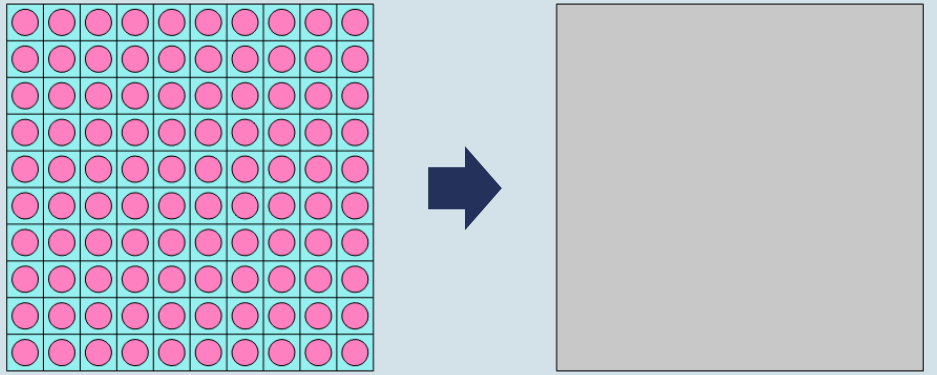
COMSOL Minicourse: Material Homogenization

Tomáš Vrbata
vrbata@humusoft.cz

What is Homogenization?

- Replace a heterogeneous material subvolume by an *equivalent homogeneous material*
- Goal: find effective material properties
  - Young's modulus, Poisson's ratio
  - Coefficient of thermal expansion
  - Thermal conductivity
  - Permittivity, permeability
  - Coupling properties



Heterogeneous microstructure

Homogeneous equivalent

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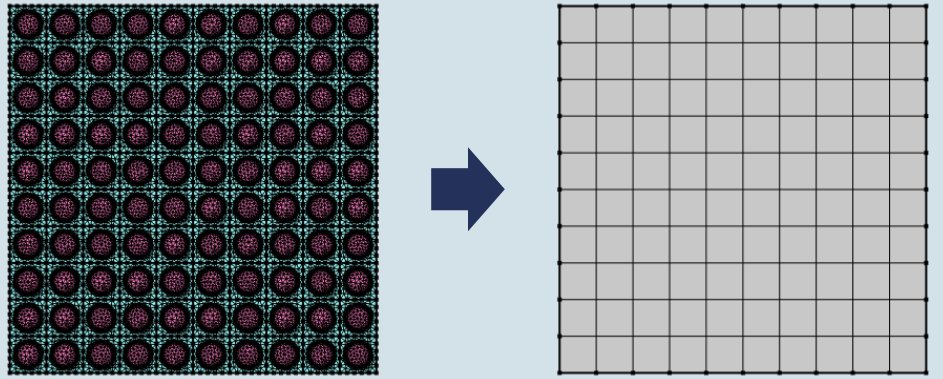
  - Permittivity, permeability
  - Coupling properties
- Fewer degrees of freedom, regular mesh

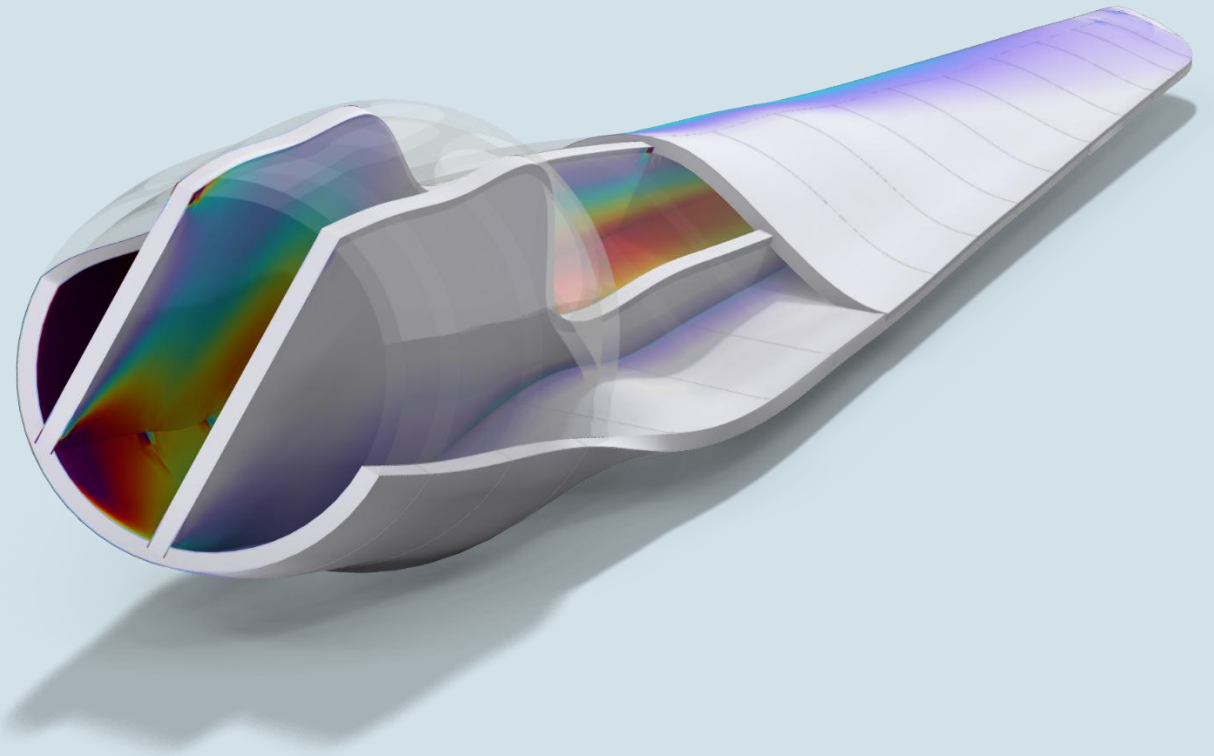


Heterogeneous microstructure

Homogeneous equivalent

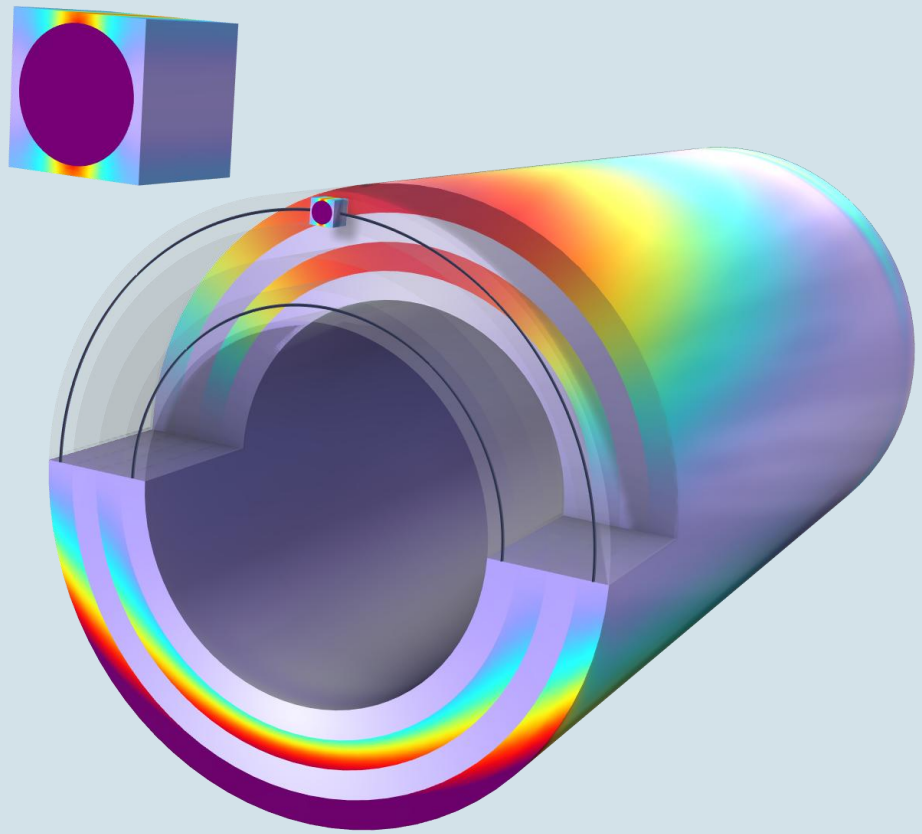
When to Use Homogenization?

- Composite structures
  - Fibers, particles, weaves, laminates
  - Wind turbines, aerospace, automotive
- Lattice and cellular structures
  - Additive manufacturing
  - Lightweight design, metamaterials
- Incomplete material data
  - Generate anisotropic data from microstructure
  - Replace expensive measurements



From Micro to Macro

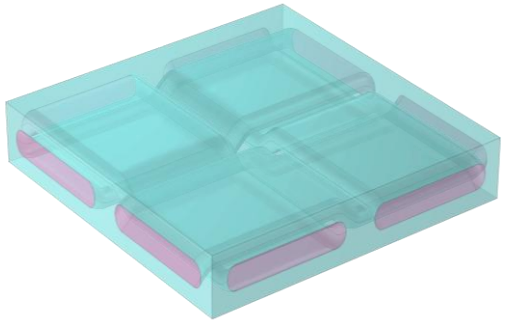
- Microscale
  - Repeating unit cell (RUC) or representative volume element (RVE)
  - Periodic or homogeneous boundary conditions
  - Output: effective material matrix
  - Analytical alternatives available
- Macroscale
  - Preferred technique for studying composite structures at global scales
  - Full part – tube, blade, panel
  - Behavior of composite structures based on homogenized materials
  - Massive reduction in DOFs



Repeating Unit Cell vs Representative Volume Element

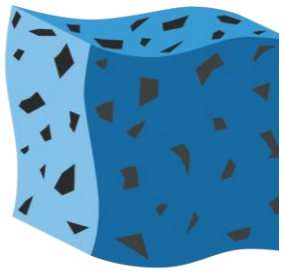
Repeating Unit Cell - RUC

- Periodic geometry
- Examples: fiber composites, lattices, gyroids
- Periodic BC – exact result
- Size-independent – one cell is enough



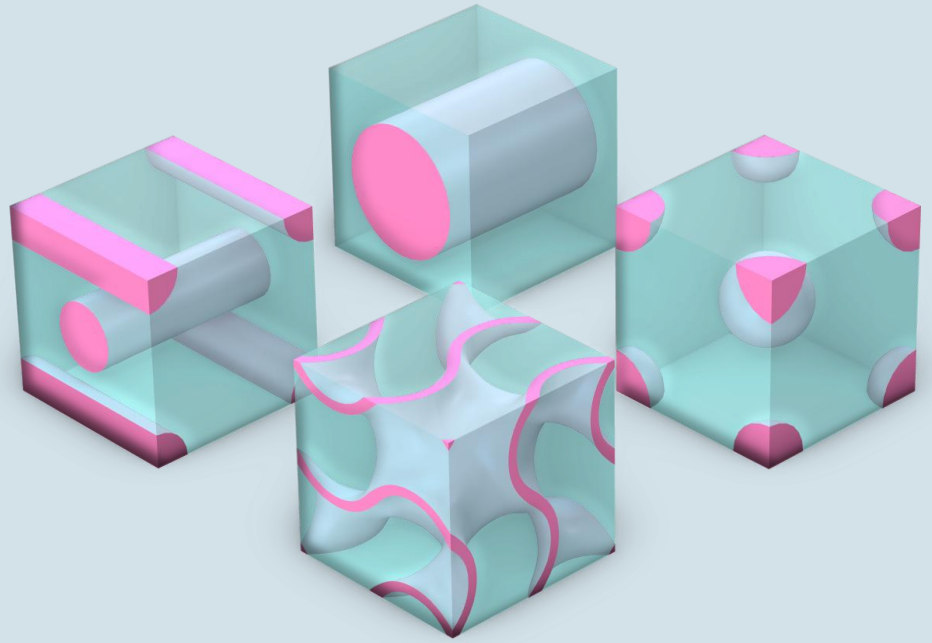
Representative Volume Element - RVE

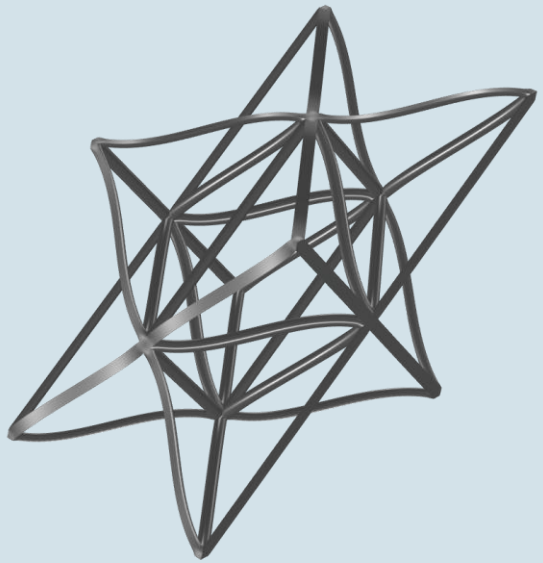
- Random microstructure – statistical sample
- Examples: random particulates, foams, batteries
- Homogeneous BC – displacement or traction
- Size dependent

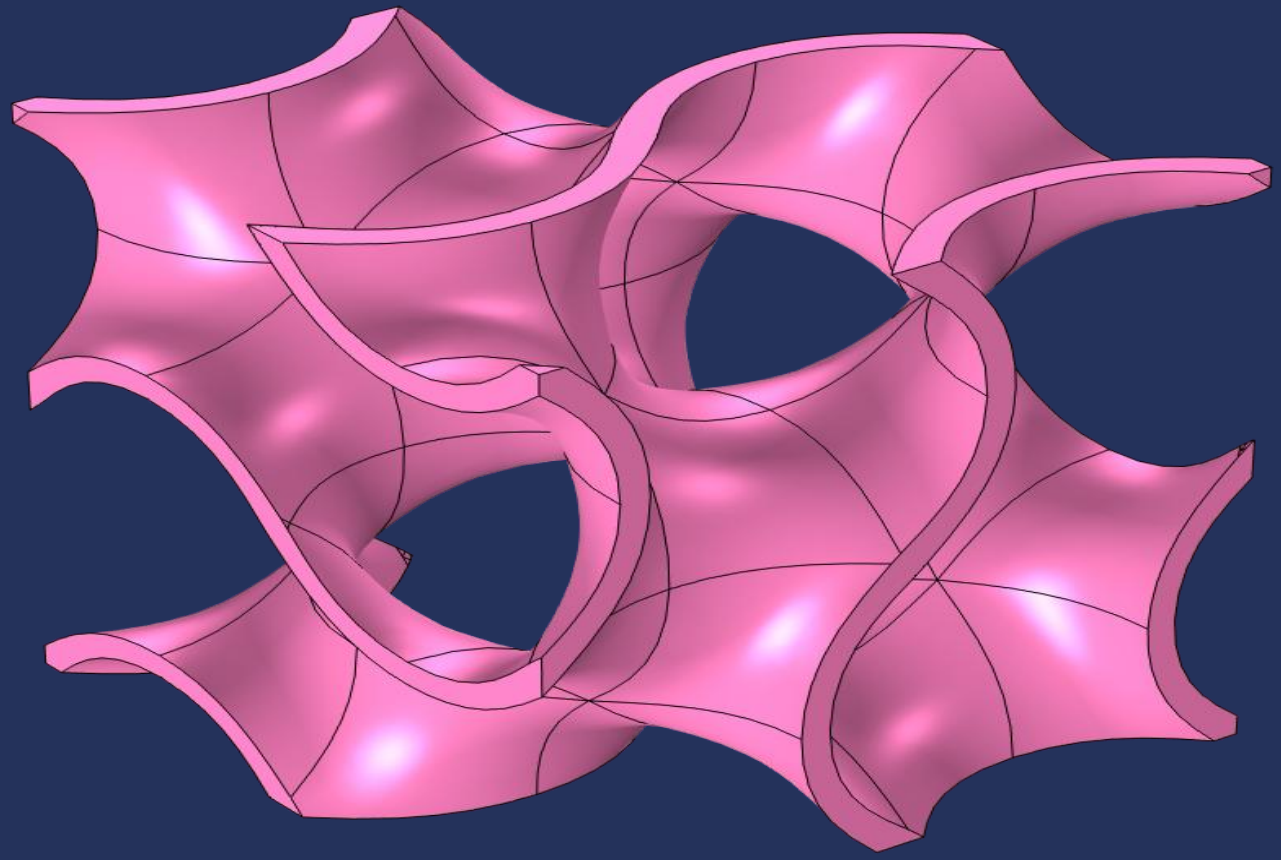


Material Homogenization in COMSOL®

- Cell Periodicity
  - Solid Mechanics, Heat Transfer, and MEMS
  - Effective stiffness, coefficient of thermal expansion, conductivity
- Part Library
  - Ready-to-use RUC and RVE geometries
  - Fiber composites, particulates, lattices, gyroids
- Random Particulate Composite RVE add-in



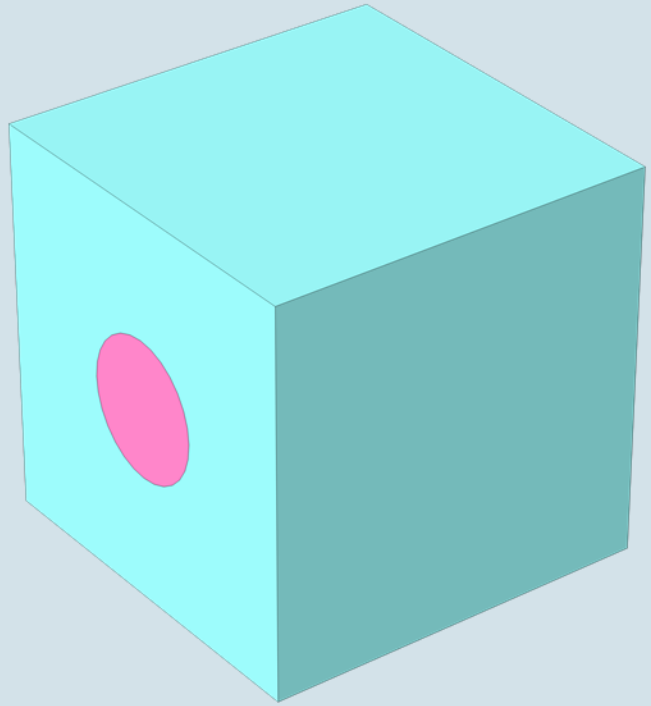




Showcase: Multiscale Modeling

Showcase Setup

- Microscale: Effective Properties
  - Unit cell (fiber + matrix) from Part Library
  - Solid Mechanics - Cell Periodicity
  - Periodic BCs → effective elasticity matrix
- Macroscale: Composite Cylinder
  - Layered Shell with Layered Material
  - Homogenized properties from microscale



Untitled.mph - COMSOL Multiphysics

File

New

Model Wizard

Blank Model

Help Cancel Show on startup

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Untitled.mph - COMSOL Multiphysics

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder | Model Manager | Component 1 | Add Component | Parameters | Variables | Functions | Parameter Case | Variable Utilities | Equation Contributions | Build All | Import | LiveLink | Part Libraries | Add Material | Solid Mechanics | Add Physics | Add Mathematics | Build Mesh | Mesh 1 | Compute | Cell Periodicity Study | Add Study | Stress (solid) | Add Plot Group | Result Templates | Windows | Reset Desktop

Workspace | Model | Definitions | Geometry | Materials | Physics | Mesh | Study | Results | Layout

Model Builder

Type filter text

- Untitled.mph *(root)*
  - Global Definitions
    - Parameters 1
    - Geometry Parts
    - Materials
      - T-300 carbon fiber *(mat1)*
      - Epoxy polymer *(mat2)*
      - Homogeneous Material *(solidcp1*
        - Basic *(def)*
        - Anisotropic *(Anisotropic)*
    - Load and Constraint Groups
    - Load Groups for Cell Periodicity
  - Component 1 *(comp1)*
    - Definitions
    - Geometry 1
      - Unidirectional Fiber Composite, S
      - Form Union *(fin)*
    - Materials
      - Material Link 1 *(matlnk1)*
      - Material Link 2 *(matlnk2)*
    - Solid Mechanics *(solid)*
      - Linear Elastic Material 1
      - Free 1
      - Initial Values 1
      - Cell Periodicity 1
        - Boundary Pair 1
        - Boundary Pair 2
        - Boundary Pair 3
        - Equation View
      - Equation View
    - Mesh 1
      - Size
      - Identical Mesh 1
      - Free Triangular 1
      - Swept 1
  - Cell Periodicity Study
    - Step 1: Stationary
    - Solver Configurations
    - Job Configurations
  - Results
    - Datasets
    - Views
    - Derived Values
    - Tables

Settings | Properties

Anisotropic

Name: Anisotropic

Output Properties

Property	Variable	Expression	Unit
Elasticity matrix	{D11, D...	{1.402647759360354...	Pa
Loss factor for elast...	eta_D_is...	0	1

Expression:

{1.4026477593603543E11, 2.1641862988512874E9, 8.172596112370869E9, 2.164186358867227E9, 1.577934945541754 2E9, 8.172596471673254E9, -4.3028340434098984E-5, -9.149254596624857E-5, -1.2437232836837755E-4, 4.615024000236719E9, 32.45433205330848, -1556.1555693366713,

Model Inputs

Physical quantity	Variable

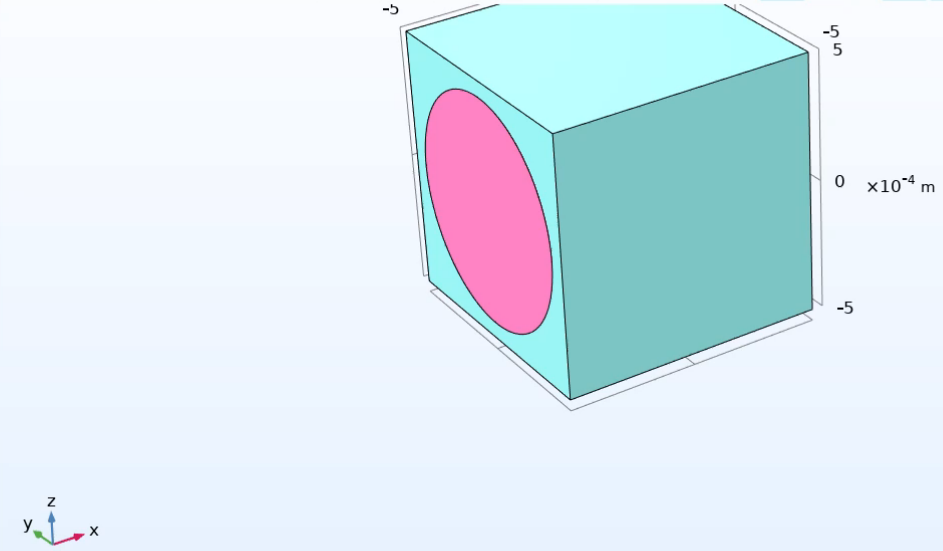
Local Properties

Name	Expression	Unit	Description

Name:

Expression:

Graphics



Messages | Progress | Log | Effective Material Properties (Cell P...

Density (kg/m^3)	Elasticity matrix (Pa)					
1556.0	1.4026E11	2.1642E9	2.1642E9	-4.3028E-5	32.454	-2.9213E-5
	2.1642E9	8.1726E9	1.5779E9	-9.1493E-5	-1556.2	-9.0913E-5
	2.1642E9	1.5779E9	8.1726E9	-1.2437E-4	1750.5	-9.9418E-5
	-4.3028E-5	-9.1493E-5	-1.2437E-4	4.6150E9	-2.6025E-4	-233.66
	32.454	-1556.2	1750.5	-2.6025E-4	2.6448E9	-3.1660E-5
	-2.9213E-5	-9.0913E-5	-9.9418E-5	-233.66	-3.1660E-5	4.6150E9

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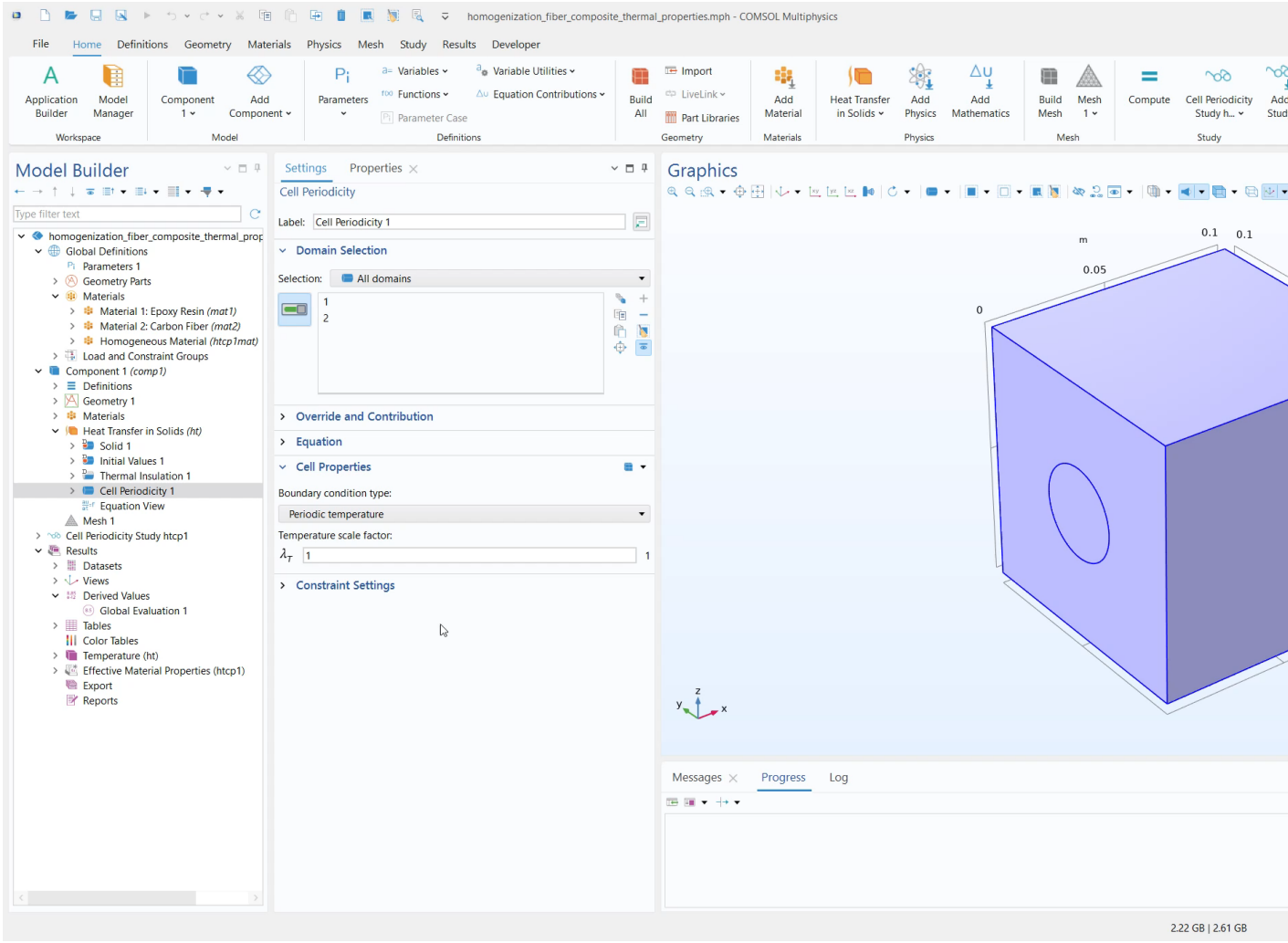
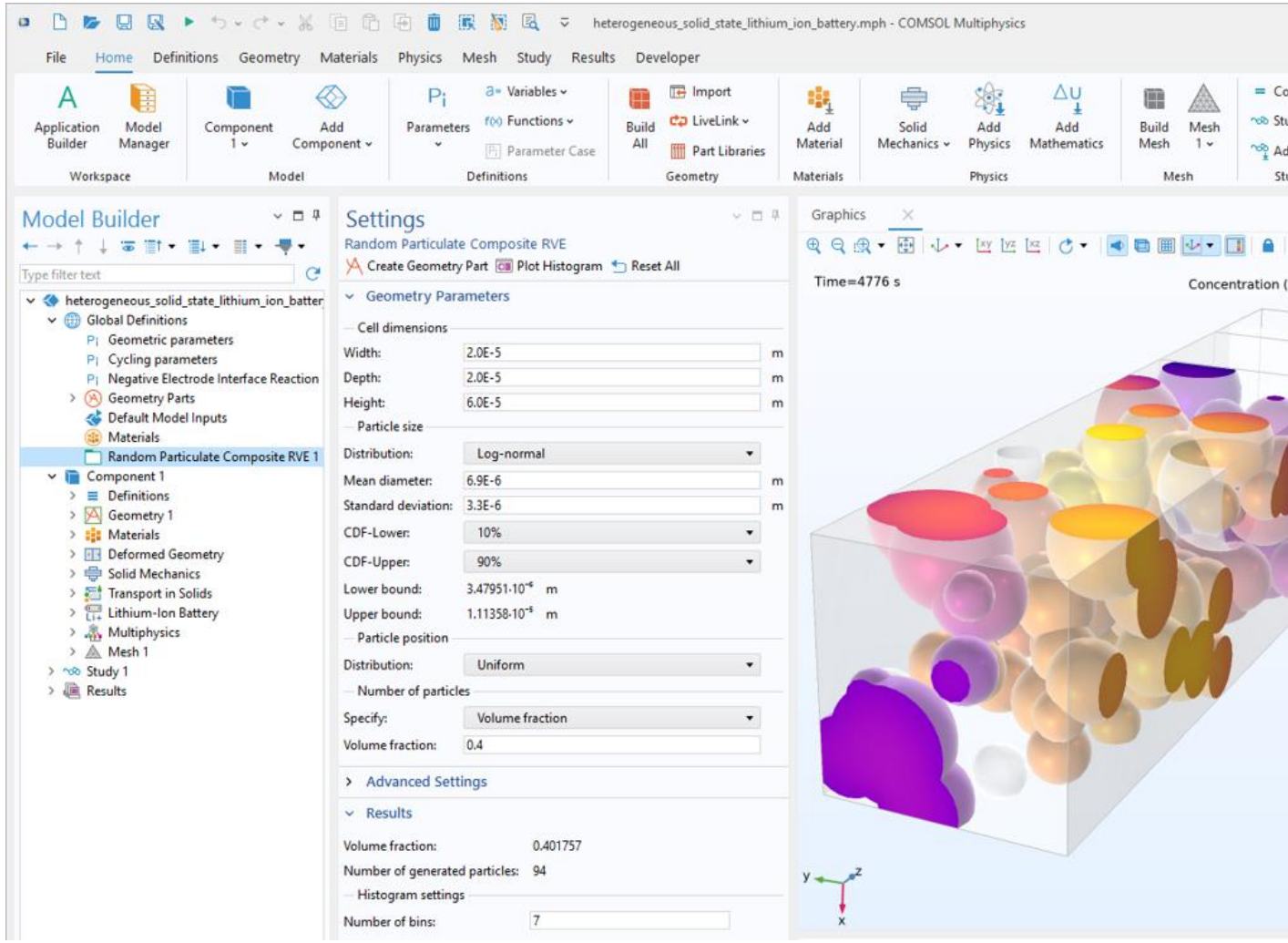
Analytical Approach

- Closed-form formulas — no simulation needed
- For fast estimate
- Built-in mixing rules in Effective Material
  - Volume/mass averages, etc.
- Limited for complex microstructures and anisotropy



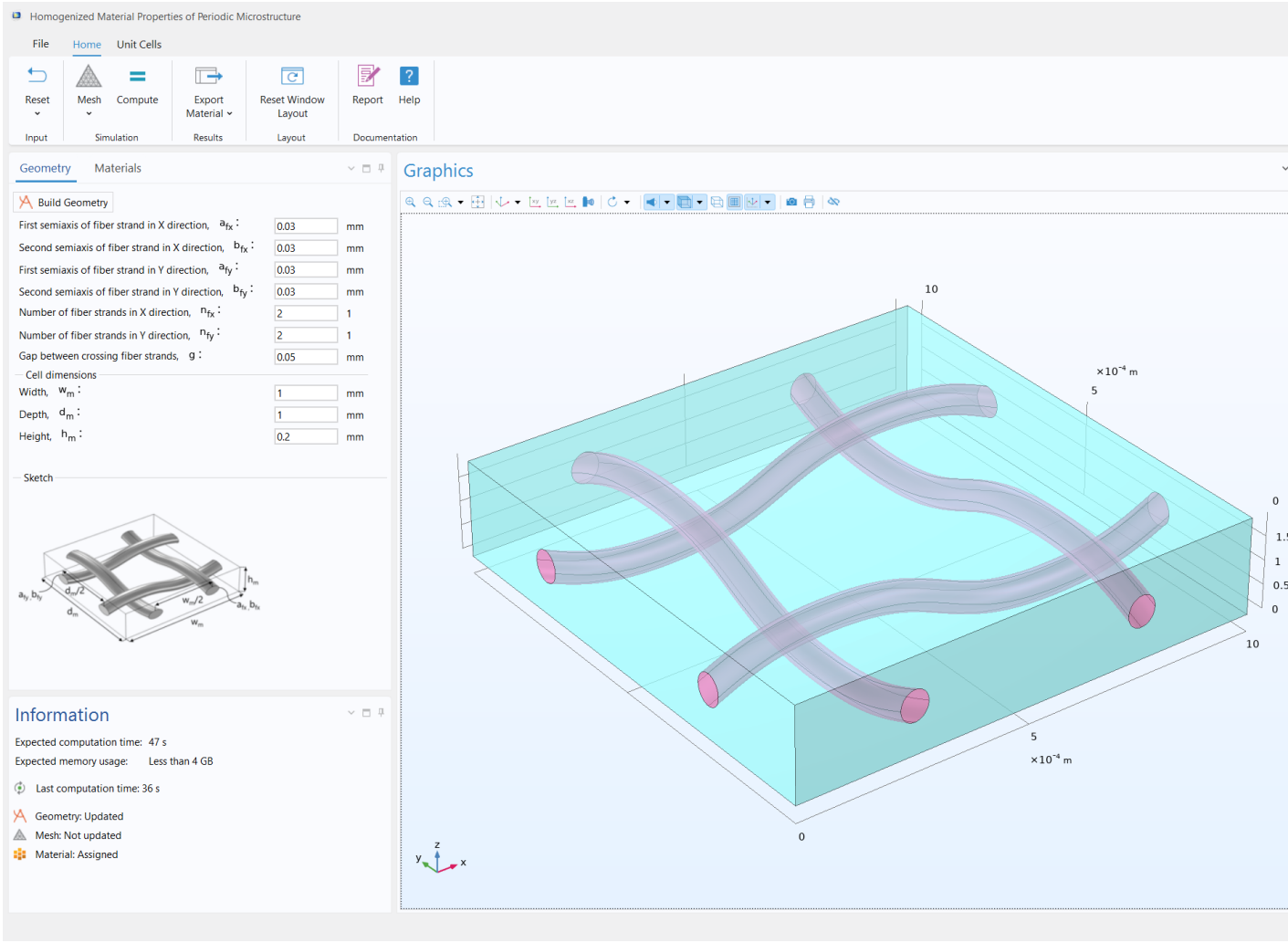
Random Particulate Composite RVE

- COMSOL Multiphysics Add-in
- Builds RVEs with random spherical particles
- Specify either number of particles or volume fraction
- Overlap control



Homogenization App

- Homogenized structural and thermal properties
- Ten different unit cell geometries
- Flexibility to modify the geometry and material properties
- Homogenized material can be exported



Try It Yourself

- Try it on our COMSOL Server
- Link: vulpecula.humusoft.cz:2036
- Username / Password: showcase / showcase

- Questions?