# Three-dimensional conductive heat spreading layouts obtained using topology optimisation for passive internal electronic cooling


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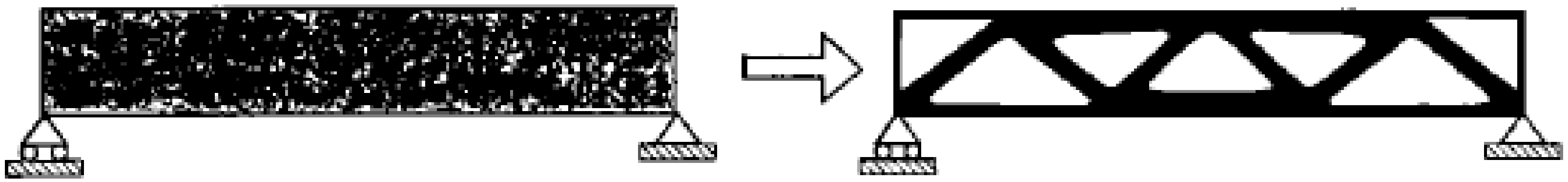
# Introduction

- Background
- Purpose of Study
- Numerical Model
- Two Dimensions and Validation
- Three Dimensions with a Partial Dirichlet Boundary
- Three Dimensions with a Full Dirichlet Boundary
- Multiple Seed Points
- Conclusion

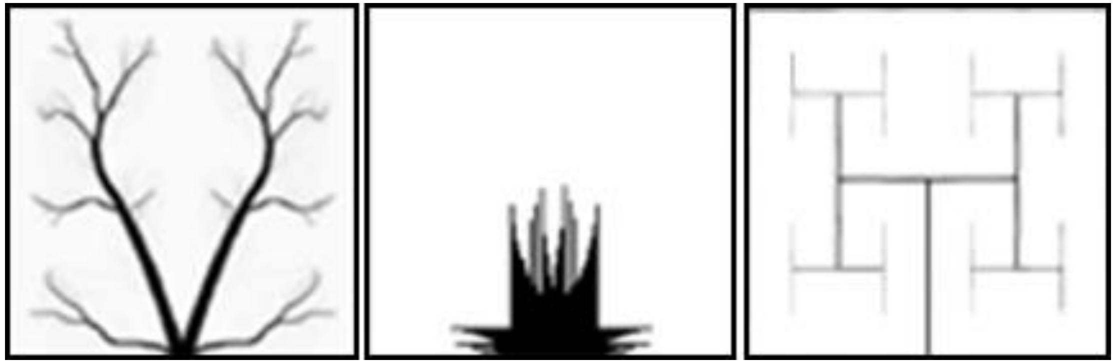
# Background

- Power density
- Conduction vs convection
- Topology optimisation
- First used in structures



# Topology Optimisation

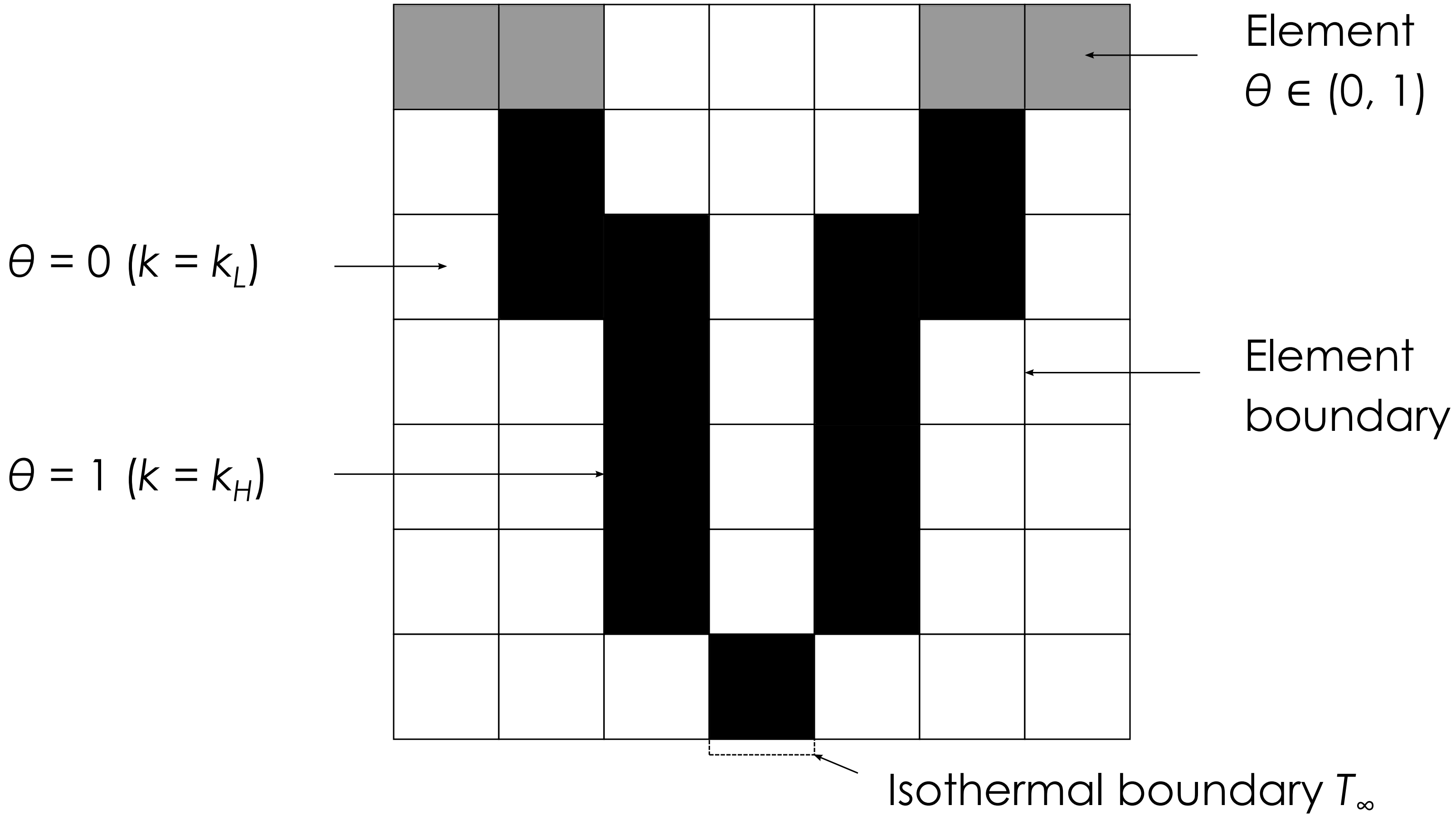
- Finding optimal order and placement of limited material
- Continuous vs Discreet
- Solid isotropic material with penalisation (SIMP) method
- 0-1 solutions



# Purpose of Study

- Develop self programmed code
- Validate and solve in two dimensions for conduction cooling
- Three dimensions
- Different boundary conditions
- Limited work in three-dimensional heat transfer was a driving factor

# Domain



Element
$\theta \in (0, 1)$
$\theta = 0$ $(k = k_L)$
Element boundary
$\theta = 1$ $(k = k_H)$
Isothermal boundary $T_\infty$

# Methodology

1. Define boundary conditions and domain parameters
2. Define initial density distribution
3. Solve temperature distribution
4. Calculate penalised sensitivities according to the objective function
5. Calculate optimised density distribution
6. Repeat step 2 to 5 for a set number of iterations

# Temperature Distribution

- Temperature distribution was discretised with the finite volume method (FVM)

$$\int_{\Delta V} \frac{d}{dn}\left(kA\frac{dT}{dn}\right) dV + \int_{\Delta V} S dV = \sum_{1}^{i} \left(kA\frac{dT}{dn}\right)_i + \bar{S}\Delta V = 0$$

- Interface conductivity ratio calculated with a harmonic mean

$$k_\iota = \frac{k_N k_P}{\alpha_\iota k_P + (1-\alpha_\iota) k_N}$$

# SIMP Method

- Conductivity and heat generation

$$k(\theta_i) = k_{\mathrm{L}} + \theta_i(k_H - k_{\mathrm{L}})$$

$$q'''(\theta_i) = q_H'''(1 - \theta_i)$$

- Penalised

$$k(\theta_i) = k_{\mathrm{L}} + \theta_i^p(k_H - k_{\mathrm{L}})$$

$$q'''(\theta_i) = q_H'''(1 - \theta_i^p)$$

# Adjoint Method

- The sensitivities of the objective function was required for the optimisation routine
- This can be done as follows

$$\frac{dg_0}{d\theta} = \frac{\partial g_0}{\partial \theta} + \frac{\partial g_0}{\partial \mathbf{T}} \frac{\partial \mathbf{T}}{\partial \theta}$$

- Or using the adjoint method

$$\left.\frac{dg_0}{d\theta_i}\right|_{f=0} = \frac{\partial g_0}{\partial \theta_i} - \boldsymbol{\lambda}^T \left( \frac{\partial K}{\partial \theta_i} \mathbf{T} - \frac{\partial \mathbf{b}}{\partial \theta_i} \right)$$

# Method of Moving Asymptotes

- The objective function was solved with the method of moving asymptotes (MMA)
- Average temperature

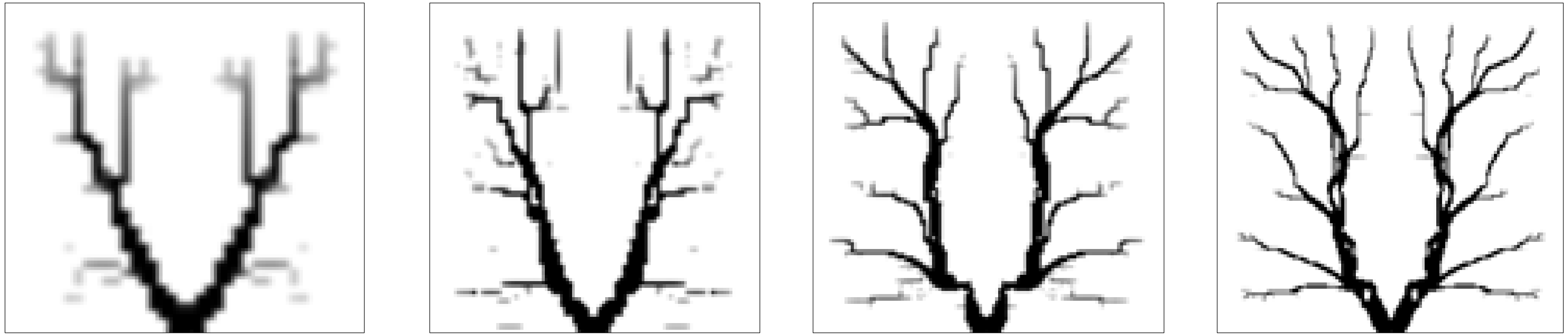
$$g_0(\mathbf{T}) = \frac{1}{M_\Omega}\sum_{1}^{M_\Omega} T_i$$

- Volume constraint

$$g_1(\boldsymbol{\theta}) = V_f = \frac{1}{M_\Omega}\sum_{1}^{M_\Omega} \theta_i \leq V^*$$

# Two Dimensions and Validation

- Code was validated against theory and existing two-dimensional topology optimisation papers



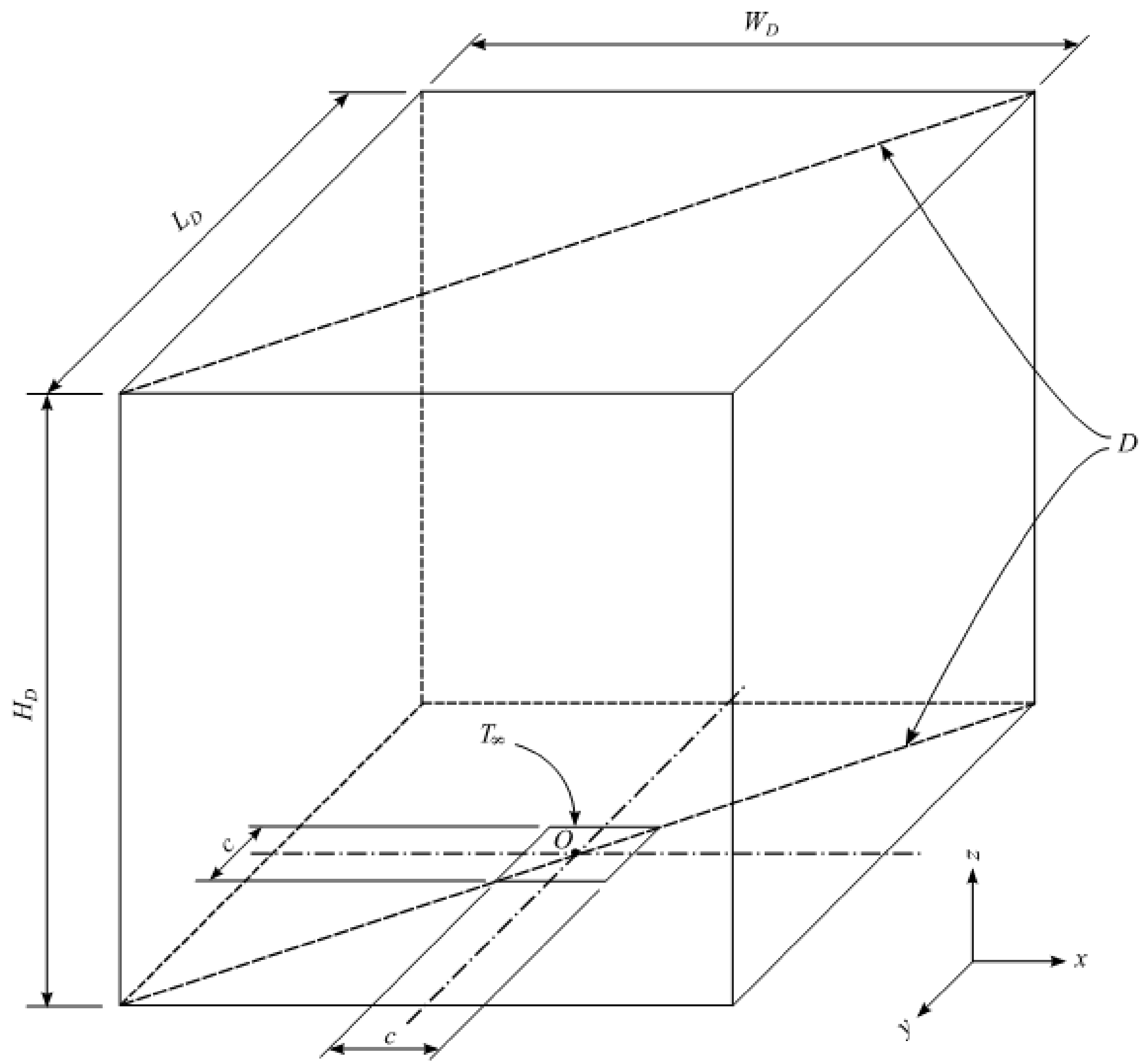
# Three Dimensions

- Convert existing two-dimensional problem to three-dimensions
- Define temperature measure

$$\tau = \frac{(T_{max} - T_{\infty})k_L}{q_H L_D^2}$$

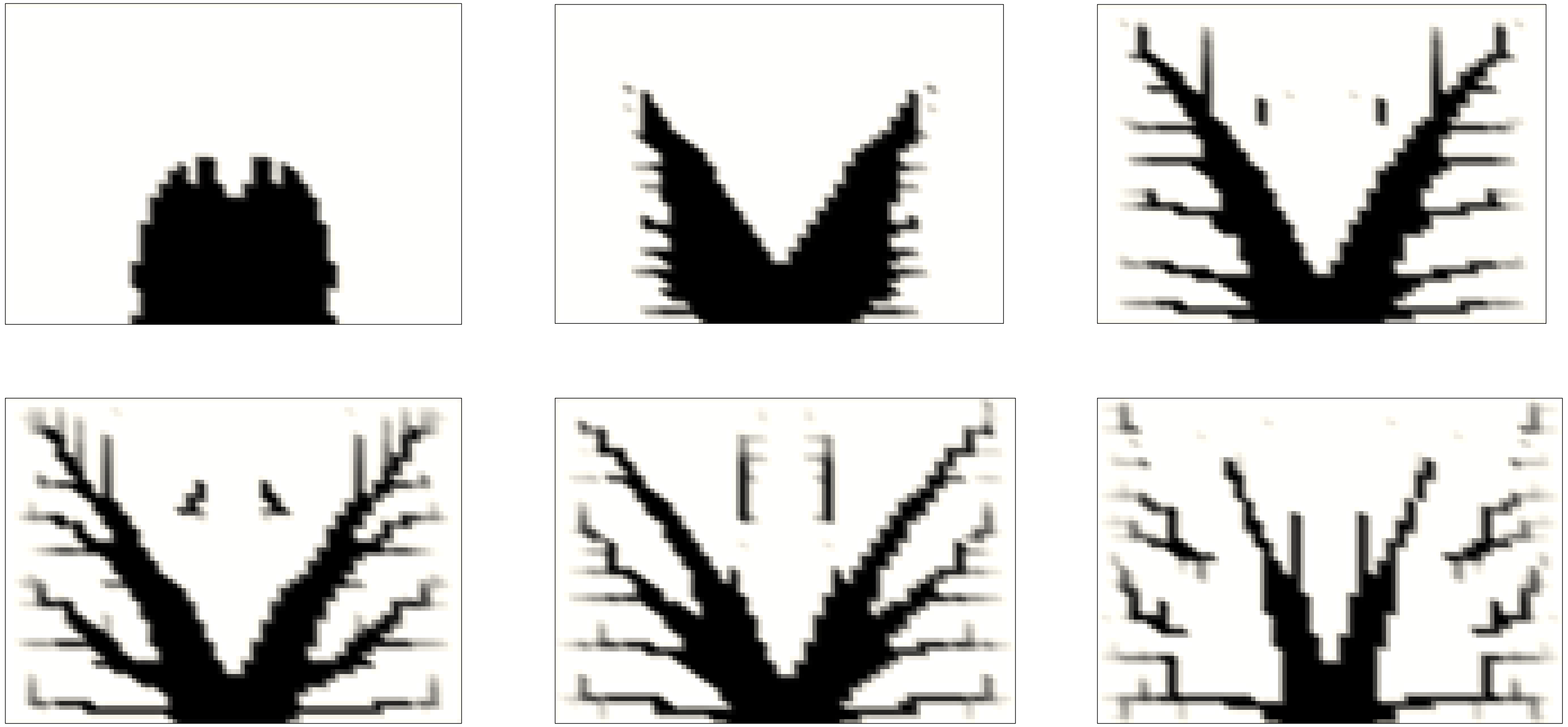
- Mesh dependence
- Iteration dependence
- Constant vs incremental increasing penalisation
- Initial density distribution

# Partial Dirichlet Boundary



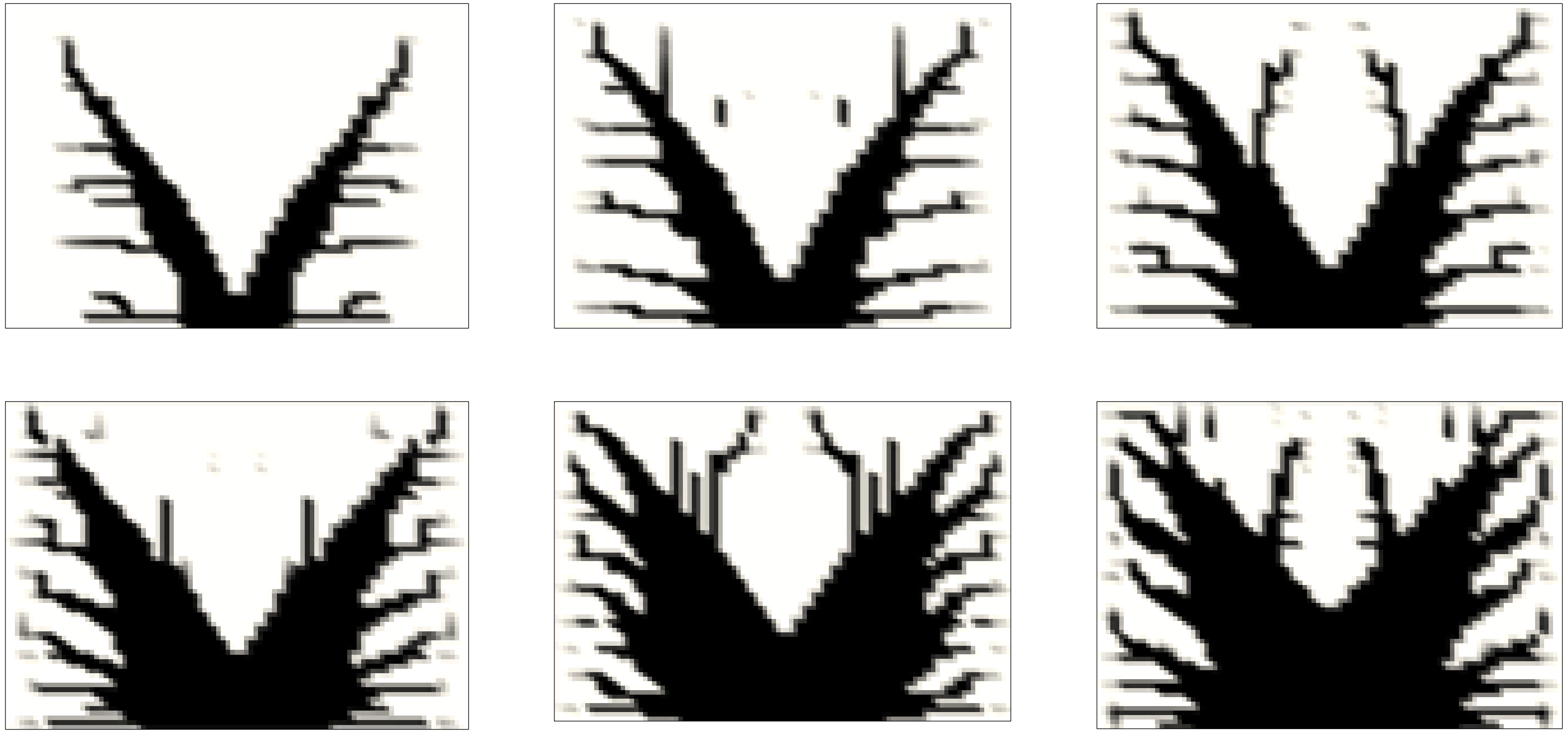
# Influence of Conductivity Ratio

- $k^*$ [-] = [5; 50; 500; 1000; 2000; 3000]

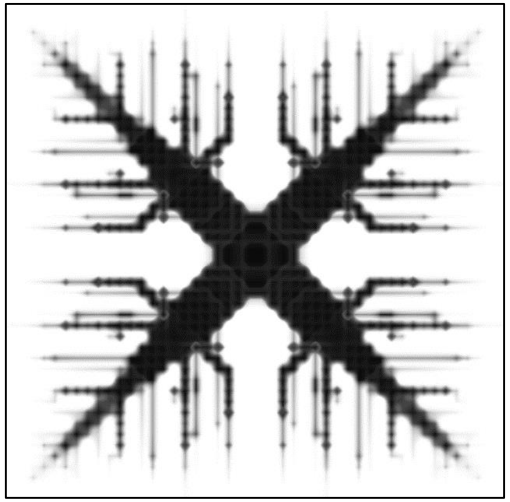


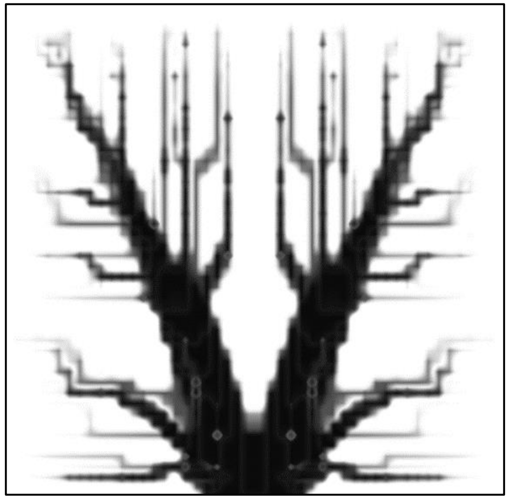
# Influence of Volume Constraint

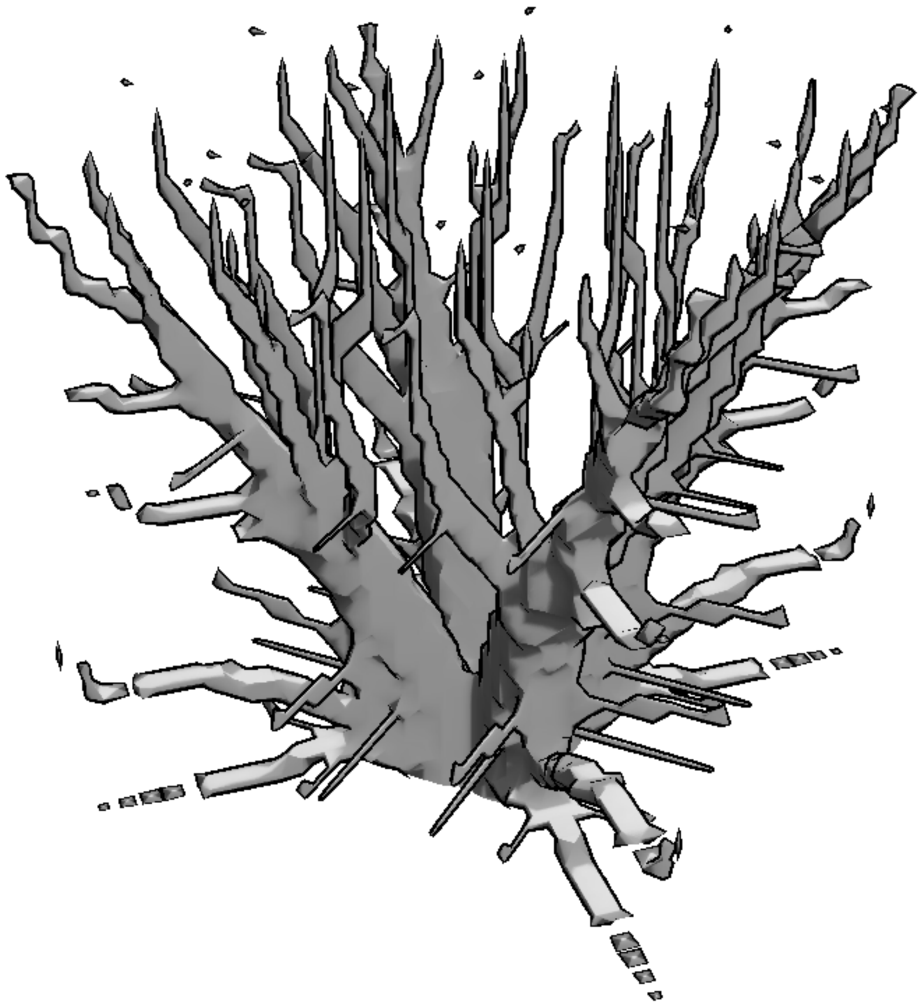
- $V^*$ [-] = [0.05; 0.1; 0.15; 0.2; 0.2; 0.3]



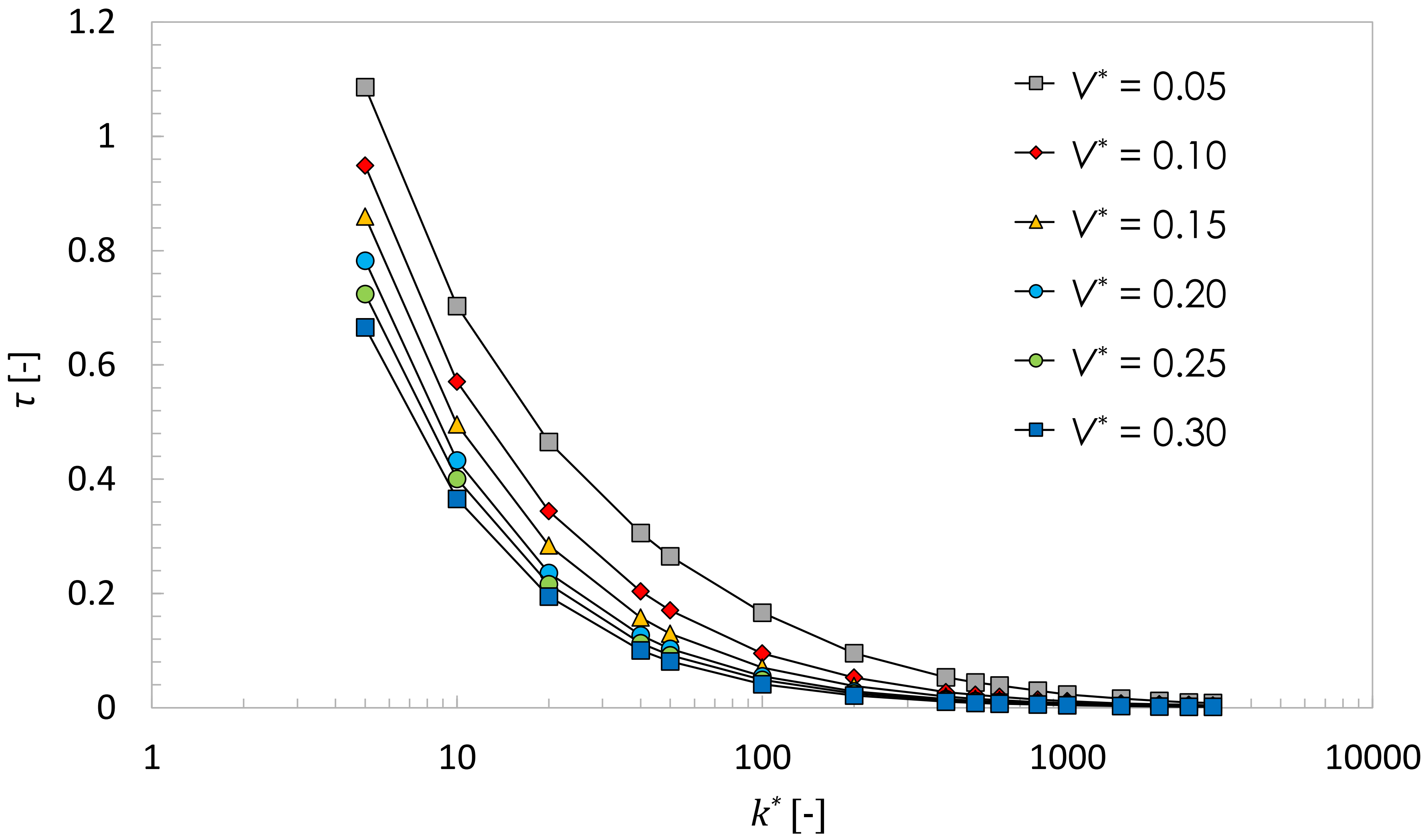
# Architectures



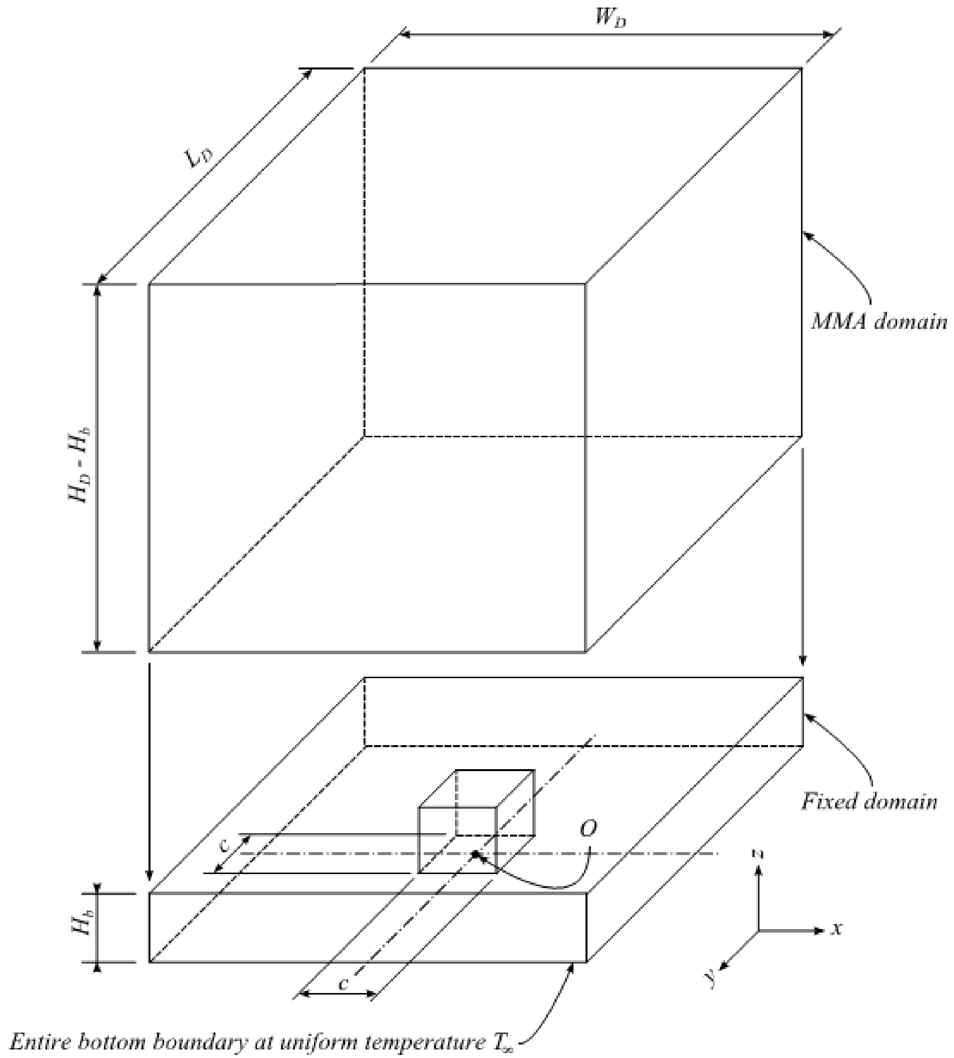




# Conductivity vs Volume

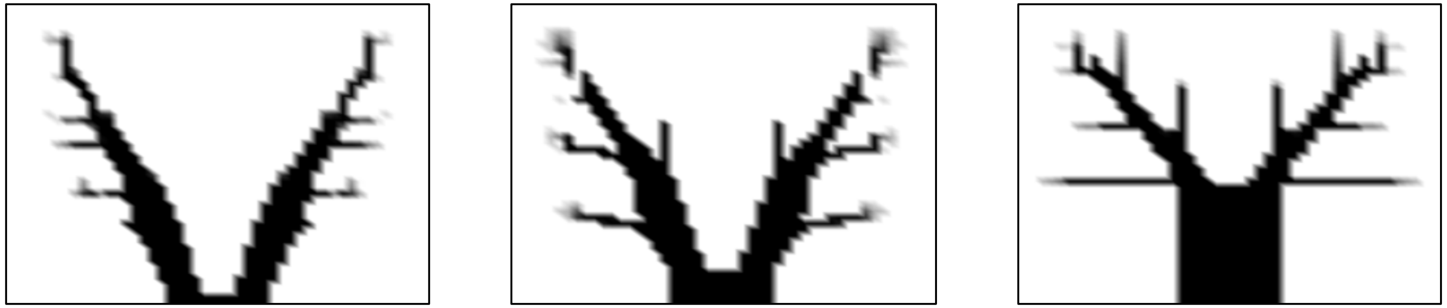


# Full Dirichlet Boundary

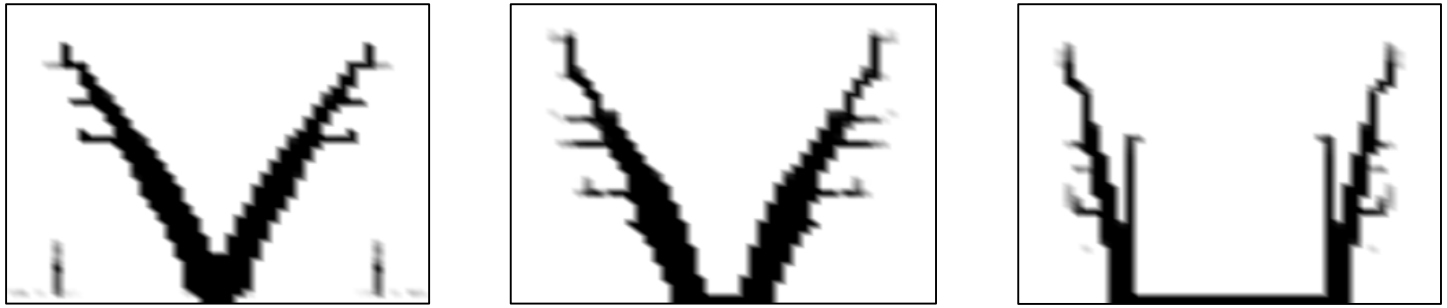


# Seed Dimensions

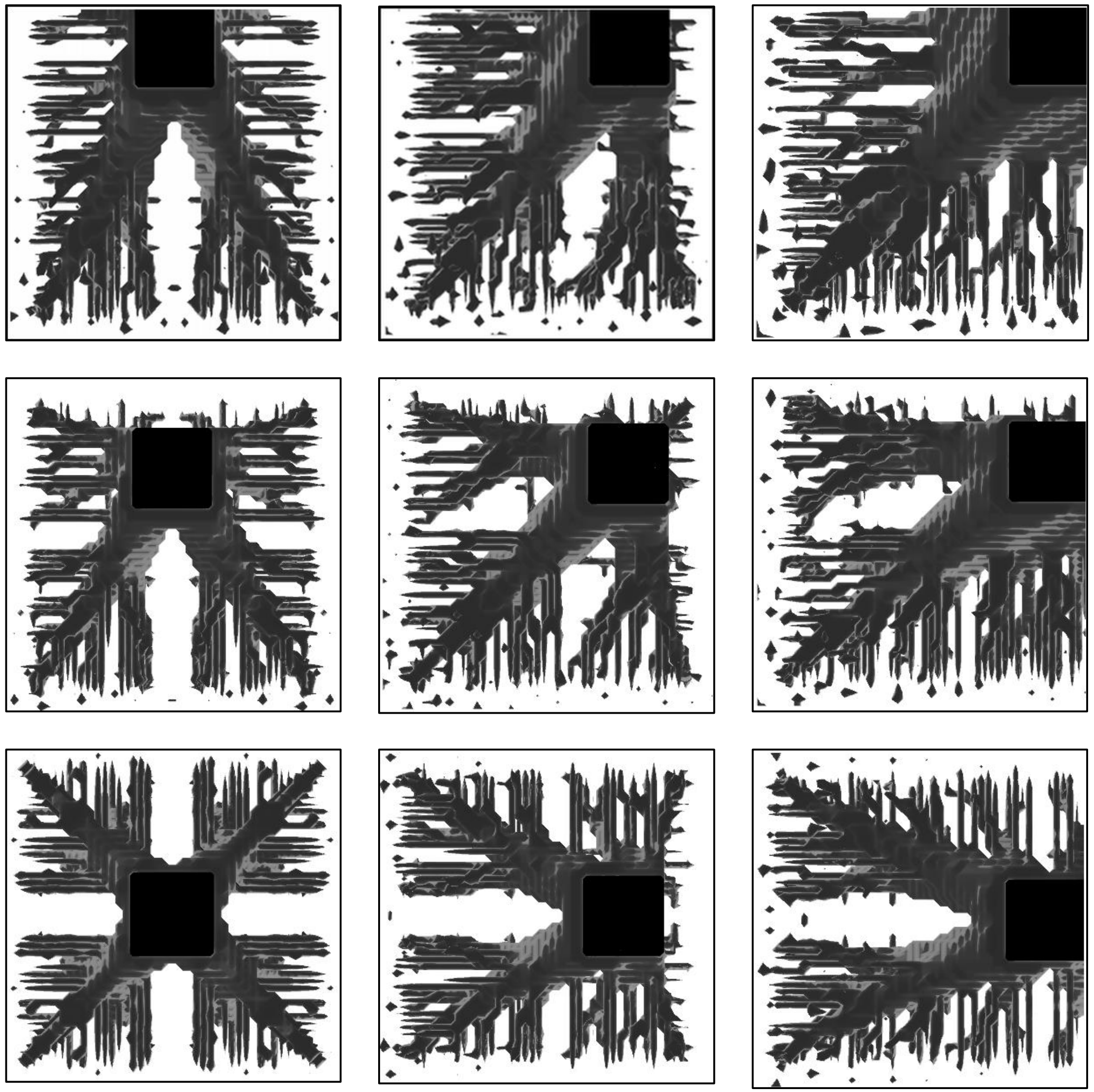
- Different seed heights



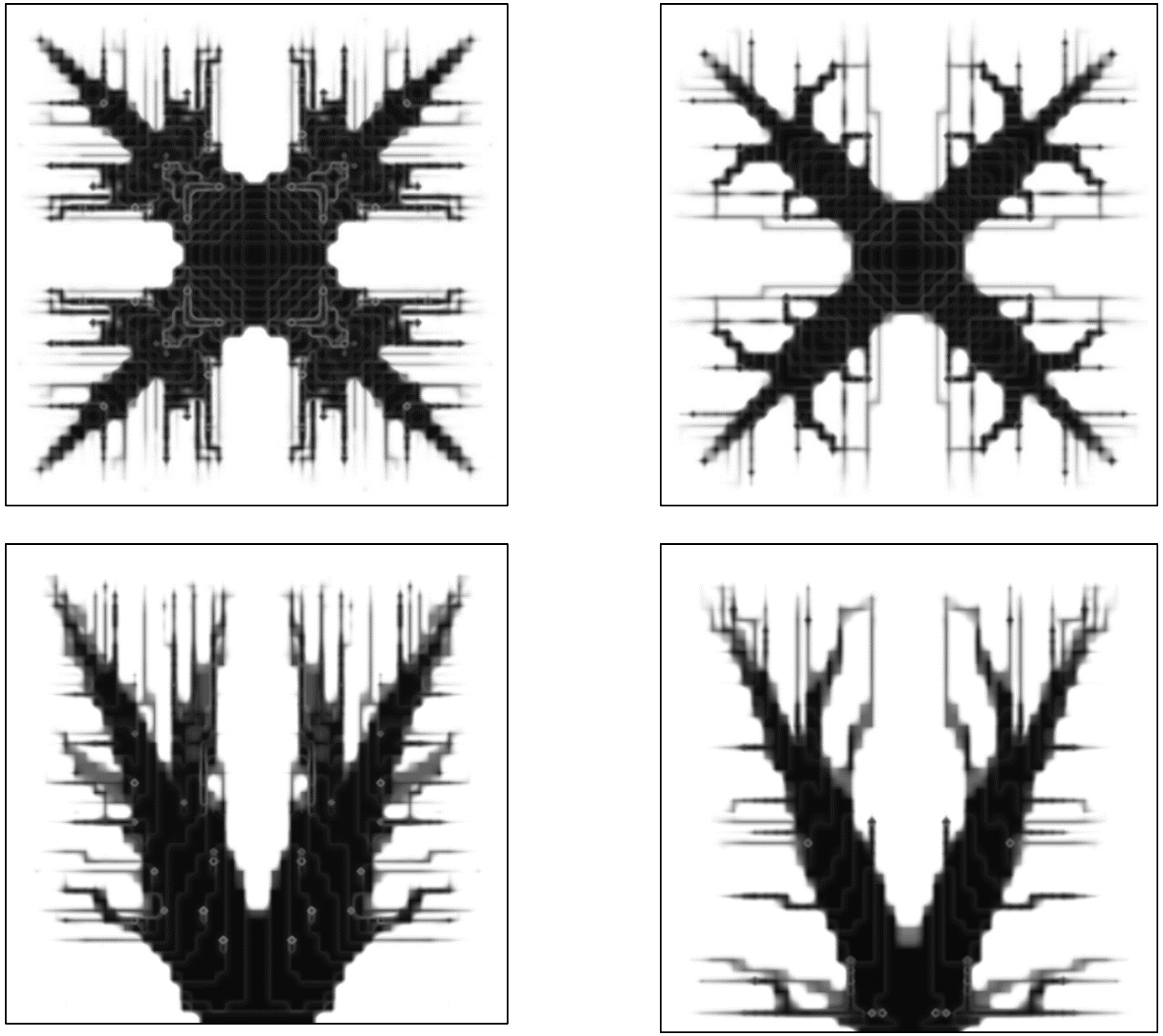
- Different seed widths



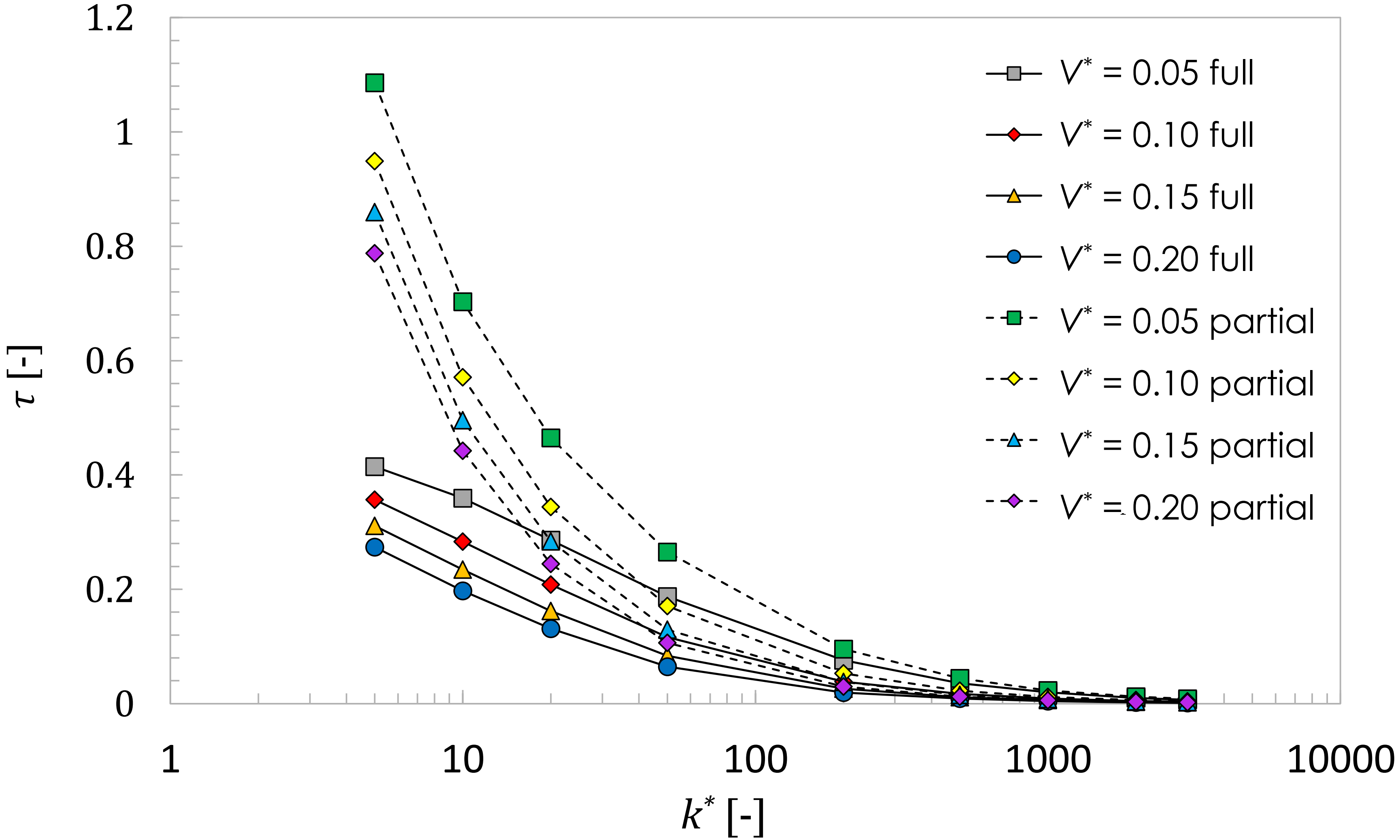
# Seed Location



# Partial vs Full Dirichlet Boundary



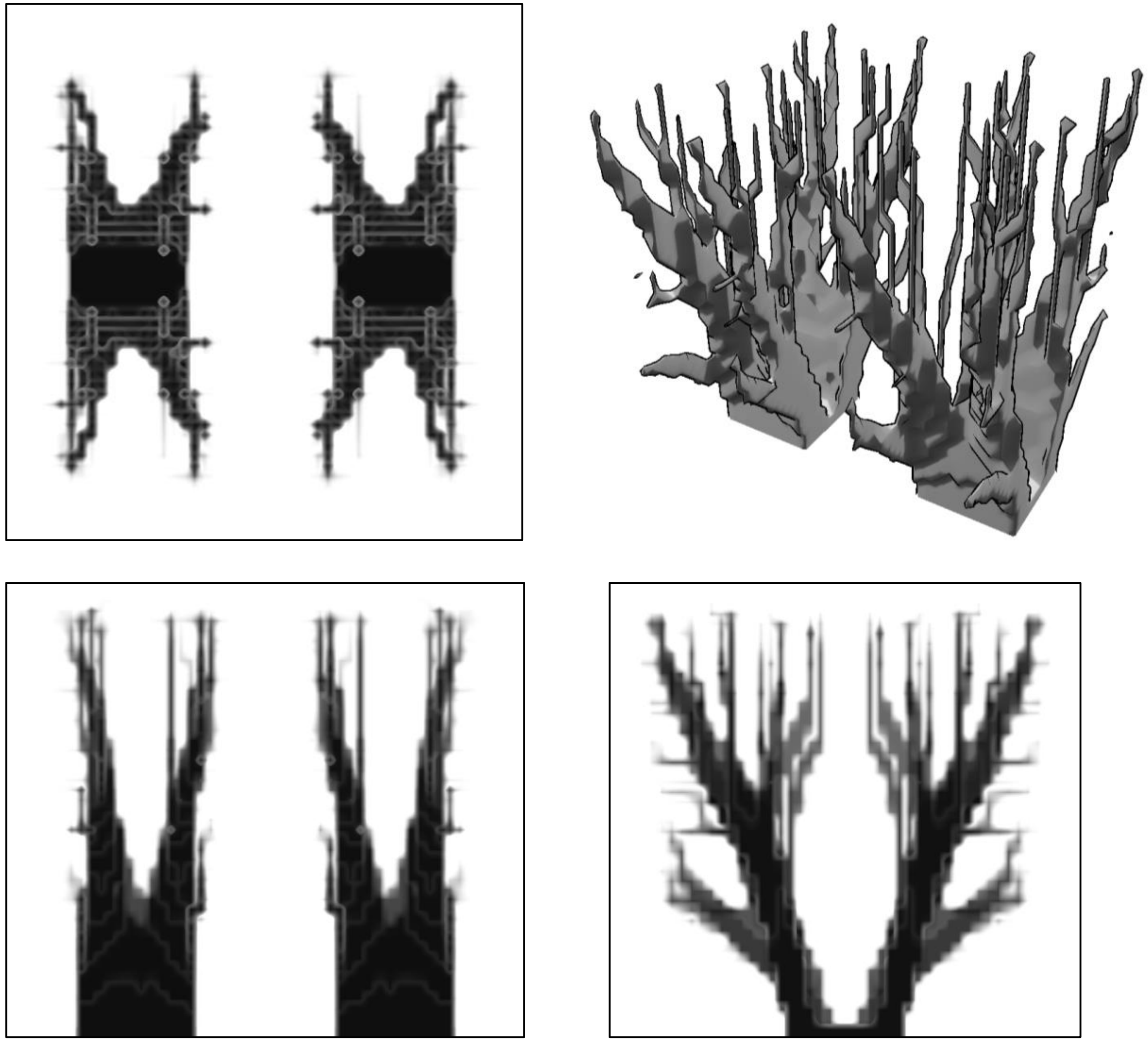
# Partial vs Full Dirichlet Boundary



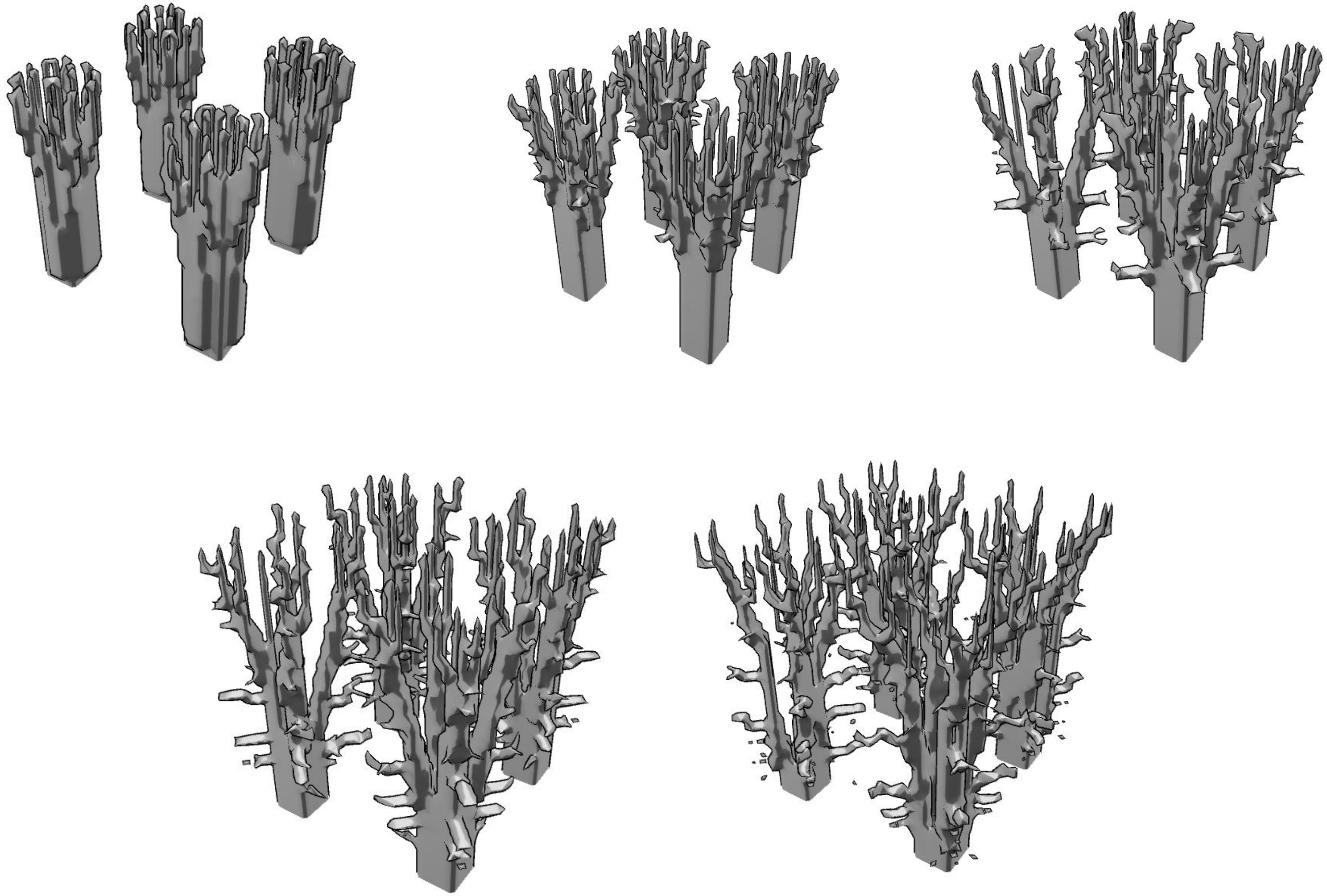
# Multiple Seed Locations

- Multiple seed locations were investigated using a full Dirichlet boundary
- Two seed locations were investigated first
- Four seed locations also investigated
- Same design parameters as with one seed location assumed

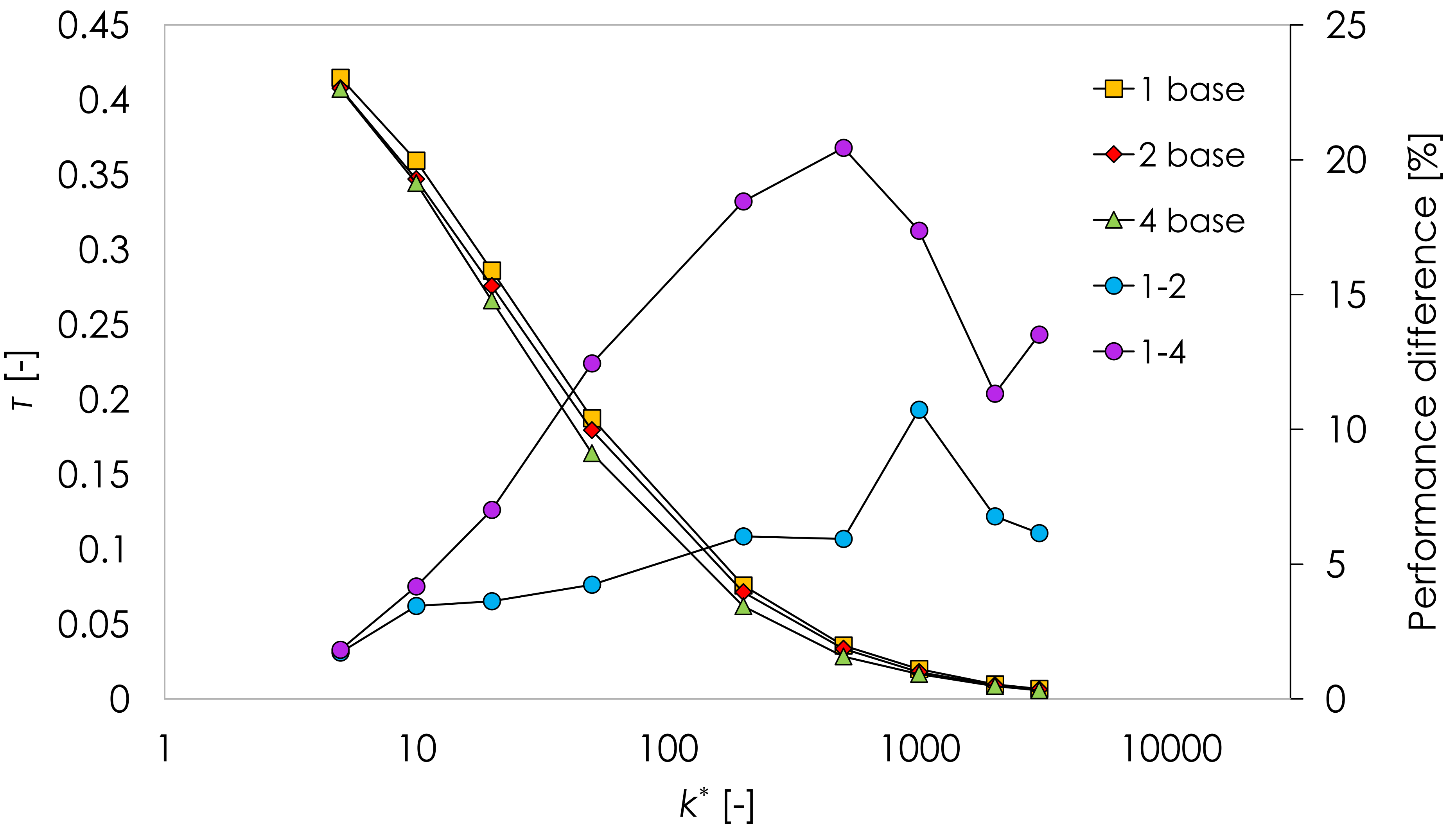
# Two Seed Locations



# Four Seed Locations



# Single vs Multiple Seed Locations



# Conclusion

- Topology optimisation is a viable solution for three-dimensional heat transfer problems
- Partial and full Dirichlet boundary shows similar results compared to two dimensions
- Full Dirichlet boundary is possible with initial seed
- Increasing the number of seeds is beneficial to the temperature distribution

Thank you for your time

Questions?