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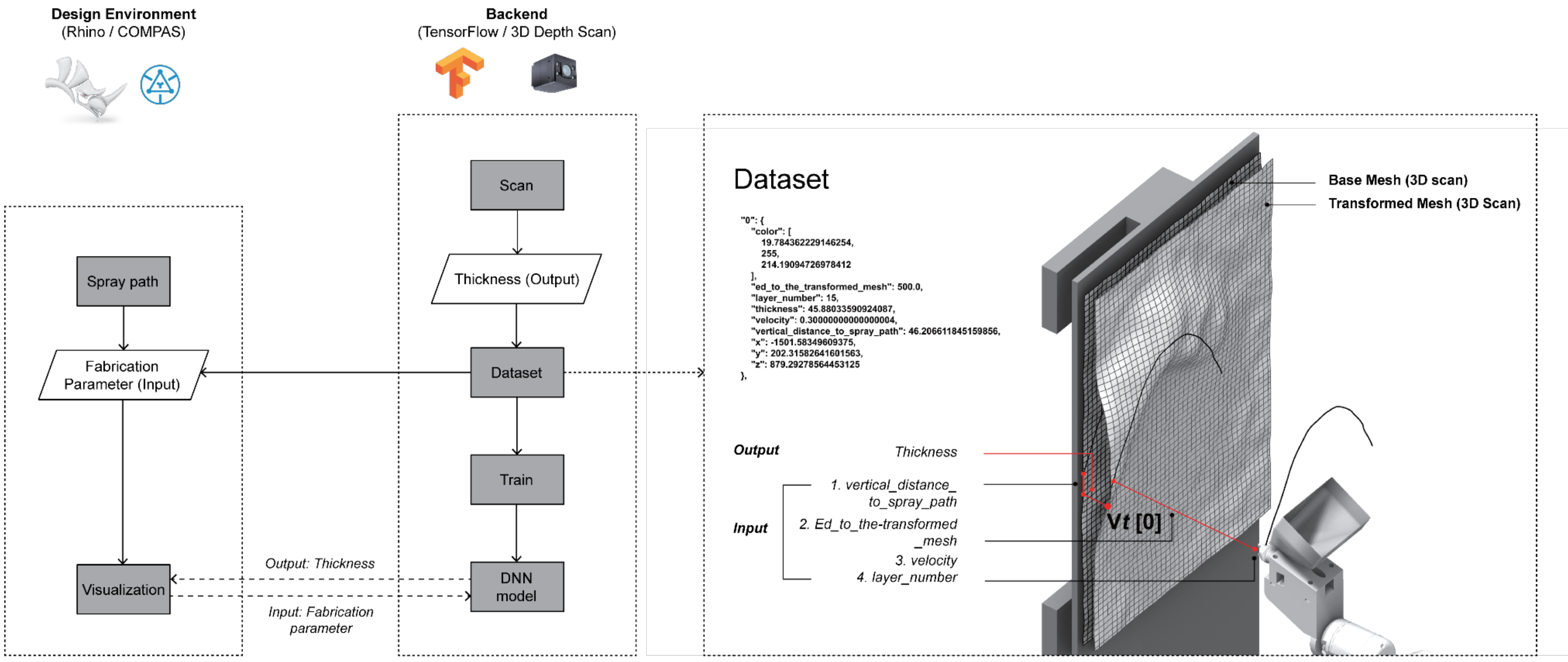
ML-Based Predictive Modeling for Robotic On-Site Plastering (ML-ROSP)

Semester Project / Master Thesis



ROSP workflow for data collection, prediction and visualization in CAD environment. Selen Ercan Jenny. “Robotic Plaster Spraying: Crafting Surfaces with Adaptive Thin-Layer Printing On-Site”, PhD thesis. Zurich: ETH Zurich, 2023. doi: 10.3929/ethz-b-000604464. Diagram by: Ping-Hsun Tsai.

Description

This project aims to develop an ML-based design and fabrication workflow for a robotic on-site plastering process – a real-world application. For this, data is collected during the robotic plastering process by a 3D depth camera, comprising the fabrication parameters (i.e., velocity and distance of spraying) as well as the acquired surface geometry. The initial multivariate regression model provided promising results for predicting and visualizing 3D-surfaces, pre-production in a CAD environment. However, to unlock the full potential of this process, this project aims to implement a novel deep learning generative architecture, that will both generate and predict the output of the plastering process, given some desired plaster pattern to be produced. Therefore, we foresee this ML-based approach for predicting complex-to-simulate cementitious material behavior in construction will enable to improve the material process, omit failures, and waste, and ultimately facilitate sustainable design and building.

First explorations of ML-ROSP show that the data collected from the fabrication process (from the resulting sprayed surface) can potentially be used to provide an ML-based design and fabrication workflow. In the first study, we collected data, including fabrication parameters (velocity and distance of spraying) and 3D depth scans, which will be available for this semester project / master thesis. While we have already achieved promising results, it is evident that iterations and improvements to the model are needed to more precisely predict and visualize the possible material formations, including the performative aspects (i.e. prediction of failure, quality through “fail/not acceptable” or “success/acceptable”, as well as the adhesive strength of the sprayed surface with pull-off tests). Beyond that, we believe this data could be further leveraged to train ML-models that allow the generation of optimal, in the sense of the performative aspects, trajectories for the robot.

Therefore, to fulfill the aforementioned goals, and harnessing the available data, we intend to implement a methodology with the following two aims in mind. First, given a target depth map, the ML-model will generate a feasible 3D trajectory that enables the replication, through the robotic plastering process, of such pattern over a base mesh. As second objective, the ML-model will provide an embedding vector, capturing both information from the requested pattern and the generated trajectory. This could be utilized in different downstream tasks, from the prediction of the failure in the generation, to sagging and deviation from the requested pattern. The deep learning architecture chosen will be a Transformer, widely used nowadays with all data types, for both generation and prediction tasks. More specifically, we will rely on an encoder-decoder Transformer model to enable the different input and output data types. As input to the encoder, we will provide two depth fields, an initial and final state, and a notion of speed encoded in some positional-encoding like vectors. From these, the representation obtained by the encoder could be readily used in downstream tasks, as those posed before. Besides, this representation will be fed to the decoder which, together with some starting position, will trigger in the decoder an autoregressive generative process describing the trajectory of the robotic arm. Each newly predicted position in the trajectory is fed back to the input of the decoder, in order to generate the next position. And end-of-generation special token will terminate the process. Even though nowadays encoder- or decoder-only architectures are more widely used, due to the different nature of input (images) and output (trajectory) data, we believe, and encoder-decoder model is better suited for this task.

The potential of this model for generation is also its main disadvantage. In order to ensure a correct training, we either rely on large amounts of data, and/or on a simplified representation of it that will facilitate the learning process. For the former, we intend to use several data augmentation methods, both on the images and the trajectories, to enlarge the data set. And for the latter, we will likely reduce the dimensionality of the input images, and henceforth the number of parameters, and simplify the generation of the trajectory as a problem of predicting the next incremental step given the current position. We believe that these methods will allow to successfully train the envisioned models.

The present project will allow the student getting a larger familiarity with the usage of different neural network architectures, as well as with up-to-date concepts in the DL field. Nevertheless, due to eminent exploratory character of the project, it is important to highlight that large dose of creative thinking is required. The project also offers future perspectives. Once a model is developed and tested with currently used plaster mixes, the data collection and machine-learning techniques will be transferred to other additive fabrication processes using earth, clay or concrete, which are being developed within the Fabrication and Material Aware Architecture (FMAA) group at USI and at the Chair for Physical Chemistry of Building Materials (PCBM) at ETH Zurich. We envision laying the foundation for a novel prediction method for complex-to-simulate material systems in a digital fabrication process and transferring the results to other material systems in addition to cementitious plaster.

Work packages

1. Revision of the state-of-the-art of deep learning generative approaches for digital fabrication.
2. Develop method to construct an ML-based predictive model for a robotic on-site plastering process.
    - Implement a first model to obtain informative representations of the input, aimed at solving downstream predictions tasks.
    - Additionally utilize the encoded information to generate suitable trajectories for the robotic arm.
3. Assessment of the developed model by performance testing.

Requirements

- Highly motivated and independent student
- Experience with state-of-the-art methods in machine and deep learning. Interest in robotics and sensing is a plus.
- Programming skills in Python are mandatory, as well as a deep learning framework, preferably PyTorch.
- Experience with ROS, COMPAS, etc. is a plus.

Supervisors

- Swiss Data Science Center (SDSC), ETHZ: Prof. Fernando Pérez Cruz, Dr. Luis Salamanca
- Physical Chemistry of Building Materials Group (PCBM), ETHZ: Prof. Dr. Robert Flatt.
- Fabrication and Material Aware Architecture (FMAA), USI: Dr. Selen Ercan Jenny, Ping-Hsun Tsai, Prof. Dr. Ena Lloret-Fritschi.