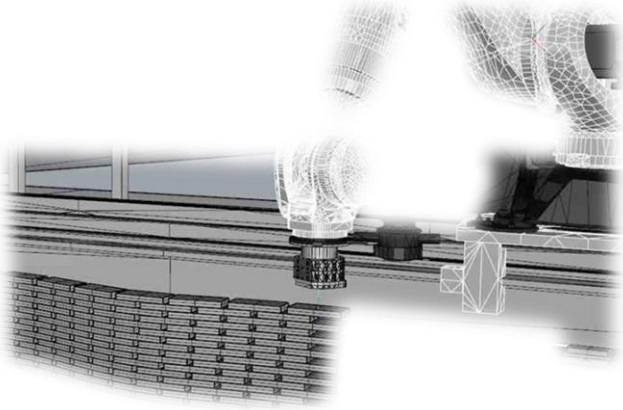
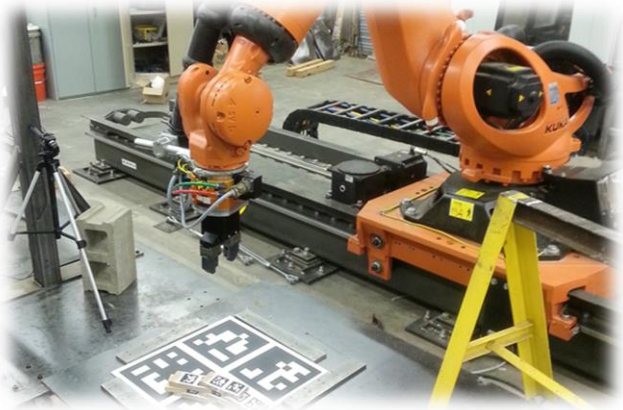



Towards Autonomous Robotic In-Situ Assembly on Unstructured Construction Sites Using Monocular Vision

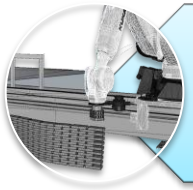
Chen Feng[1)], Yong Xiao[1)], Aaron Willette[2)],
Wes McGee[2)], Vineet Kamat[1)]

1) Department of Civil and Environmental Engineering
2) College of Architecture and Urban Planning
University of Michigan

July 10, 2014

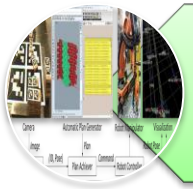
UNIVERSITY OF MICHIGAN

Outline



Introduction

Motivation



Methodology

Experiment

Conclusion

- Among all industries, construction has seen a significant productivity decrease over the last several decades (Rojas, 2003).

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- Construction has also been documented to have some of the highest rates of workspace injuries and fatalities (Bureau of Labor Statistics, 2012).

- Among all industries, construction has seen a significant productivity decrease over the last several decades (Rojas, 2003).
- Construction has also been documented to have some of the highest rates of workspace injuries and fatalities (Bureau of Labor Statistics, 2012).
- Automation and robotics in construction (ARC)
  - Has potential to relieve human workers from repetitive and dangerous tasks;
  - Has been extensively promoted in the literature as means of improving construction productivity and safety (Balaguer, 2004).

- Unlike *manufacturing* industry, *construction* industry is still exploring feasible and broadly deployable ARC applications.

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  - Commercial challenges
    - fragmented and risk-averse nature
    - little investment in ARC research

- Unlike *manufacturing* industry, *construction* industry is still exploring feasible and broadly deployable ARC applications.
  - Commercial challenges
    - fragmented and risk-averse nature
    - little investment in ARC research
  - Technical challenges
    - Unstructured Construction Environments
    - Mobility of Construction Manipulators

- Manufacturing

- Construction

- Manufacturing
  - Fixed manipulator
- Construction
  - Mobile manipulator

- Manufacturing
  - Fixed manipulator
  - Structured environment
- Construction
  - Mobile manipulator
  - Unstructured site

- Manufacturing
  - Fixed manipulator
  - Structured environment
  - Fixed motion
- Construction
  - Mobile manipulator
  - Unstructured site
  - Dynamic motion

- Manufacturing
  - Fixed manipulator
  - Structured environment
  - Fixed motion
  - Tight tolerance

- Construction
  - Mobile manipulator
  - Unstructured site
  - Dynamic motion
  - Loose tolerance

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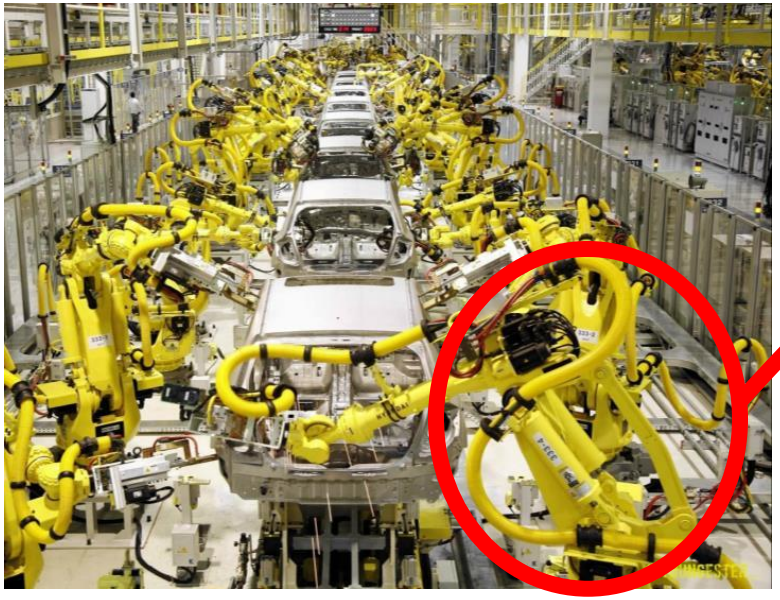
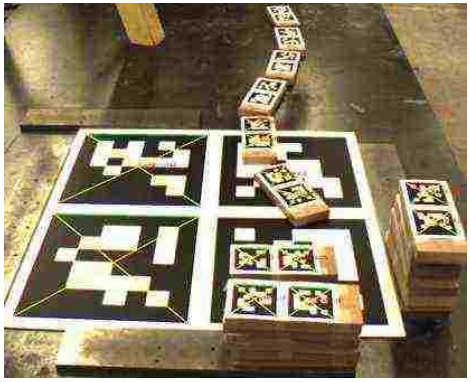
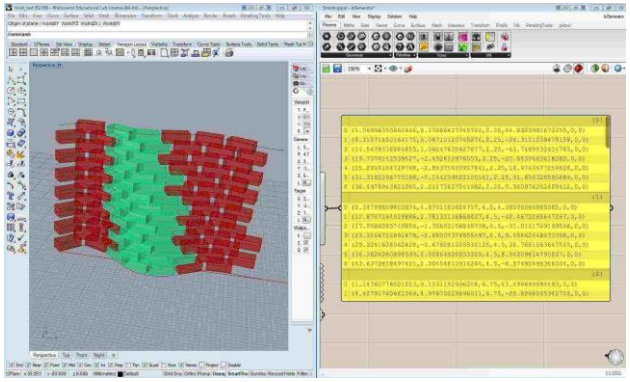
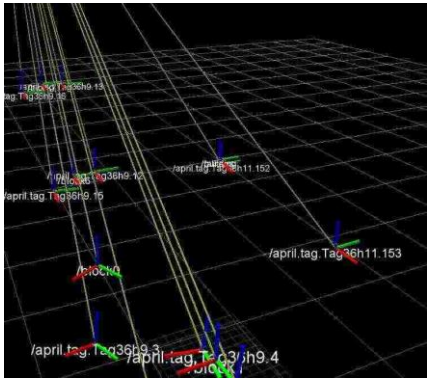








Camera

Automatic Plan Generator

Robot Manipulator

Visualization

Image

Plan

Robot Pose

Pose Estimator

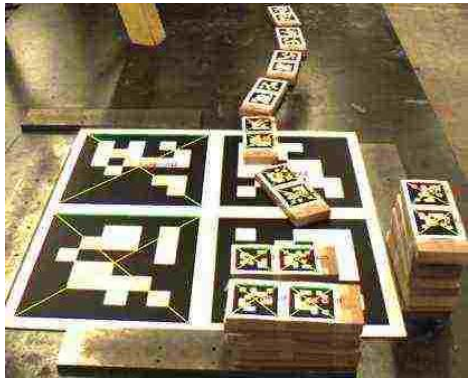
(ID, Pose)

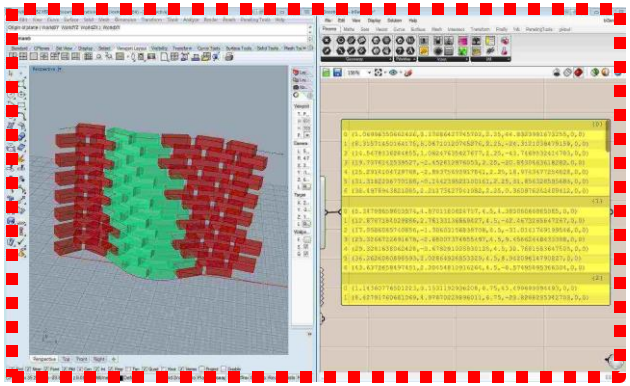
Plan Achiever

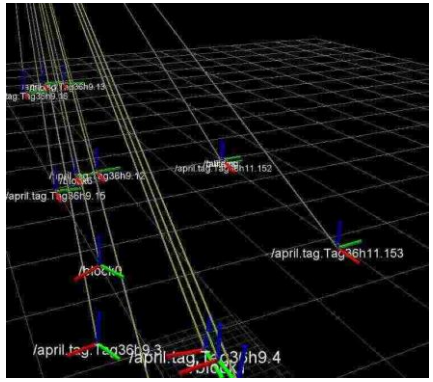
Command

Robot Controller

(ID, Pose)



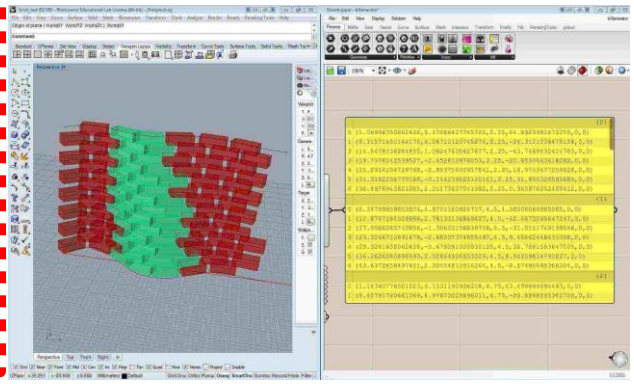


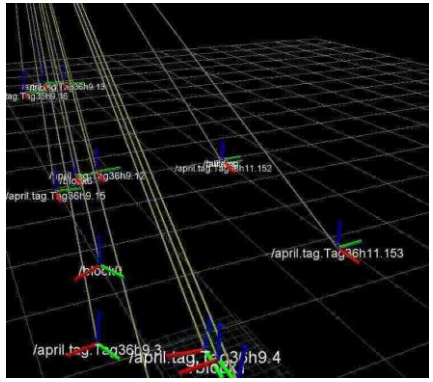


Camera | Automatic Plan Generator | Robot Manipulator | Visualization

Image | *Plan* | *Robot Pose*

Pose Estimator —*(ID, Pose)*→ Plan Achiever —*Command*→ Robot Controller —*(ID, Pose)*→ Pose Estimator





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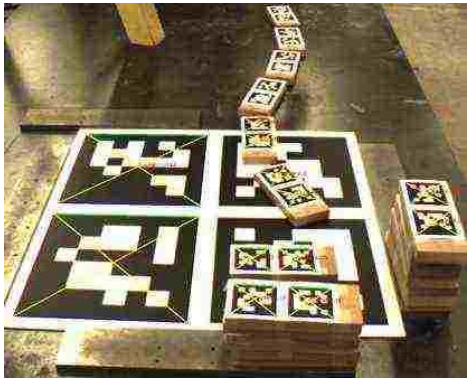

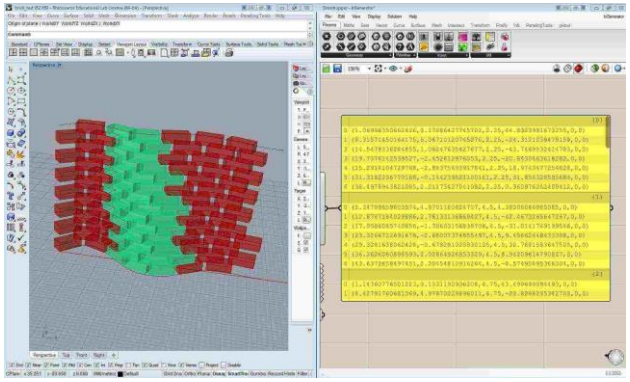

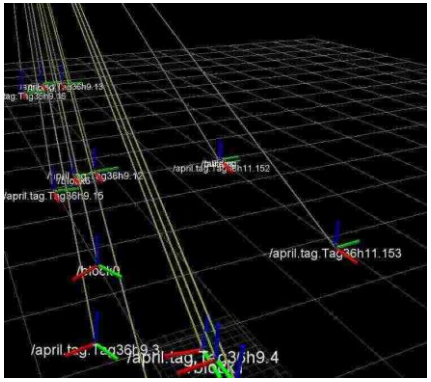

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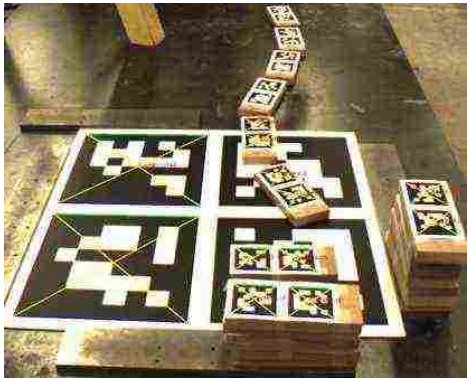

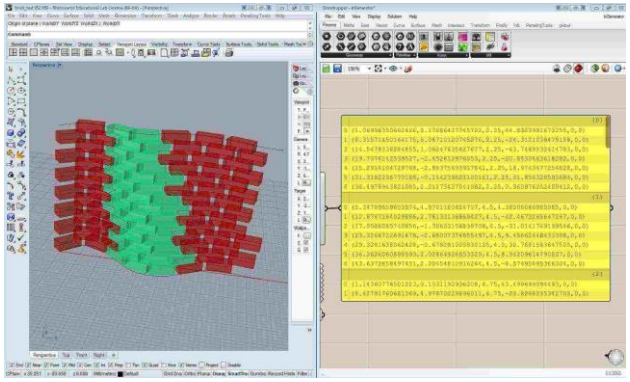

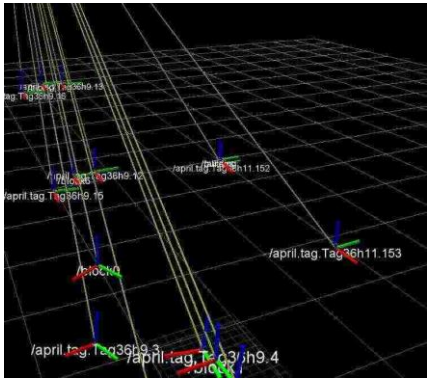

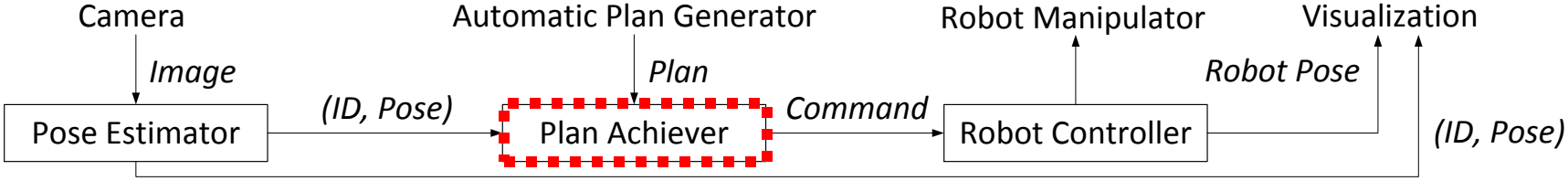
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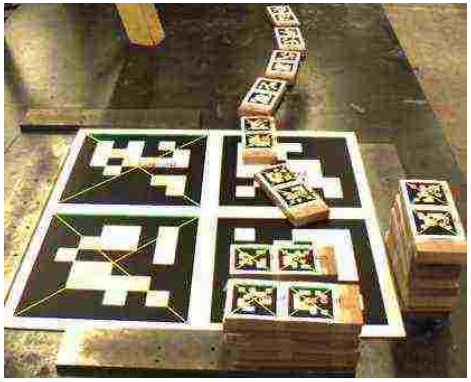

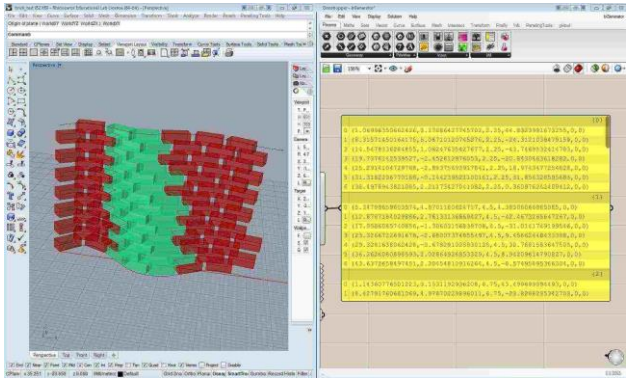

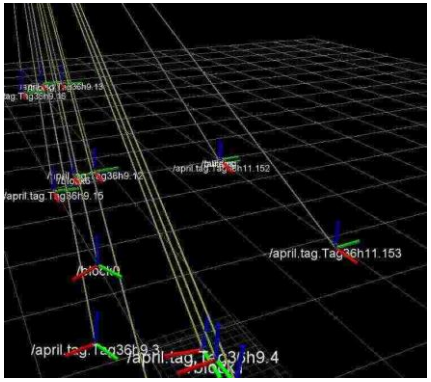

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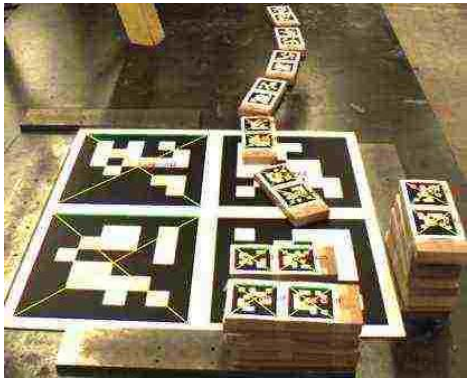

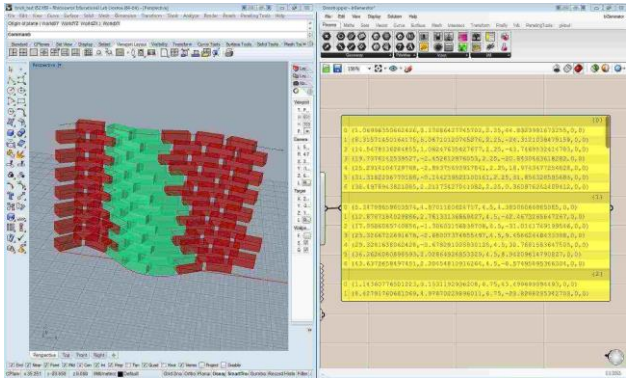

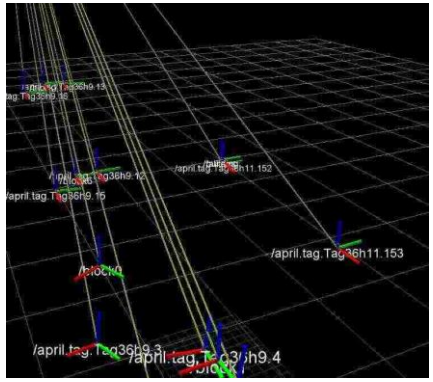
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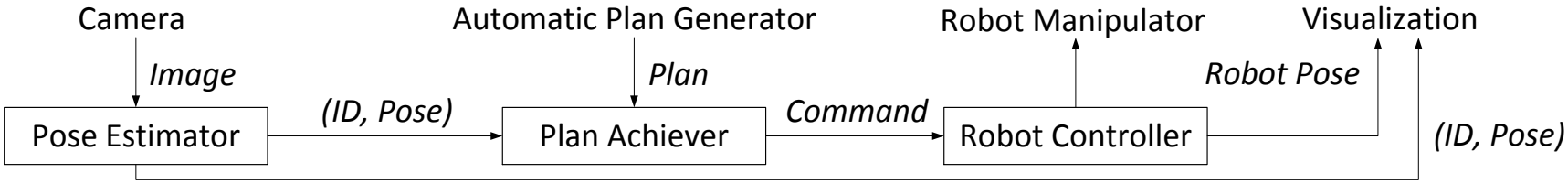
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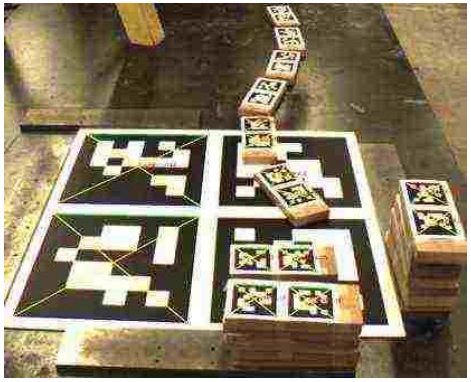

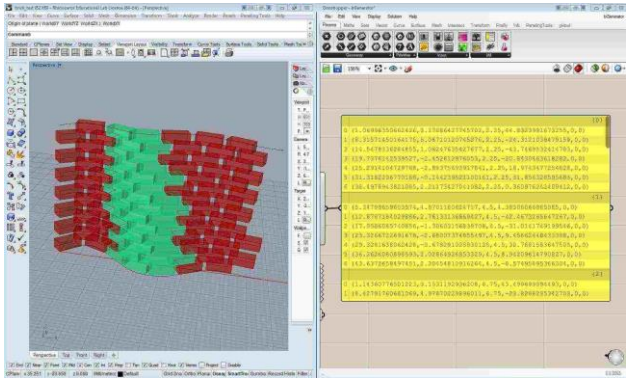

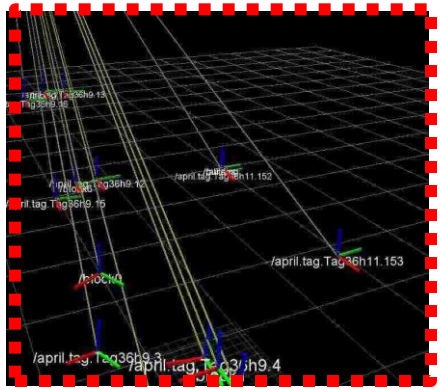

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Image | *Plan* | *Robot Pose*

Pose Estimator → *(ID, Pose)* → Plan Achiever → *Command* → Robot Controller

(ID, Pose)

- Intrinsic calibration

$$\arg\min_{\mathbf{K},\{\mathbf{R}_i,\mathbf{t}_i\}} \sum_{i=1}^{N}\sum_{j=1}^{18} \left\| \mathbf{U}_{i,j} - \mathbf{K}(\mathbf{R}_i \mathbf{X}_j + \mathbf{t}_i) \right\|^2$$

- Intrinsic calibration

$$\arg\min_{\mathbf{K},\{\mathbf{R}_i,\mathbf{t}_i\}} \sum_{i=1}^{N}\sum_{j=1}^{18} \left\| \mathbf{U}_{i,j} - \mathbf{K}(\mathbf{R}_i\mathbf{X}_j + \mathbf{t}_i) \right\|^2$$

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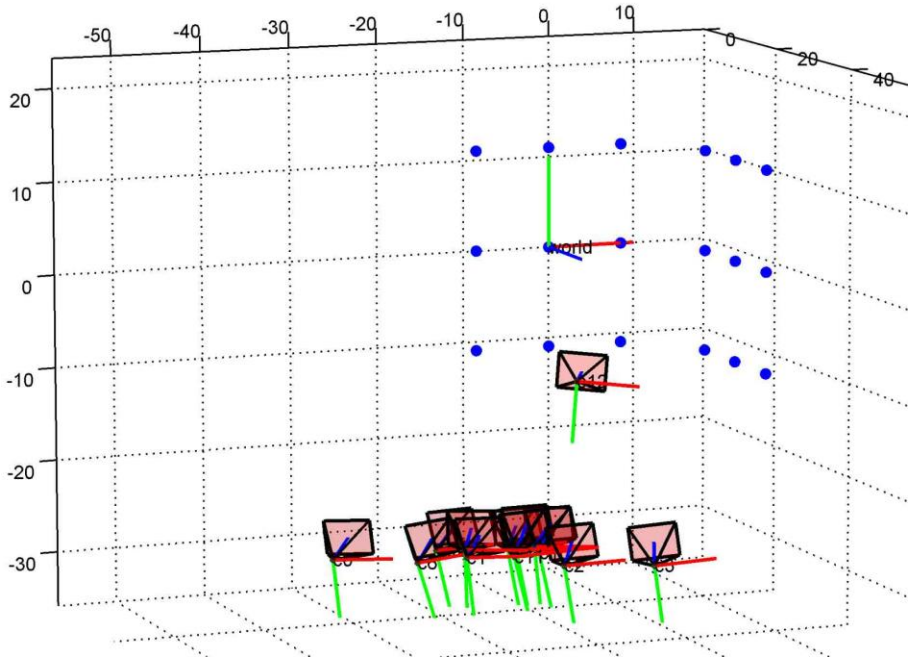
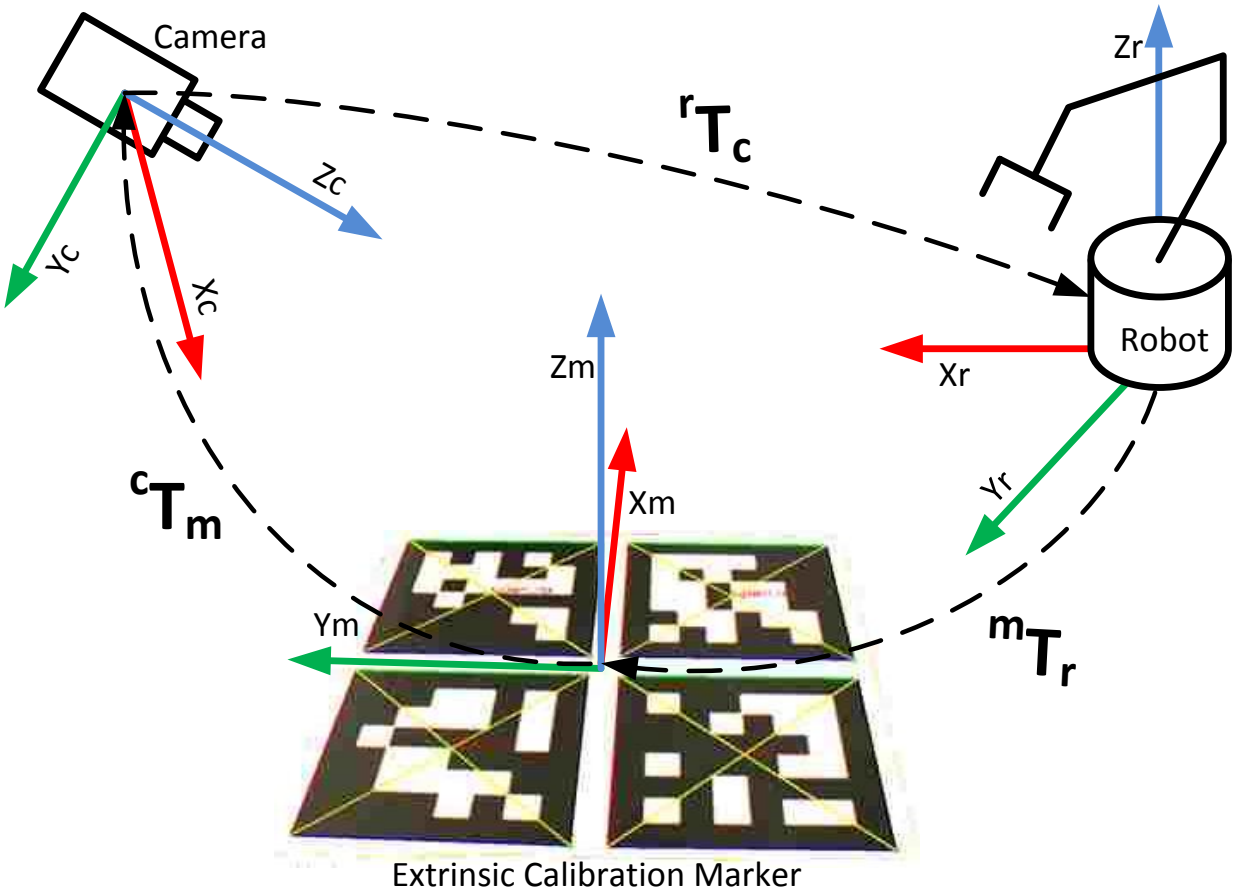


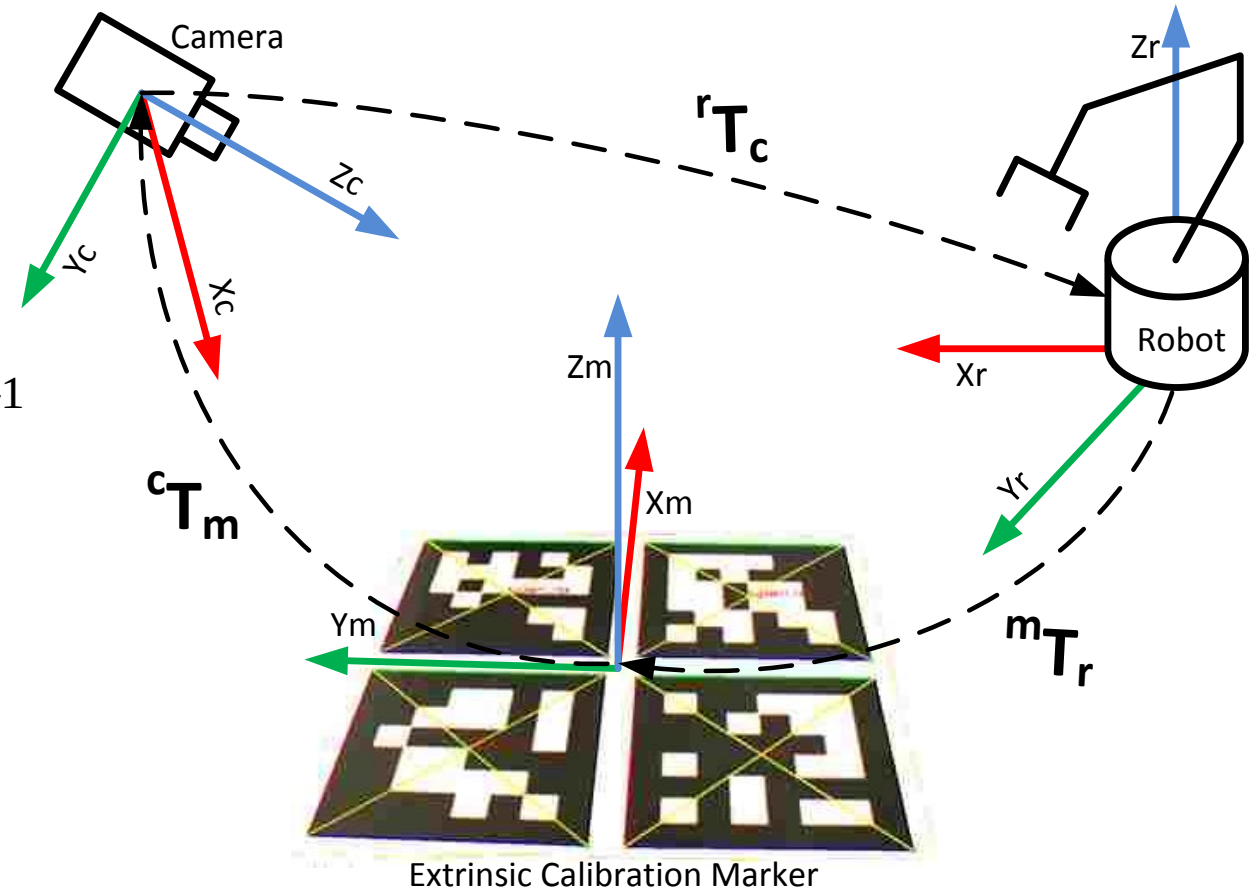
Intrinsic Calibration RMS=0.844679 pixel

- Extrinsic calibration



- Extrinsic calibration

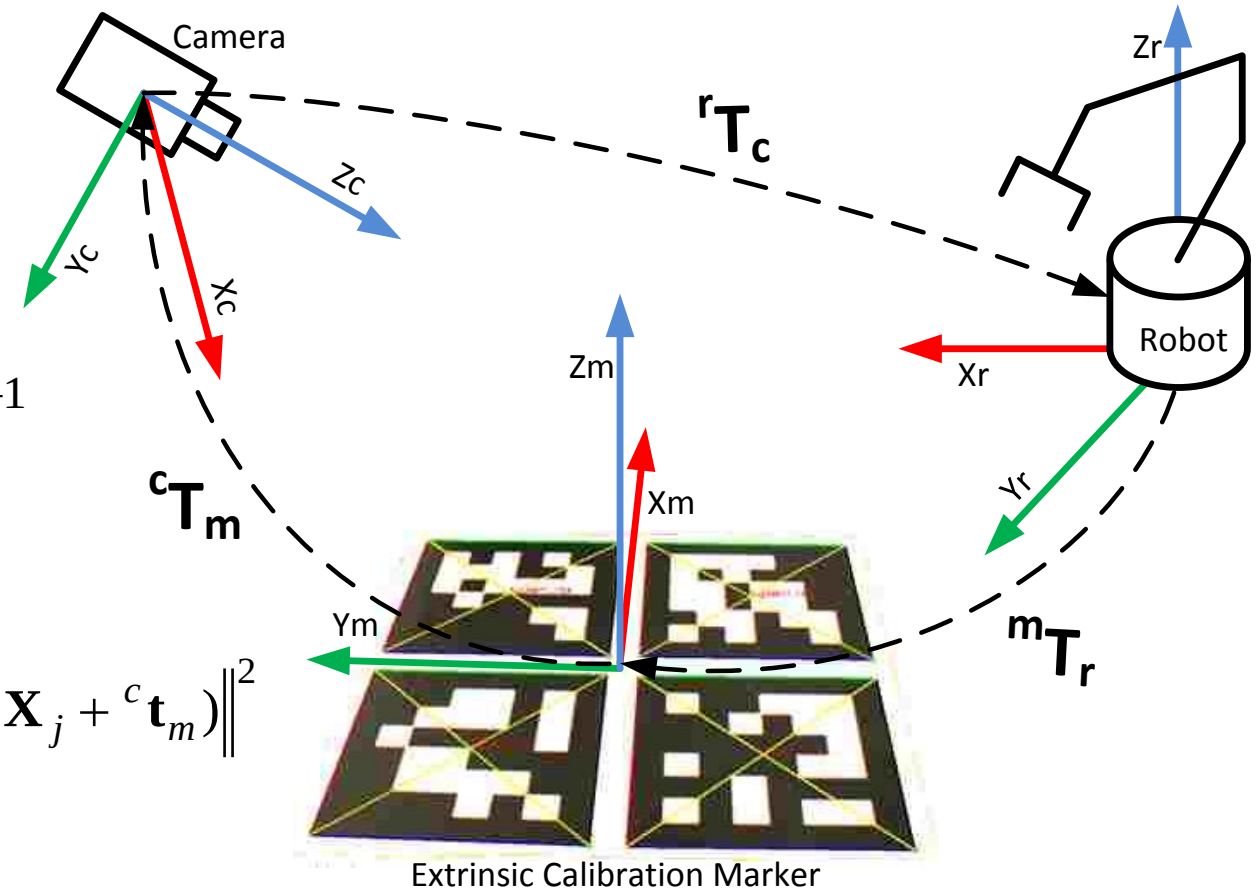
$$ {}^{r}\mathbf{T}_{c} = ({}^{c}\mathbf{T}_{m}\,{}^{m}\mathbf{T}_{r})^{-1} $$



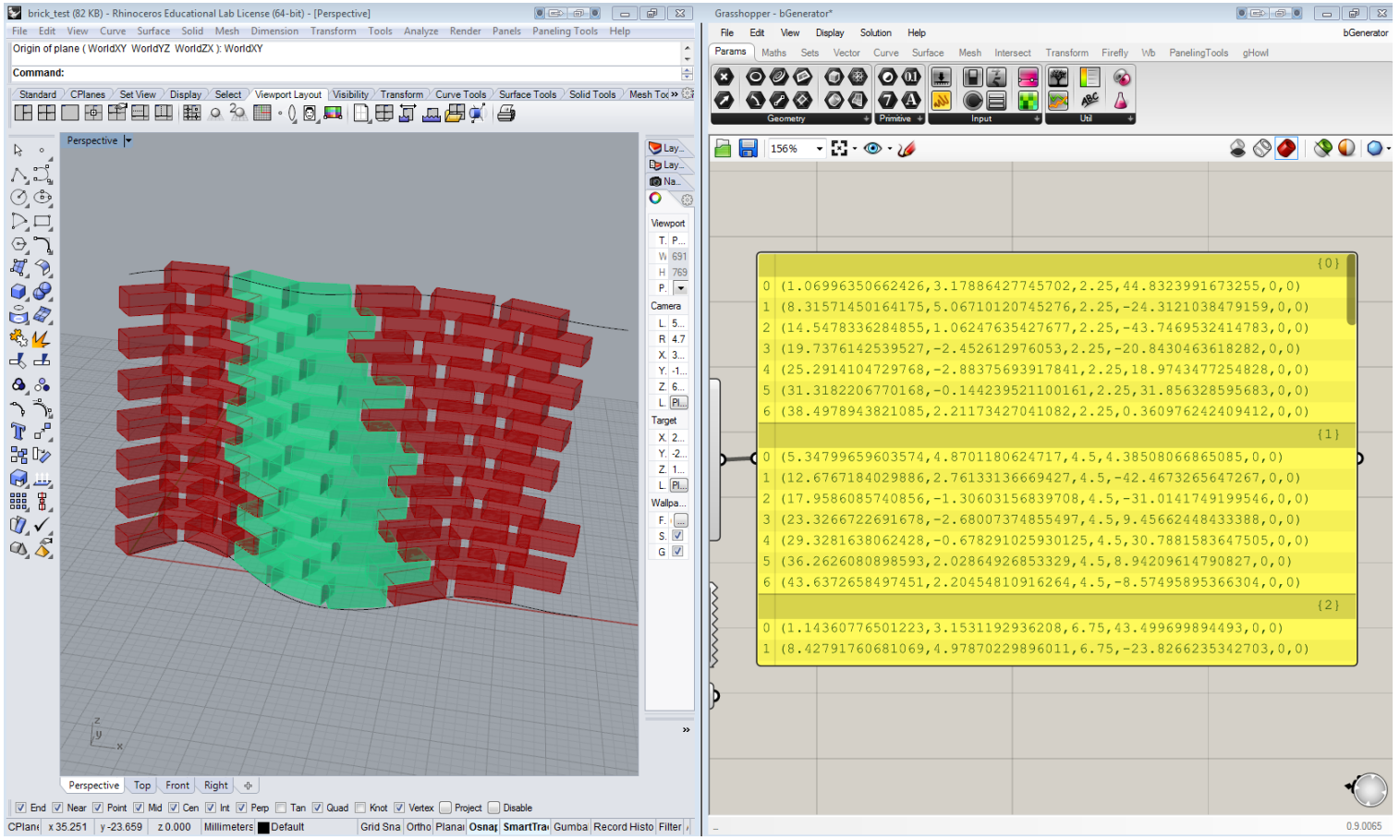
- Extrinsic calibration

$$ {}^{r}\mathbf{T}_{c} = ({}^{c}\mathbf{T}_{m}\,{}^{m}\mathbf{T}_{r})^{-1} $$

$$ \arg\min_{{}^{c}\mathbf{R}_{m},\,{}^{c}\mathbf{t}_{m}} \sum_{j=1}^{16} \left\| \mathbf{U}_{j} - \mathbf{K}({}^{c}\mathbf{R}_{m}\,{}^{m}\mathbf{X}_{j} + {}^{c}\mathbf{t}_{m}) \right\|^{2} $$



- Algorithmic Architectural Design



- Building Plan Generation and Simulation

Gripper 0
Goto block0 0 0 500 0 0 0
Goto block0 -12 -10 -10 0 0 0
Gripper 1
Shift 0 0 500 0 0 0
Goto building 200.00 -300.00 500.00 -63.92 0.00 0.00
Goto building 200.00 -300.00 19.05 -63.92 0.00 0.00
Gripper 0

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Gripper 0
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Shift 0 0 500 0 0 0
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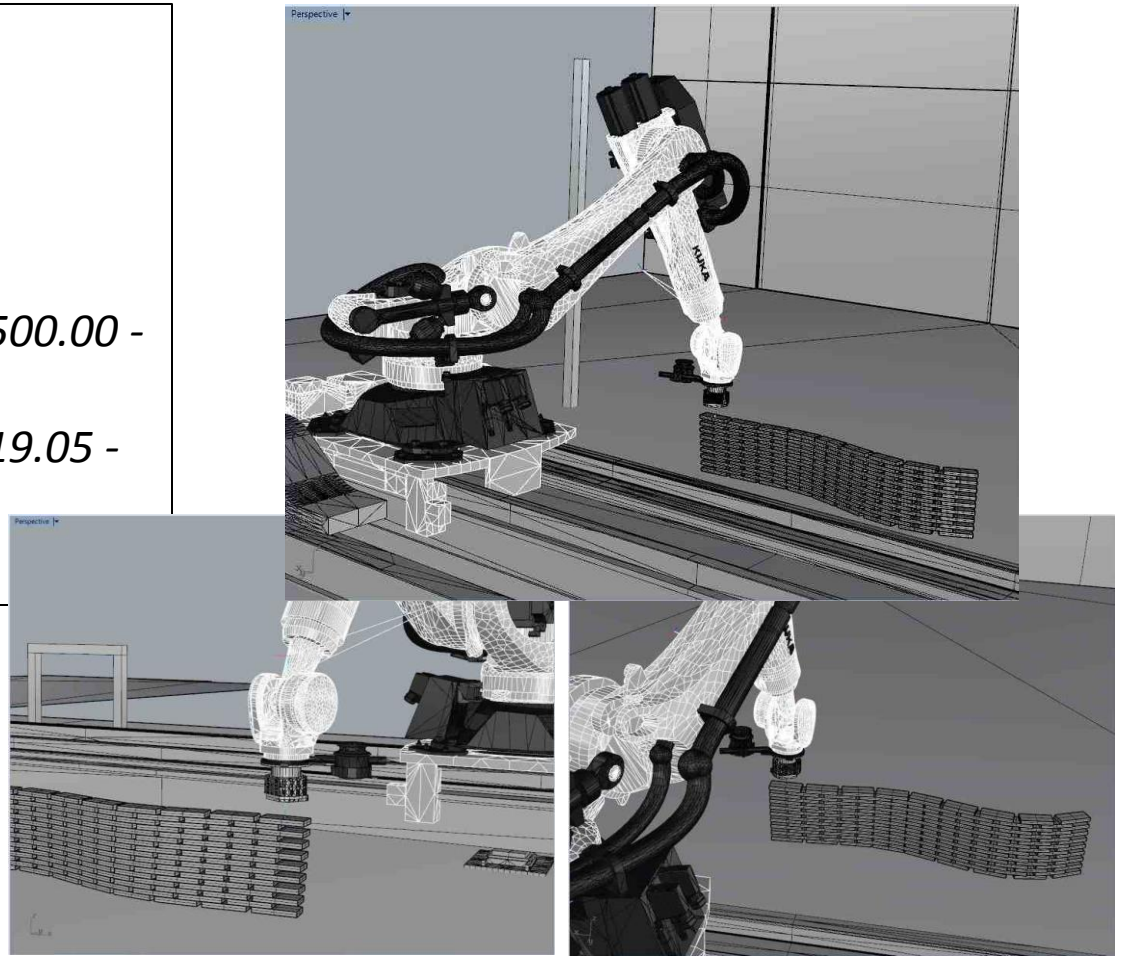

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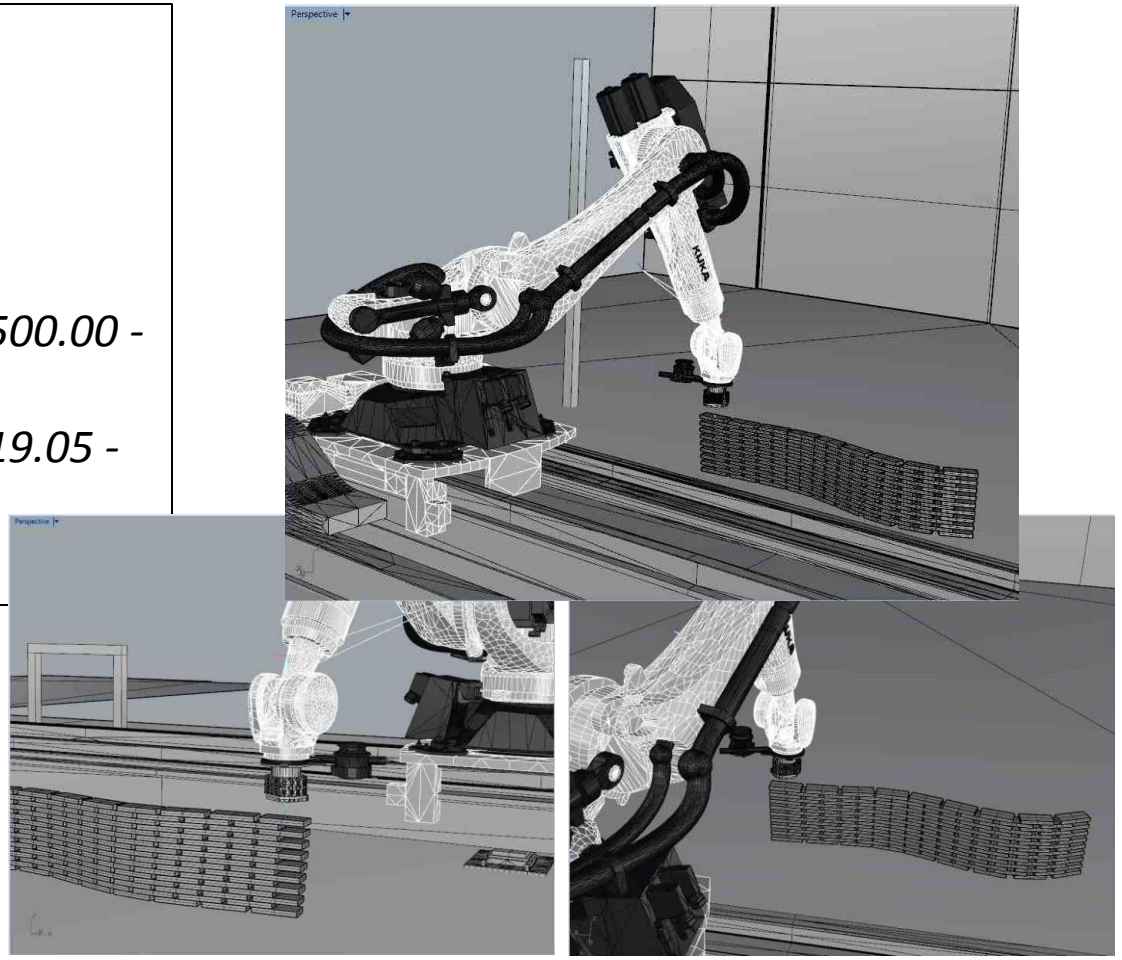

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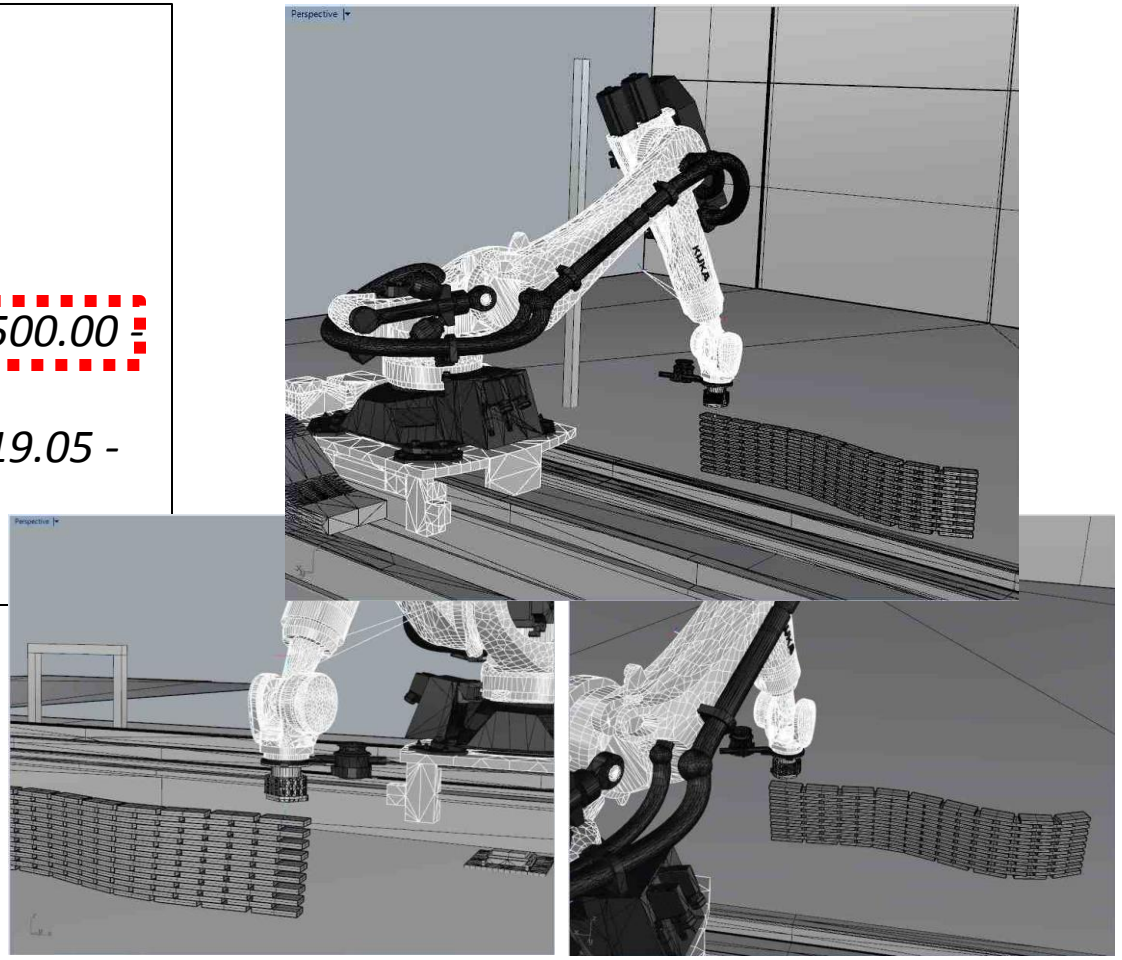
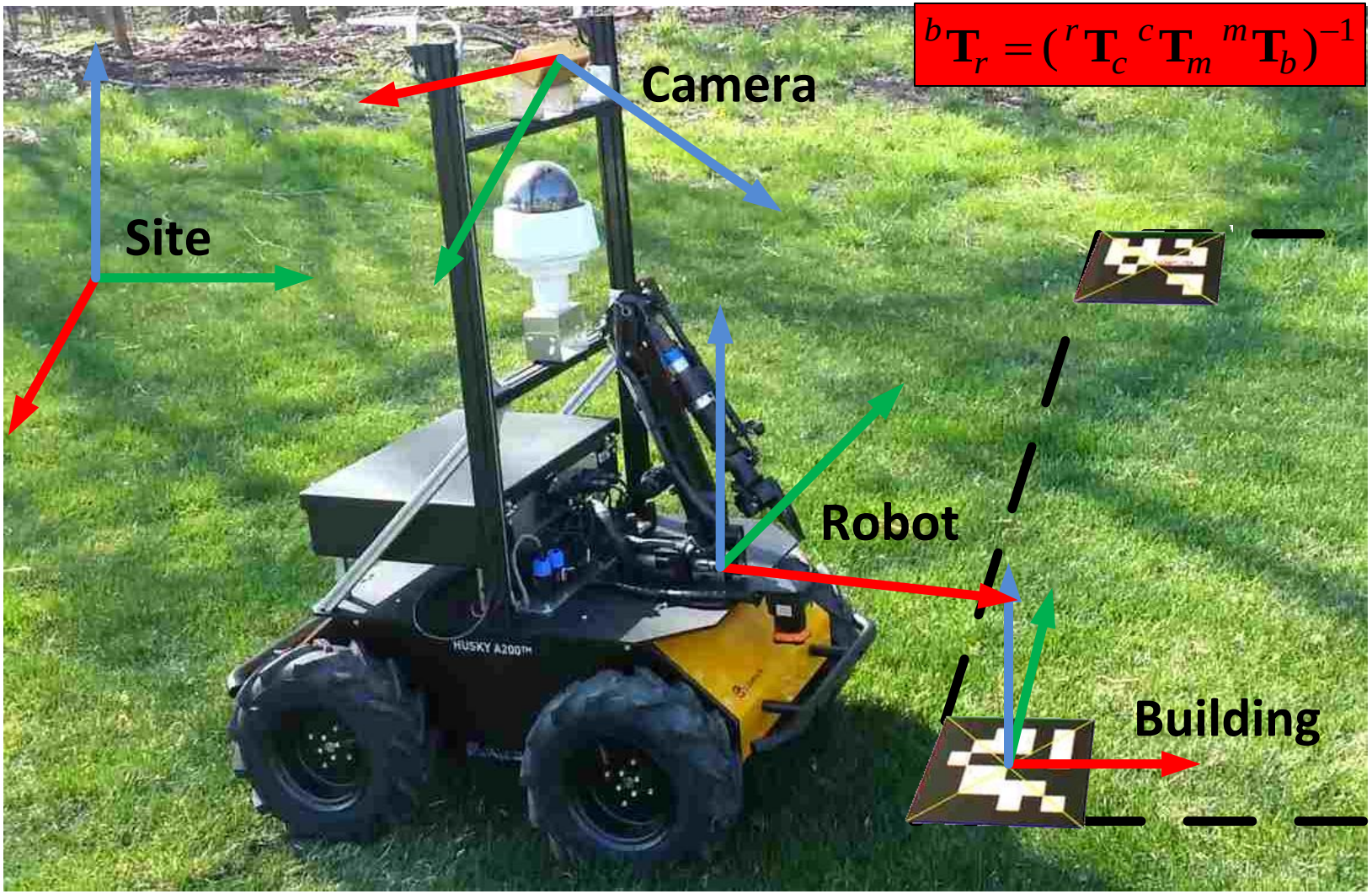
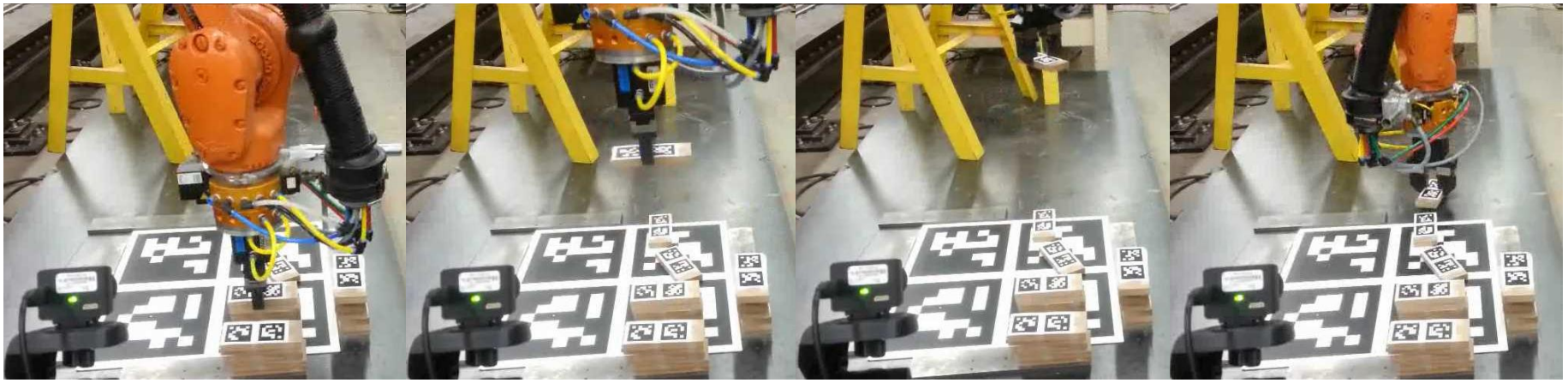


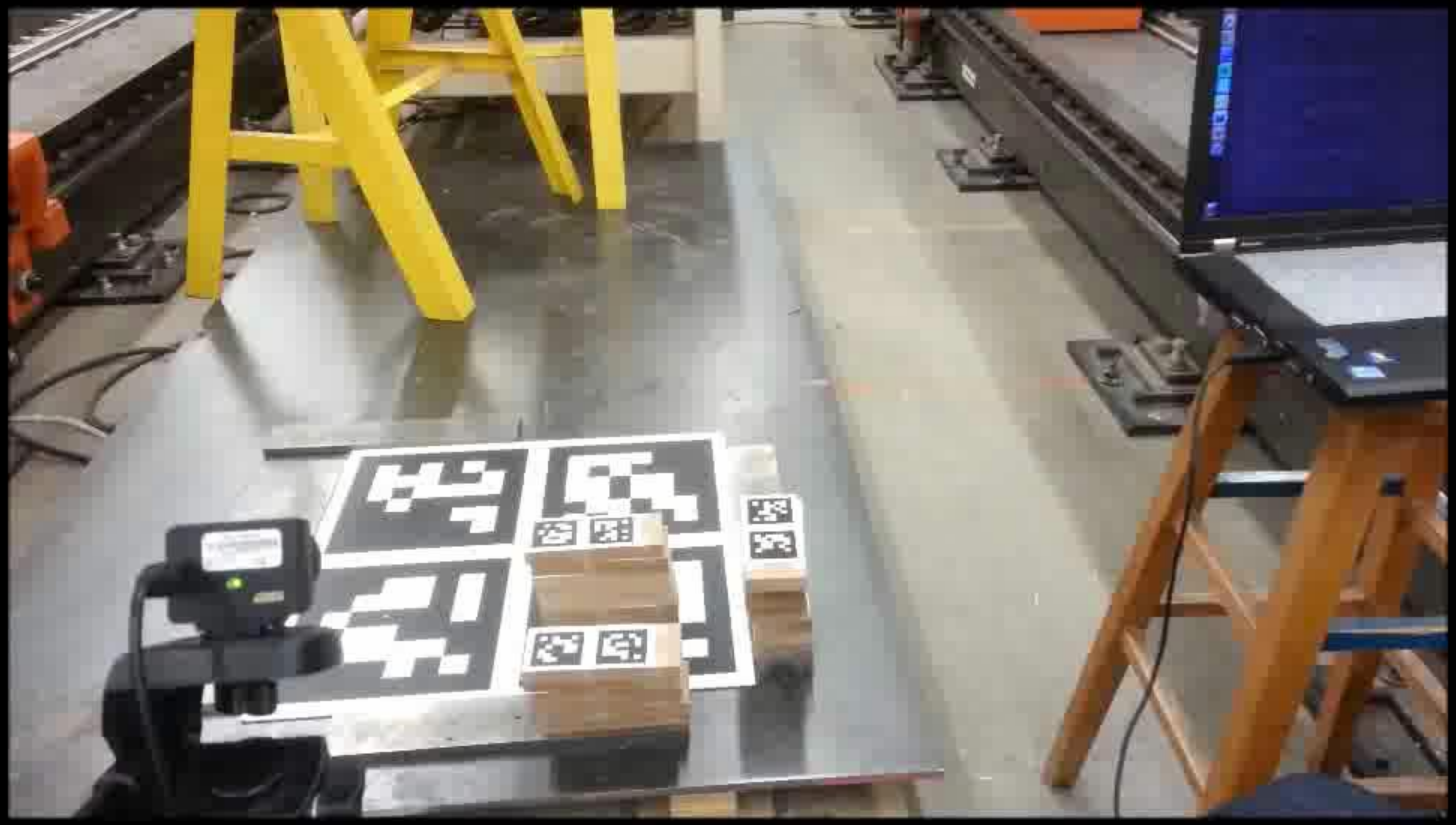

$^{b}\mathbf{T}_{r} = (^{r}\mathbf{T}_{c}\,^{c}\mathbf{T}_{m}\,^{m}\mathbf{T}_{b})^{-1}$
Camera
Site
Robot
Building
HUSKY A200™

KUKA

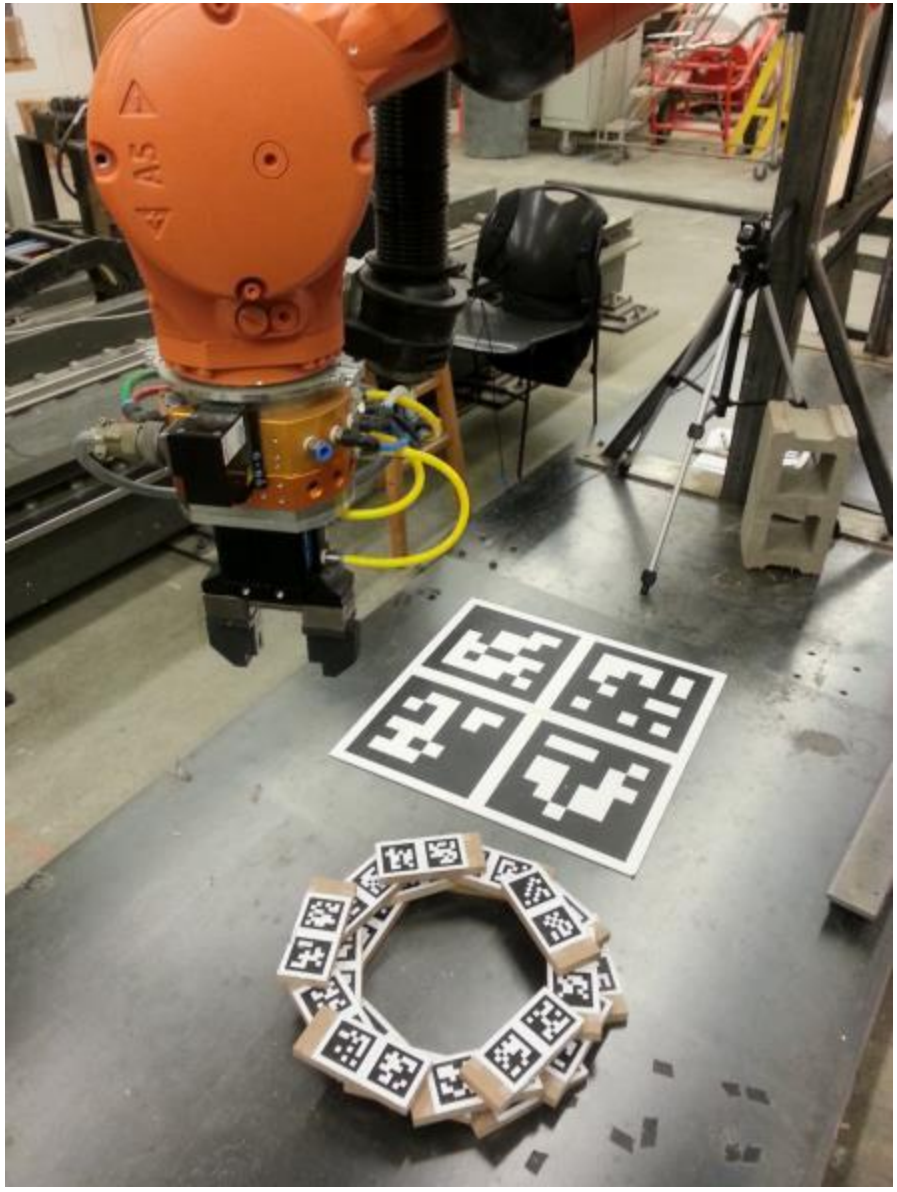


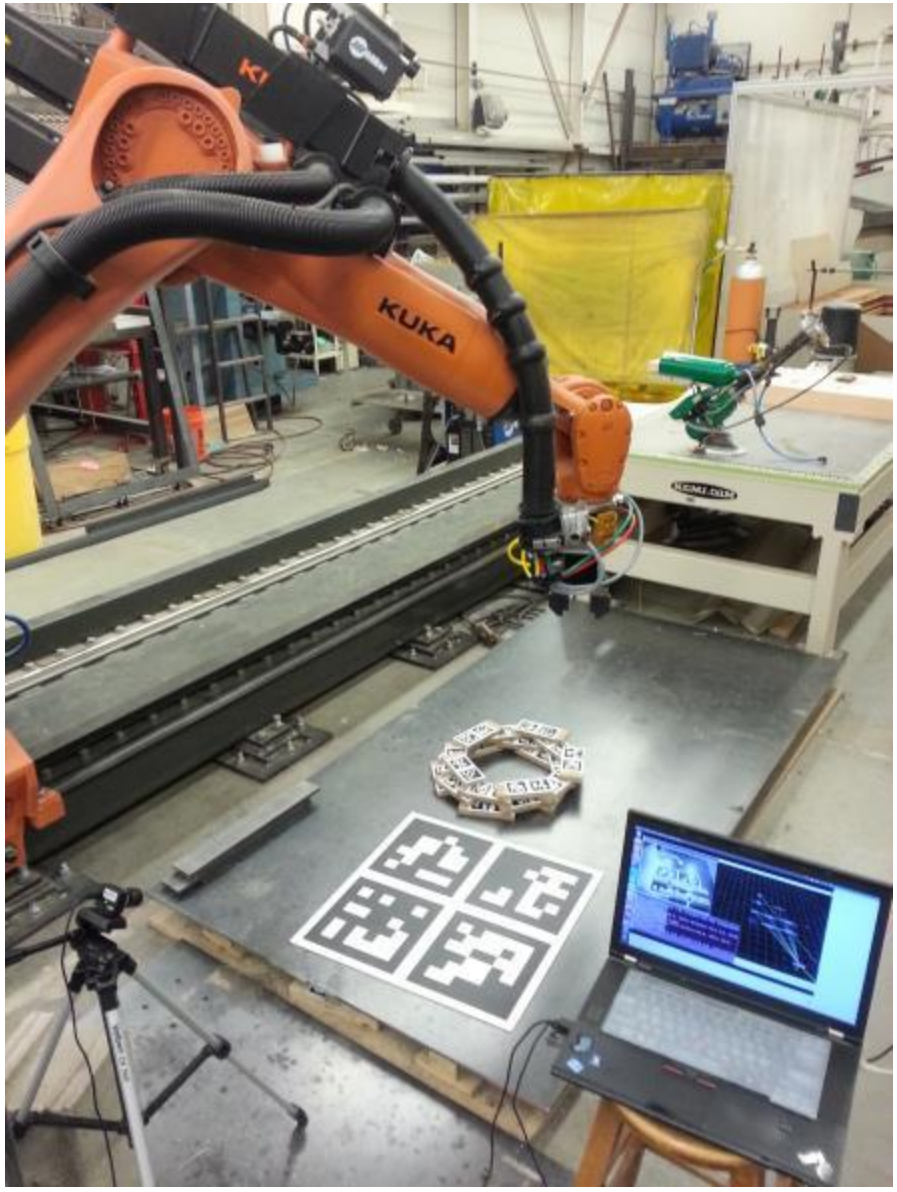
(a) Pick (b) Lift (c) Move (d) Drop

(e) Before change (f) During change (g) Auto-adapt to change (h) Successfully pick up



Autonomous Onsite Assembly (16x speed)

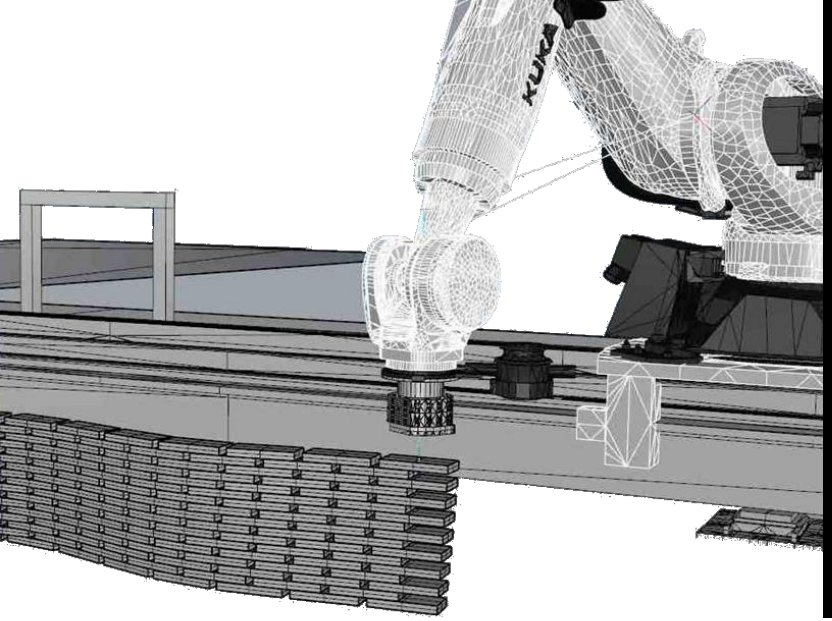



KUKA

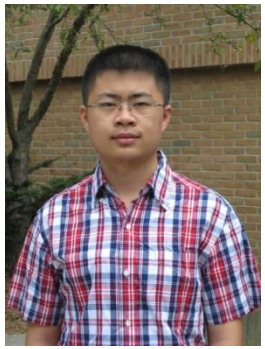
Feng C., Taguchi Y. and Kamat V.R. **Fast Plane Extraction in Organized Point Clouds Using Agglomerative Hierarchical Clustering**. *In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, 2014.

- Two major technical challenges for ARC
- The reported algorithms and an implemented robotic system
  - automatically generate building plans from computational architectural designs
  - achieve these plans autonomously on construction sites
- A computer-vision-based sub-centimetre-level metrology

- Continuously improving this system:
  - 3D perception
  - autonomous navigation
  - Improve control algorithms
  - more complicated assembly tasks
  - …



Thank you! Any questions?



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