Machine Learning for Advanced Building Construction

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Reducing building emissions requires developing scalable retrofit methods

Buildings conforming to today's energy codes and standards are typically 30% more efficient than those of 10 years ago; however, 55% of US homes and 50% of commercial buildings were built before 1980. In order to significantly reduce the emissions impact of the existing building stock on a short enough time horizon to meet current climate goals, there needs to be a significant increase in scaling efficiency of retrofit techniques, including cost reduction, labor reduction, resident disruption minimization, and reproducibility.

AI/ML can reduce labor associated with retrofit design processes

Prefabricated panel systems have the potential to allow for more modular, potentially scalable retrofits; however, these systems have yet to achieve significant cost reduction or market growth and still require extensive custom design from an architect at a per building level. Here we demonstrate an **AI/CV enabled automated modeling framework that converts building envelope condition and dimensional data into manufacturing and installation specifications.**

Methods demonstrated on an NREL test facade

A test facade was constructed at NREL to demonstrate the pipeline including scanning, automated retrofit recommendation, and physical installation of the prefabricated panels. While this is a limited test-case with significantly simplified geometry, it demonstrates the utility and applicability of the workflow.

Significant reduction in estimated labor, construction time, and emissions

By comparing 3 different approaches to retrofits in a cost modeling study we find that our system should be able to reduce prep work labor by 70% and on-site labor by 59%. There will be an estimated 15-30% reduction of custom overclad costs at scale, bringing costs in-line with traditional retrofits, but with a reduction in construction time in comparison to conventional techniques. Furthermore, in a sample of simulated low-rise multi-family housing units building shell retrofits have a per site energy reduction potential of 34-50% of the thermal load.

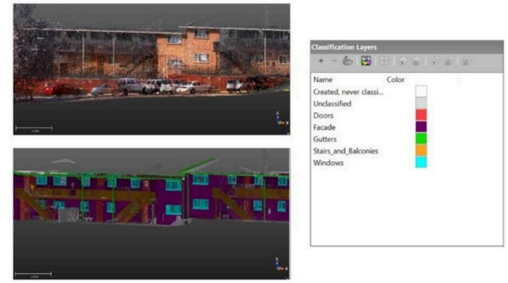
Multi-step, AI/CV-enabled algorithm for automating retrofit design

1) Scan building to create point cloud

To obtain data detailing the physical characteristics of the existing site a building envelope scanning tool is required. In this study we utilize the Trimble X7 high-speed 3D laser scanning system. This integrated system includes automatic calibration and leveling across multiple scans, producing a fully graded 3D point cloud of the building envelope, with colors, intensity, and normal plane for every point. The resolution of the point cloud depends on the number of scans taken for a given area; in our test dataset this ranges from less than a centimeter to up to 5 cm in less dense regions.

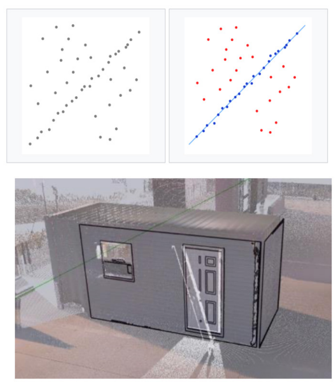
Through collaboration with Trimble, we assembled a collection of building scans for training, testing, and validation of the machine-learning algorithms. During on-site visits we compiled scan data from a building on the Colorado State University campus, two units in a local multifamily apartment building, and a modular unit on the NREL campus. We then supplemented these data with previously scanned buildings from other Trimble projects, including two collections of whole street scans with multiple building facades. The initial target building typology was low-rise timber-framed multifamily buildings; however, if training data representing additional typologies are provided the model can easily be extended.

2) Extract labels using point cloud segmentation



To train the facade feature segmentation algorithm we leveraged an early research program version of Trimble's ML infrastructure. This pipeline accepts manually labeled point cloud data, automatically extracts a series of custom 2.5D tensor images from the point cloud and applies a convolutional neural network architecture to classify the points. Upon model finalization this trained segmentation network can be integrated directly into Trimble RealWorks for on-the-fly segmentation with minimal user input.

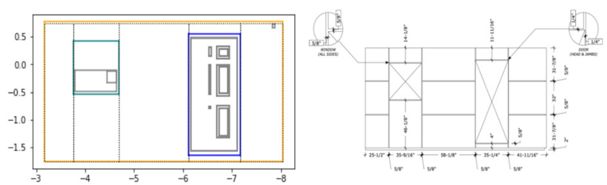
3) Use edge detection to vectorize features



To identify facade features with labels and precise dimensions in a vector format we developed an algorithm for combining the labeled points with geometric algorithms for edge extraction on the raw point cloud. The combination of the CV techniques with the labeled data maximizes interpretability of the features, while minimizing the potential physical dimension error and providing vectorized features as necessary for translating into panel specifications

1. Select points associated with a single facade plane and define plane equation and bounds through RANSAC plane fitting
2. Project points within plane tolerance onto plane
3. Iteratively find the minimum resolution dx such that a given fraction of grid cell on plane f_{facade} have at least N_{pts}
4. Create a binary plane image via thresholding number of projected points and extract edges through contouring of the binary image
5. Use clustering of feature labels and edges to fit feature dimensions and associate with the corresponding label

4) Extract features to panel design



From the extracted building feature model, we then apply a workflow for automatically translating the features into retrofit panel configuration recommendations and manufacturing dimensions. Each facade element is subdivided into sections with widths ranging from a given minimum to maximum panel size. The widths are automatically selected so large-scale features such as doors are placed along panel interface edges to minimize the impact of accumulated error.

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