CPS: Synergy: Autonomous Vision-based Construction Project Monitoring

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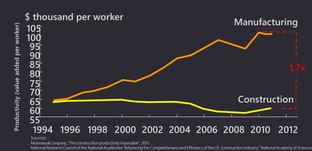
Introduction

- U.S. construction industry

$1,153,175,000,000 +5-12% growth rate

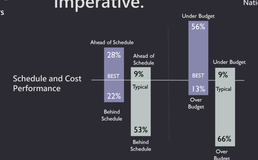
Value of Construction Put in Place in the United States, 2016 Commercial and industrial building sectors



Source: National Academy, "The Impact of Productivity Statistics" 2015
National Research Council of the National Academies "Advancing the Competitiveness and Efficiency of the US Construction Industry." National Academy of Sciences, Washington, DC. 2009.

- Improving efficiency of the US construction industry is a national imperative.

National Academies 2009



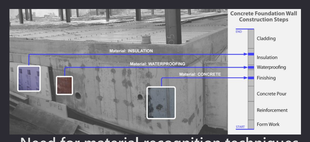
Dodge Data and Analytics, ENR (2016). " How satisfied, really satisfied, are Owners?"

- Why: Factors in poor productivity

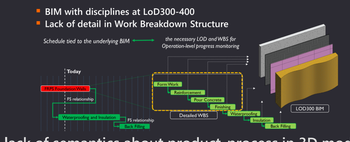
I. Inadequate communication
II. Flawed performance management
III. Poor short-term planning
IV. Missed connections to actual progress
V. Insufficient risk management

Time consuming Generic Non intuitive

- Limitations in current visual sensing methods



Need for material recognition techniques



lack of semantics about product-process in 3D models

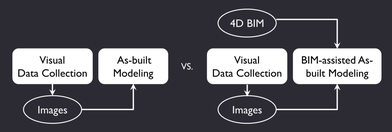
Project Objectives

Improve frequency, detail, and applicability of construction monitoring by automating collection, analysis, and reporting via camera-equipped UAVs and 3D building models, with following:

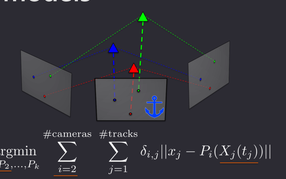
- Data Collection: record videos for progress monitoring and place cameras for activity monitoring using aerial robots. Objectives: guarantee completeness of model capture, improve control mechanisms to enable camera placement and close observations, and coordinate recordings and camera placement with feedback from visual analysis.
- Progress Monitoring: create 3D models of ongoing construction and compare to 3D plan models. Objectives: improve efficiency and reliability of image-based reconstruction, recognizing material properties and geometry, and provide confidence measures to pick informative camera viewpoints.
- Activity Monitoring: annotate crew and equipment activities from a network of cameras and to inform their placement. Objectives: recognize worker/equipment trajectories and activities from videos, and characterize modes of error in object detection as the basis for choosing camera viewpoints.
- Reporting: provide analytics that predict reliability of work plans based on current progress. Objectives: create reliability metrics for plans, formalize a classification mechanism to evaluate and generate both "sequencing" and "crew-balance chart" control alternatives for ongoing tasks and activities.

Project-Level Monitoring

- Generate image-based point cloud models

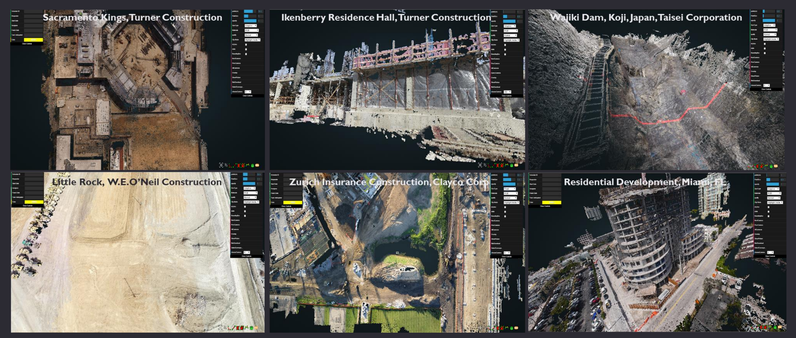


Pipeline of Structure from Motion + Dense Reconstruction



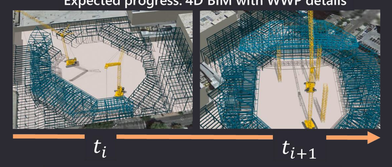
$$\underset{t_i,P_k,\ldots,P_k}{\operatorname{argmin}} \sum_{i=2}^{\#\text{cameras}} \sum_{j=1}^{\#\text{tracks}} \delta_{i,j} ||x_j - P_i(X_j(t_j))||$$

Using 3D building model to form a constraint-based Structure from Motion

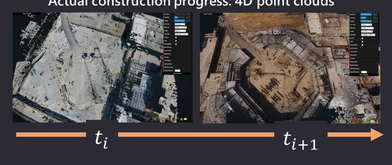


- Alignment of as-built and as-planned models.

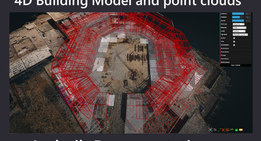
Expected progress: 4D BIM with WWP details



Actual construction progress: 4D point clouds

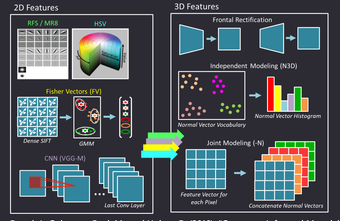


Jointly registered 4D Building Model and point clouds



- As-built Documentation
- Progress Monitoring
- Quality Control
- Safety Monitoring
- Contractor Hand-Over

- Geometry helps in Material Recognition – Knowledge of Materials helps with progress monitoring



Best 2D (FV+CNN) vs. Best 3D (FV-N+CNN+N3D): 68.92 vs. 73.84

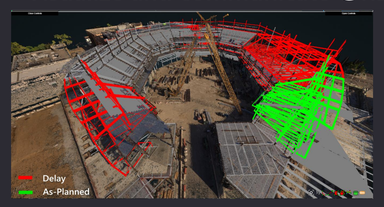
Both joint (-N) and independent (N3D) representations improve mean classification accuracy.

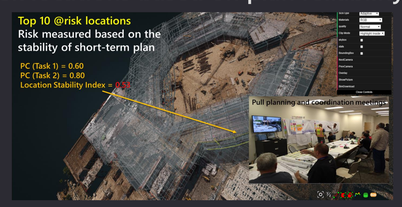
	-	+N3D
FV	60.97	65.87
FV-N	66.95	68.16

	-	+N3D
FV + CNN	68.92	72.08
FV-N + CNN	73.80	73.84

Degol, J., Golparvar-Fard, M., and Hoiem, D. (2016). "Geometry-Informed Material Recognition" Proceedings, IEEE Computer Vision and Pattern Recognition (CVPR) Conference

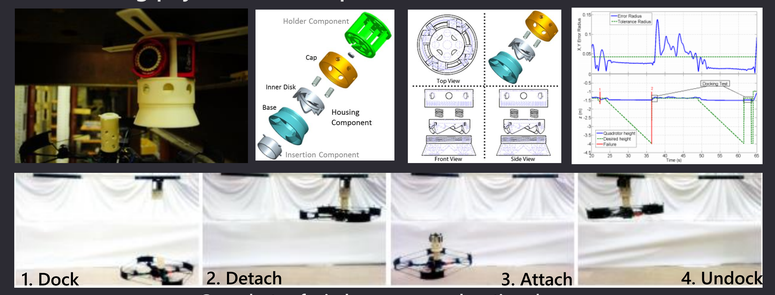
- Visualize and communicate @risk locations based on plan reliability





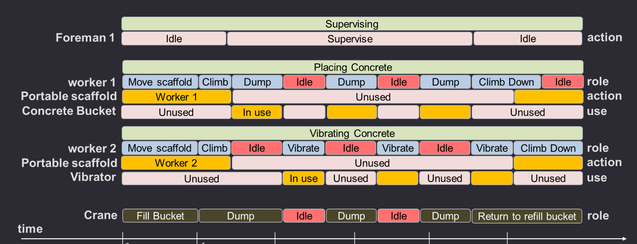
Task-Level Monitoring

- Automated camera installation via "passive mechanism for relocating payloads with a quadrotor"



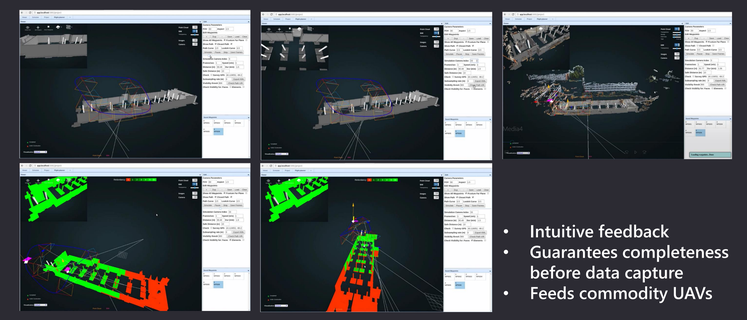
Snapshots of wireless camera relocation demo.

- Worker detection, tracking and activity analysis



Example of inferred activity, roles, actions, and use

- Goal-Driven 3D Visual Data Capture
  - 4D BIM as a prior for both geometry and appearance
  - Color-code elements for visibility and redundancy in visibility



- Intuitive feedback
- Guarantees completeness before data capture
- Feeds commodity UAVs

Ongoing Work

- Automated Progress Monitoring using Geometry and Appearance
- Autonomous and Model-driven Indoor Mapping
- Create video-based activity recognition methods via compositional structure of role-activity-tool-body posture
- Examine the impact of location-driven monitoring
- Investigate conservative estimations in look-ahead schedules

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