Optimising Flow and Print Quality in 3D Concrete Printing using DEM simulations

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Project Summary

3D Concrete Printing (3DCP) is a rapidly evolving technology in construction that relies on the continuous and stable extrusion of mortar through a nozzle. One of the most critical factors influencing the nozzle flow and print quality is the particle size distribution of the fine aggregate, often quantified by the Fineness Modulus (FM).

Fine aggregates, with a low FM [1], tend to produce high-yield-stress mortars [2], making it prone to nozzle clogging, whereas coarse aggregates (high FM) improve flowability but can produce a weaker, discontinuous filament with poor surface quality [3]. Despite this trade-off, there are no clear guidelines on the optimal FM range for reliable extrusion in modern 3DCP systems.

This project aims to fill that gap through simulation-based research, complemented by basic experimental insights. The goal is to identify an optimal FM range that balances extrusion flow quality and nozzle clogging risk, thereby contributing to more robust 3DCP processes.

Objectives

1. **Characterize FM Variations:** Define a representative range of aggregate gradations ranging from low to high FM for simulation studies.

2. **Develop DEM Nozzle Model:** Build a computational model of the extrusion nozzle simulate mortar flow.

3. **Simulate Clogging and Flow Behaviour:** Run simulations for each FM value, logging pressure buildup, flow rate, and clogging events.

4. **Analyse Flow Quality:** Evaluate the uniformity of particle distribution and any irregularities in the extrudate.

5. **Identify Optimal FM and Guidelines:** Determine which FM values yield the best performance and propose a simple guideline.

Methodology

This project will primarily employ a simulation-driven methodology, using the Discrete Element Method (DEM). MercuryDPM will be the core tool for modelling particle flow because it allows flexible wall geometries and can efficiently simulate a wide range of particle sizes.

Simulation Setup: A typical 3DCP nozzle (e.g. 20 mm outlet diameter) will be modelled. Sand particles are generated above the nozzle and driven through it, using particle size distributions corresponding to target FM values (e.g., FM 2.2, 2.6, 3.0).

Data Collection: During each simulation, pressure on the nozzle walls and particle motion will be logged. Any instance of clogging will be identified by pressure spikes or halted flow.

Validation: Basic lab observations may be used to qualitatively validate simulation outcomes.

Analysis: Results for each FM will be compared to analyse trends. Statistical or regression analysis will be used to correlate FM with flow quality and clogging risk.

Expected Outcome

The project will reveal how FM affects nozzle performance. It is hypothesized that FM around 2.5–2.8 will support smooth extrusion. Very fine (FM < 2.2) or very coarse (FM > 3.0) sand may increase clogging or weaken print quality. The results will be translated into practical guidelines, such as the relation between FM and nozzle size.

References

[1] ACI Education Bulletin E1-07. Aggregates for Concrete.

[2] Roussel, N. Rheology of fresh concrete: from measurements to predictions of casting processes. Mater Struct 40, 1001–1012 (2007). https://doi.org/10.1617/s11527-007-9313-2

[3] Le, T.T., Austin, S.A., Lim, S. et al. Mix design and fresh properties for high-performance printing concrete. Mater Struct 45, 1221–1232 (2012). https://doi.org/10.1617/s11527-012-9828-z