Development of Lignin Biopolymer-Bound Composites For Construction

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Research Motivation

The construction industry accounts for 11% of global carbon emissions [1,2]. The development of biopolymer-bound soil composite (BSC) will help decarbonize the construction industry, and will bring the following benefits:

- BSC is cement free and uses nature-based biopolymers as binders
- Use biopolymers (e.g., polysaccharides, protein) as binders to form composites as strong as concrete [1, 3, 4]
- Sequestration of carbon-rich biopolymers results in carbon negative footprint [2]

Existing BSCs are vulnerable to exposures to water due to the hydrophilic nature of their biopolymers.

- We introduce lignin-based BSC, the first BSC variant that uses a hydrophobic biopolymer [5].

This study expands the materials, structures, systems, and evaluation portions of the Sustainable and Integrated Materials, Structures and Systems (SIMSS) framework.

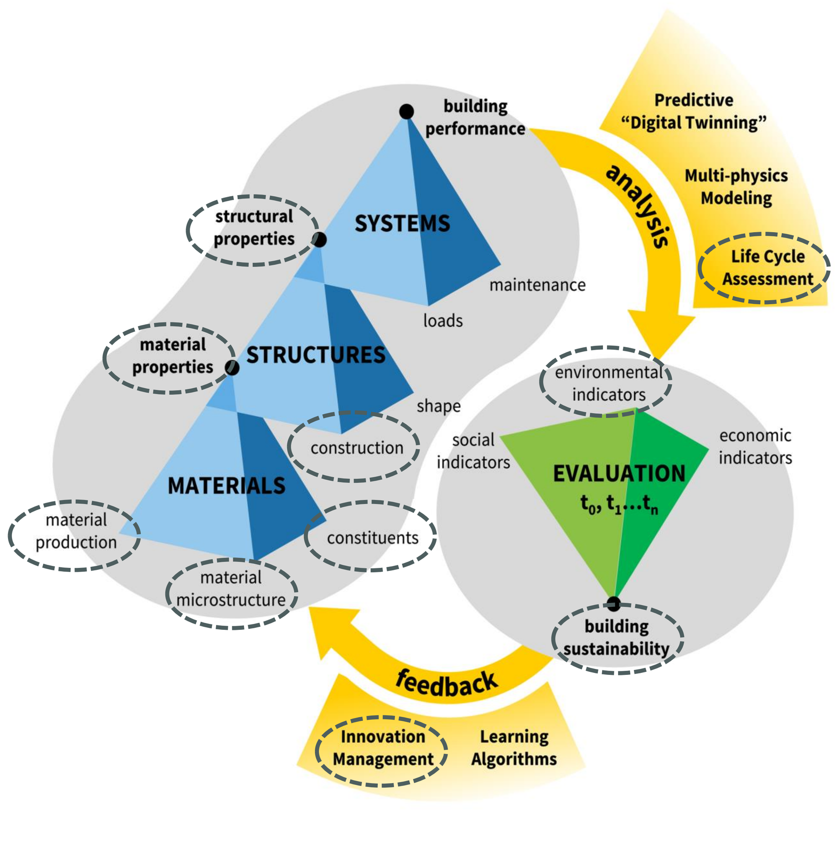

Figure 1: Sustainable Integrated Materials, Structures, Systems (SIMSS) design framework

Design of Lignin Biocomposite

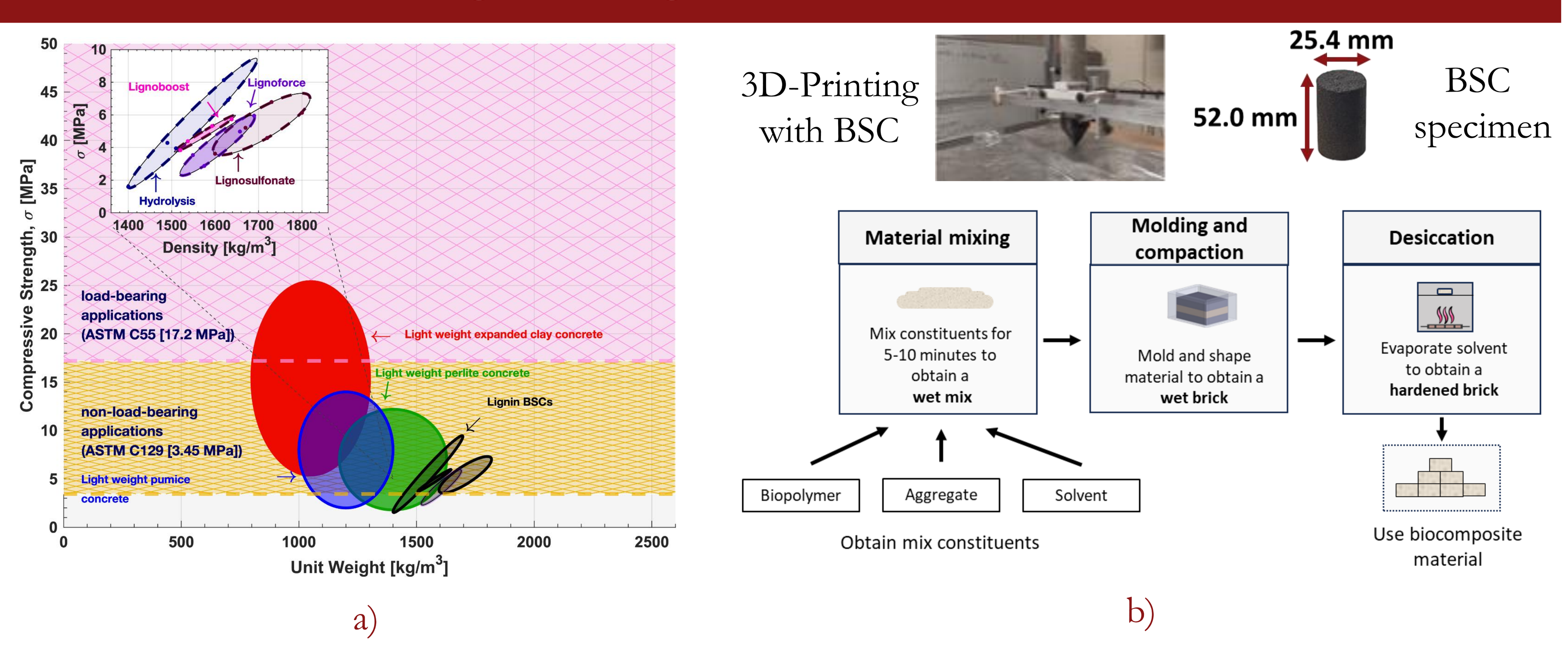

Figure 2: a) Key attributes to consider during the life cycle design and manufacture of lignin-based biocomposites b) manufacture process of lignin-based BSC

- Lignin is a waste product from paper and pulp production (e.g., Alkali lignin and Kraft lignin) and from the production of cellulosic bio-fuels (e.g., Hydrolysis lignin).
- To manufacture lignin biocomposite: lignin, Grade 90 sand, and a solvent are used
- Lignin biopolymer is dissolved in solvent to form a biopolymer binder that binds together granular material into a composite material. BSC is cement-free
- Design relationships for four types of lignin-based BSC are developed based on uniaxial compressive tests on varying mix designs.
- Two most significant design parameters for predicting compressive strength are dry bulk soil density and biopolymer content of the finished BSC [1].

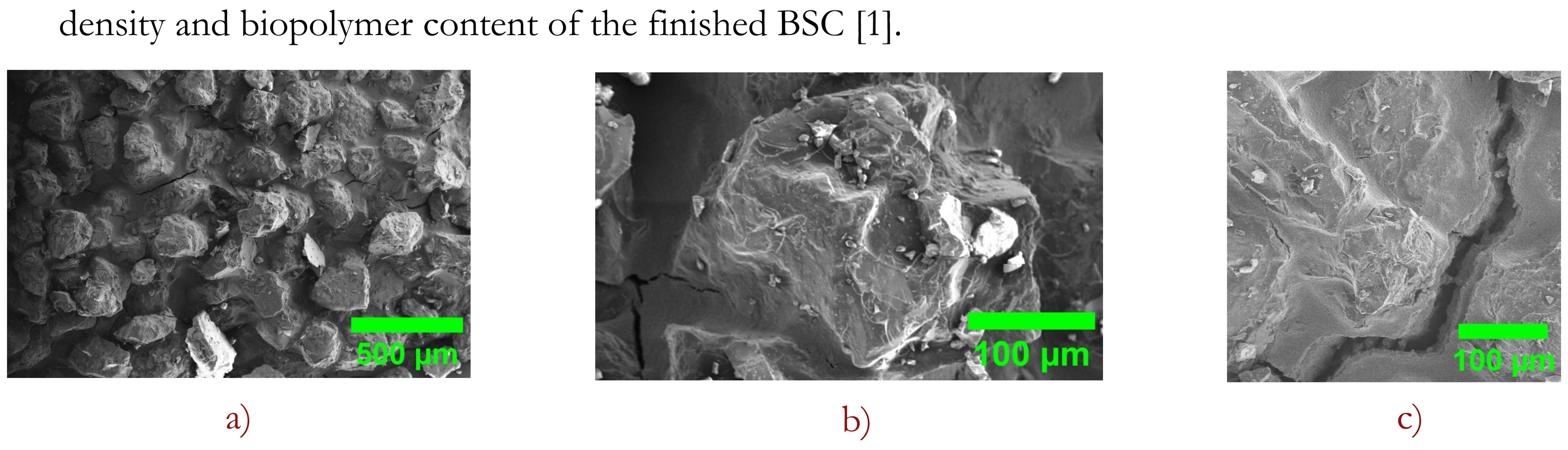

Figure 3: Scanning electron microscopy (SEM) of lignin biocomposite

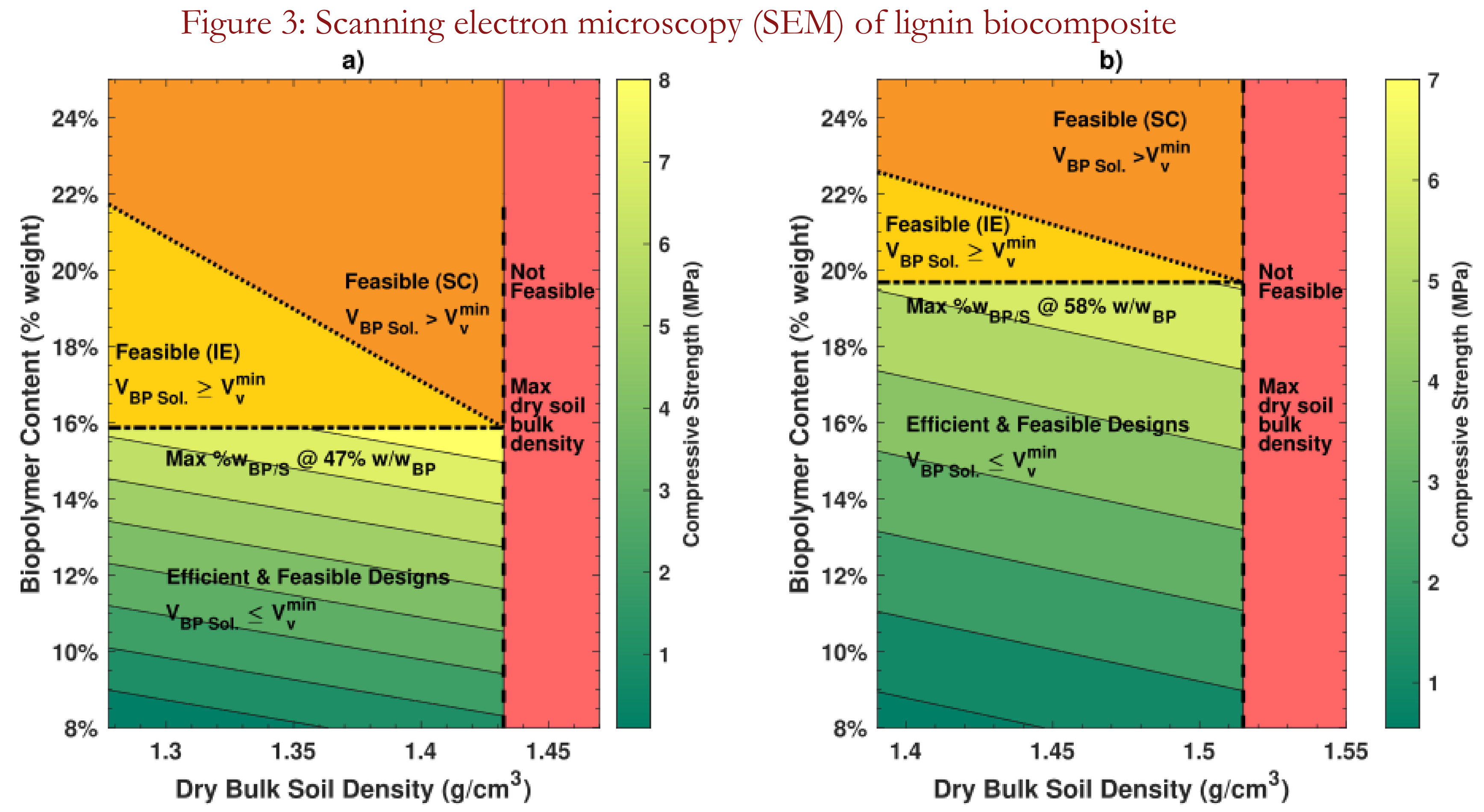

Figure 4: Design relationships for virgin lignin-based BSC using a) Hydrolysis lignin and b) Alkali lignin

Life Cycle Assessment of Lignin Biocomposite

- The carbon footprint of lignin biocomposite is dependent on the transportation distance, energy use (mixing and desiccation), solvent use, and lignin production.
- Lignin-based BSC is a carbon negative construction material [2]

$$Carbon\ Footprint = Transportation_{Imp.} + Electricity_{Imp.} + Solvent_{Imp.} + Lignin_{Imp.}$$

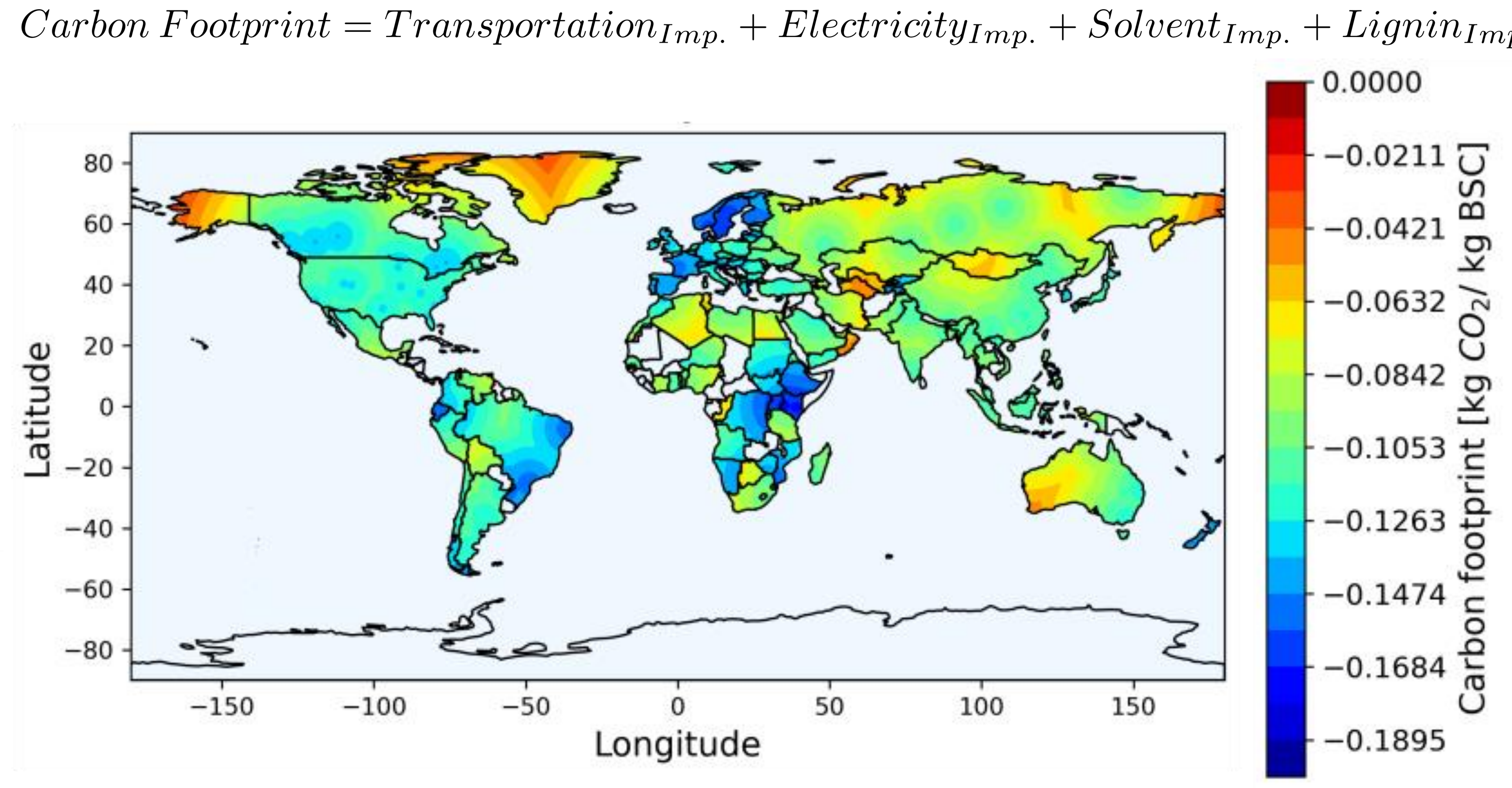

Figure 5: Carbon footprint for producing 1 kg of lignin biocomposite

End of Life Considerations for Lignin Biocomposite

- Lignin biocomposite can be recycled at the end of life by reusing recycled lignin aggregates in place for virgin lignin and virgin aggregate
- The compressive strength of recycled lignin biocomposite is 50% higher than virgin lignin biocomposite [3]

Microstructural characterization was performed by X-ray computed tomography, from which two microstructure correlation functions are computed on the segmented images:

1. Linear path function: Probability that a line of a given length lies completely in one phase
2. Two-point function: Probability that a certain phase correlation are separated by a given distance

From this analysis we can speculate that the strength increase in recycled lignin biocomposite is from closer particle to particle association, aggregate size or distribution, or enhanced bridging formation.

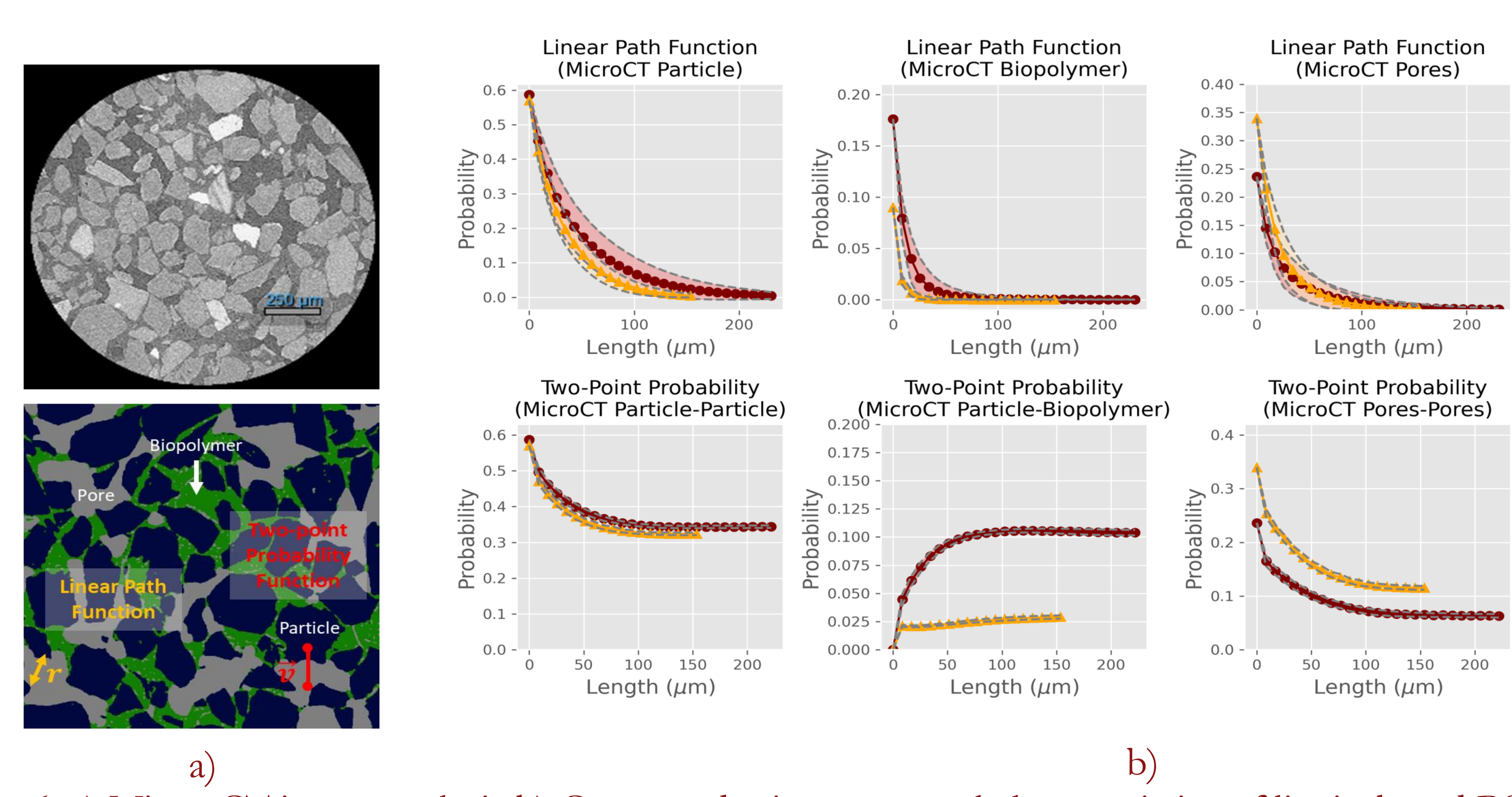

Figure 6: a) Micro-CT image analysis b) Computed microstructural characteristics of lignin-based BSC

Conclusions

- Lignin biocomposite can replace lightweight concrete and clay bricks → Consequential impact
- Sequestration of carbon-rich lignin in the composite allows lignin biocomposite to be a carbon negative building material that is applicable in most of the world. → Sustainable building materials
- Lignin biocomposite is a fully recyclable building material → Material circularity is achieved

Acknowledgements

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Reference

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Reference #1

Reference #2

Blume Earthquake Engineering Center

Reference #3

Reference #4