# AMORPHOUS MATERIAL REDISTRIBUTION PLANNING IN CONSTRUCTION TASKS

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TD3 Robotic Components, Sensors and Actuators

## GOAL

We propose a **"next-best-sweep"** algorithm to plan redistribution actions to shape a sand distribution.

Our approach aims at replicating how **humans** typically work: **iterating** and **adapting** their manipulation actions to the observed and desired material states.

We investigate different **domain-inspired** methods to guide planning [1].

## MOTIVATION

- **Amorphous materials** are involved in many construction applications: excavation, shotcreting, plastering …
- **Sand properties**, like for other amorphous materials, are difficult to estimate and **emergent effects** such as collapses may occur which both influence the manipulation outcome.
- Existing commercial technologies focus on **standard** tasks (e.g., plastering flat walls).

→ Need for **versatile** robot systems to handle **on-site** variability and challenging material properties.

## APPROACH

Redistribution planning **algorithm:**

**1:** $\mathcal{A} \leftarrow$ **Generate_sweep_candidate**$(H_{\text{des}}, H_{\text{mes}})$
**2:** **for** $a$ **in** $\mathcal{A}$ **do:**
**3:** $H_{\text{obtained}} \leftarrow$ **Sweep_prediction**$(a)$
**4:** $C_a \leftarrow$ **Evaluate_prediction**$(a, H_{\text{obtained}})$
**5:** **if** $C_a < C_{best}$ **then**
**6:** $a_{best} \leftarrow a$
**7:** $C_{best} \leftarrow C_a$
**8:** **end if**
**9:** **end for**
**10:** **Execute_best_candidate**$(a_{best})$

### 1/ Candidate generation

The grading actions $a = (x_{\text{start}}, y_{\text{start}}, x_{\text{end}}, y_{\text{end}})$ are represented as linear sweeps.

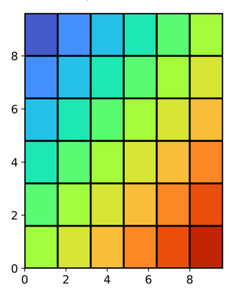
We propose 3 generation methods from domain expertise:

(1) Optimal Transport

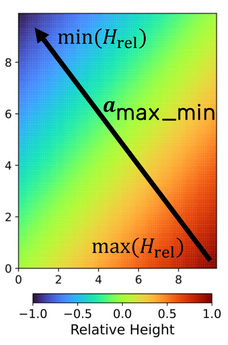
Optimal transport plan:

$$T = \begin{pmatrix} t_{0,0} & \cdots & t_{0,n} \\ \vdots & \ddots & \vdots \\ t_{n,0} & \cdots & t_{n,n} \end{pmatrix}$$

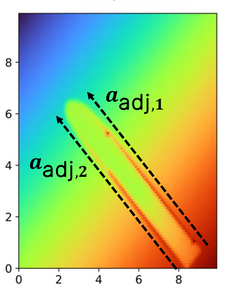
→ $a_{\text{OT}} = \{x_i, y_i, x_j, y_j\}$ such that $\mathbf{t_{i,j}} = \boldsymbol{max(T)}$



(2) Max-to-min

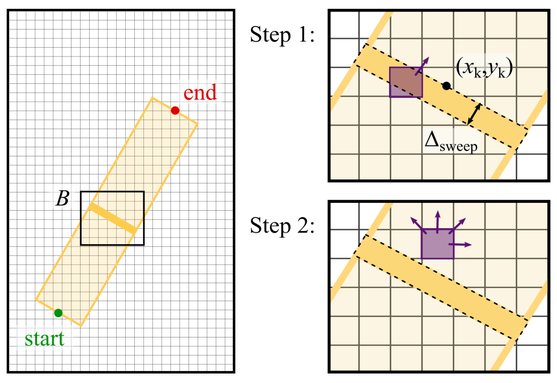



(3) Adjacent




### 2/ Model prediction

Step 1: Tool displacement.
Step 2: Natural material flow equilibrium.




### 3/ Candidate evaluation

$$C_{\text{sweep}} = \sqrt{\sum_{i=1}^{n} \frac{\left(z_{i,\text{des}} - z_{i,\text{obtained}}\right)^2}{n}}$$

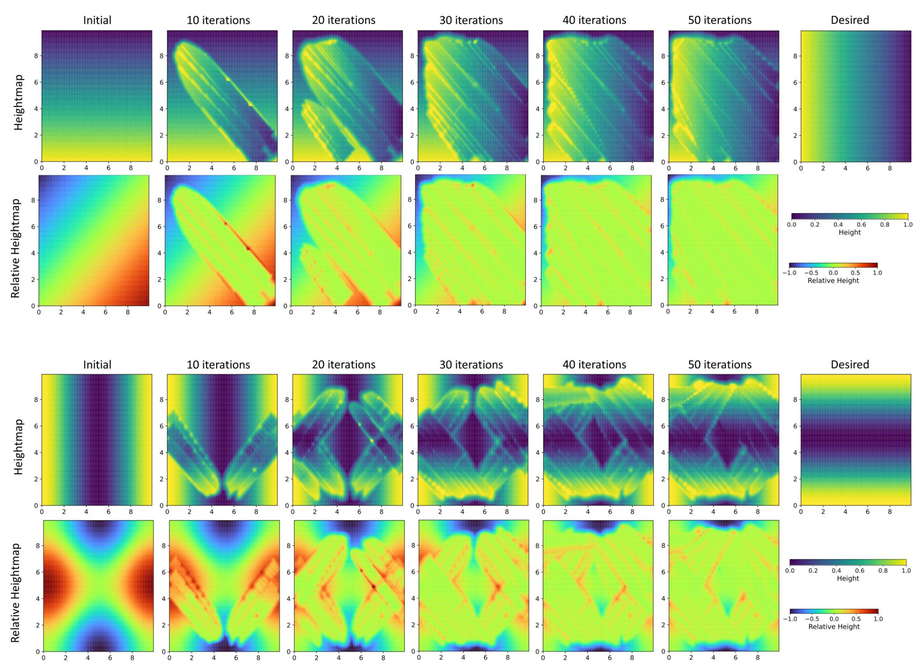
### 4/ Best candidate execution

## RESULTS

We **evaluate** the redistribution with the different candidate generation methods in **simulation**.

Results for linear distribution:

| Candidate generation | RMSE | Travelled distance | Planning time |
|---|---|---|---|
| OT | 0.2056 | 368.67 | 164.3 |
| Max-to-min | 0.2060 | 446.57 | 199.37 |
| Adjacent | 0.3033 | 256.4 | 68.15 |
| Our method | 0.1420 | 448.94 | 383.02 |




**Discussion:**

- Adjacent method is a good complement to include local refinements in planning.
- Planning time is acceptable for real execution.
- OT contains spatial information but down sampling can lose details.

**Future work** will focus on scenarios with obstacles and integration with low-level controller [2].

## KEY TAKE-AWAYS

- The important elements to plan redistribution sweeps in amorphous materials are tool-material interaction **modelling**, **feedback** and **domain expertise**.
- **Better redistribution quality** is obtained with a rich set of candidates combining the 3 generation methods.
- Future **integration** with **real-time control** during sweep execution [2] will provide more **robustness** and compensate for model **inaccuracies**.

## FURTHER READING

[1] L. Hanut, Y. Du, R. Detry, and H. Bruyninckx, "Exploring Planning of Redistribution Trajectories for Profile Grading in Amorphous Materials," in Block by Block Collaborative Strategies for Multi-Agent Robotic Construction Workshop at ICRA 2025.

[2] L. Hanut, Y. Du, A. Vande Moere, R. Detry, and H. Bruyninckx, "Robotic Framework for Iterative and Adaptive Profile Grading of Sand," in IEEE International Conference on Robotics and Automation, 2025.

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