Computational Modeling in Tissue Engineering; Case Studies for Tissue Growth and Degradable Scaffolds

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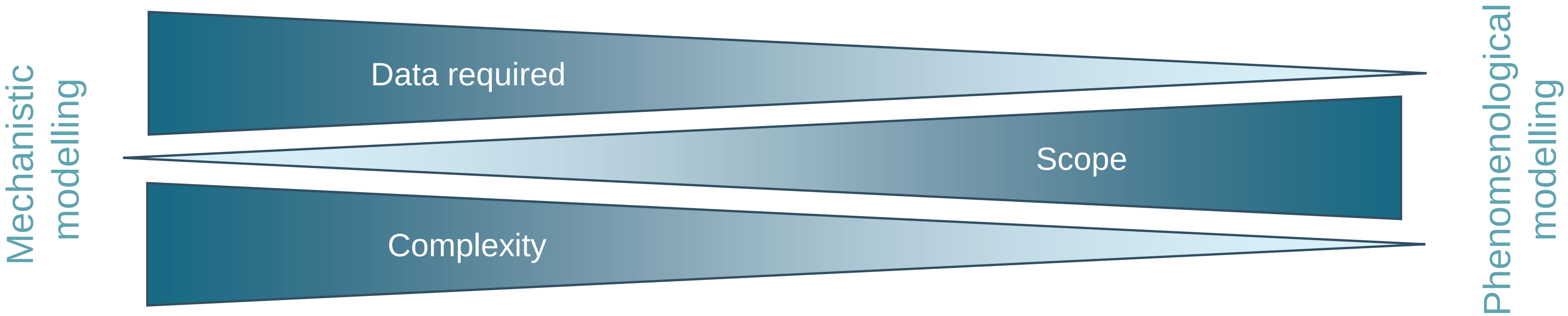
Computational Tissue Engineering

- Taking advantage of:
  - Development on mathematical physics/chemistry/biology
  - Rapidly growing computing power and advancements
- Using computer models for:
  - Optimizing TE products
  - Optimizing TE processes
  - Assessing the influence of *in-vitro*/*in-vivo* environment on the behavior of TE products virtually

(source: tech.eu)

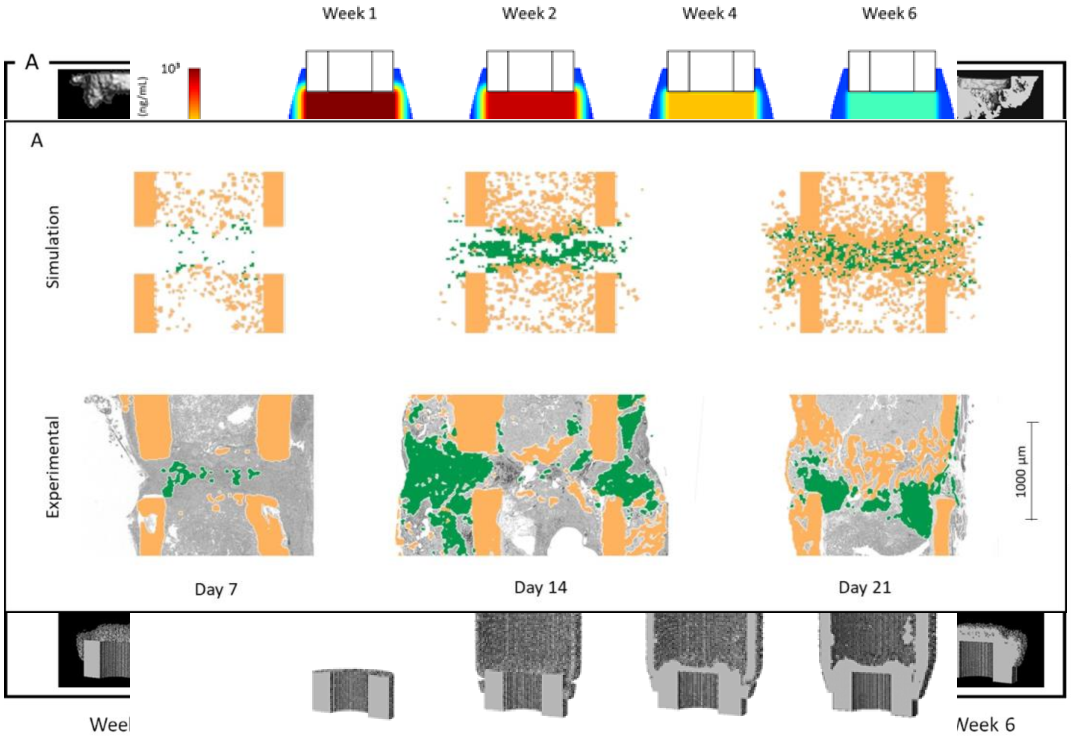
Various Model Types

- Data-driven or based on first principles
- Deterministic or stochastic
- Mechanistic or phenomenological



Example on Bone Healing

- Multiscale modeling
- Stochastic model of tissue formation (in rats without BMP)
- Deterministic model of cell proliferation (in rats with BMP)
- Semi-mechanistic models for bone and cartilage growth (in mice)



(Borgiani et al., Biomech Model Mechanobiol , 20, 2021)

Computational TE Workflows

Underlying Science → **Mathematical Models** → **Computational Models**

- **Underlying Science**: Laws of biology, chemistry, physics, biochemistry, etc.
- **Mathematical Models**: Equations describing the underlying phenomena
- **Computational Models**: Using computers to solve the equations

Use Case for Biodegradable Implants and Scaffolds

Biodegradable Metals

- Mg, Zn, and Fe
- Gradually disappear/absorbed and replaced by new tissue/bone
- Great mechanical/biological properties
- The controlled release profile is an issue for different types of implants
- The degradation behavior should be tuned/optimized for various applications

(Han et al., Mater. Today, 23, 2019)

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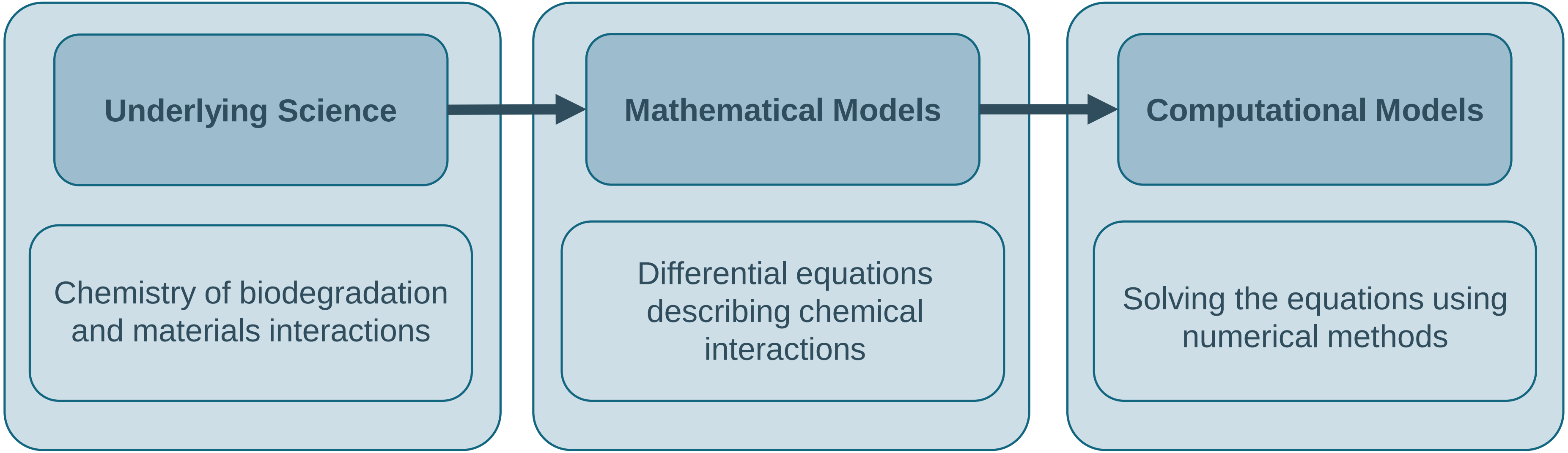
Building Material Biodegradation Model



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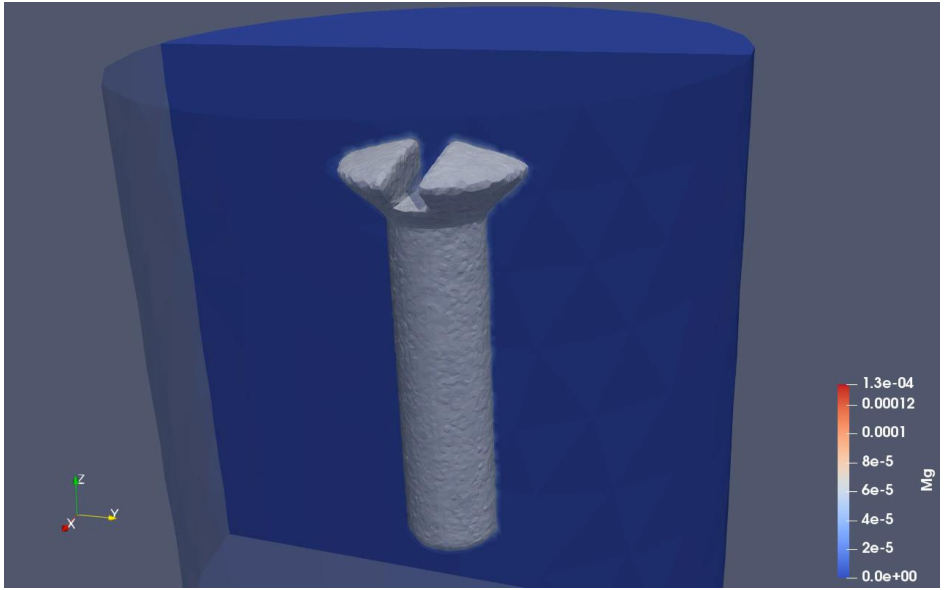
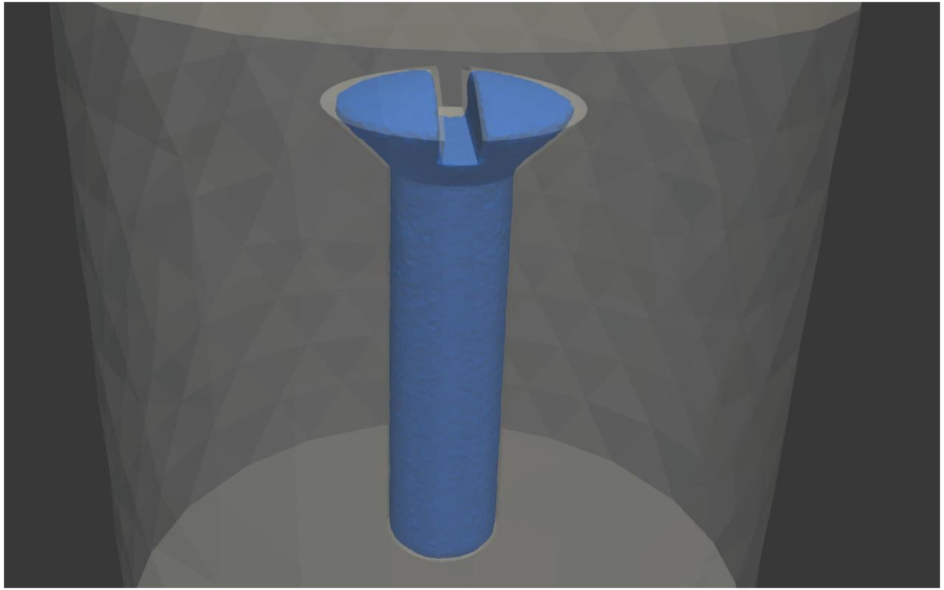
Orthopedics Screw Degradation





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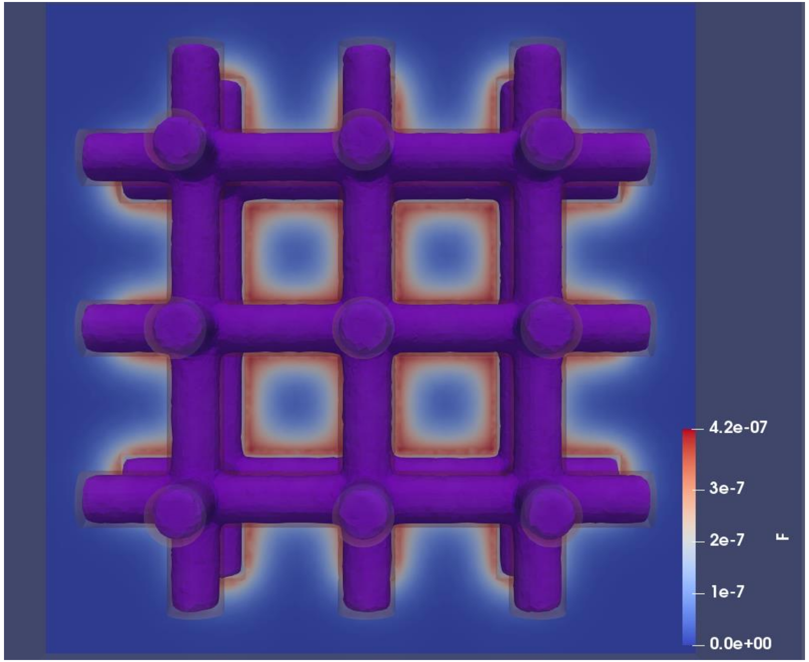
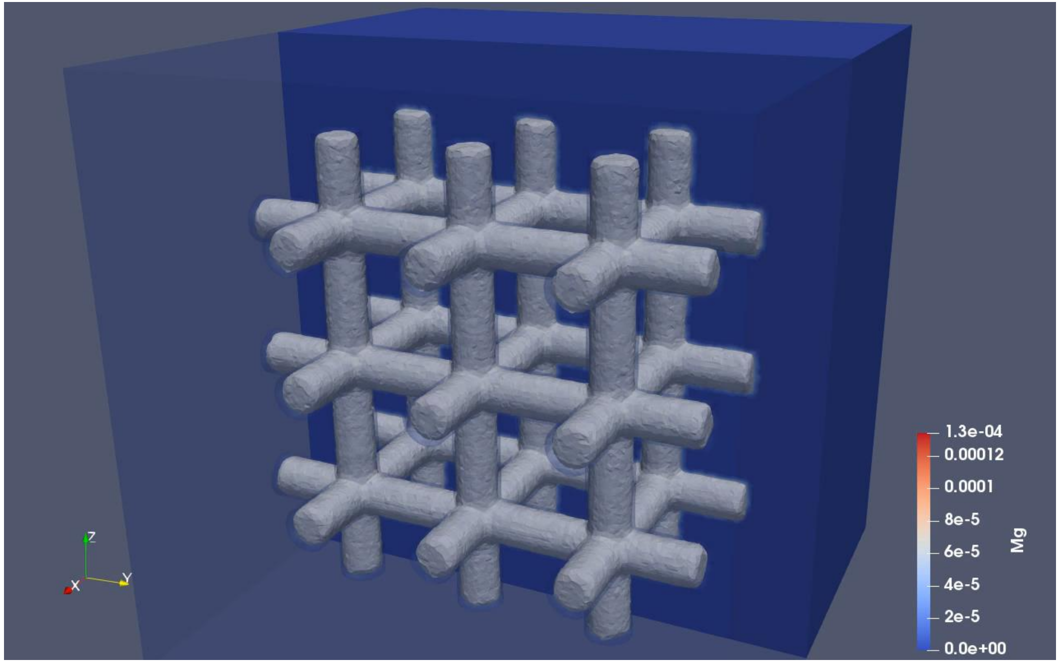
Porous Scaffold Degradation





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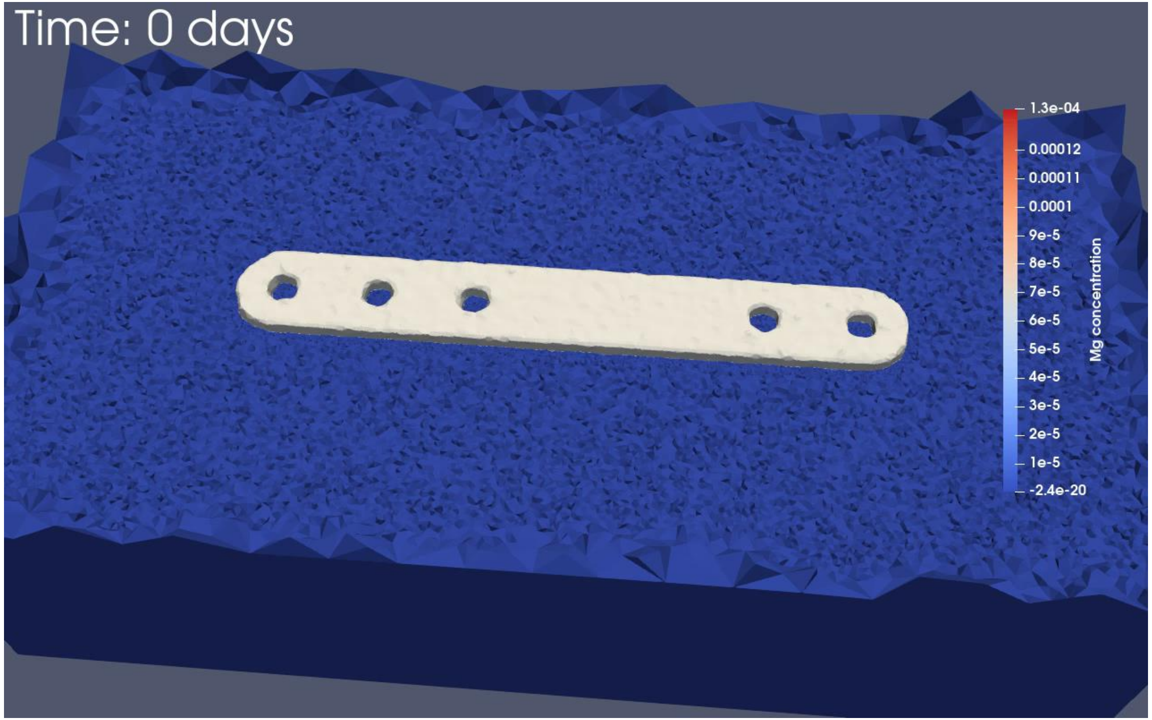
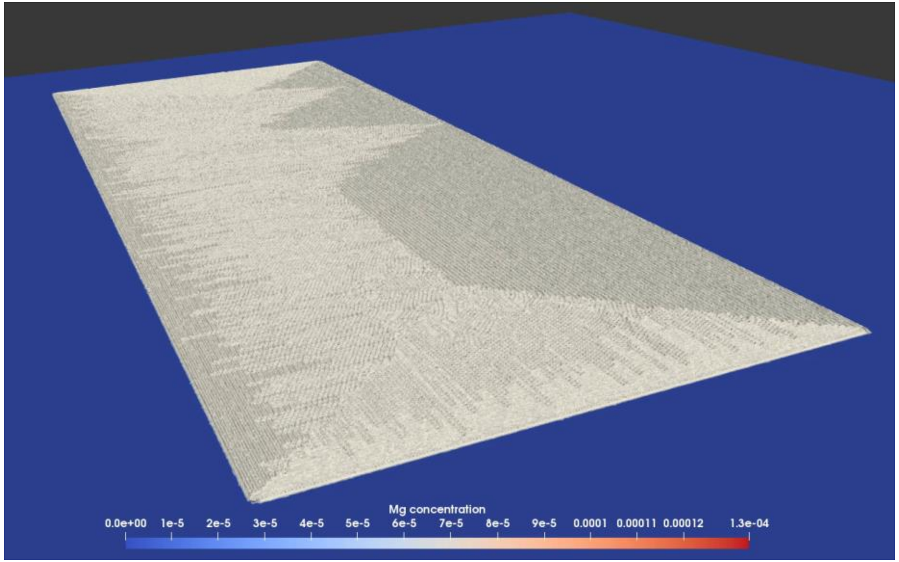
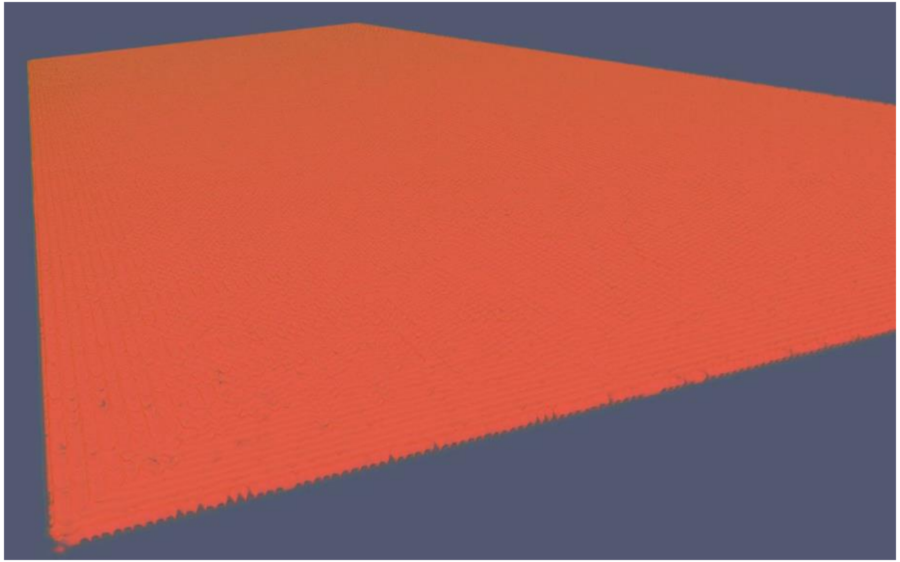
Jaw Bone Plate Degradation



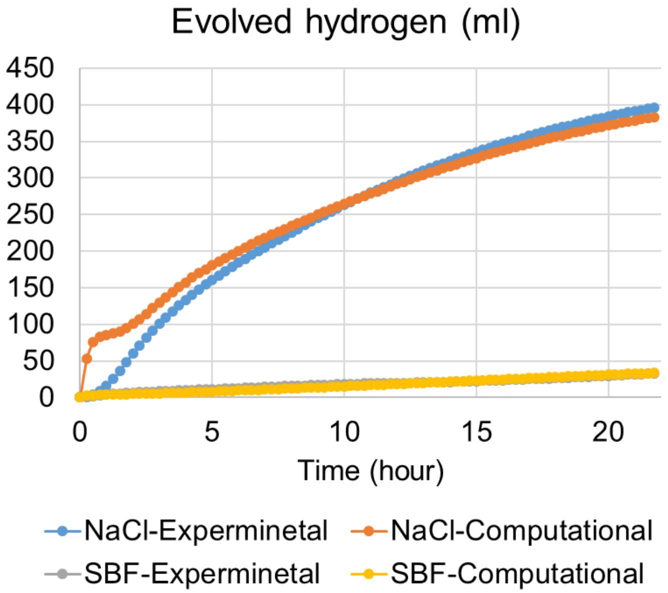
Simulation Results - Degradation

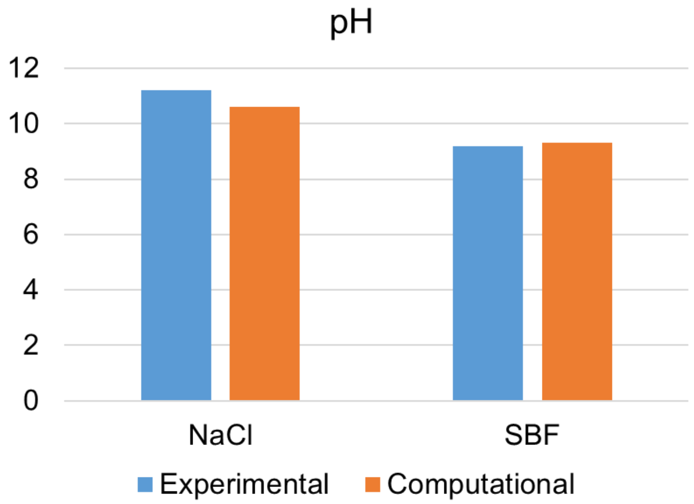




(Barzegari et al., Corrosion Science, 190, 2021)

Quantitative Results for Validation





(Barzegari et al., Corrosion Science, 190, 2021)

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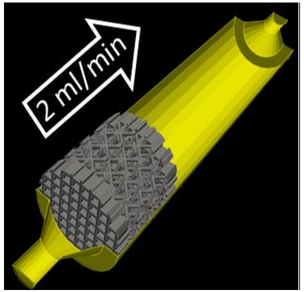
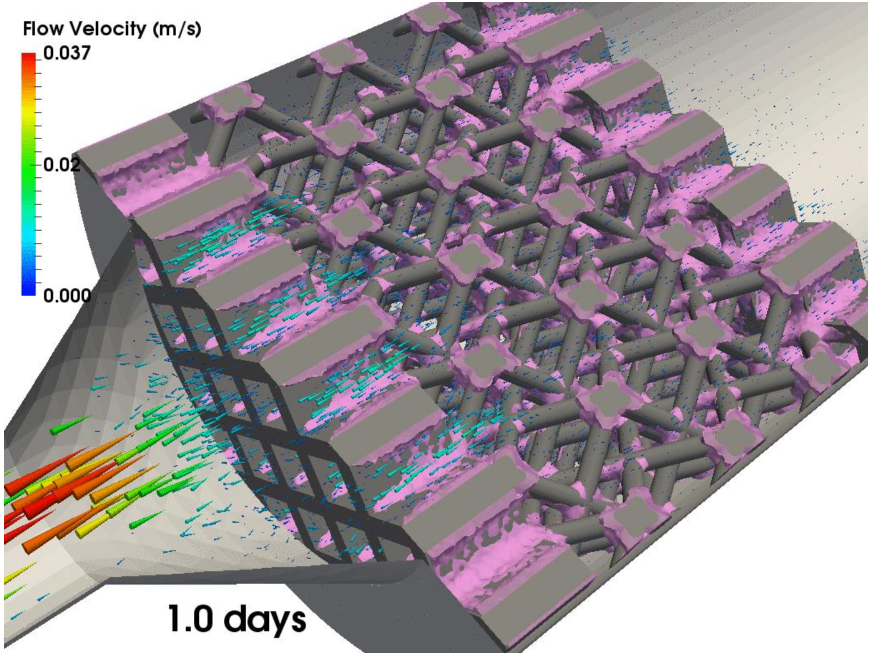
Use Case for Tissue Growth on Open Porous Scaffolds

Tissue Growth Simulations

- Cell growth on open porous scaffolds
- Effect of geometrical characteristics (pore size, shape, and curvature)
- Computational models for the growth of neotissue and cell proliferation process
- Modeling growth as a moving interface problem





(Guyot et al., Biomech Model Mechanobiol., 15, 2016)

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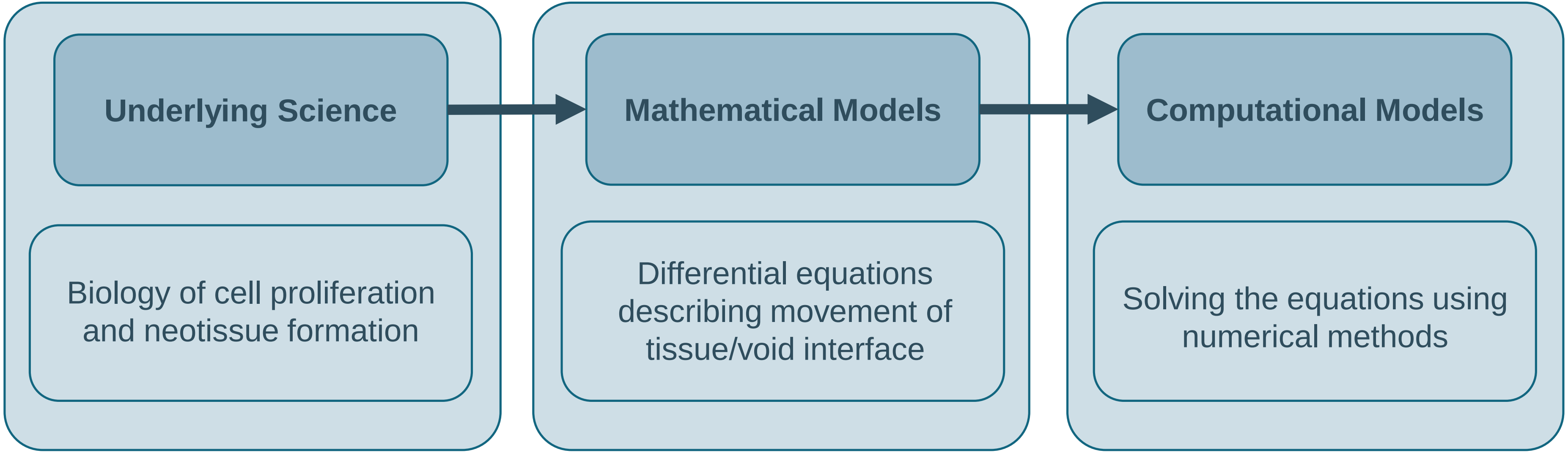
Building Tissue Growth Model



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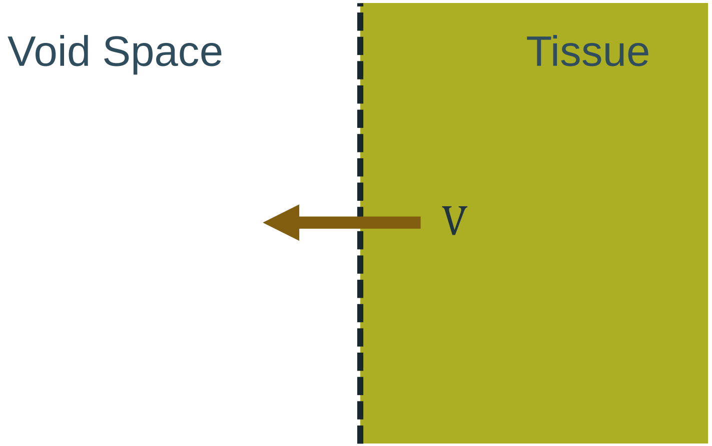
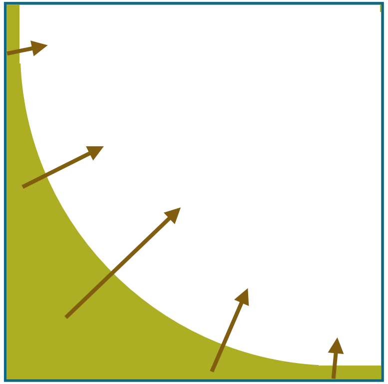
Capturing the Moving Interface

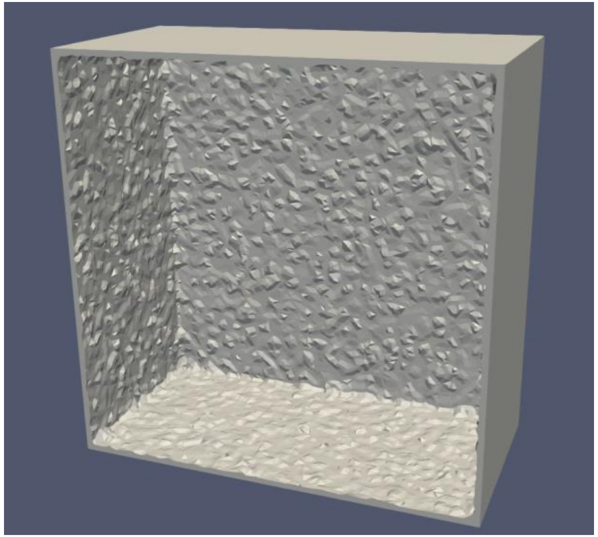
- Identifying interface is crucial
- Mathematical representation of the tissue/void interface



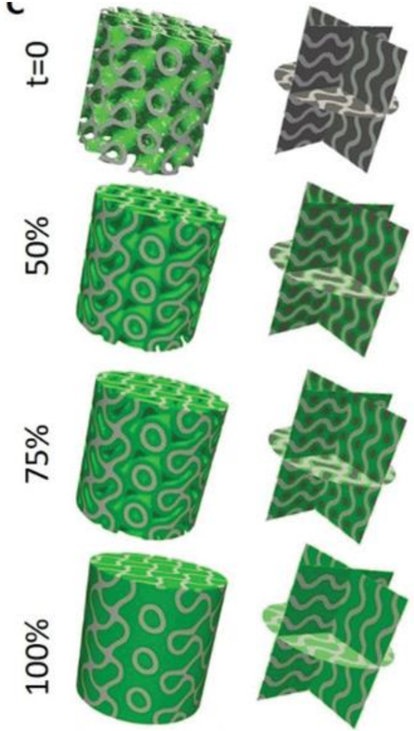
Curvature-based Tissue Growth

- Higher the curvature is, faster the tissue grow





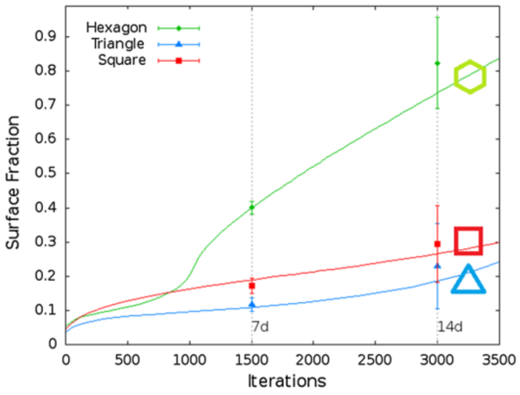
Tissue Growth on Gyroid Scaffolds

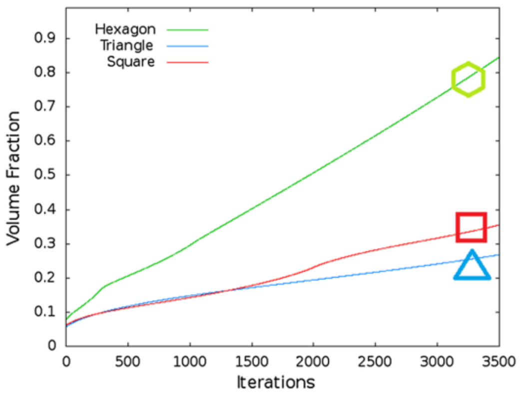


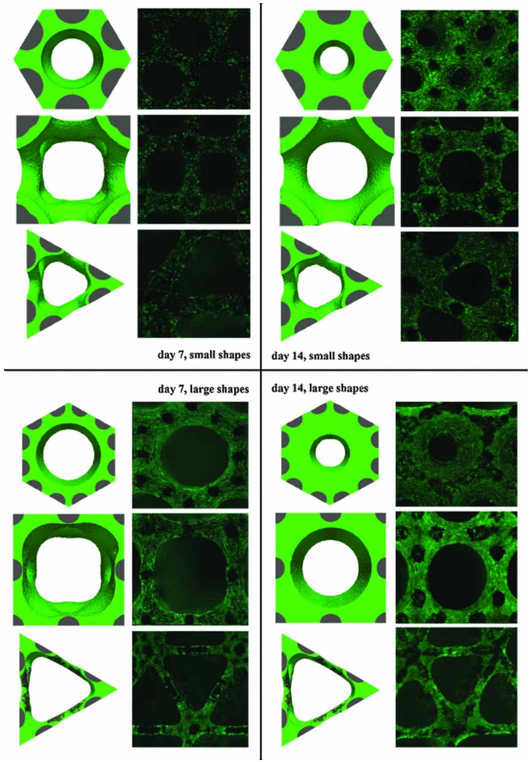
(Van hede et al., Adv. Funct. Mater., 2021)

Validation

- Validating the models is sometimes the most difficult part
- Qualitative or quantitative



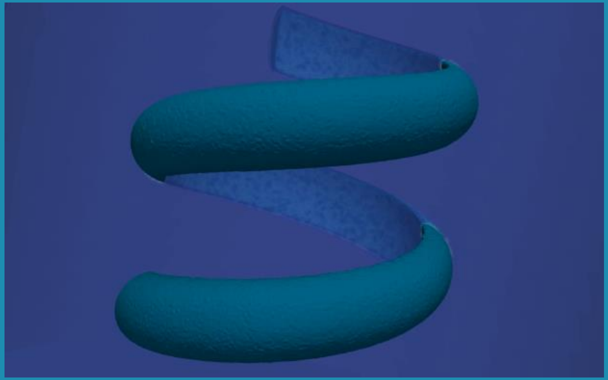




(Guyot et al., Biomech Model Mechanobiol., 13, 2014)

Conclusion

- Role of computational modeling and *in-silico* medicine in tissue engineering
- Use-case 1: a quantitative computational model to assess the degradation behavior of biodegradable metallic implants
- Use-case 2: a semi-quantitative computational model to investigate the neotissue growth in cell culture conditions
- Once fully validated, these approaches can save lots of resources by allowing performing experiments virtually



Thank you for your attention

https://mbarzegary.github.io

@MojBarz

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