

Why do we need recycled concrete ?

Key issues [1, 2]:

- 1/3 of global waste
- 25% of CO₂ emissions
- 50% of infrastructure were constructed before 1980 in Europe

⇒ We need to recycle !

Do we need to change its composition?

Do the mechanical properties change?

Composition of Concrete

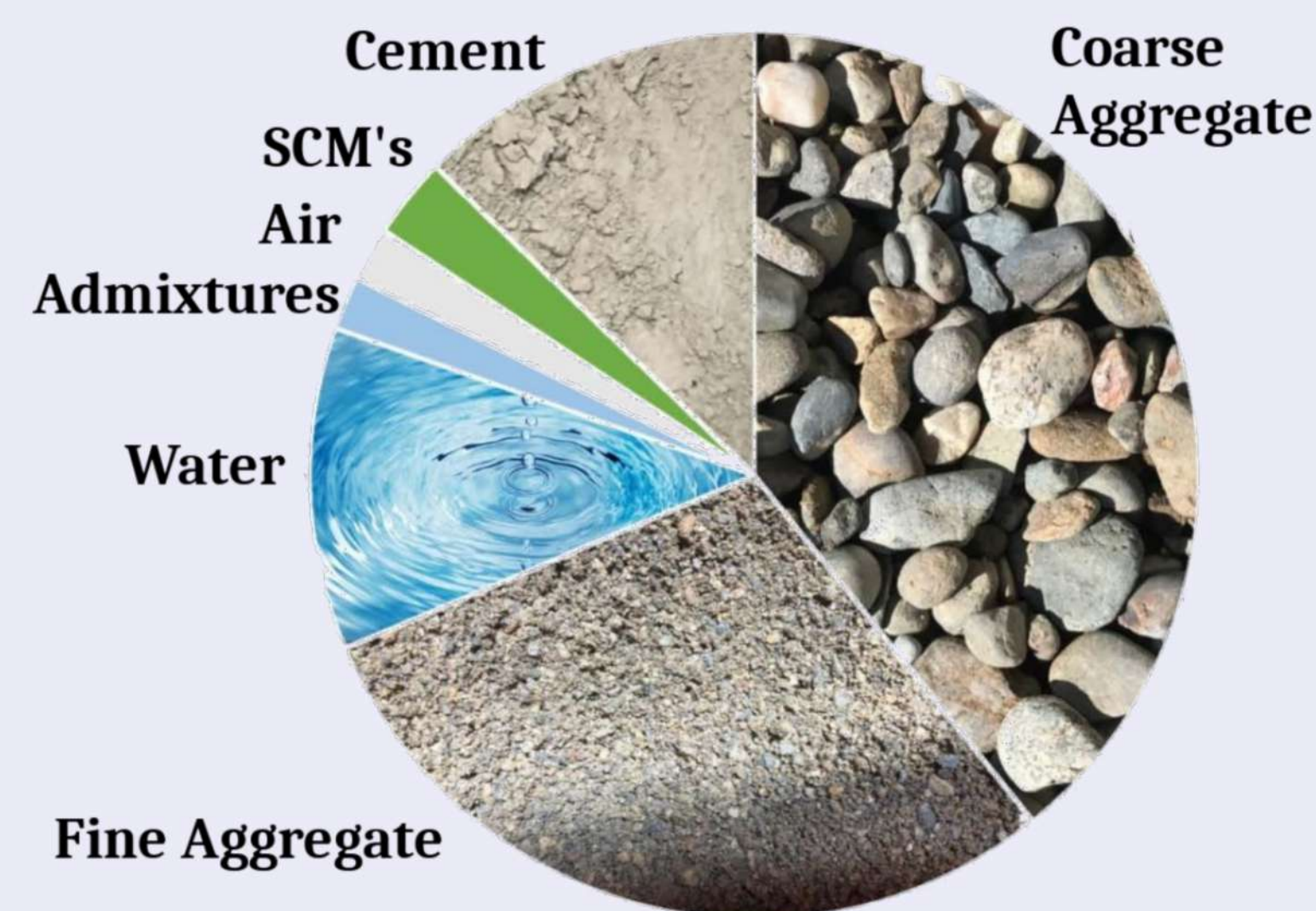


Figure 1. Typical composition of concrete. Image Credit: MathewsReadymixLLC

How to simulate an aggregate with the Discrete Element Method ?

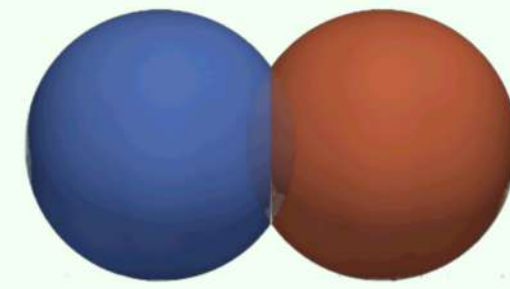
Newton's Second Law
 $\mathbf{F} = m\mathbf{a}$

Euler's Equation
 $\mathbf{I} \cdot \frac{d\boldsymbol{\omega}}{dt} + \boldsymbol{\omega} \times (\mathbf{I} \cdot \boldsymbol{\omega}) = \mathbf{M}$

Contact model: Hertz-Mindlin with overlapping spheres.

Overlap (δ) = 0.036844

Time: 0.300



$$F = \sqrt{\delta} \sqrt{\frac{R_1 R_2}{R_1 + R_2}} (k_n \delta \mathbf{n}_{ij})$$

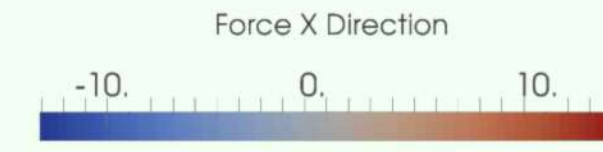
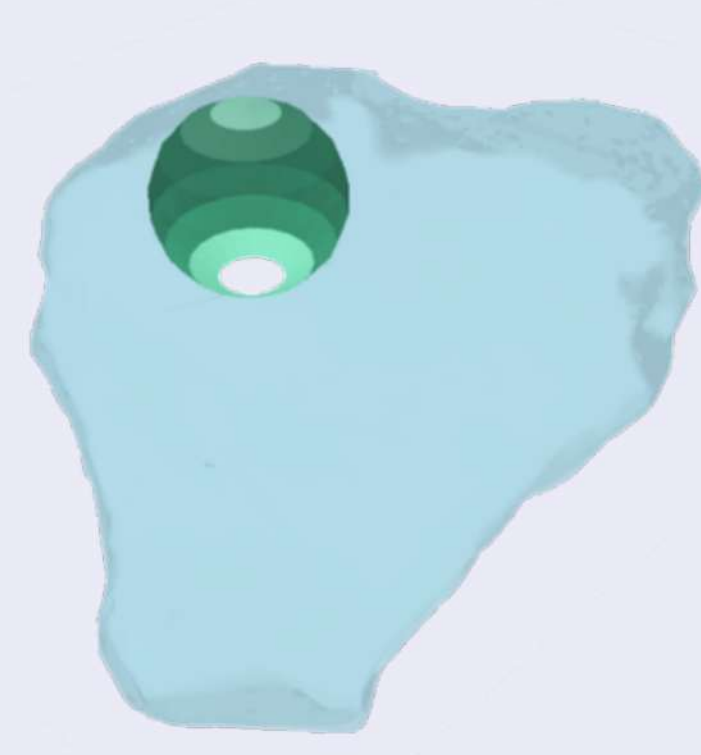
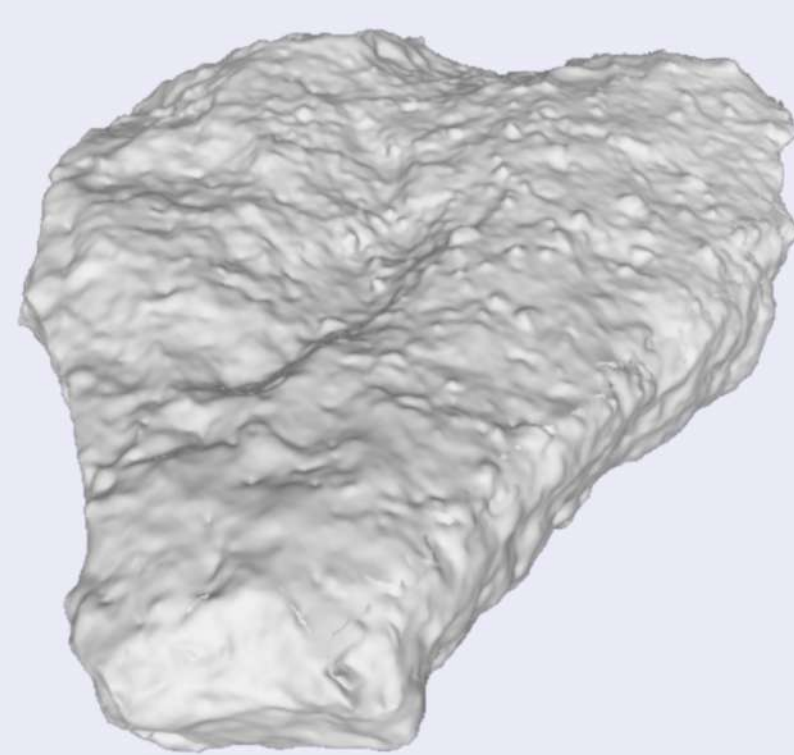


Figure 2. Typical contact of two spheres. Image Credit: Coreform_Greg on YouTube.

How can we efficiently describe the aggregate?

3D SCAN

1 Sphere



25 Spheres

1000 Spheres



Figure 3. Scan of a rock and its representation with different number of spheres using CLUMP [3].

Rugosity description



Figure 4. Sketch of the concept of Meso and Macro-Rugosity

Rod, Cross, and Star as Toy Models

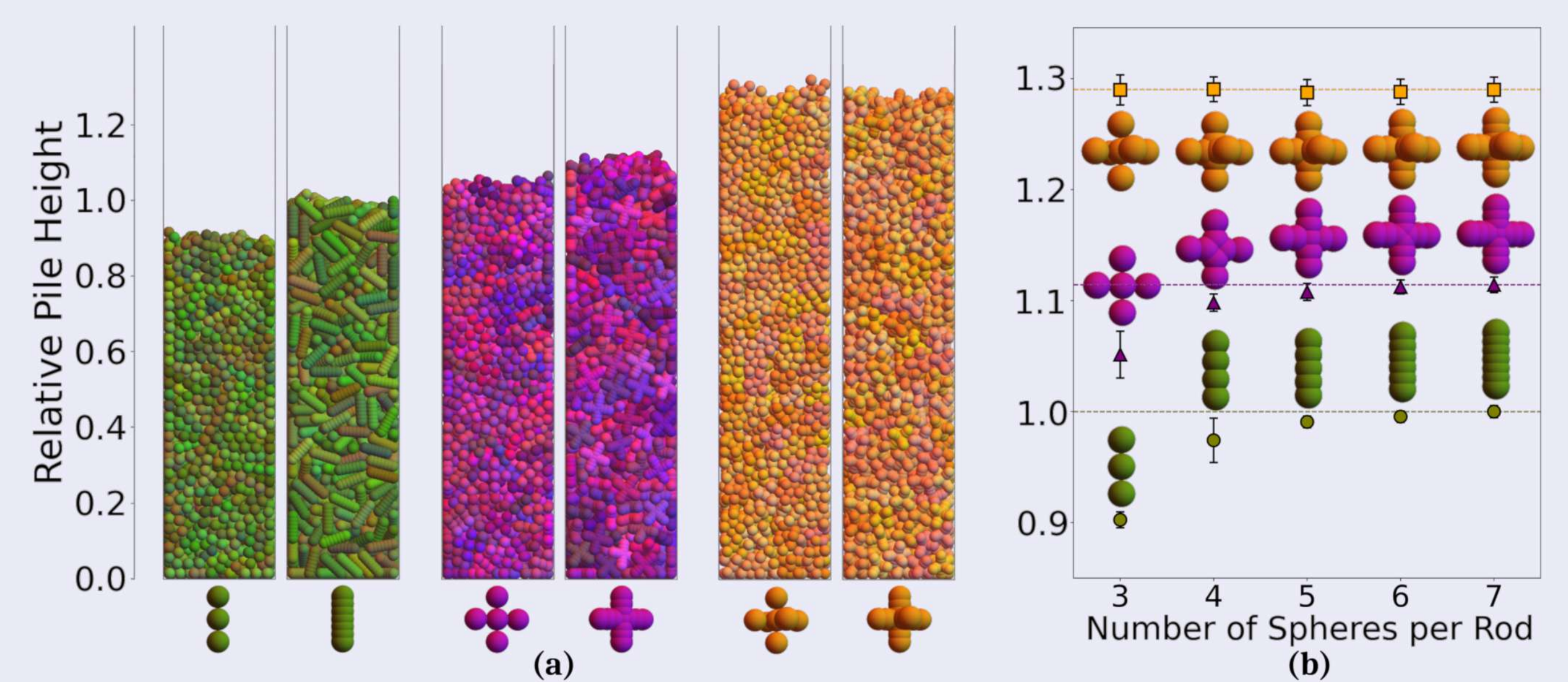


Figure 5. (a) Piles with 3 and 7 spheres per rod (green: rod, purple: cross, orange: star; color variations enhance visualization). (b) Relative pile heights for the three particle types with spheres per rod ranging from 3 to 7, averaged over 100 simulations and normalized to the final rod measurement. A dashed line highlights the limiting behavior observed.

Extrapolation : Packing Fraction

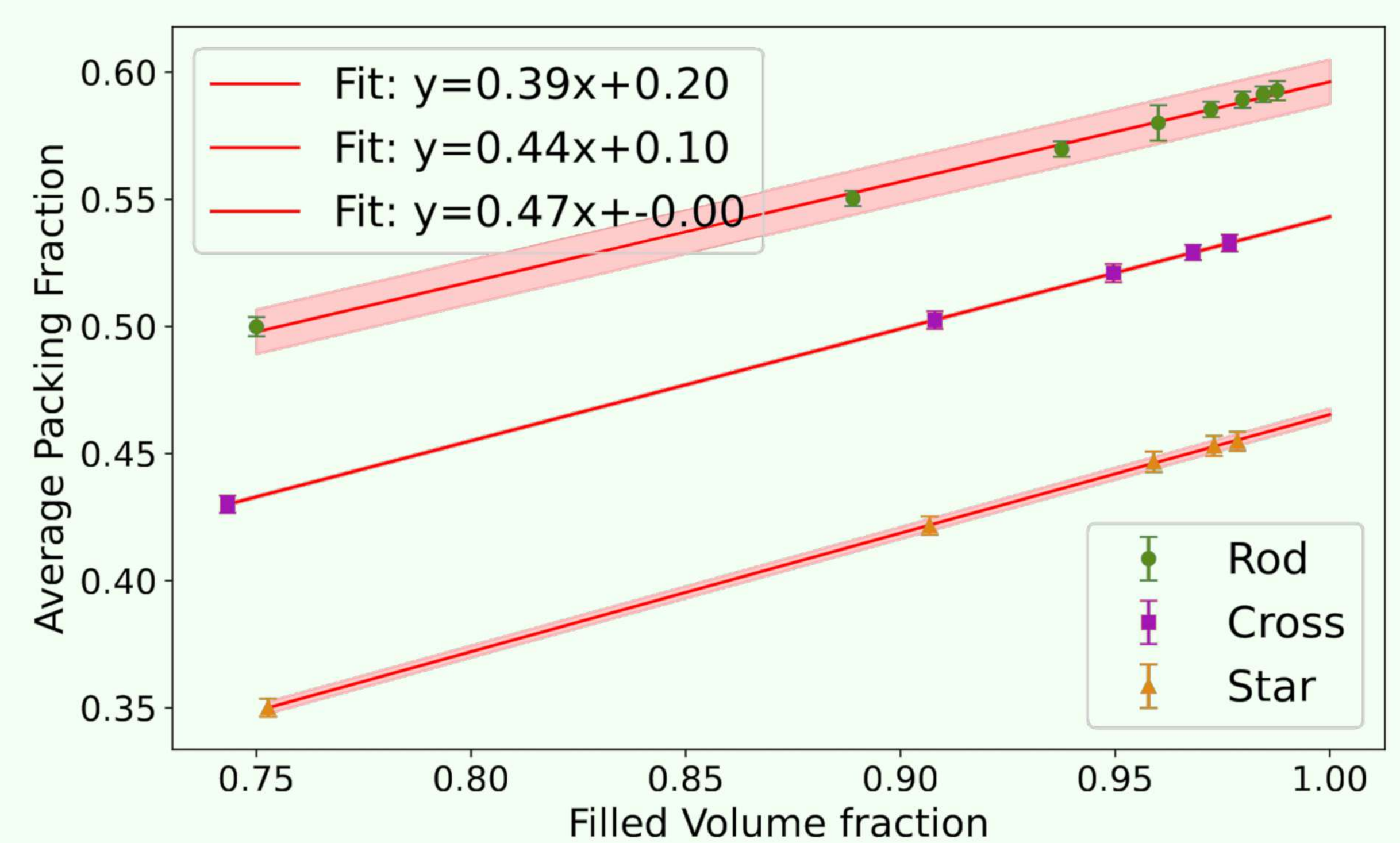


Figure 6. Evolution of the packing fraction as a function of the filled volume fraction.

Conclusions

Key findings are the following:

- Possibility to transform real object into clump of spheres using 3D scan.
- Depending on the macro-rugosity of the particles, the impact of meso-rugosity varies for different mechanical properties.
- For each macro-rugosity, a small number of spheres can correctly represent complex shapes
⇒ Reduce computational cost.
- It is feasible to extrapolate the limiting properties of complex shapes.

Future prospects

Engineering aspects

- Characterize real coarse aggregate of concrete.
- Explore mechanical properties of recycled concrete.

Computational aspects

- Implement breakage of clumps.
- Implement fluids and chemical reaction for wet concrete.
- Explore computational complexity of the problem and its scalability.

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Figure 7. Other PhD Student of ARC EsPOIR (Lankcohr Sophie, Gamaralalage Chathura and Thommes Eliott).

References

- [1] Eurostat (2024). Waste statistics. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics. Accessed: 2025-04-17.
- [2] Gevorgian, A., Pezzutto, S., Zambotti, S., Croce, S., Oberegger, U. F., Lollini, R., Kranzl, L., & Müller, A. (2021). *European Building Stock Analysis: a country by country descriptive and comparative analysis of the energy performance of buildings*. Eurac Research.
- [3] Angelidakis, V., Nadimi, S., Otsubo, M., & Utili, S. (2021). CLUMP: A Code Library to generate Universal Multi-sphere Particles. *SoftwareX*, 15, 100735. <https://doi.org/10.1016/j.softx.2021.100735>.
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