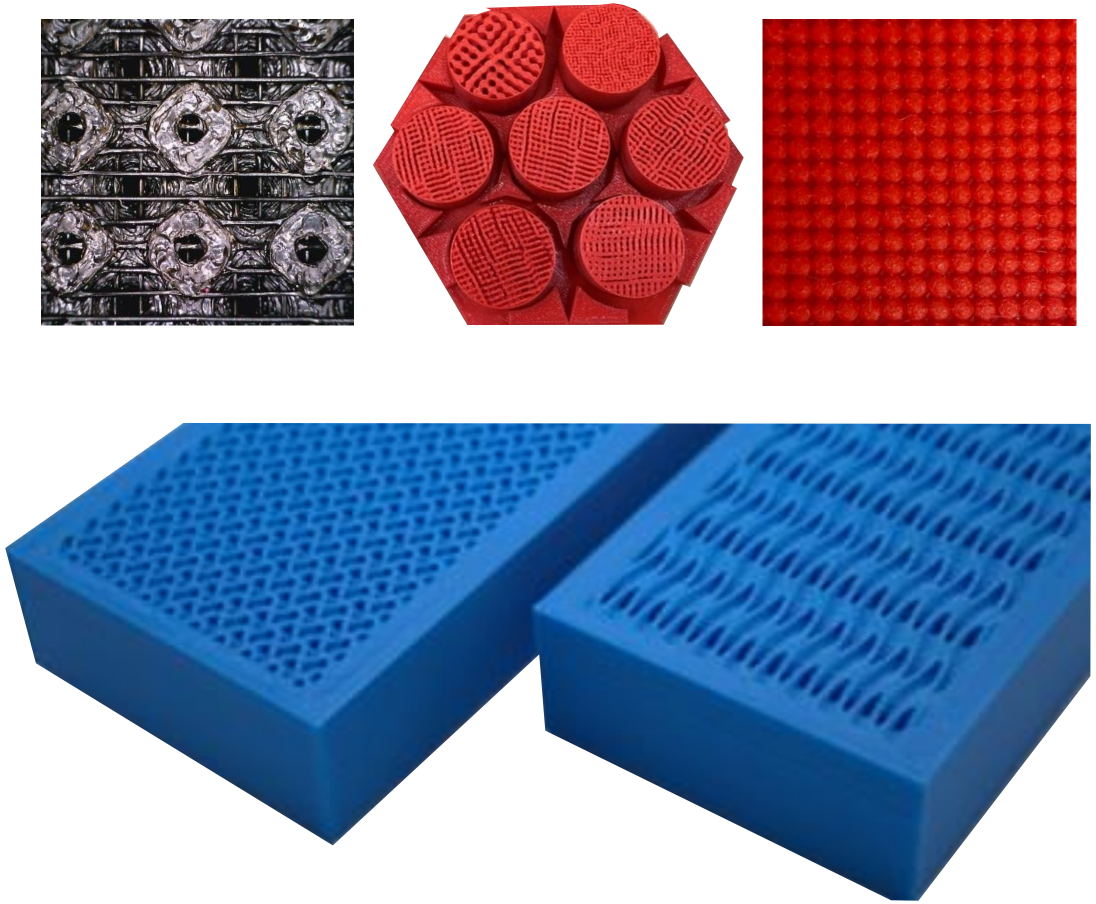
Bulk Porous Absorbers

Traditional Manufacturing or Natural

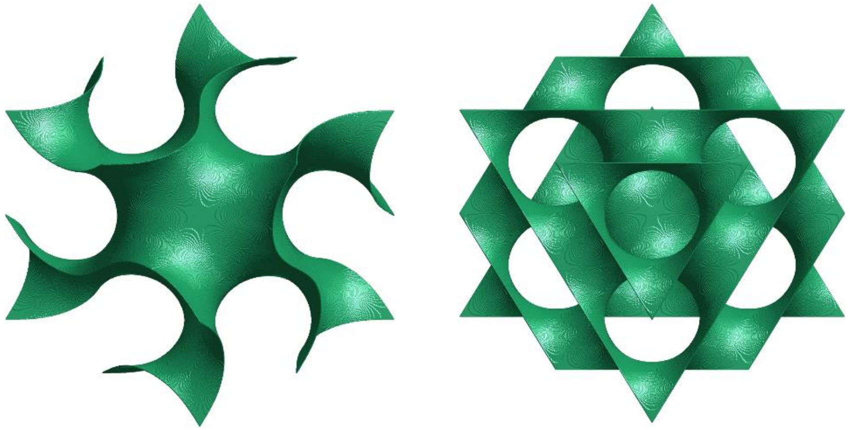


Additive Manufacturing

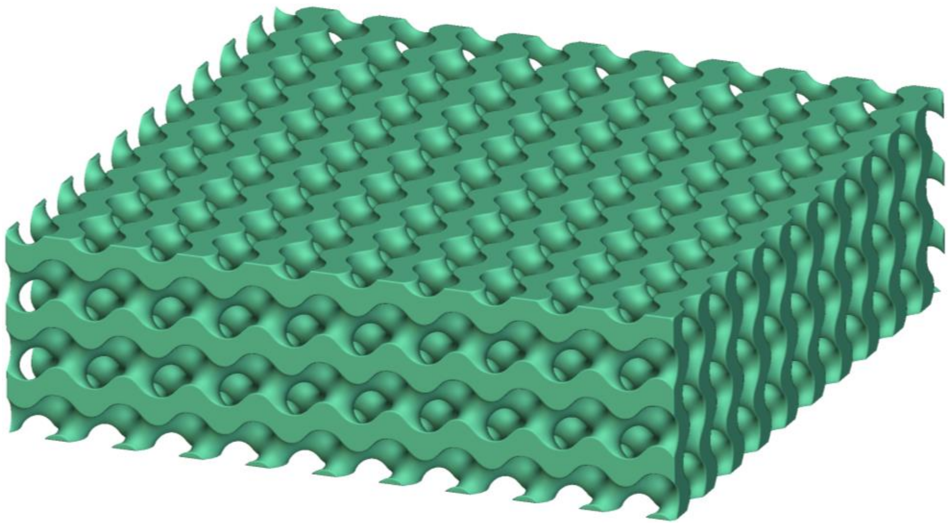


Triply Periodic Minimal Surfaces

Unit Cells

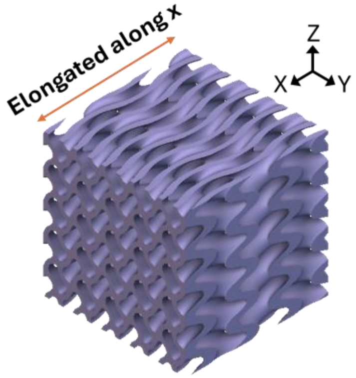


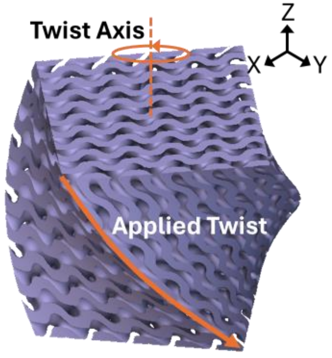
Lattice

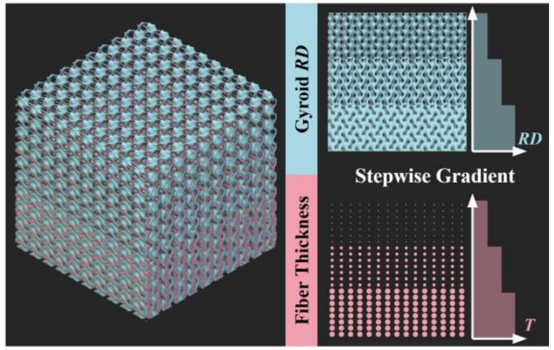


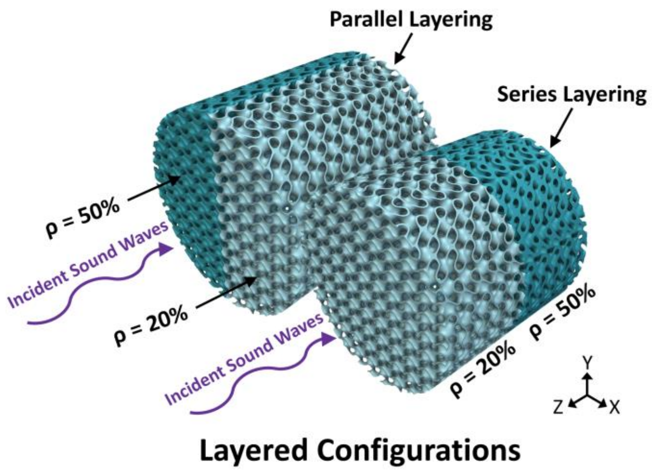
MADLab TPMS Studies

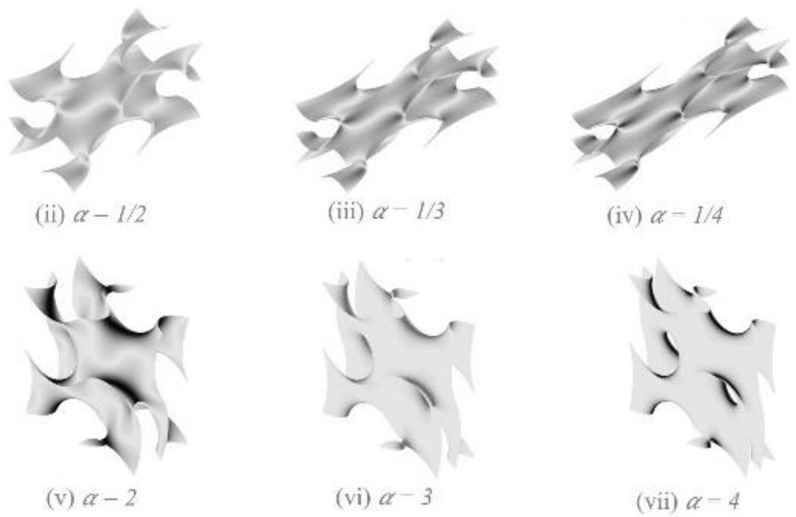
- Fiber integration
- Gradients
- Symmetry breaking





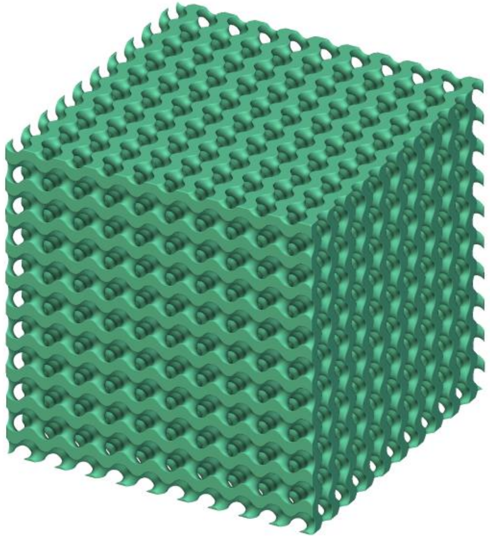






Acoustic Absorber Modeling

Equivalent Fluid



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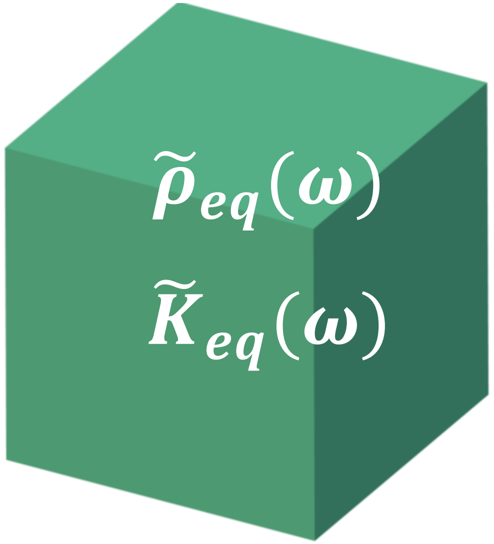

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Johnson-Champoux-Allard-Lafarge (JCAL) Model

$$\rho_0\left[\alpha_\infty + \frac{\nu\phi}{j\omega k_0}\sqrt{1+\frac{j\omega}{\nu}\left(\frac{2\alpha_\infty k_0}{\phi\Lambda}\right)^2}\right]$$

$$\gamma P_0\left[\gamma-(\gamma-1)\left(1+\frac{\nu'\phi}{j\omega k_0'}\sqrt{1+\frac{j\omega}{\Lambda'}\left(\frac{2k_0'}{\phi\Lambda'}\right)^2}\right)^{-1}\right]^{-1}$$

$$\alpha_\infty = \frac{\lim\limits_{\omega\to\infty}\tilde{\rho}_{eq}(\omega)}{\rho_0}$$

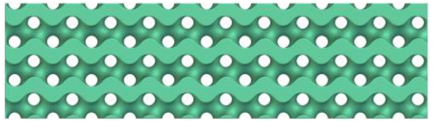
Transport Parameters

- α_∞ Tortuosity, high ω limit
- Λ Viscous Characteristic Length
- k_0 Static Viscous Permeability
- ϕ Open Porosity
- Λ' Thermal Characteristic Length
- k_0' Static Thermal Permeability

Acoustic Tortuosity

Ultrasonic Measurement

Emitter



Detector

Inverse Characterization

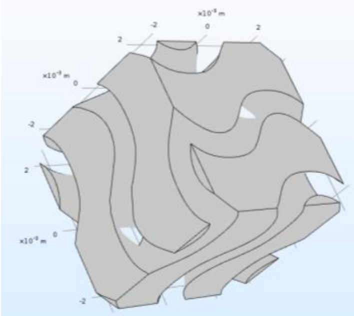
If

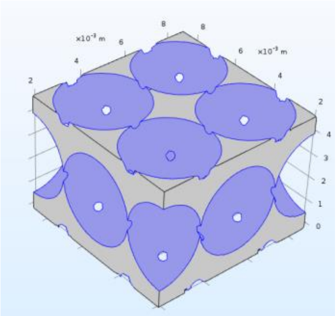
$$\alpha = f(\phi, \alpha_\infty, \Lambda, \Lambda', k_0, k_0')$$

Then

$$\begin{aligned} \alpha_\infty &= g(\alpha_{meas}) \\ \Lambda &= g(\alpha_{meas}) \\ \Lambda' &= g(\alpha_{meas}) \\ k_0 &= g(\alpha_{meas}) \\ k_0' &= g(\alpha_{meas}) \end{aligned}$$

Electrical Conductivity Problem





$$\begin{aligned} E &= e - \nabla q && in\ \Omega_f \\ \nabla \cdot E &= 0 && in\ \Omega_f \\ E \cdot \hat{n} &= 0 && on\ \Gamma_{sf} \end{aligned}$$

$$\alpha_\infty = \frac{\langle E \cdot E \rangle}{\langle E \rangle \cdot \langle E \rangle}$$

Physical samples only

Difficult test

Physical samples only

Semi-empirical

Model or unit cell only

Periodic only

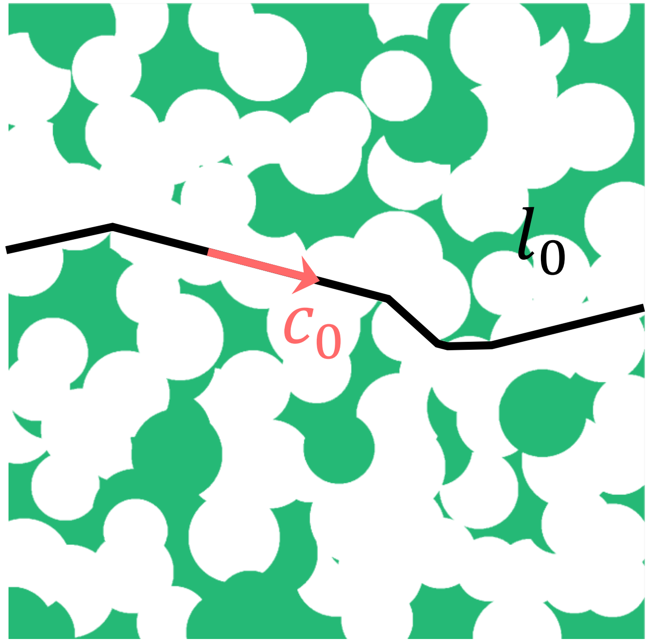
Geometric Tortuosity

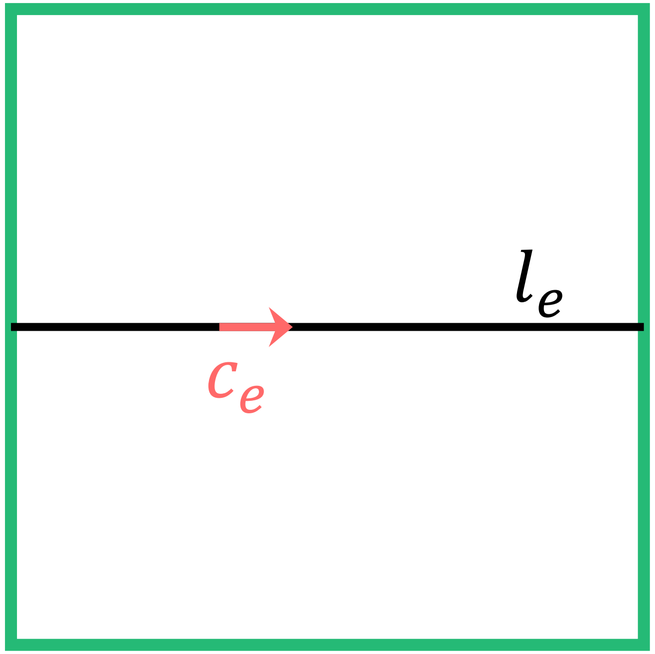
$$\alpha_\infty = \frac{\lim_{\omega\to\infty} \rho_e(\omega)}{\rho_0} = \frac{T_0}{T_e} = \left(\frac{c_0}{c_e}\right)^2 = \left(\frac{l_0}{l_e}\right)^2 = \tau^2$$

Ideal gas

Sound speed

Equal transit time





Geometric Tortuosity

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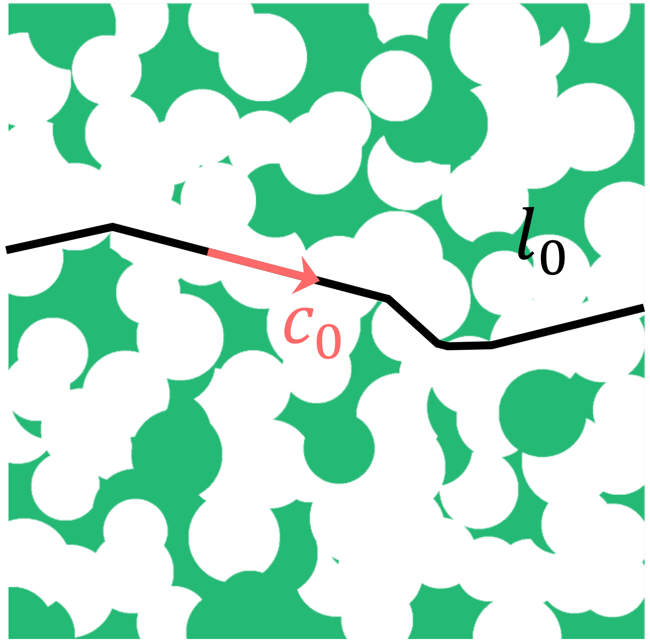
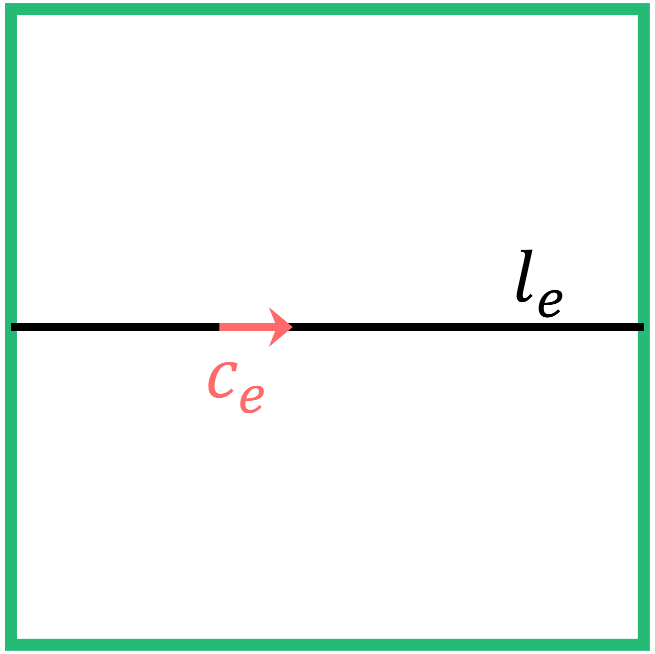


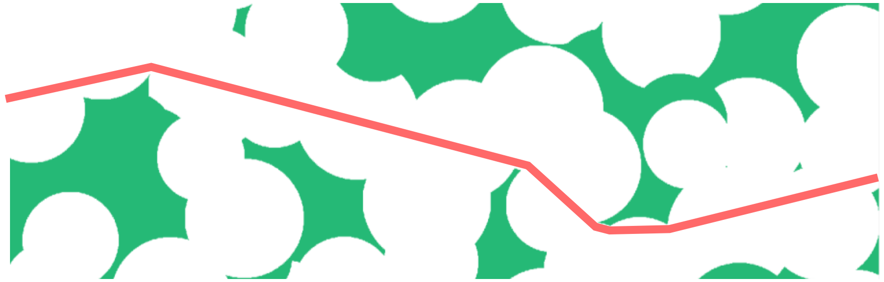


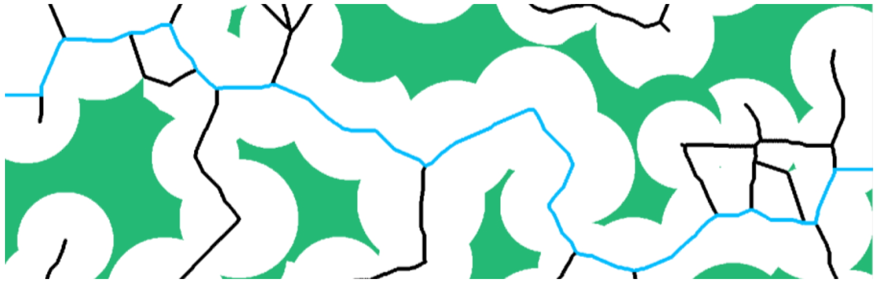
What is the effective length?

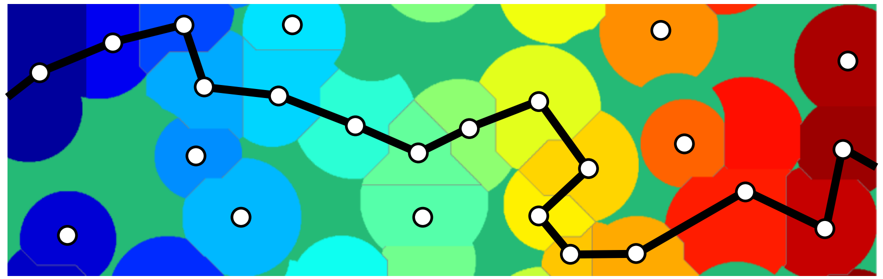
Unconstrained

Pore Skeleton

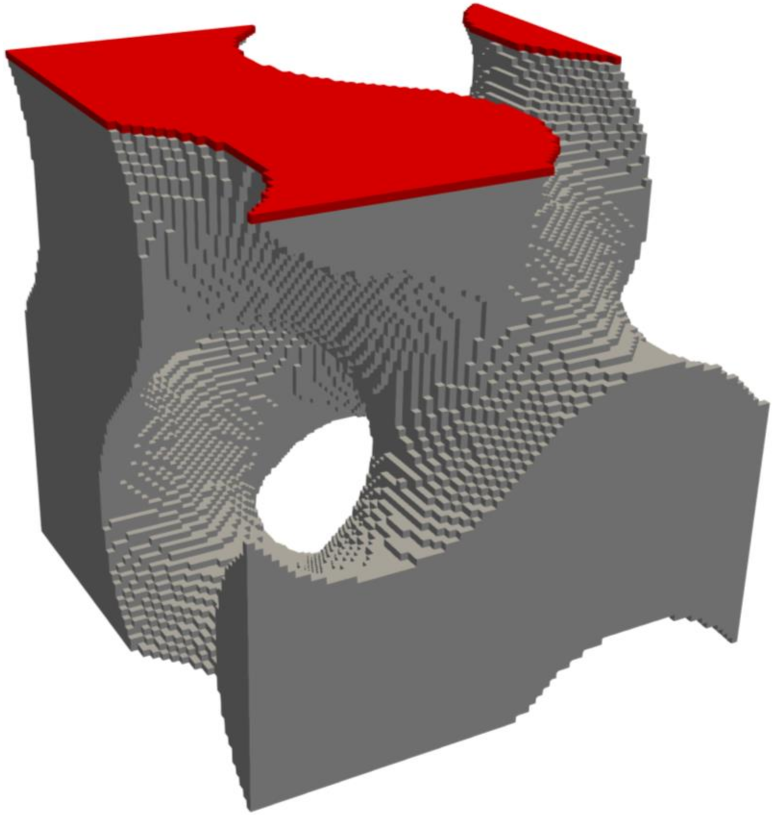
Pore Centroid – Pore Centroid







1) Initial temperatures



The Heat Method

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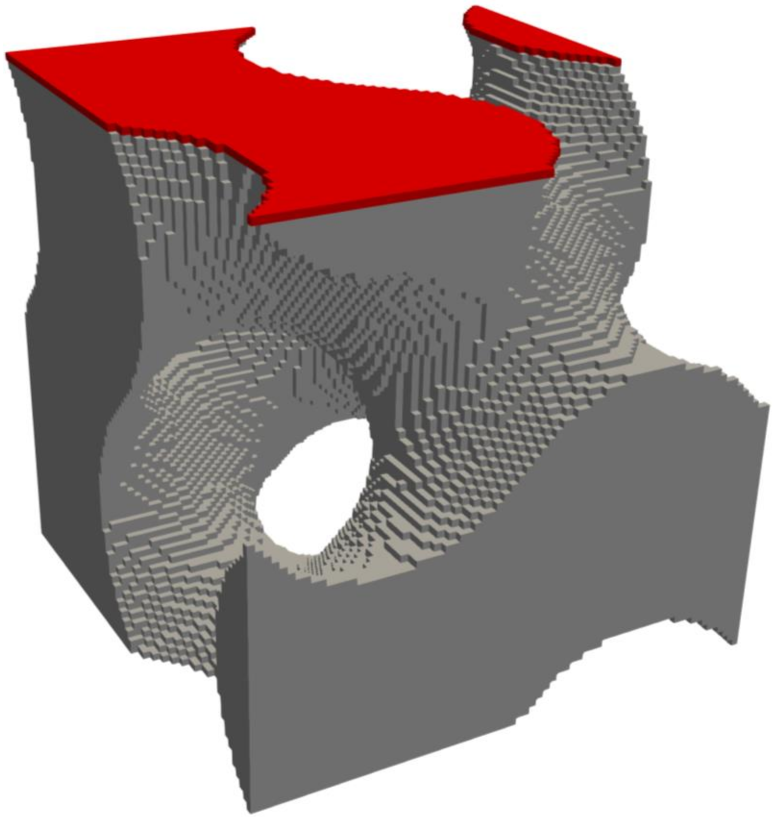
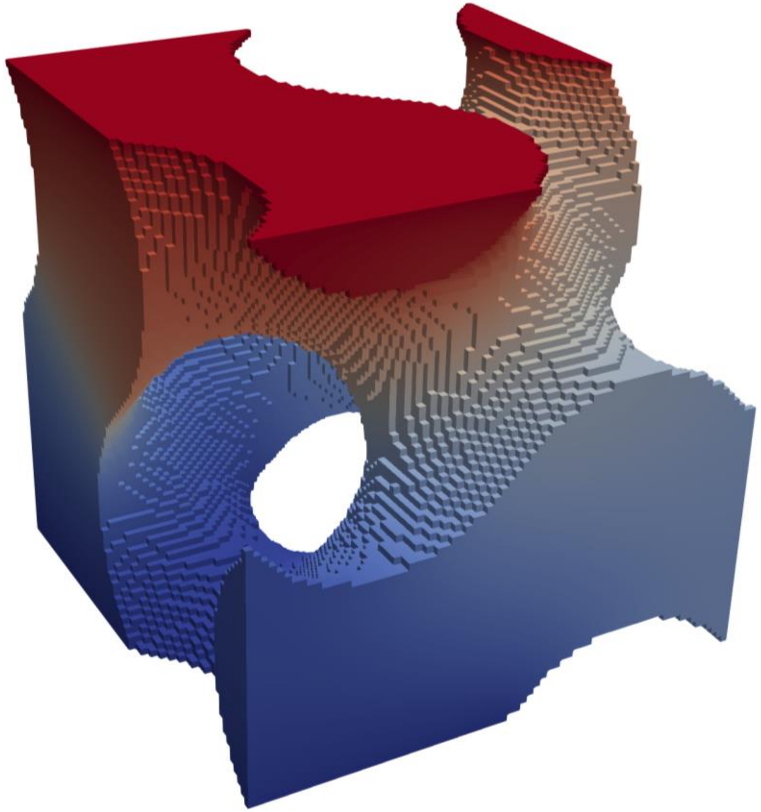


2) Heat propagation for time t



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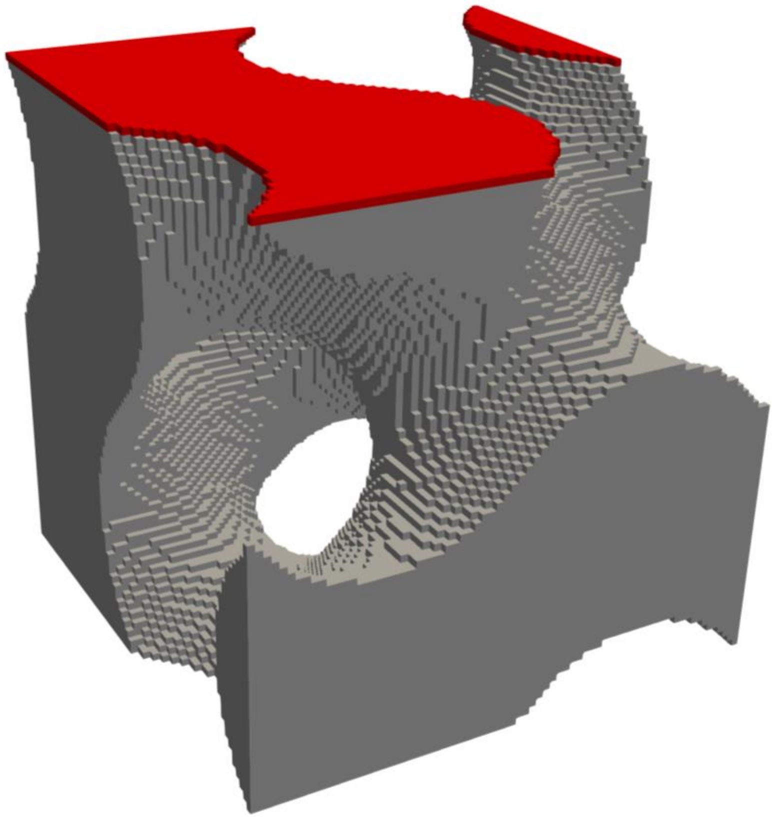

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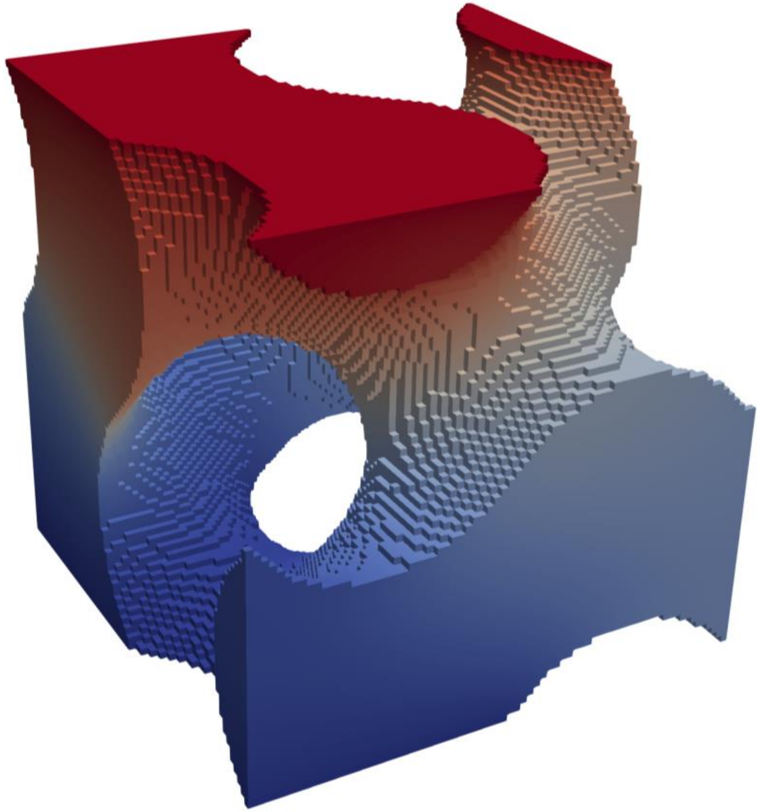
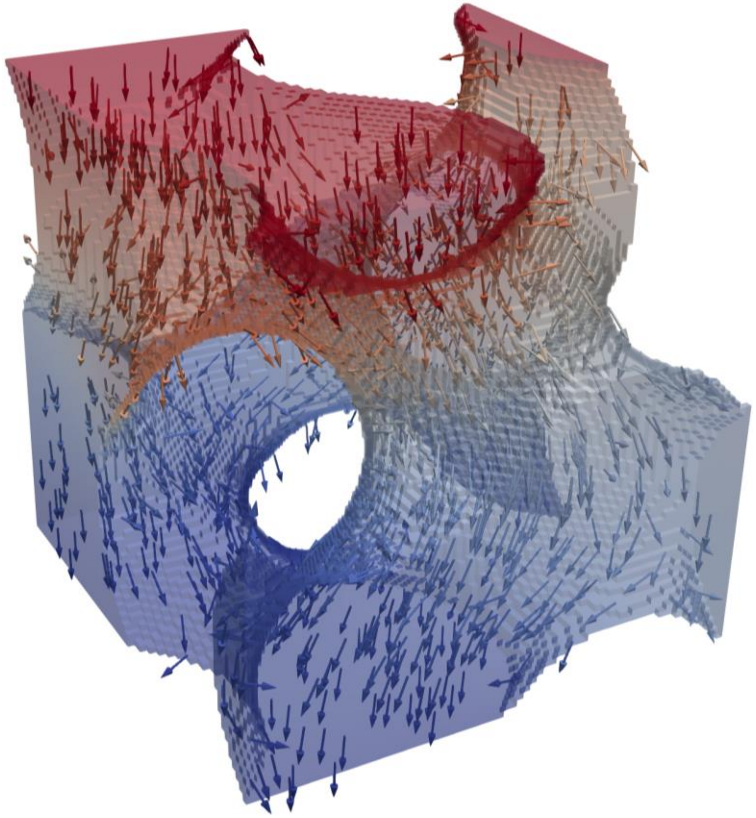


3) Compute $\widehat{\nabla T}$



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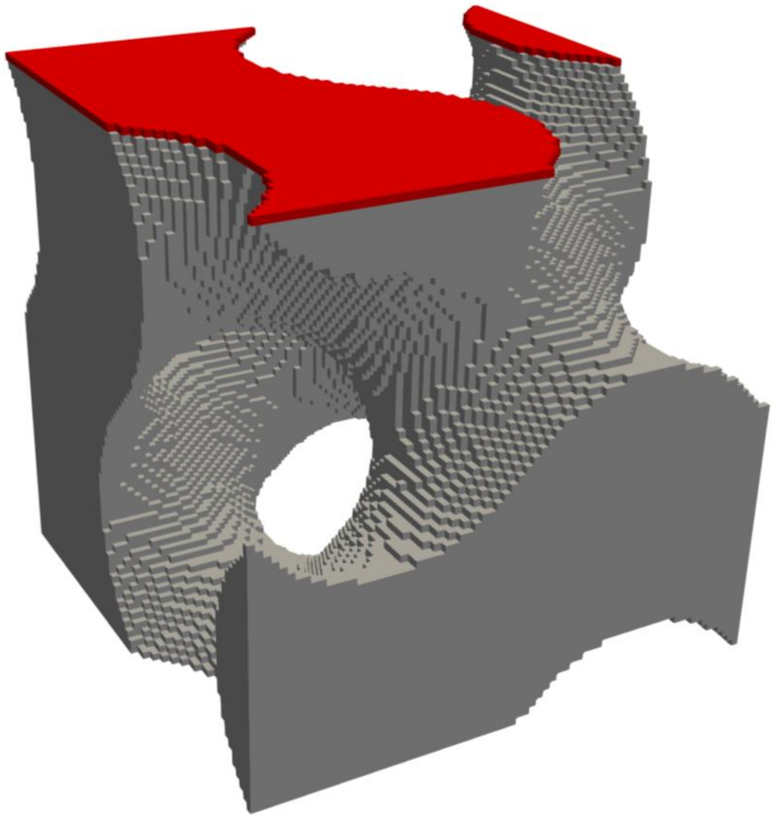

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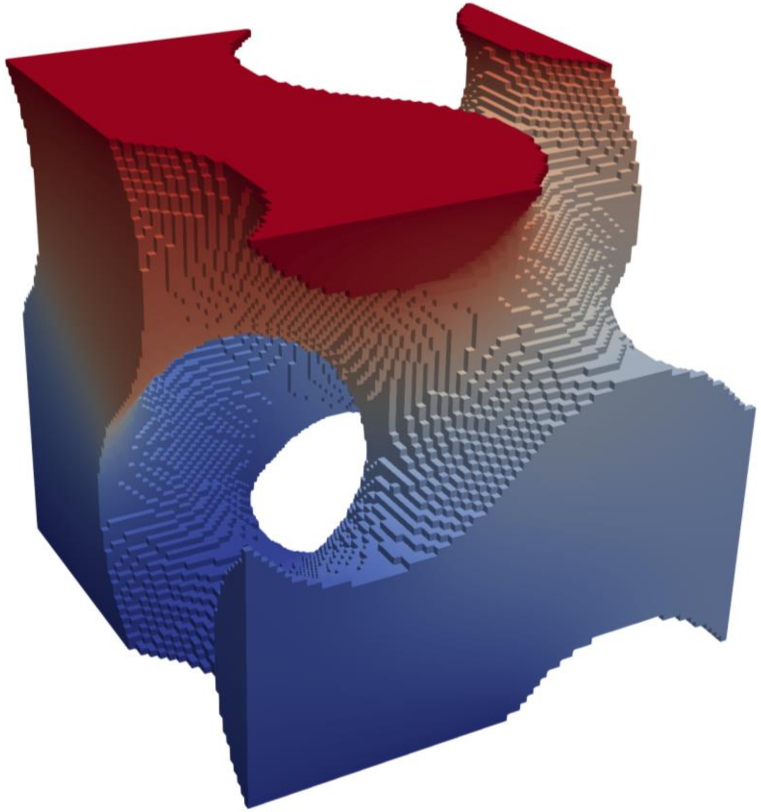

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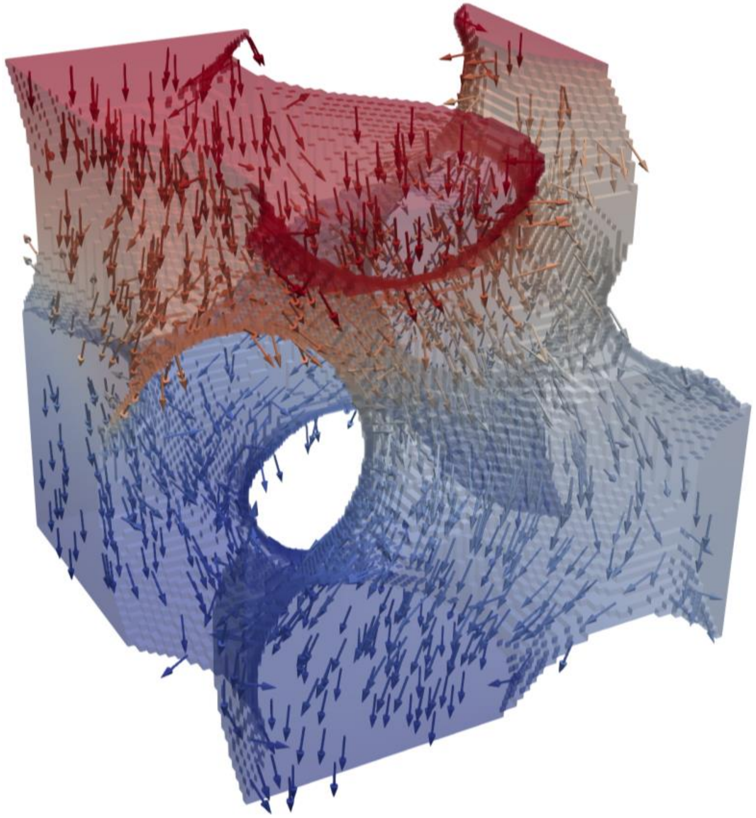
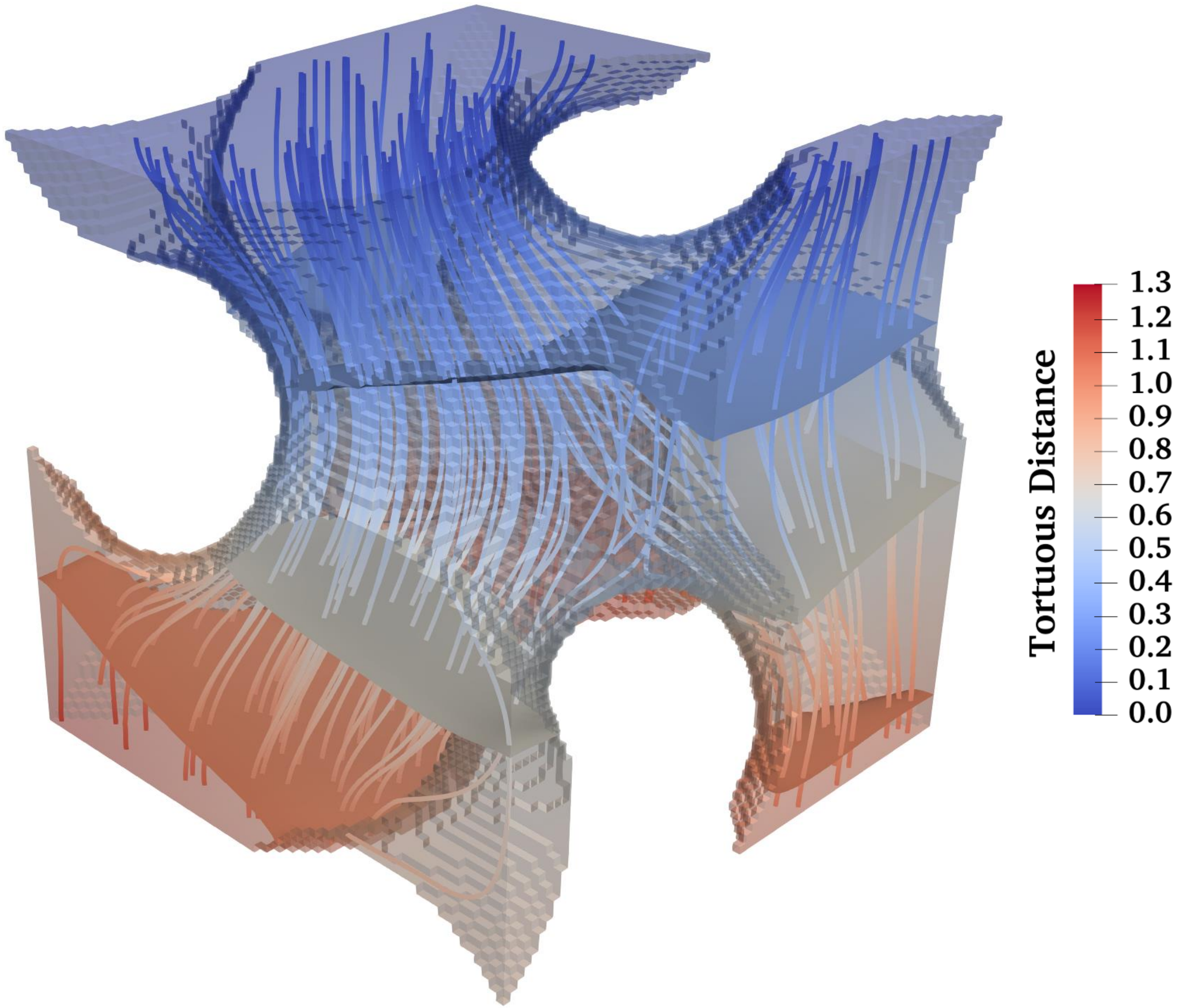


4) Solve Poisson's equation

$$\nabla^2 \phi = \nabla \cdot \widehat{\nabla T}$$

Where ϕ is a scalar field of approximate tortuous distance

Gyroid Unit Cell: 50% Porosity



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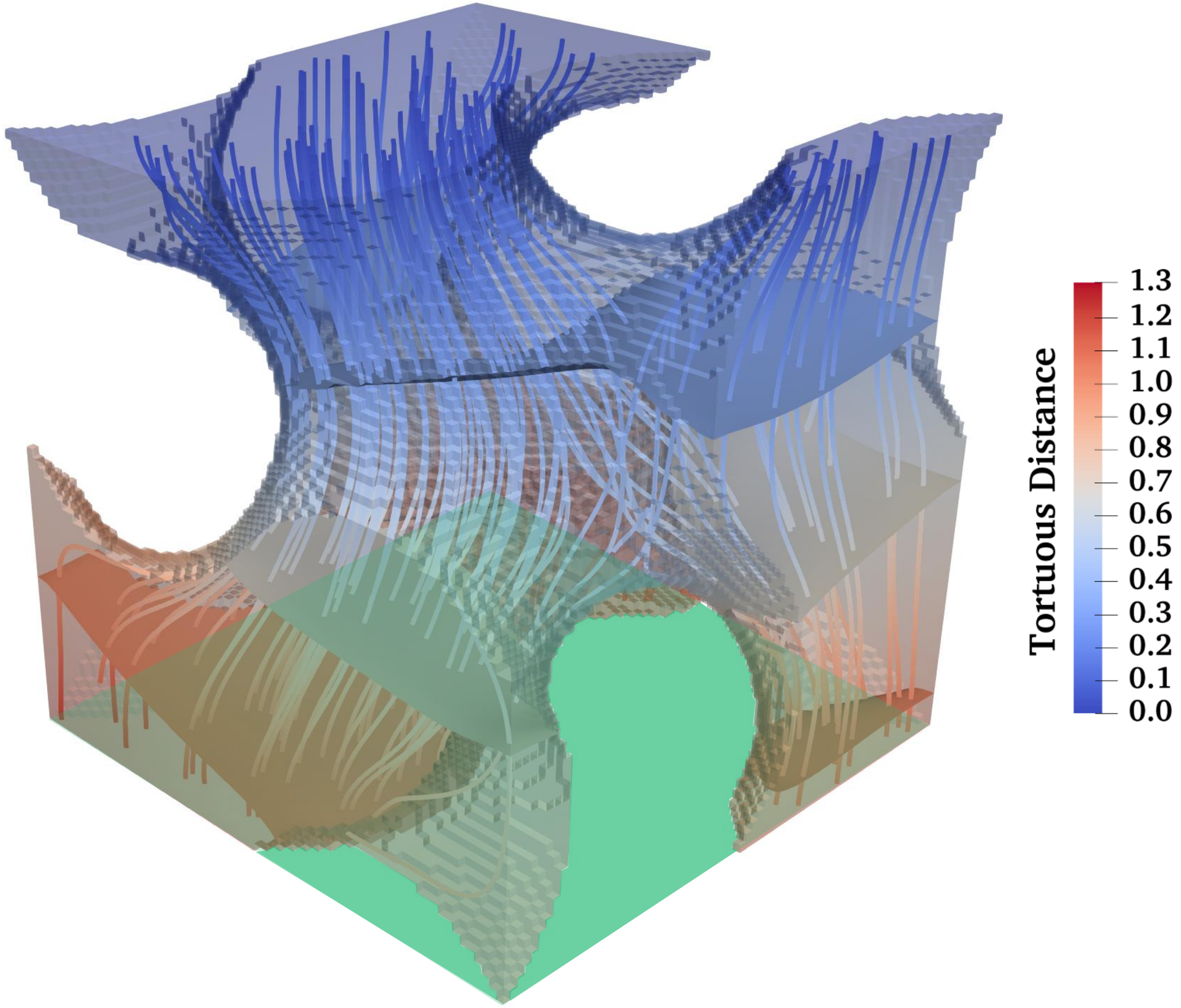

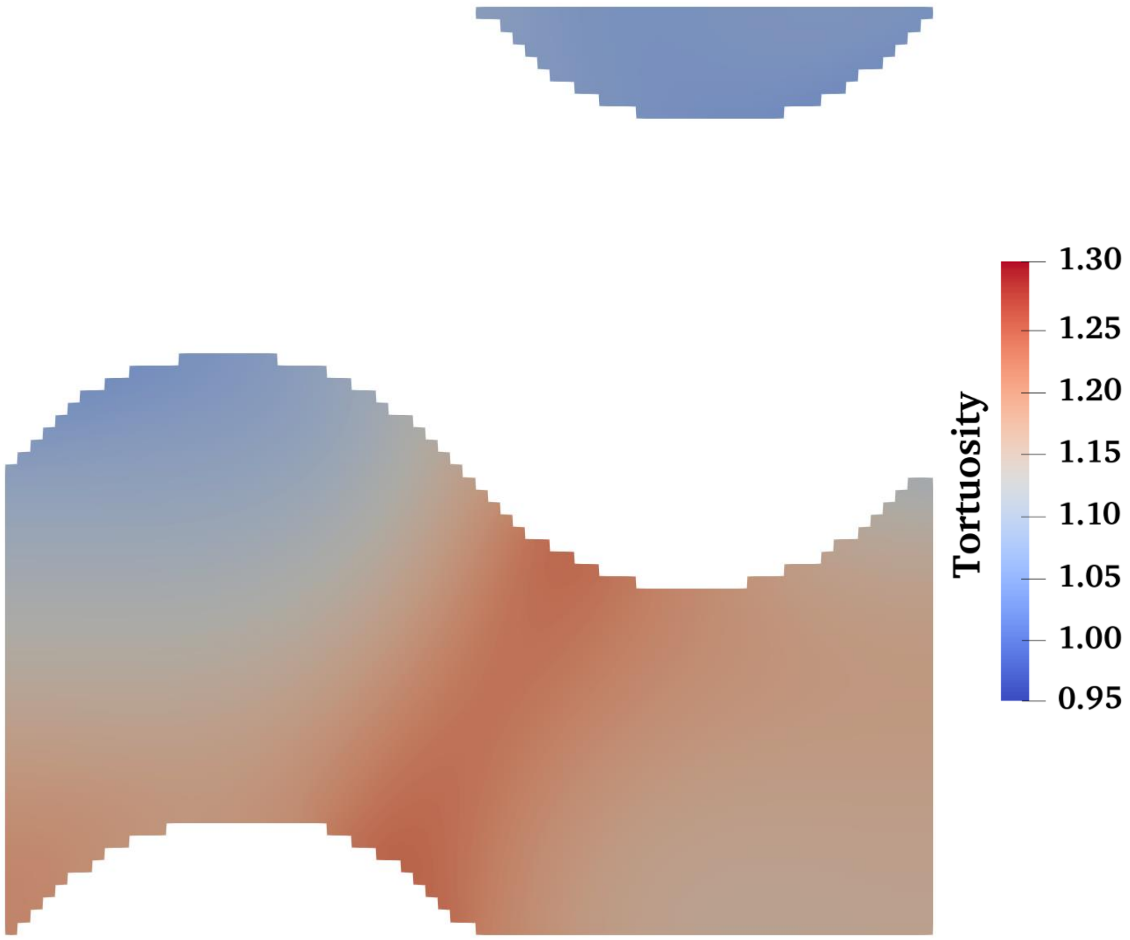

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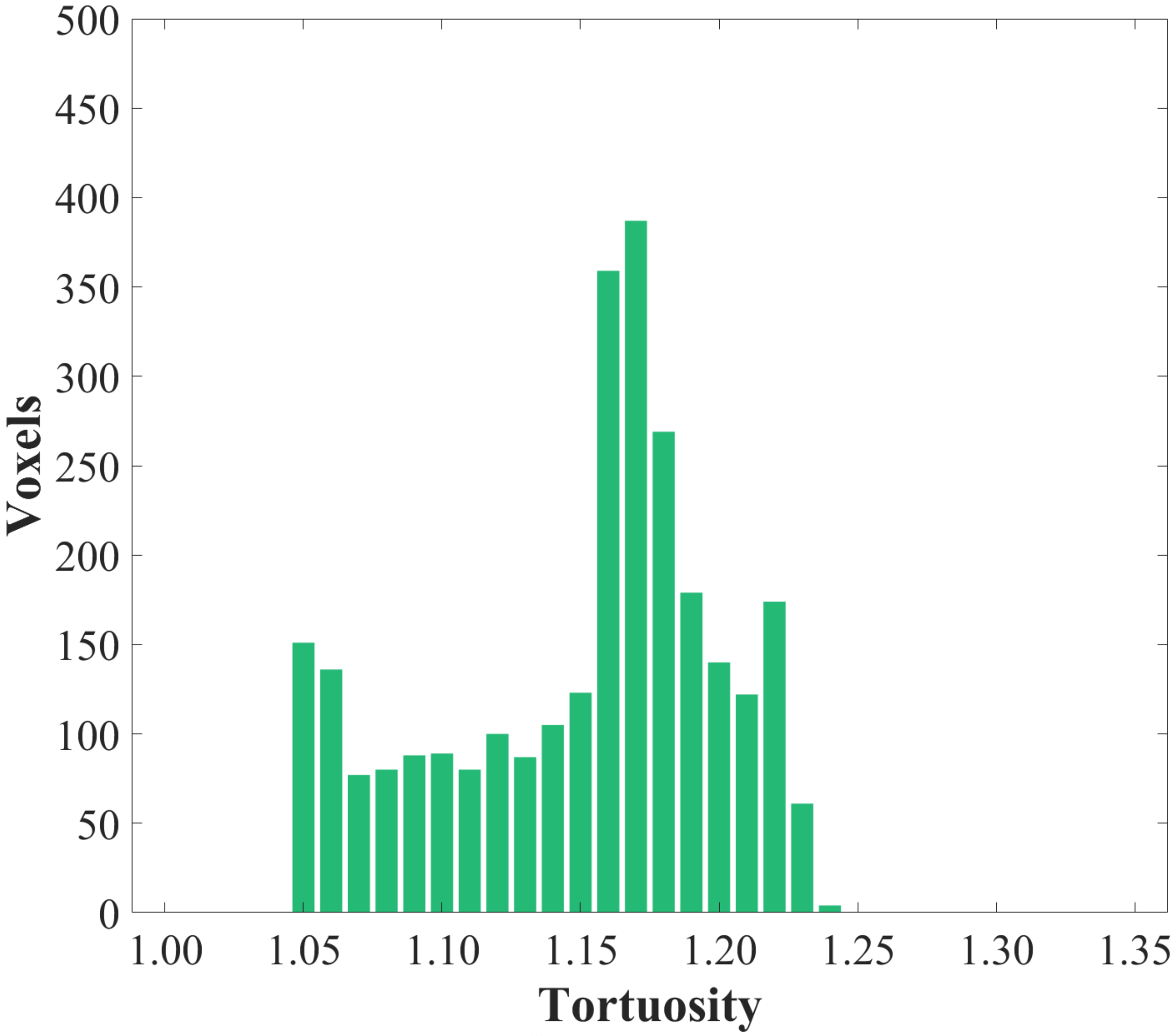
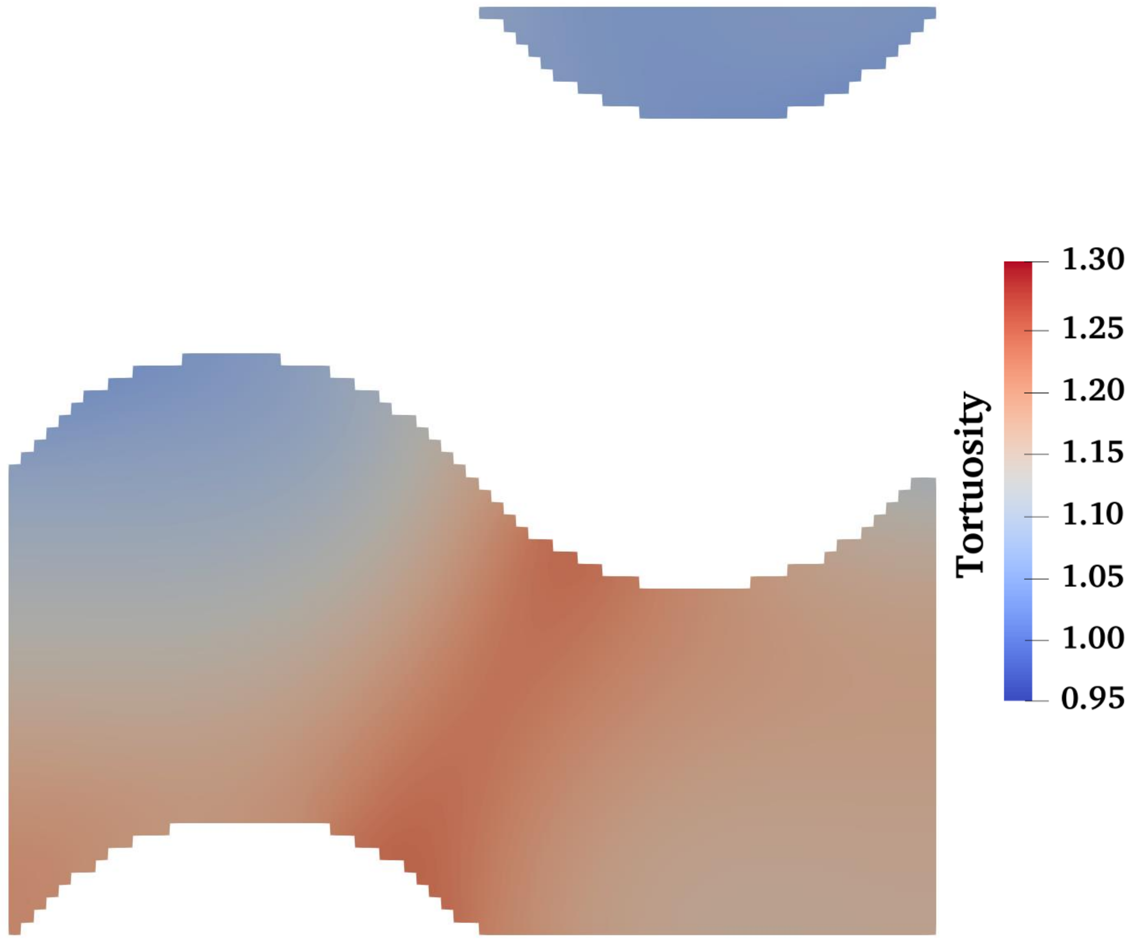
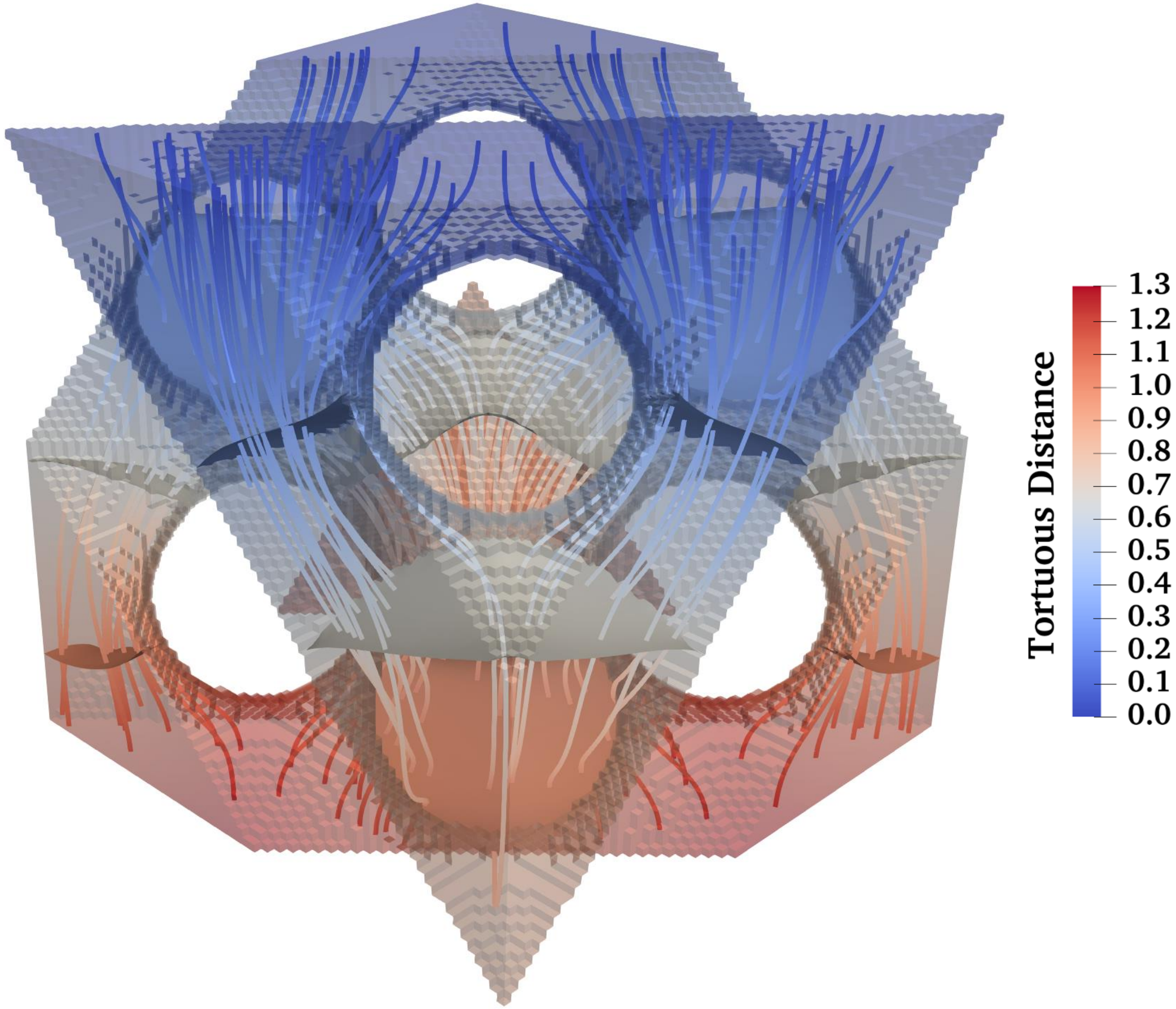




Diamond Unit Cell: 50% Porosity



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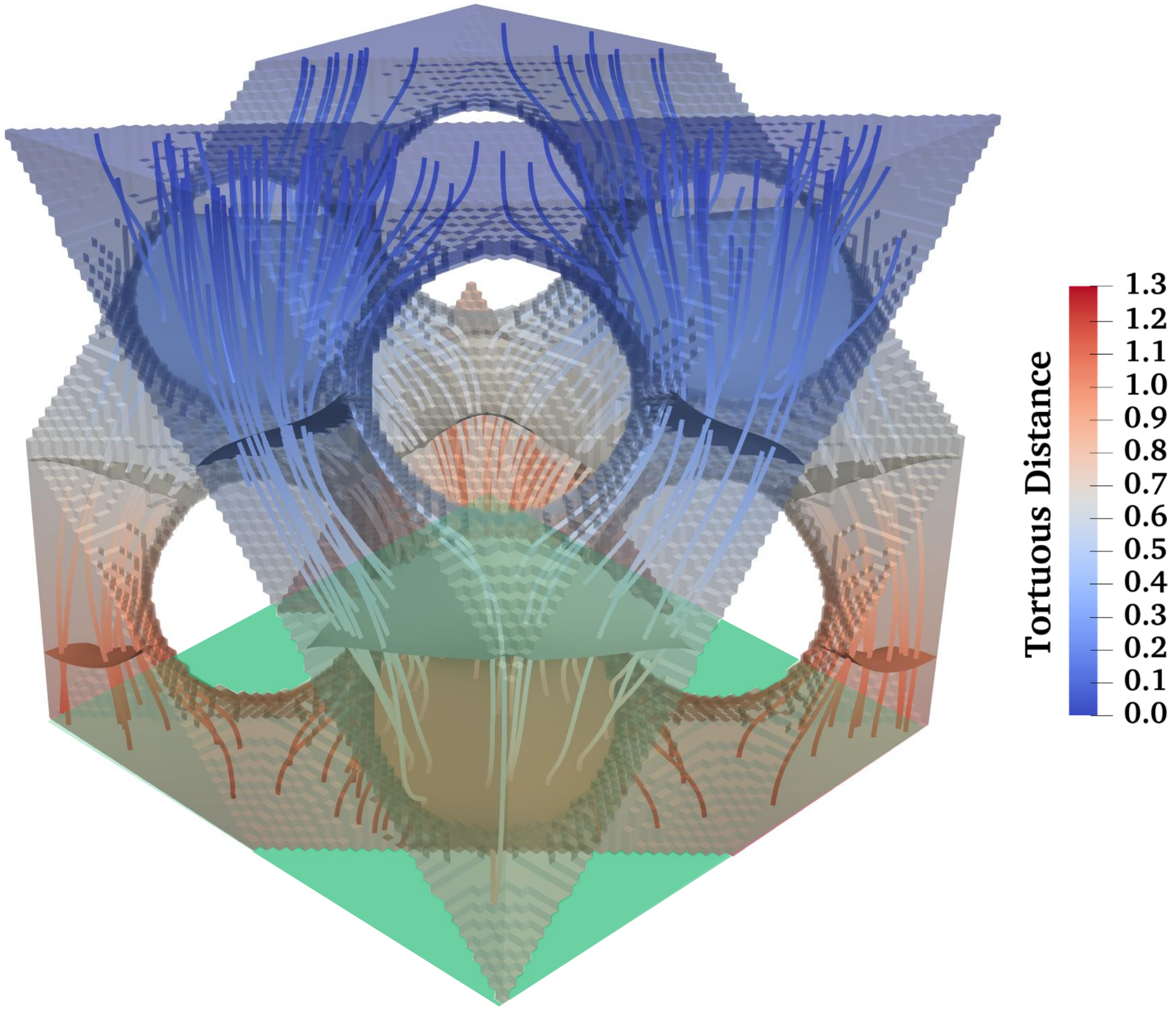

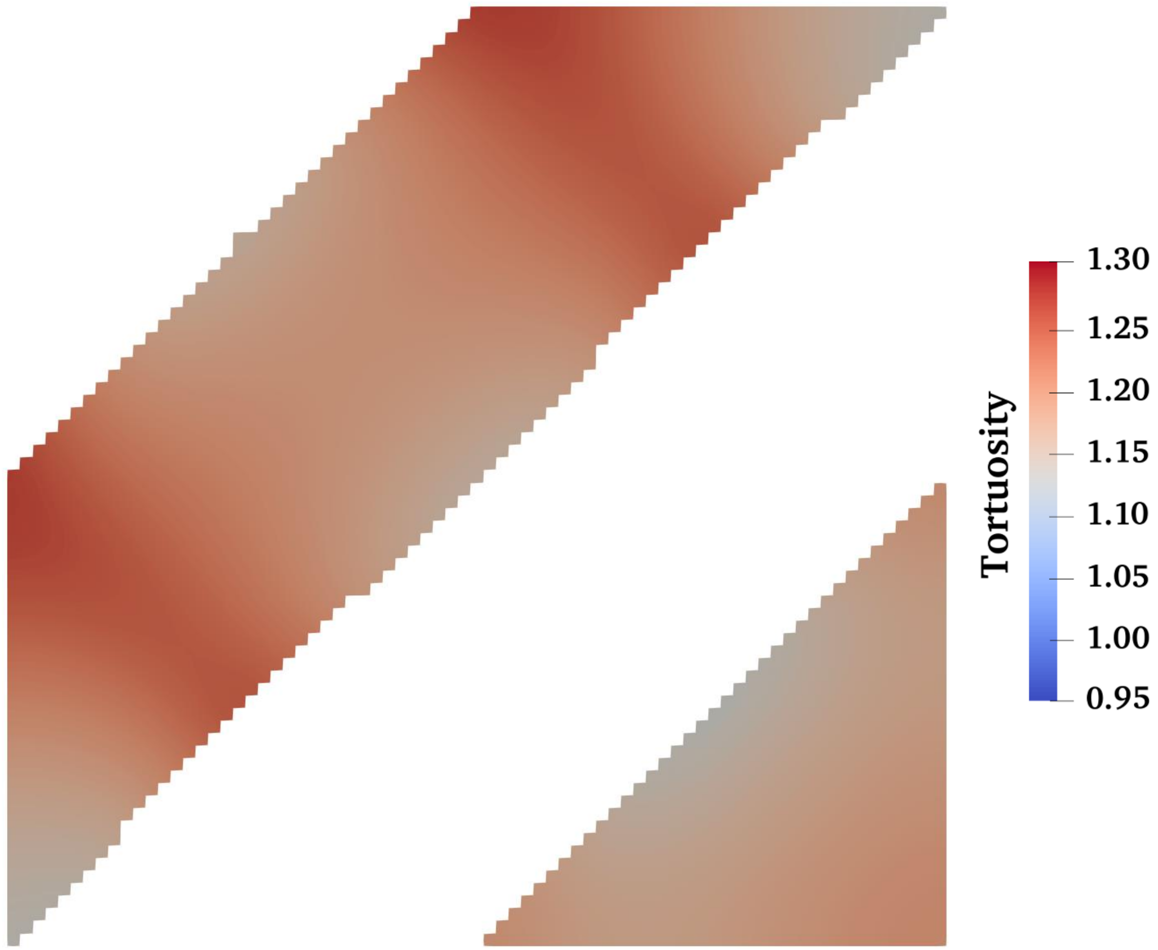

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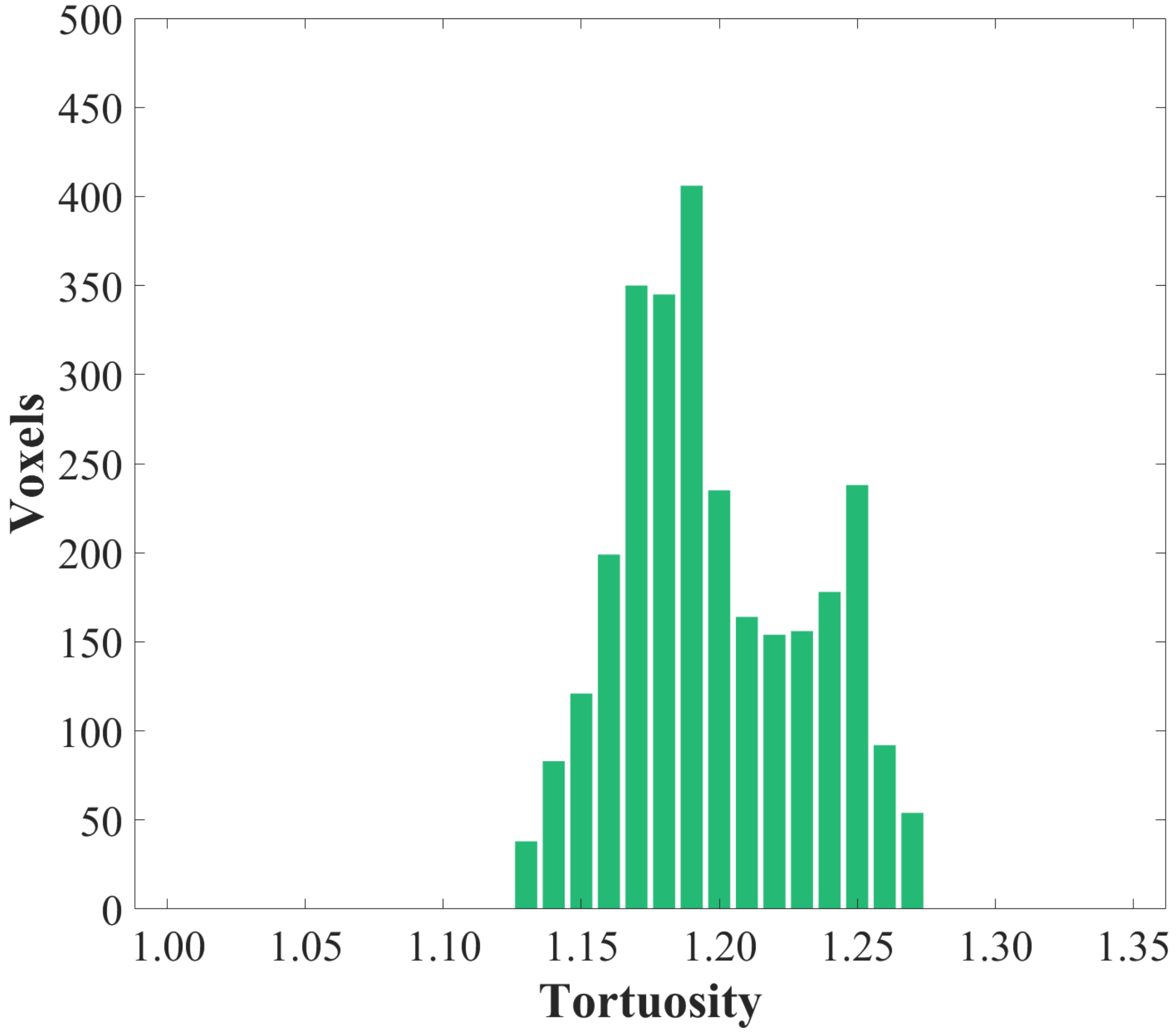
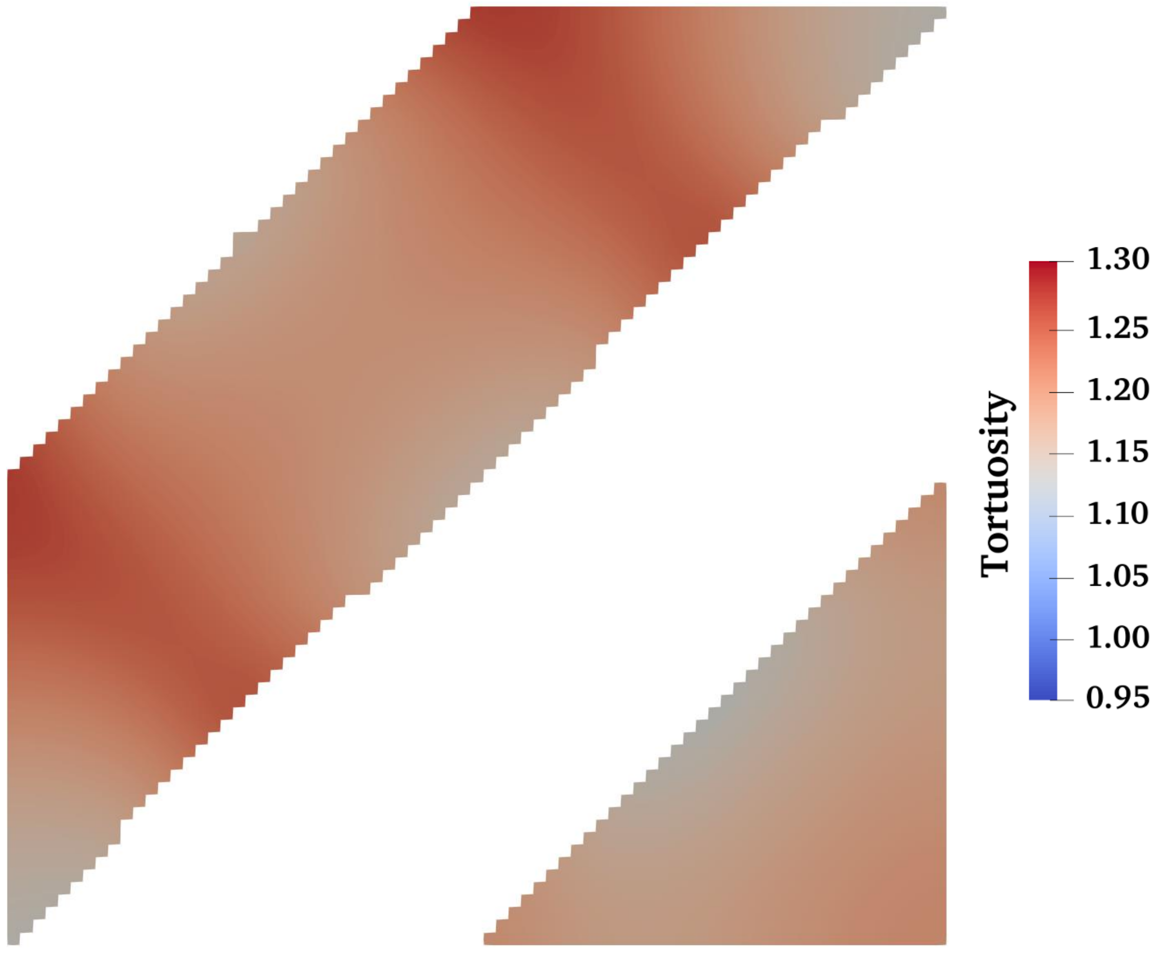
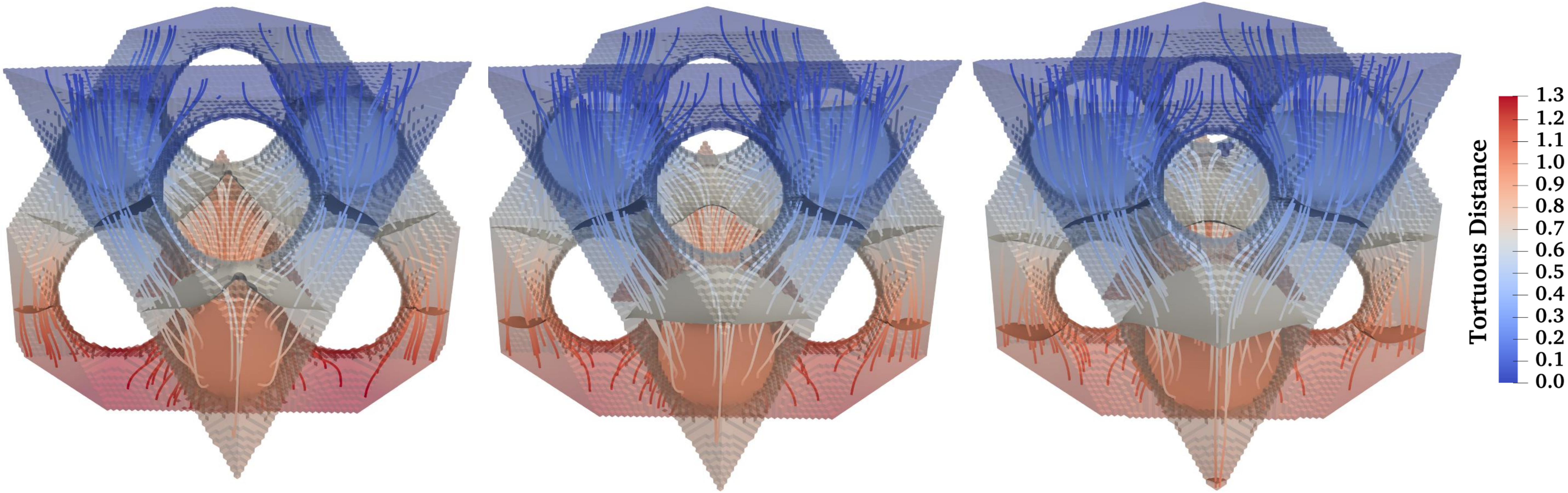




Varying Porosity

40% 50% 60%



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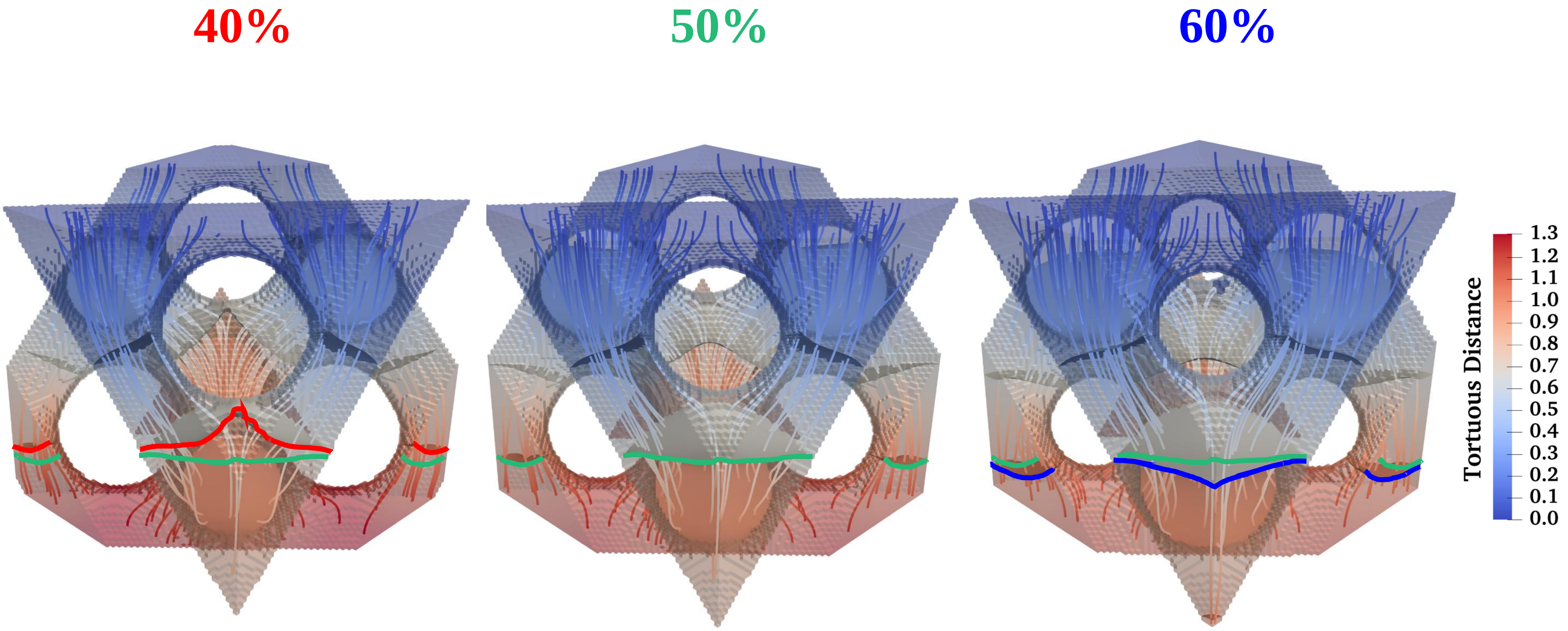

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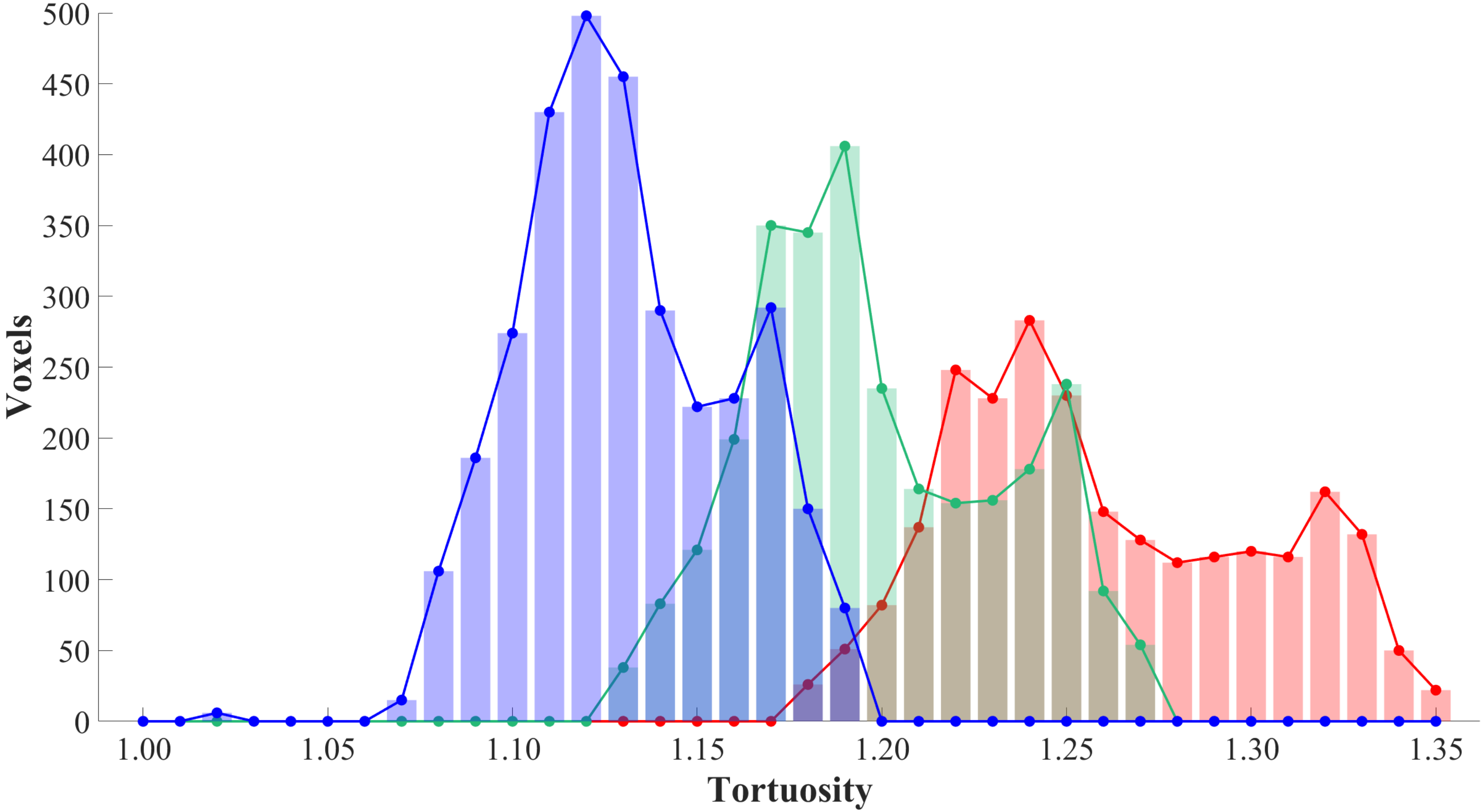
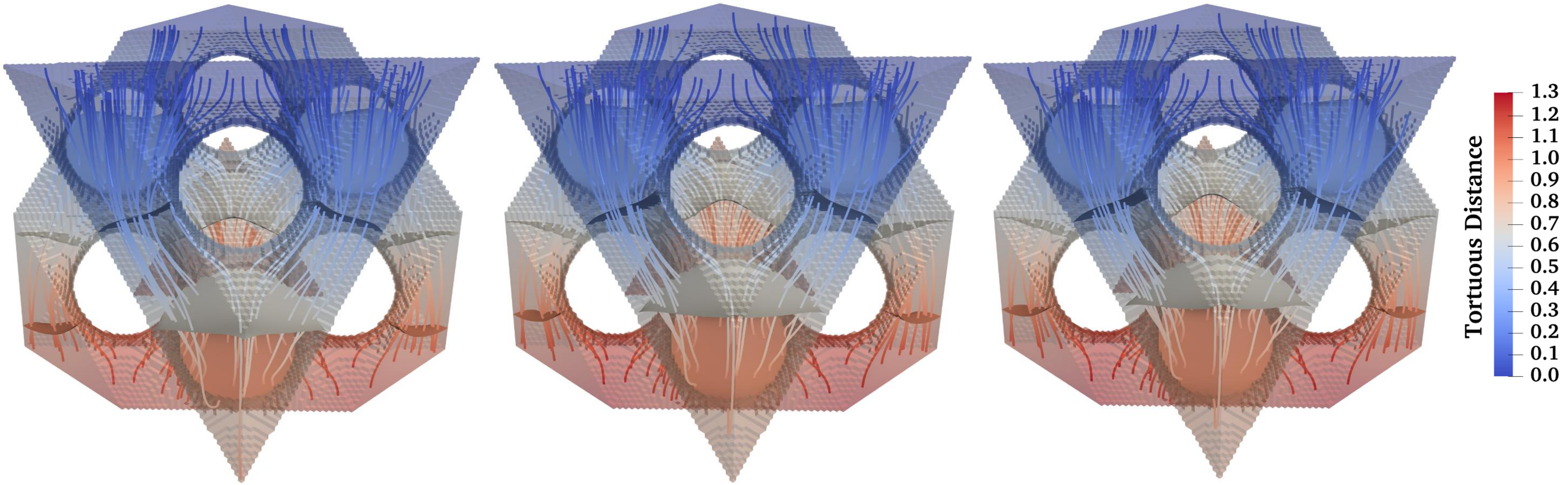


Varying Timestep

0.1 s **1 s** **10 s**



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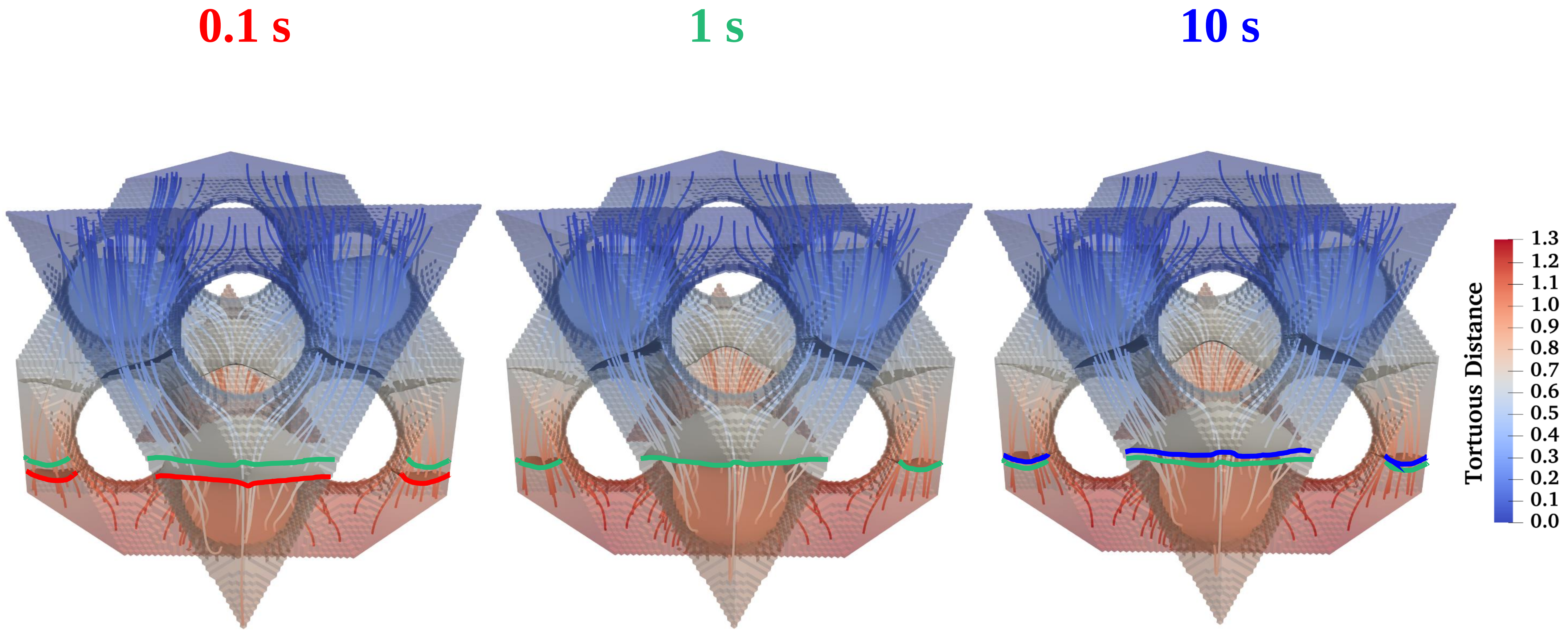

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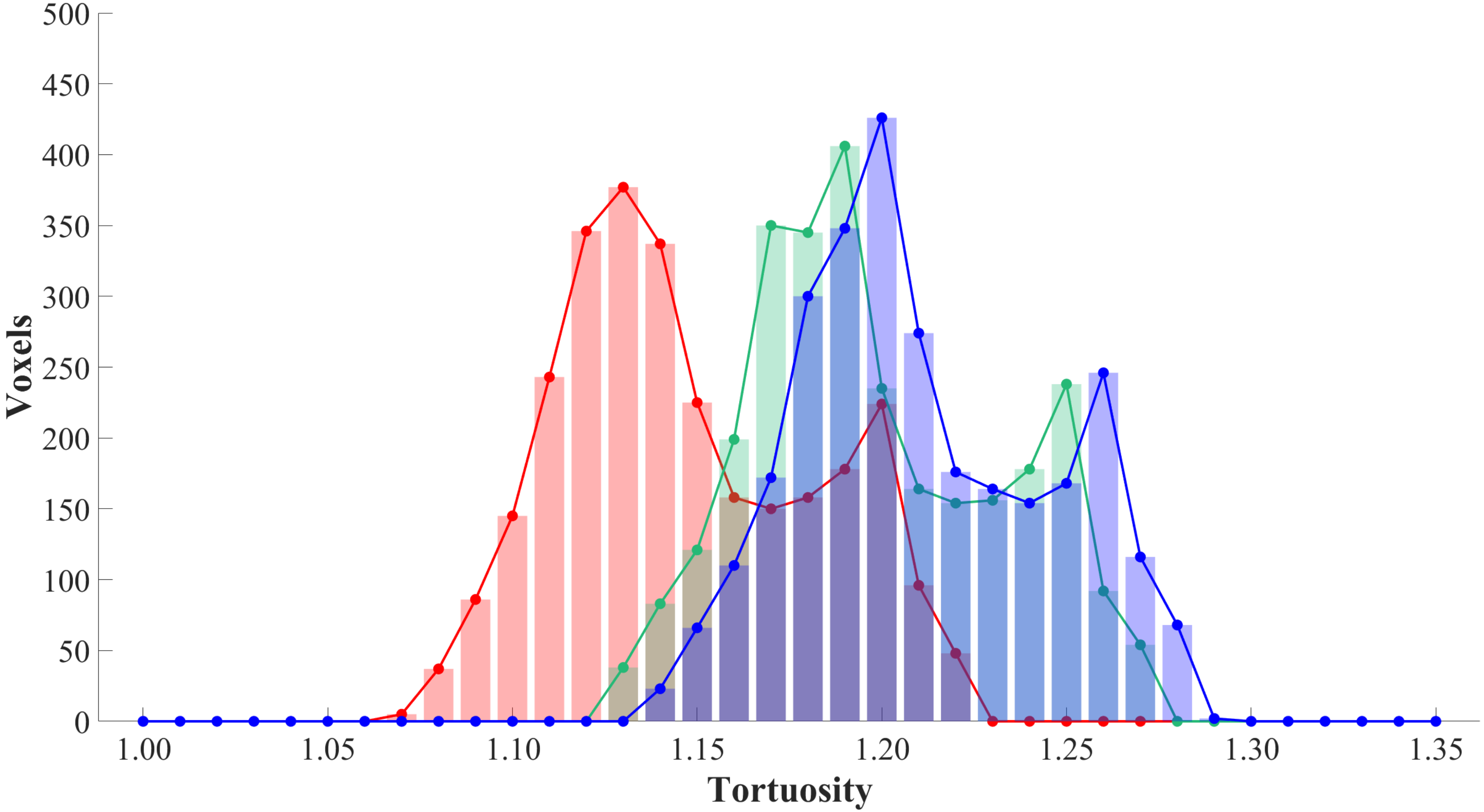
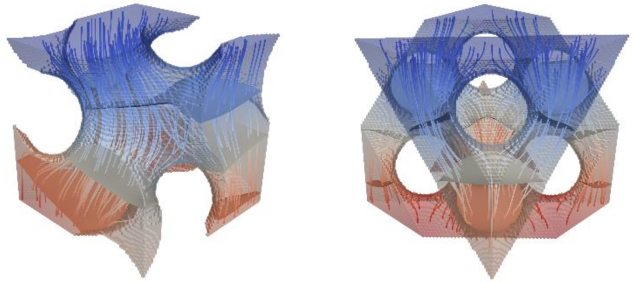


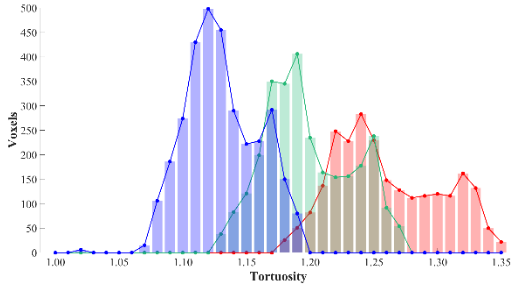
Conclusions

Outcomes

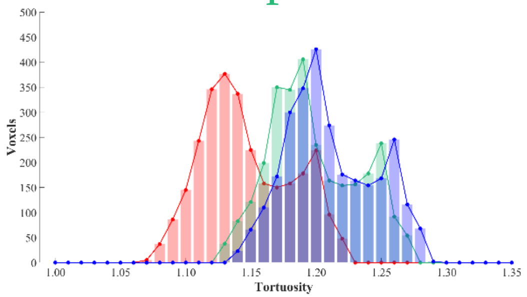
Diamond and Gyroid TPMS unit cells



Porosity variation

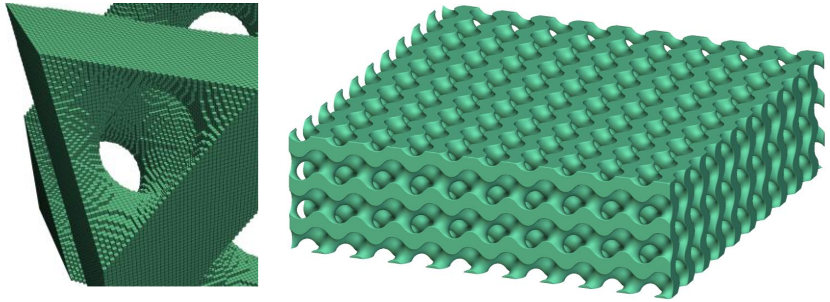


Time step variation

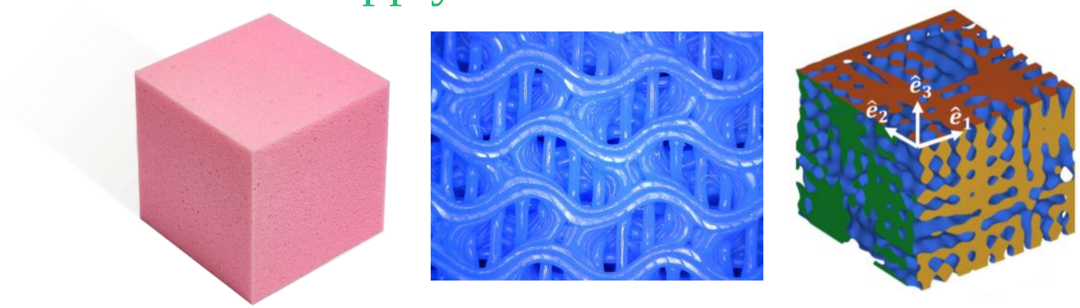


Future Work

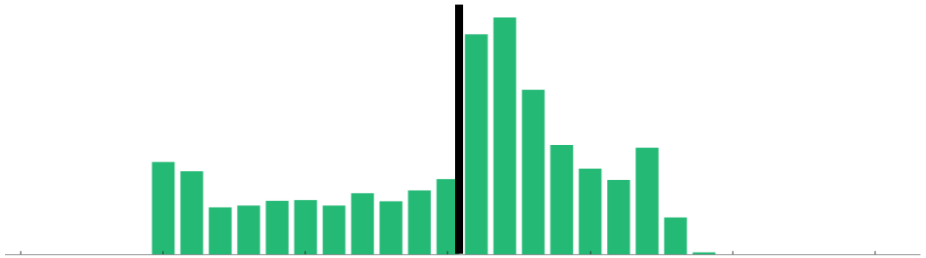
Resolution and lattices



Apply to more structures



Extract single tortuosity value



Thank You!

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Questions?

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Student Paper Competition Survey

QR code

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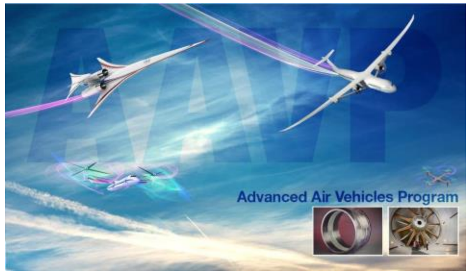
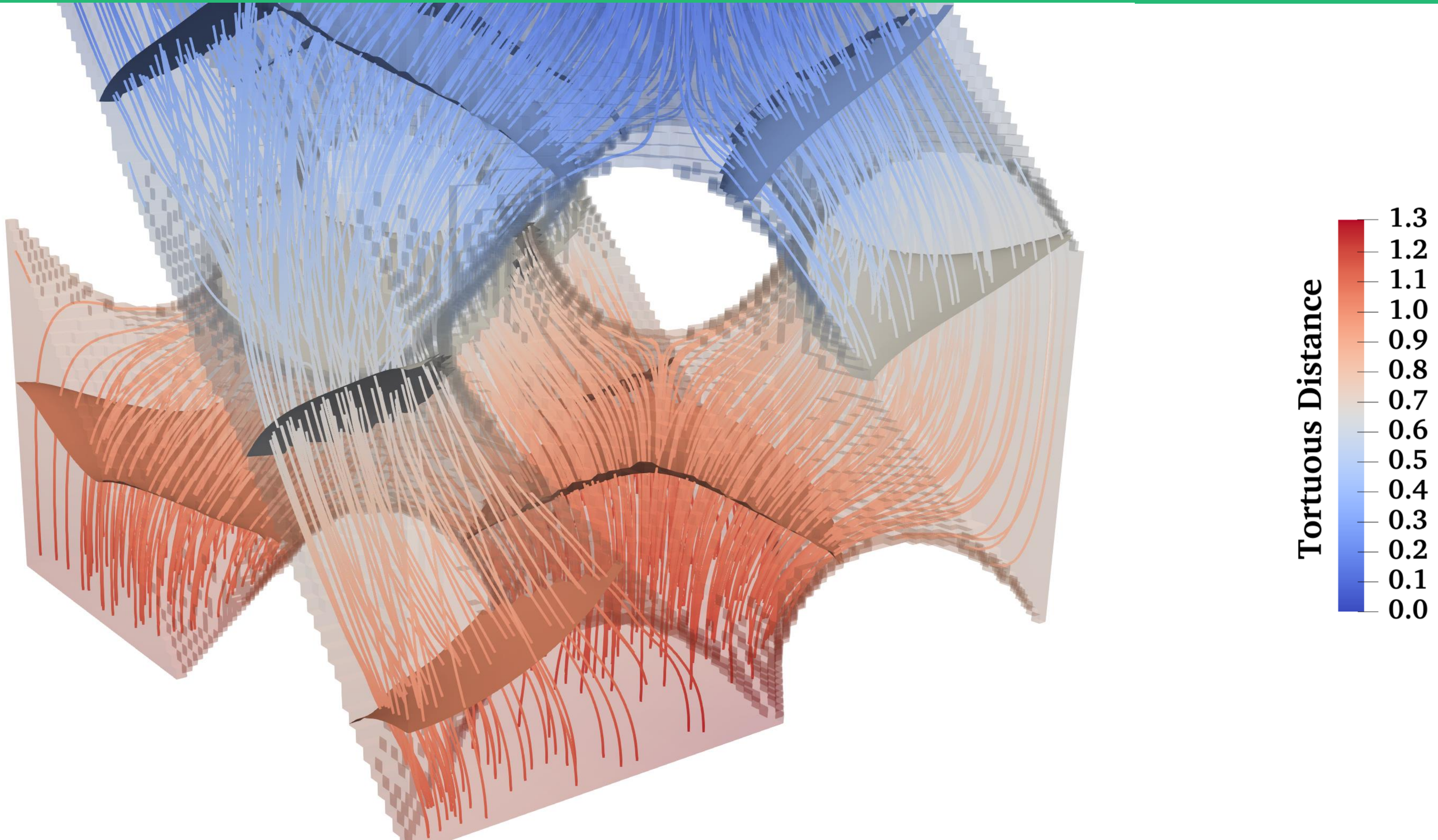


EXTRA: Closer Views (Diamond 50%)



EXTRA: Closer Views (Gyroid 50%)