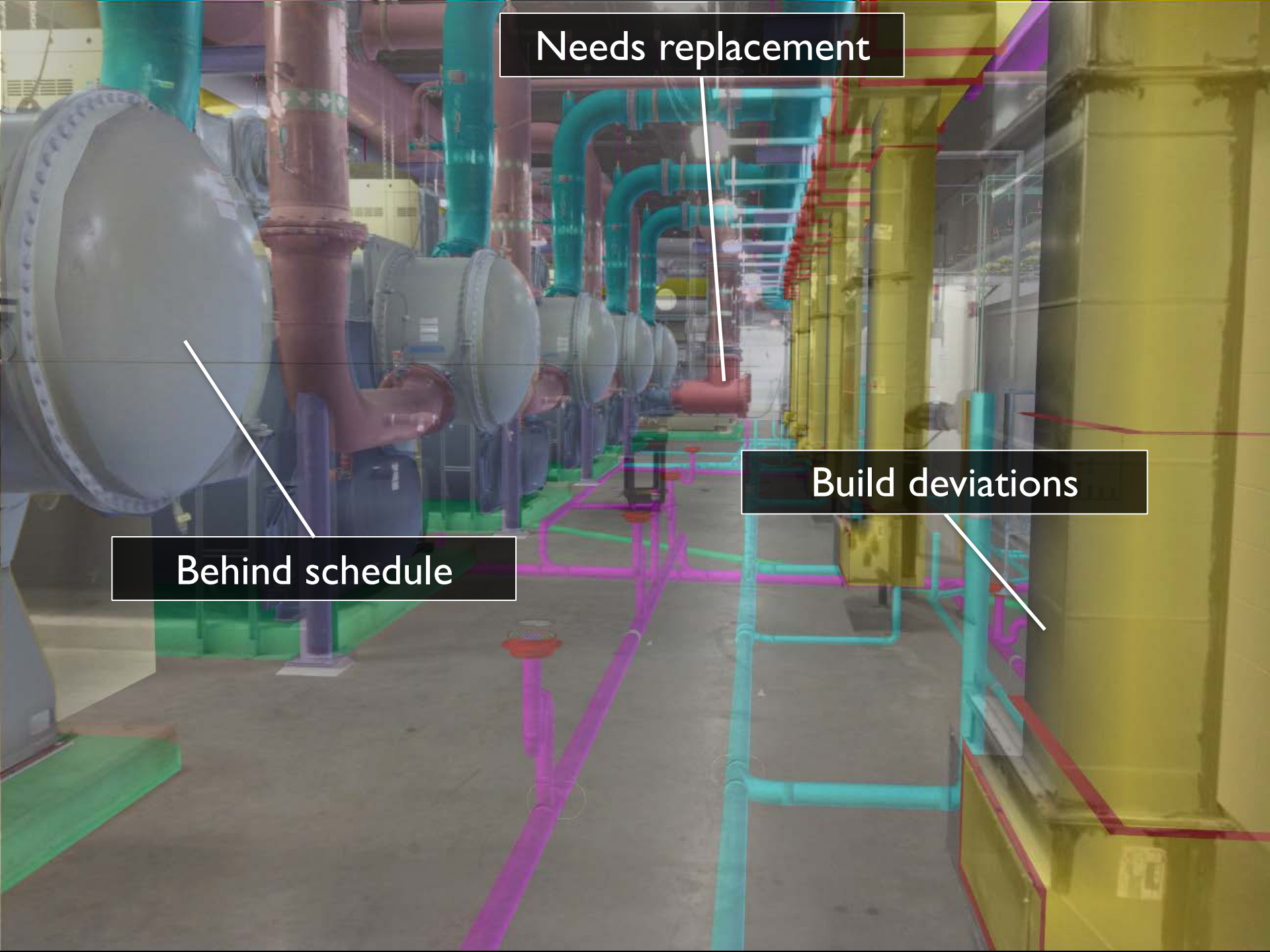
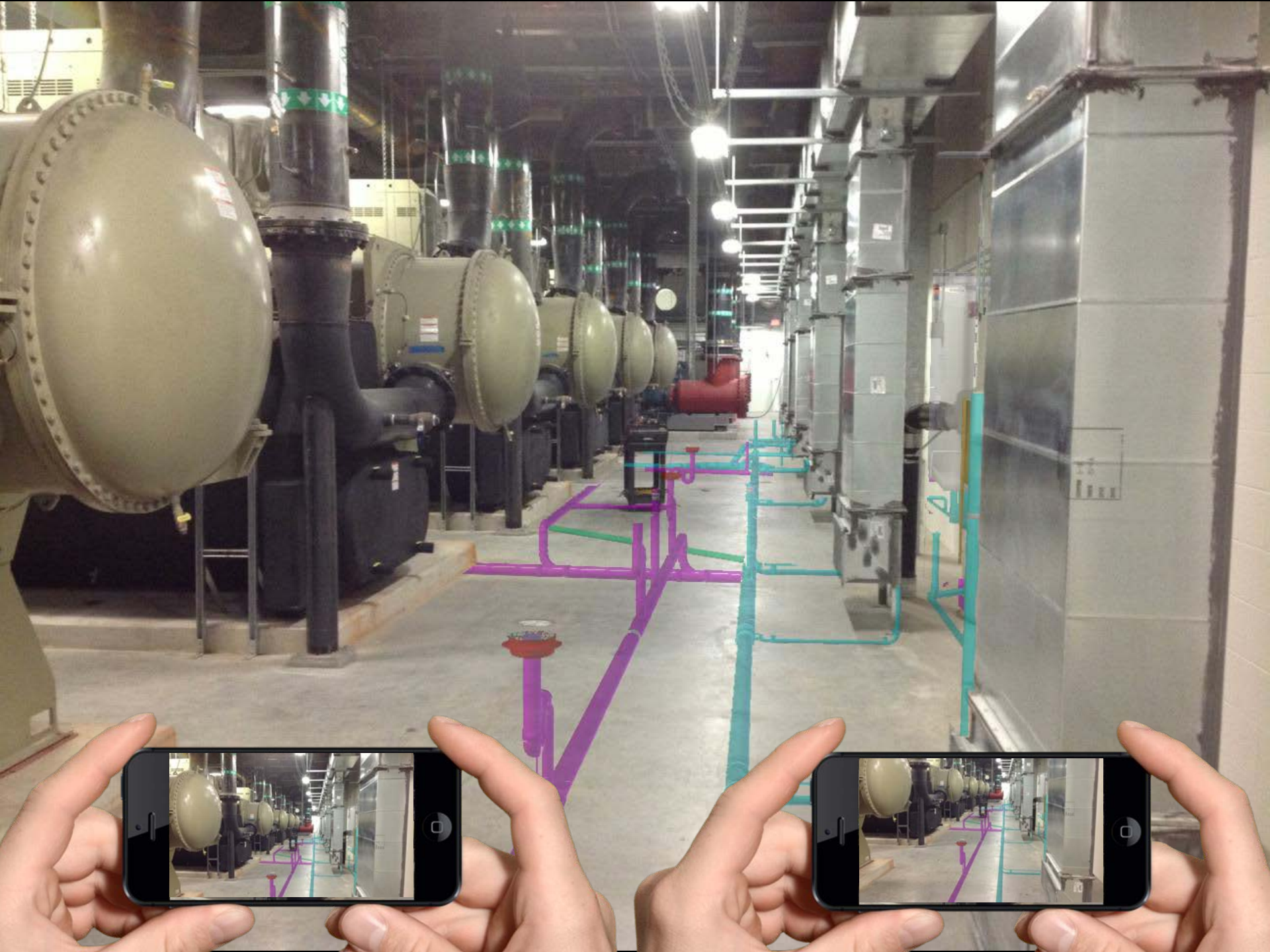
ConstructAide:

Analyzing and Visualizing Construction Sites through Photographs and Building Models

Kevin Karsch Mani Golparvar-Fard David Forsyth

University of Illinois


Needs replacement
Behind schedule
Build deviations



Existing Techniques

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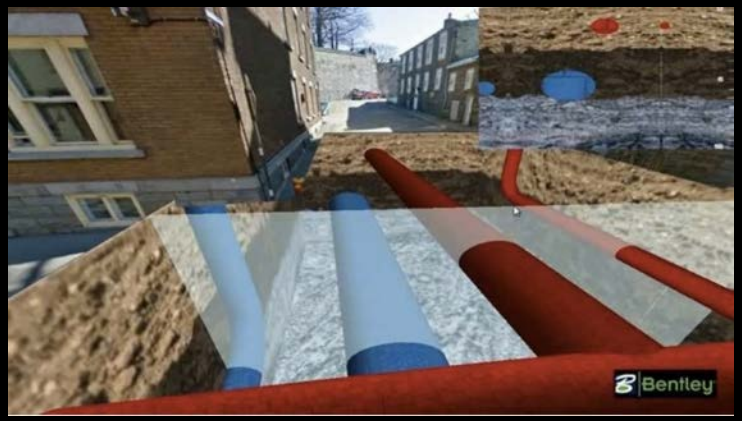


Manual registration + hardware tracking
[Cote et al. 2013, 2011; Hakkarainen et al. 2009; Irizarry et al. 2012; Woodward et al. 2010; Lee and Akin 2011; Shin and Dunston 2010; Yabuki et al. 2010]

Occlusion visualization
[Zollmann et al. 2010, 2012]

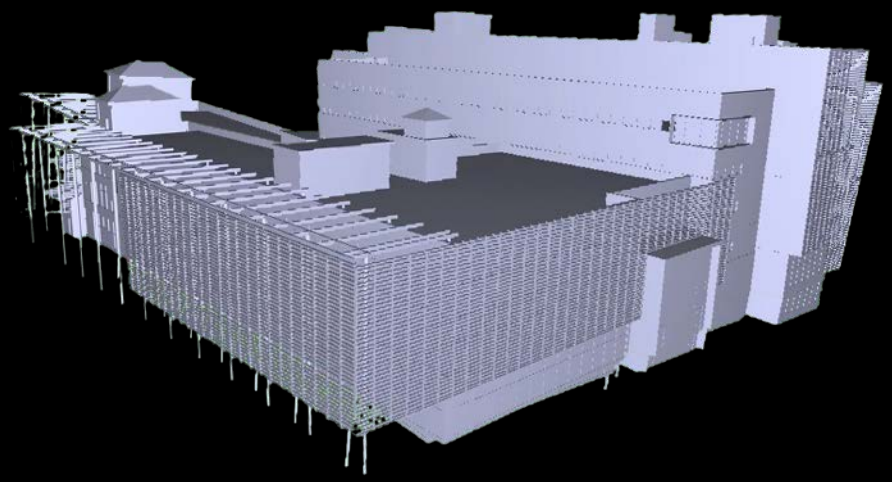
D4AR [Golparvar-Fard et al. 2011]

System Overview

System Overview

Inputs:

- 4D Building Information Model (BIM)



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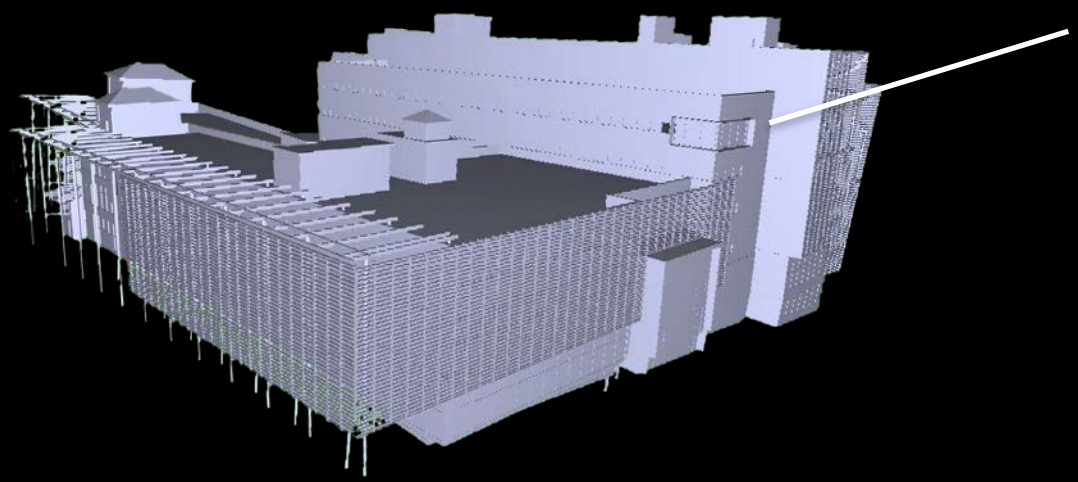


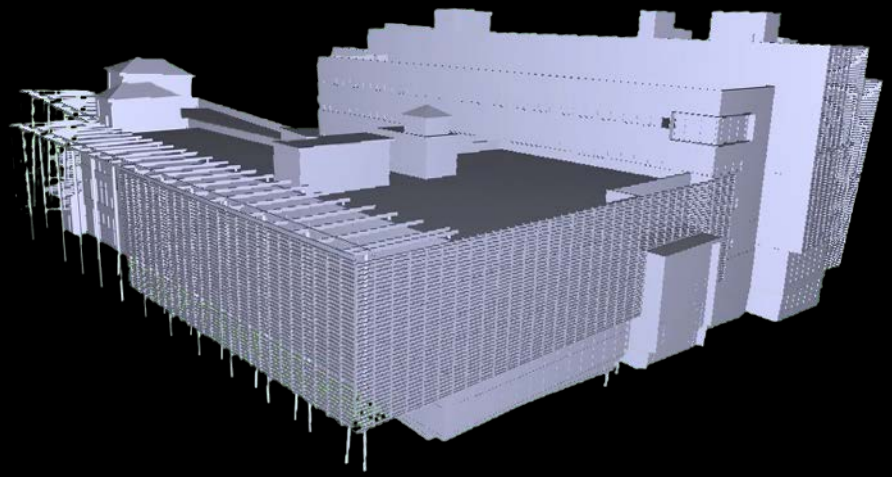
BIM data:

- Semantic 3D mesh
- Scheduling info
- Materials
- GPS data
- …

System Overview

Inputs:

- 4D Building Information Model (BIM)
- One or more site photographs



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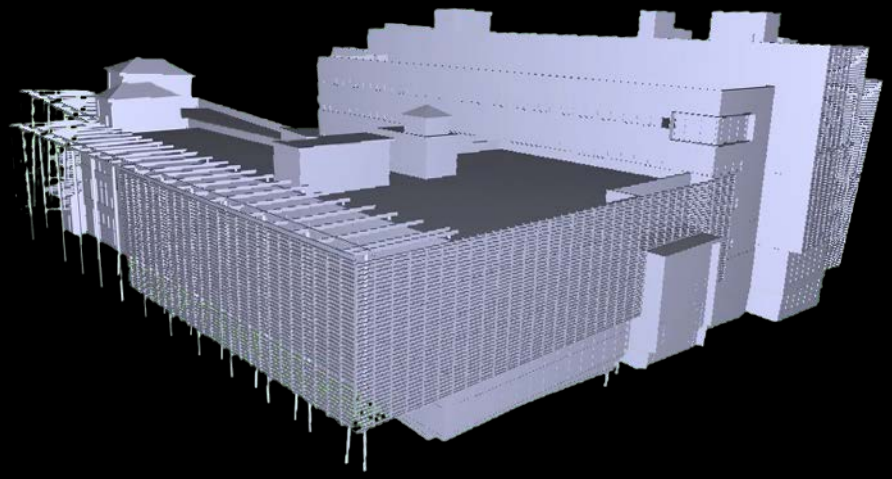

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Model registration via Model-assisted SfM

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Model registration via Model-assisted SfM

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ConstructAide provides tools for:

- 4D navigation
- Identifying occlusions
- Visualization
- Progress monitoring

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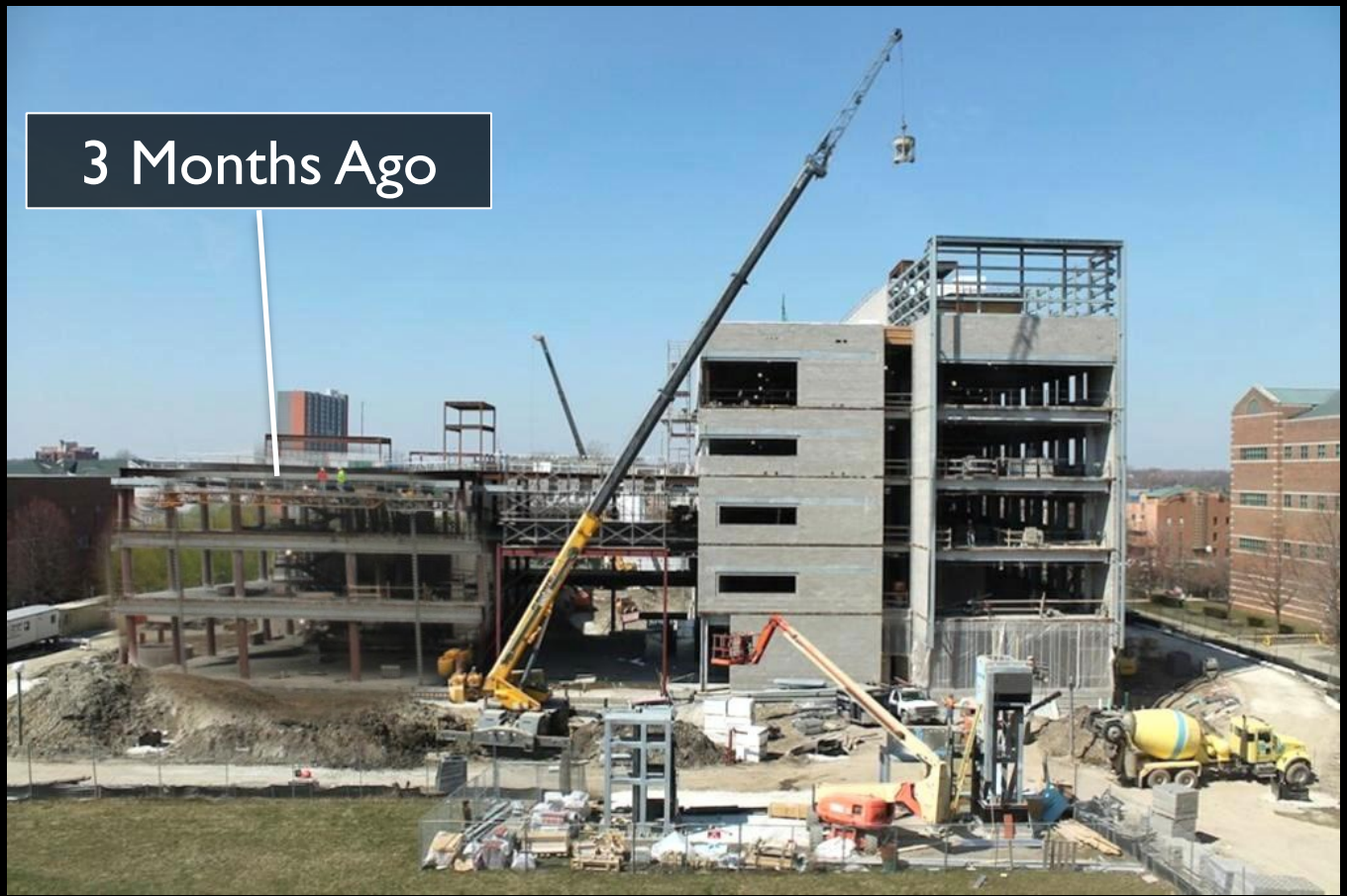

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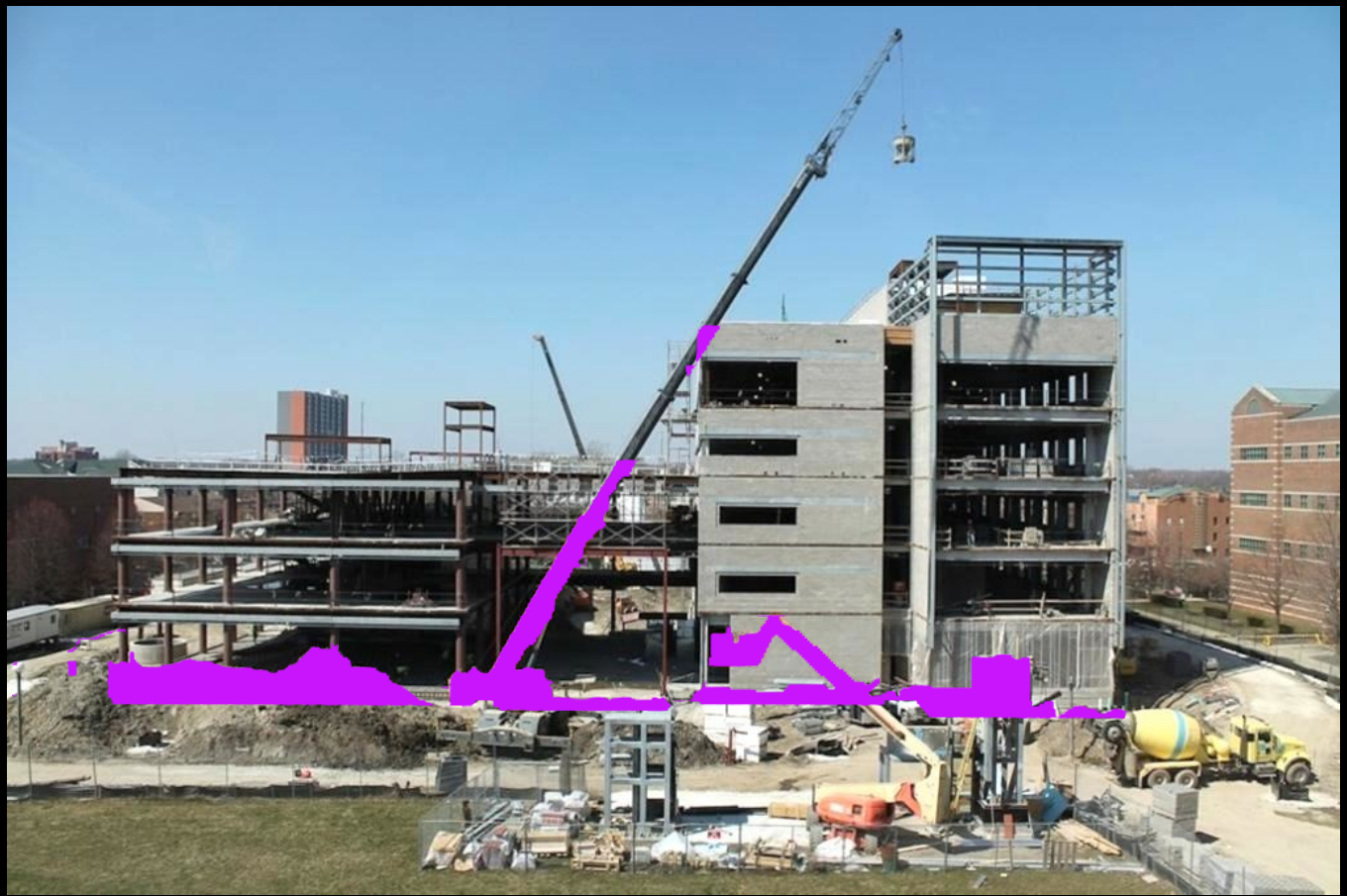

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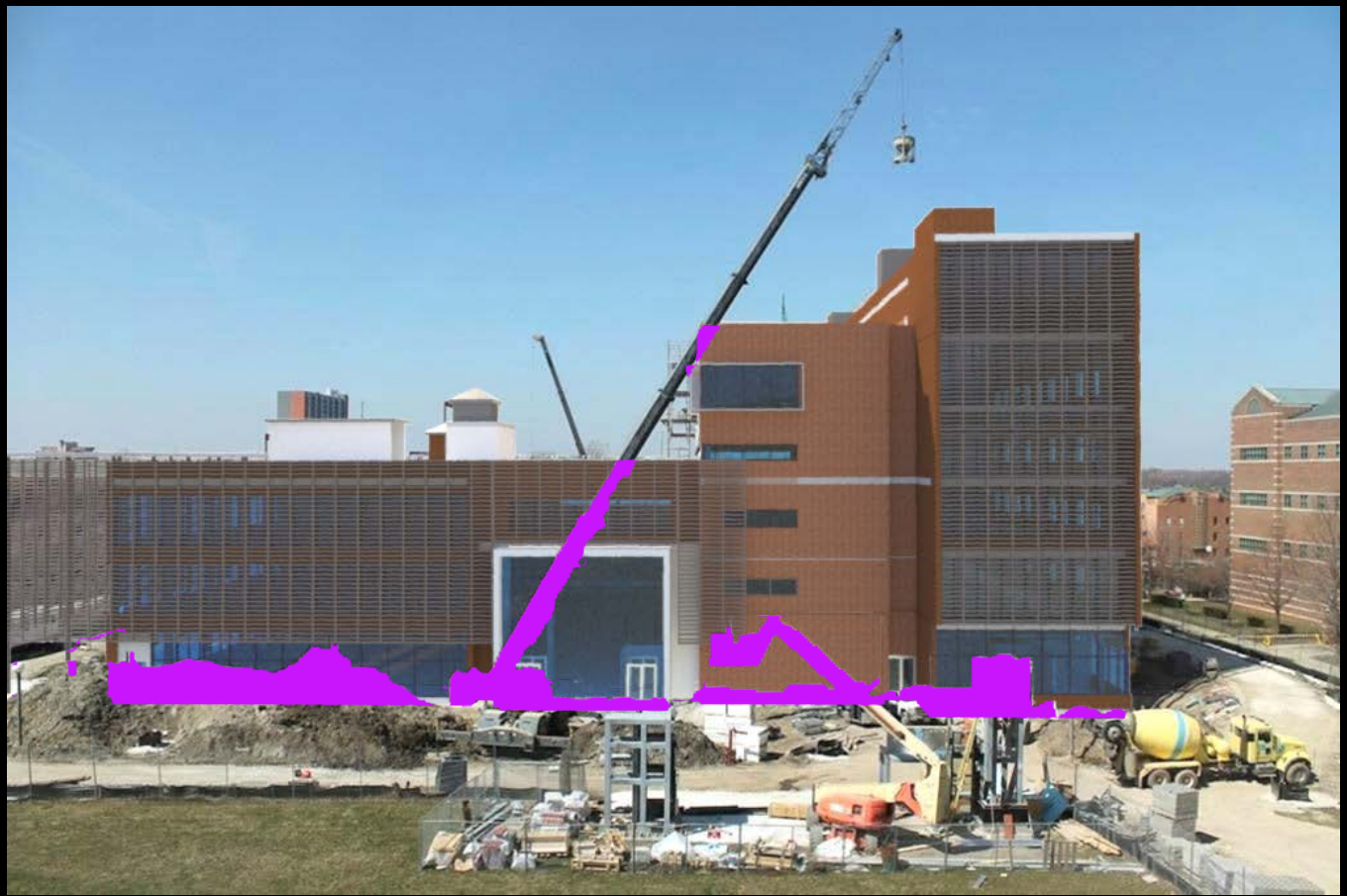

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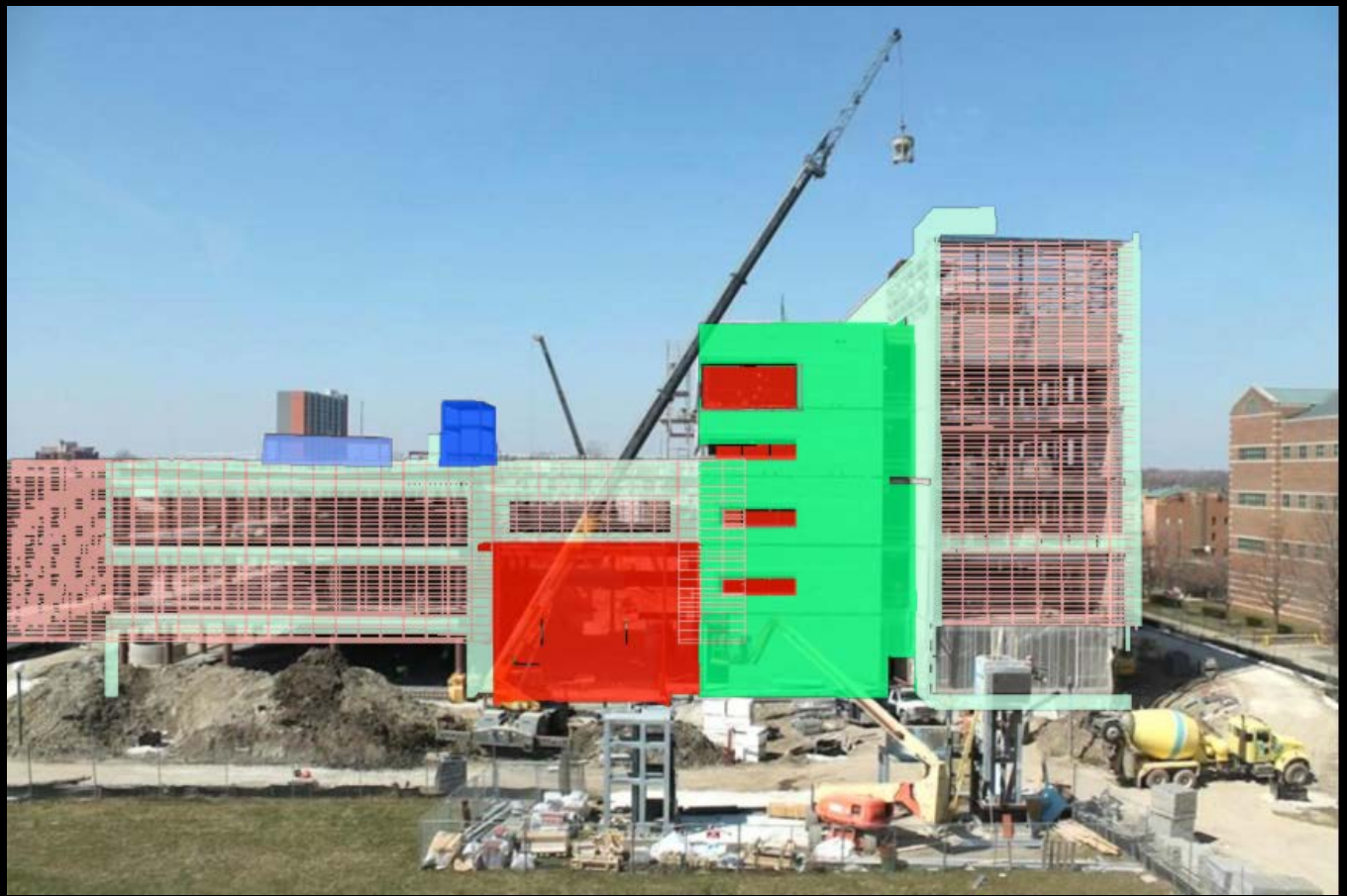

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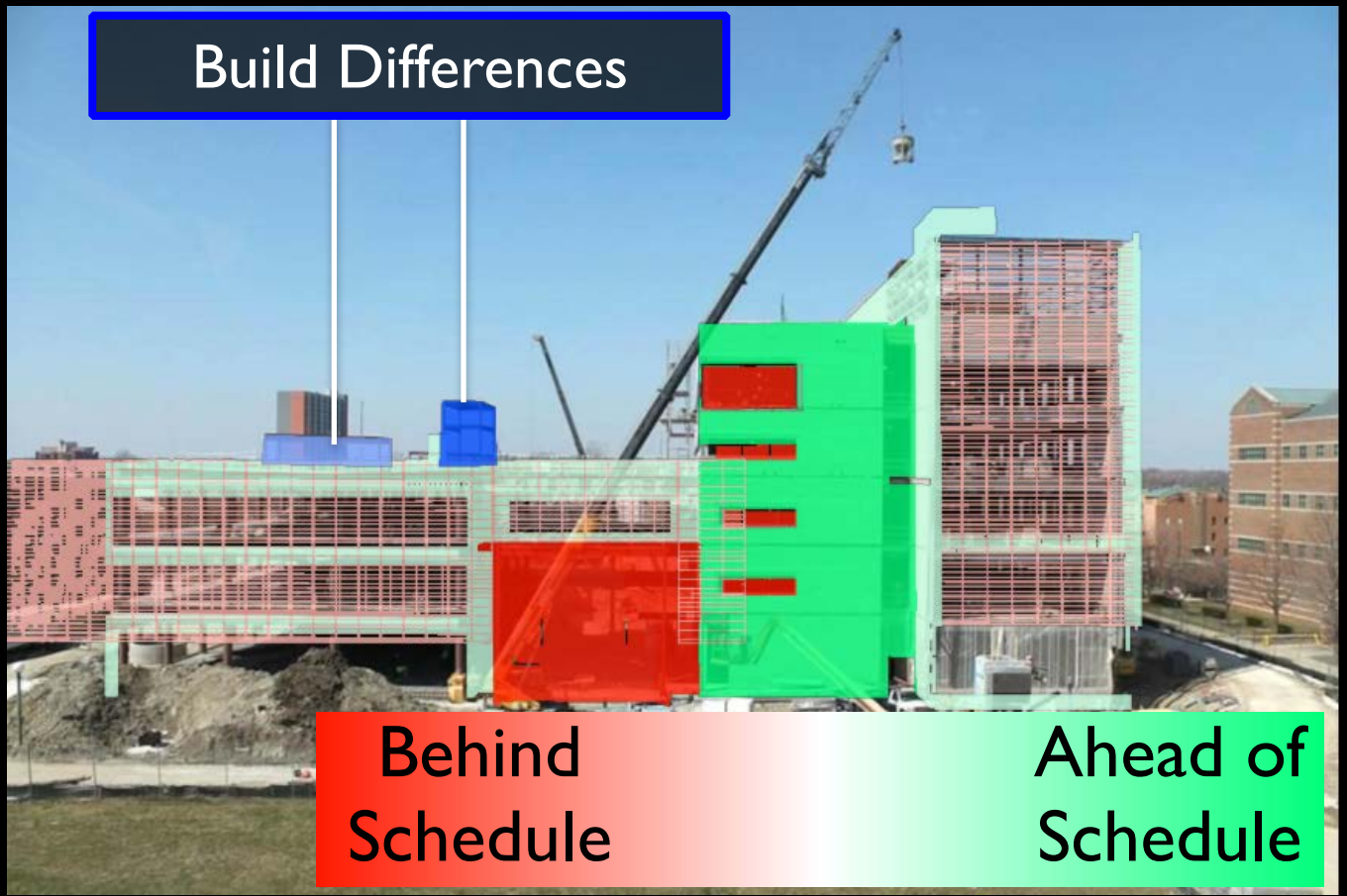
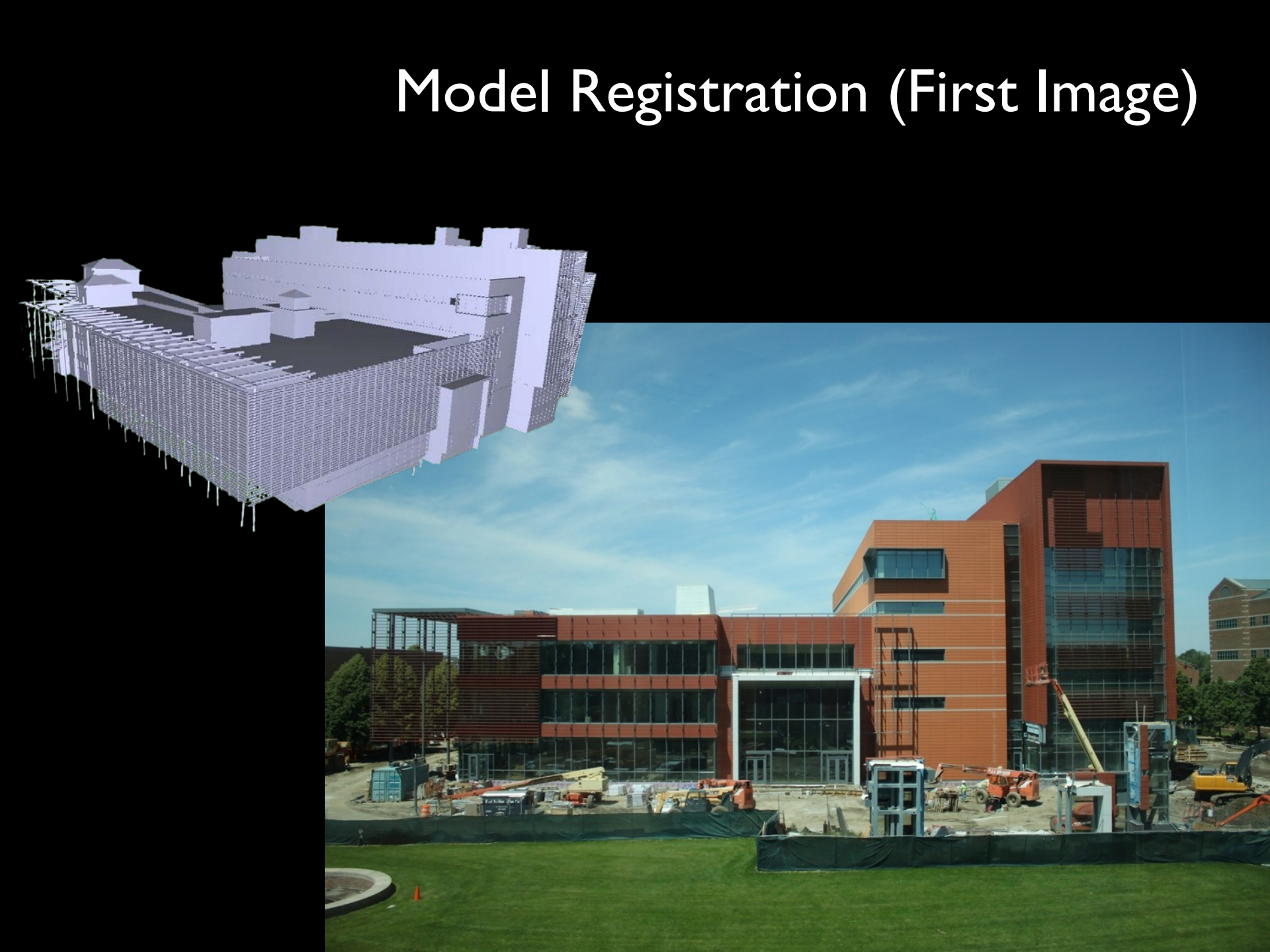
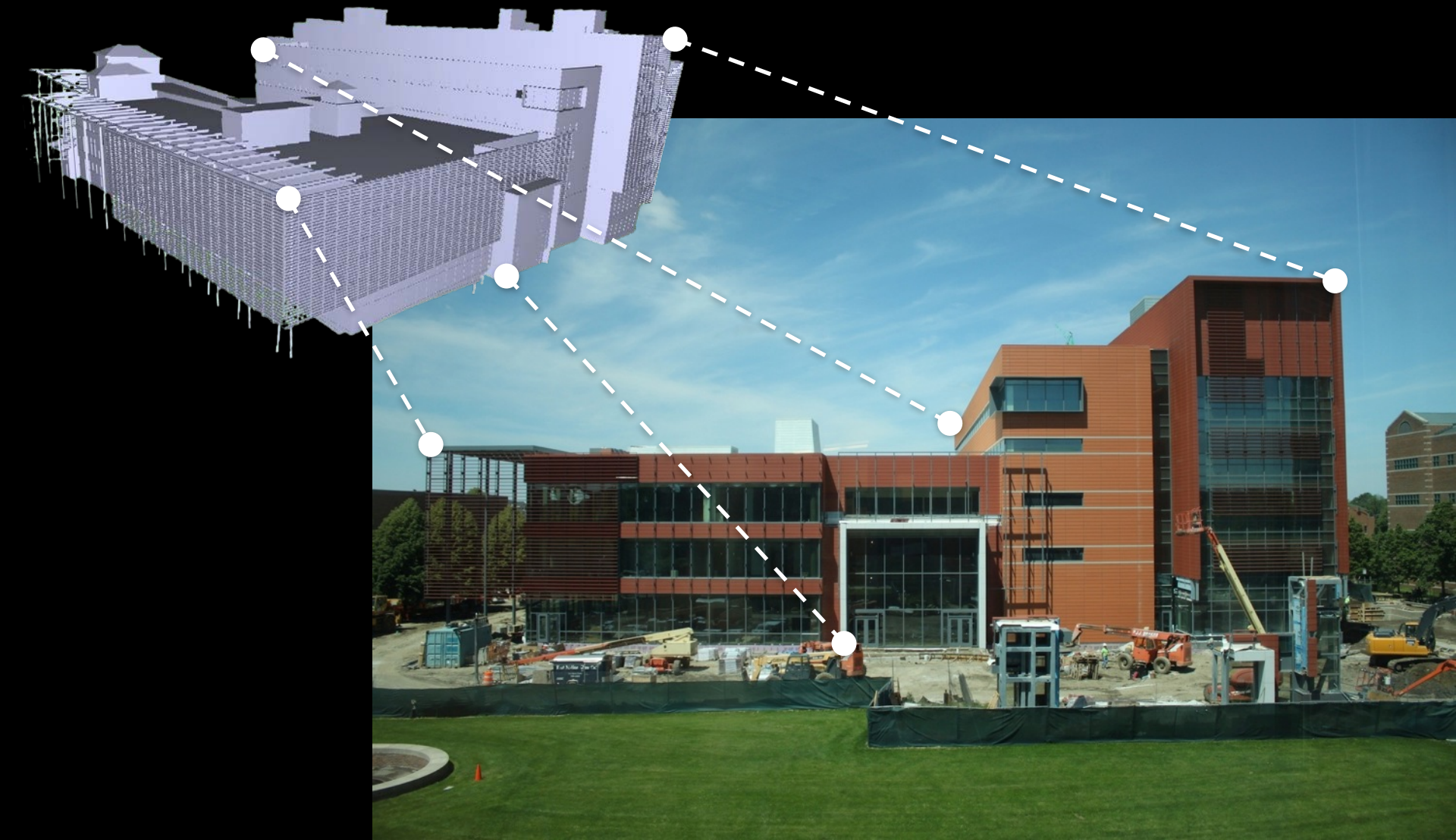


Model-assisted Structure-from-Motion

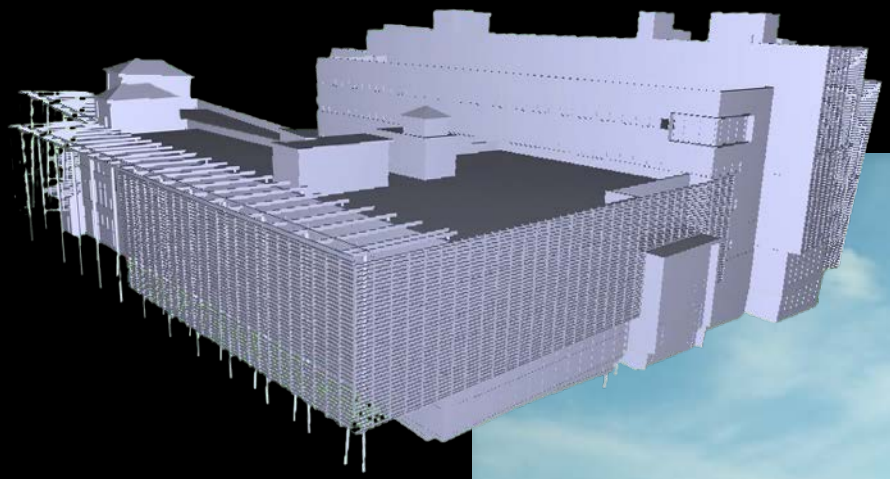
Model Registration (First Image)



Model Registration (First Image)



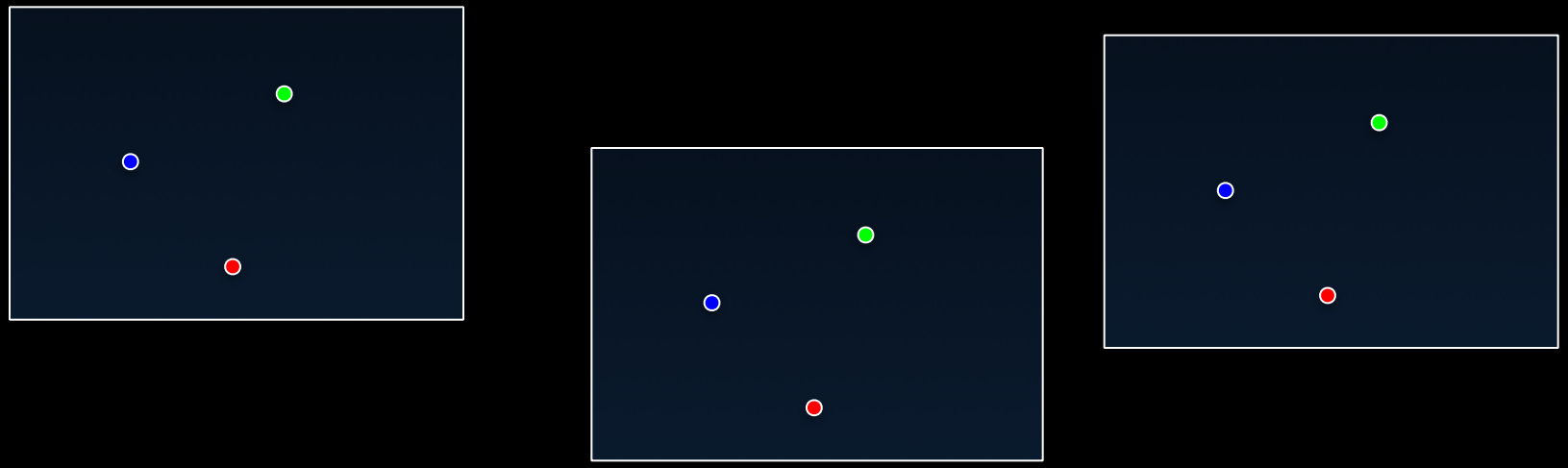
Model Registration (First Image)



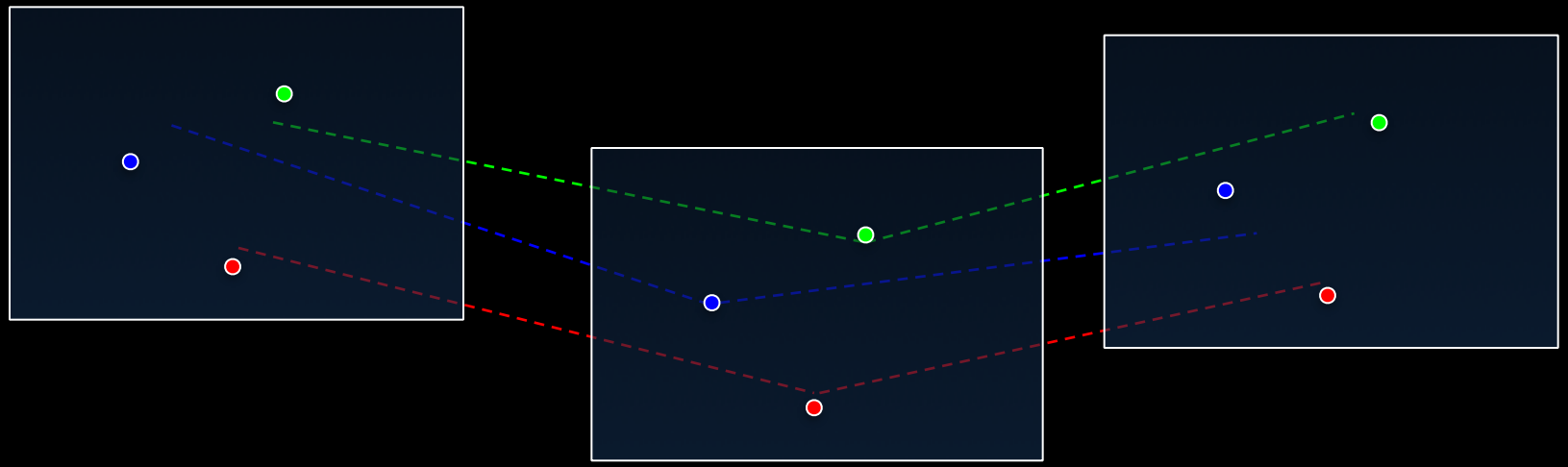
Model Registration (Subsequent Images)

Structure-from-Motion Refresher

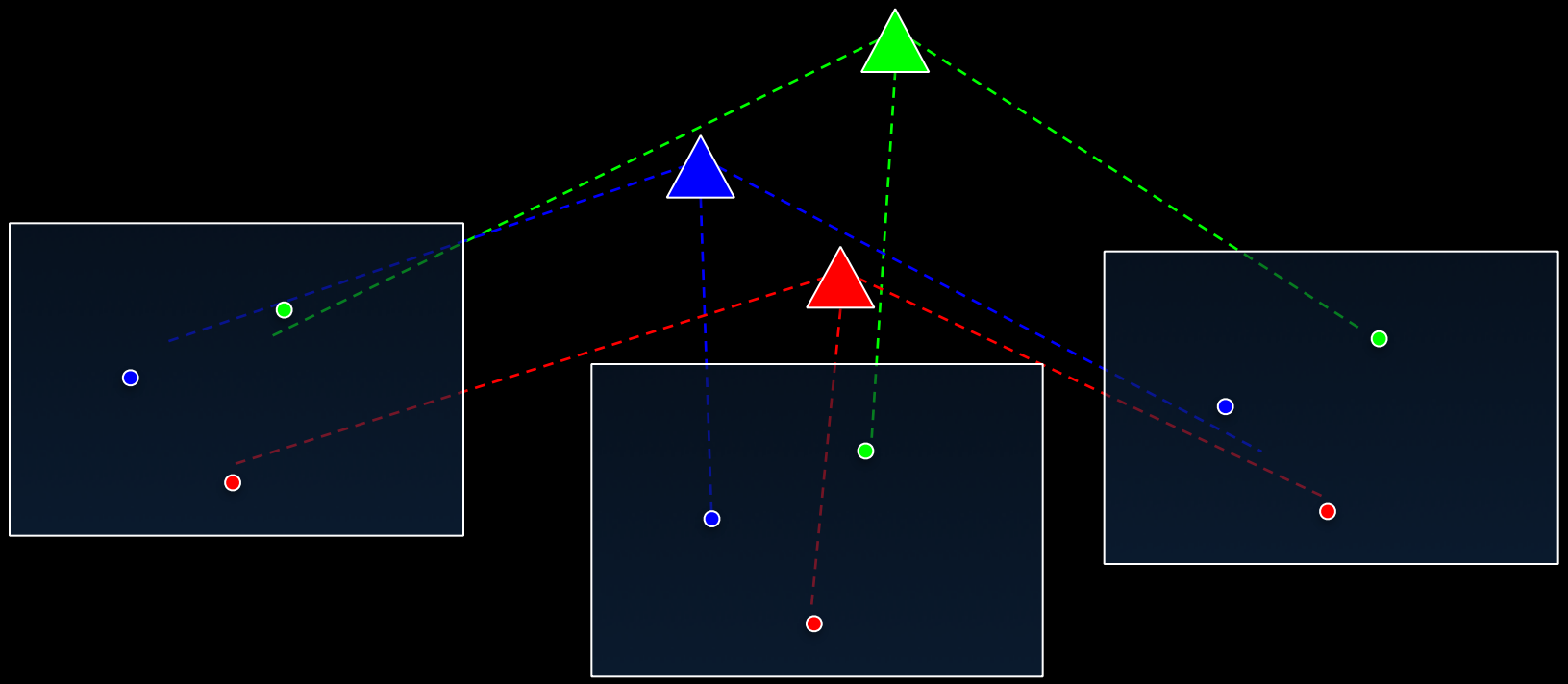
Structure-from-Motion Refresher



Structure-from-Motion Refresher

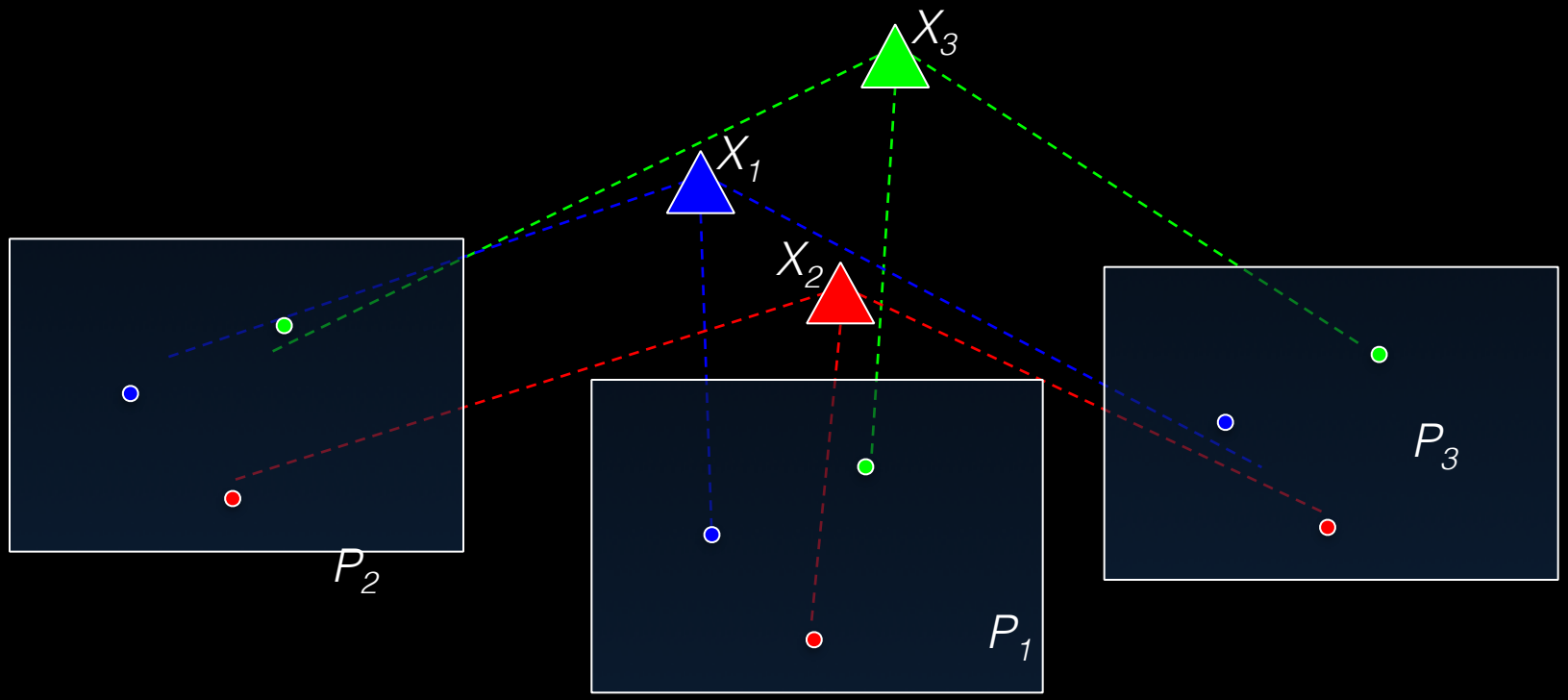


Structure-from-Motion Refresher



$$\underset{X,P_1,\ldots,P_k}{\operatorname{argmin}} \sum_{i=1}^{\#\text{cameras}} \sum_{j=1}^{\#\text{tracks}} \delta_{i,j} ||x_j - P_i(X_j)||$$

Structure-from-Motion Refresher



$$\underset{X, P_1, \ldots, P_k}{\operatorname{argmin}} \sum_{i=1}^{\#\text{cameras}} \sum_{j=1}^{\#\text{tracks}} \delta_{i,j} ||x_j - P_i(X_j)||$$

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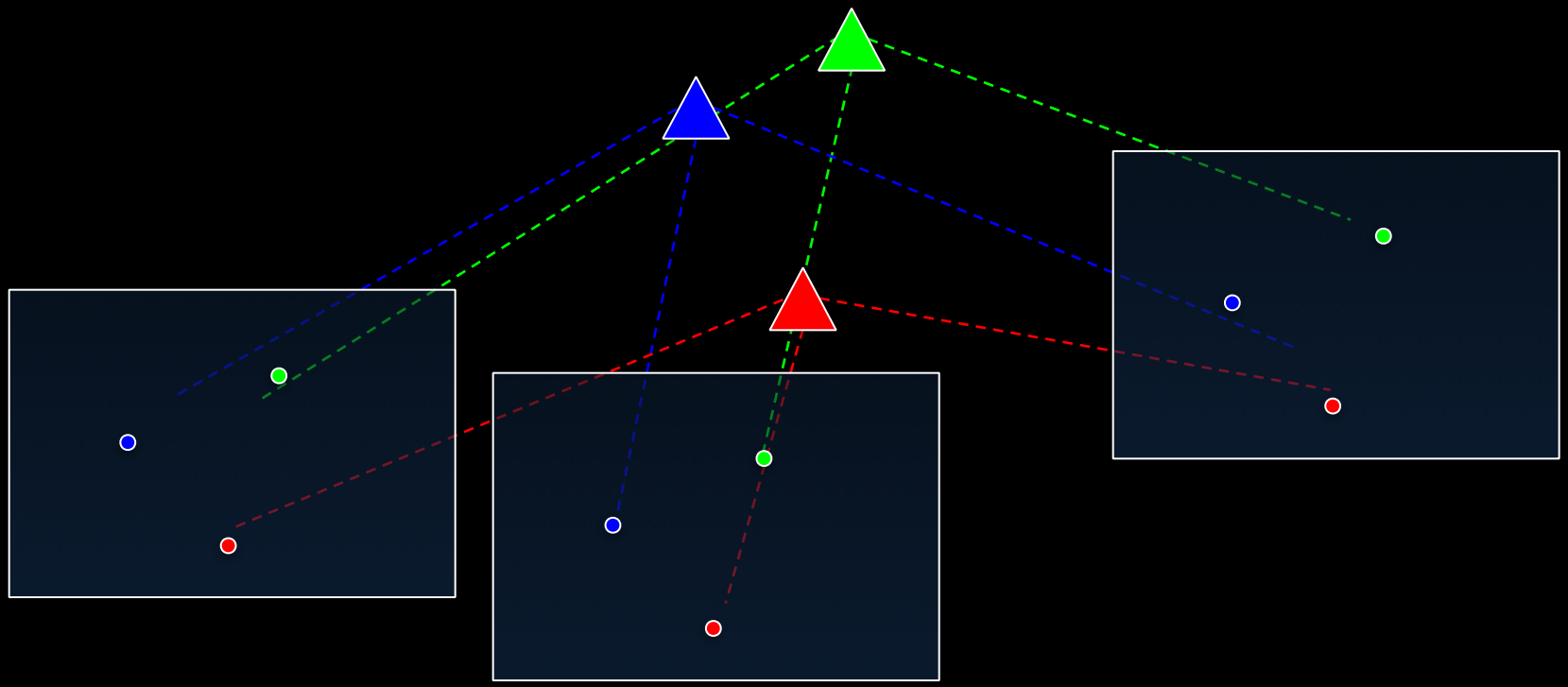

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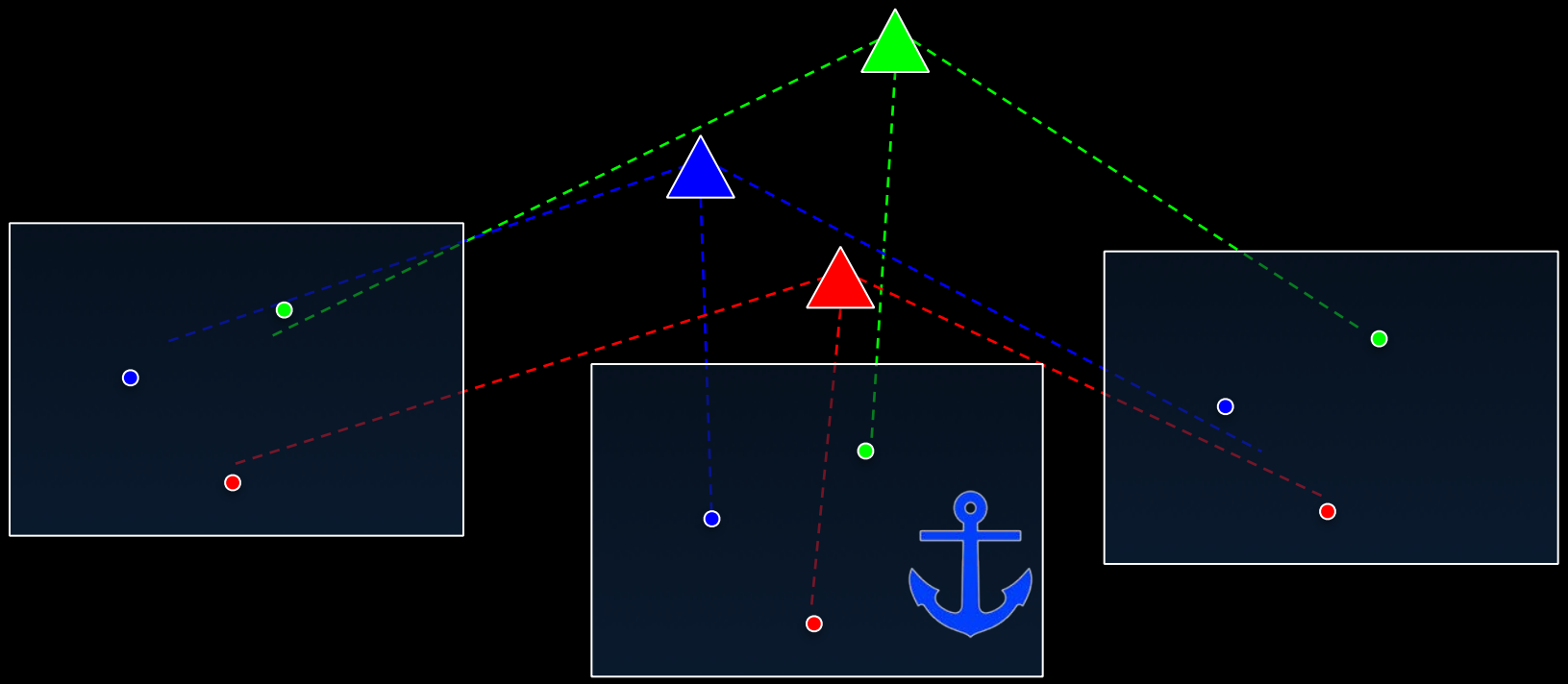
Constrained Structure-from-Motion



$$\underset{t,P_2,\ldots,P_k}{\operatorname{argmin}} \sum_{i=2}^{\#\text{cameras}} \sum_{j=1}^{\#\text{tracks}} \delta_{i,j} ||x_j - P_i(X_j(t_j))||$$

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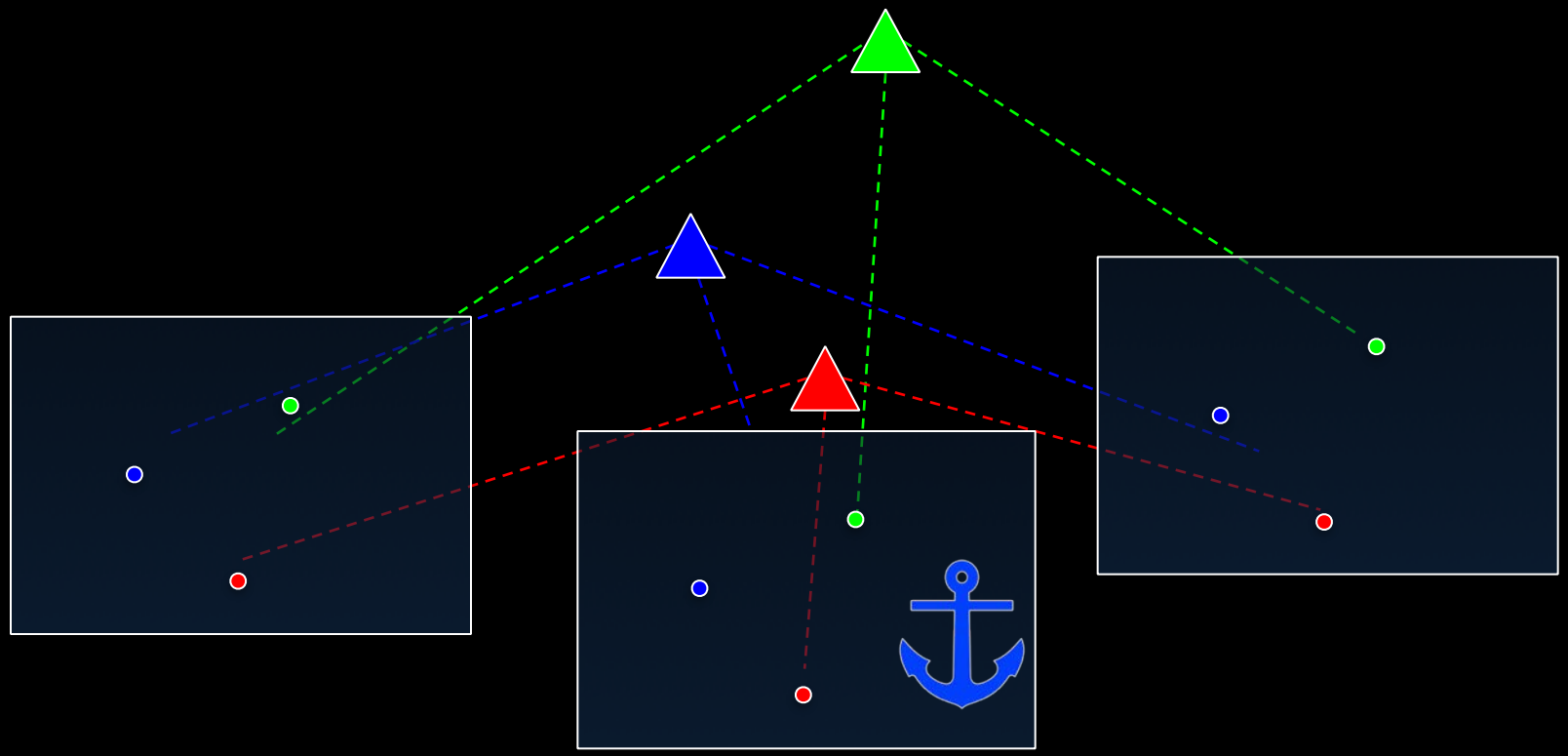

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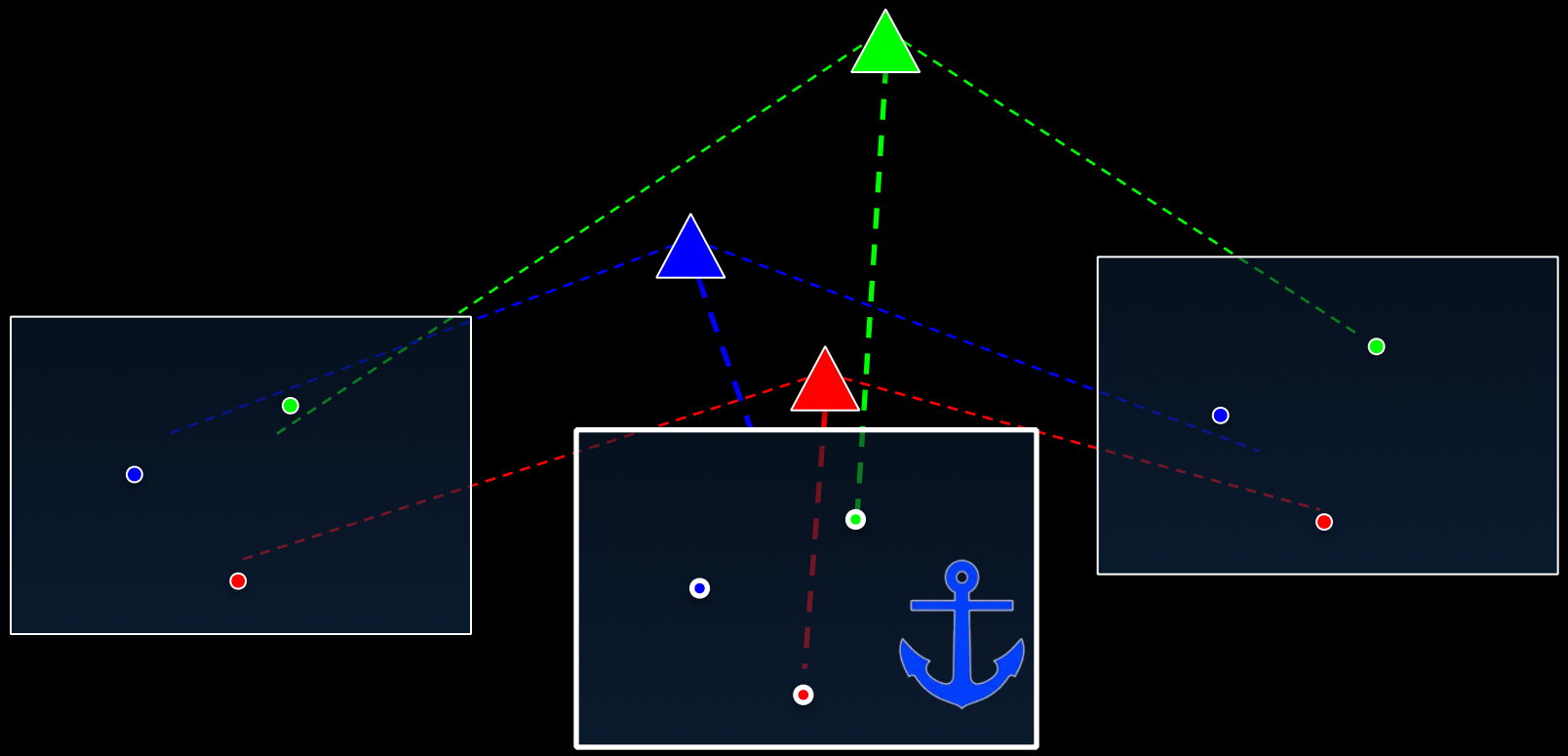

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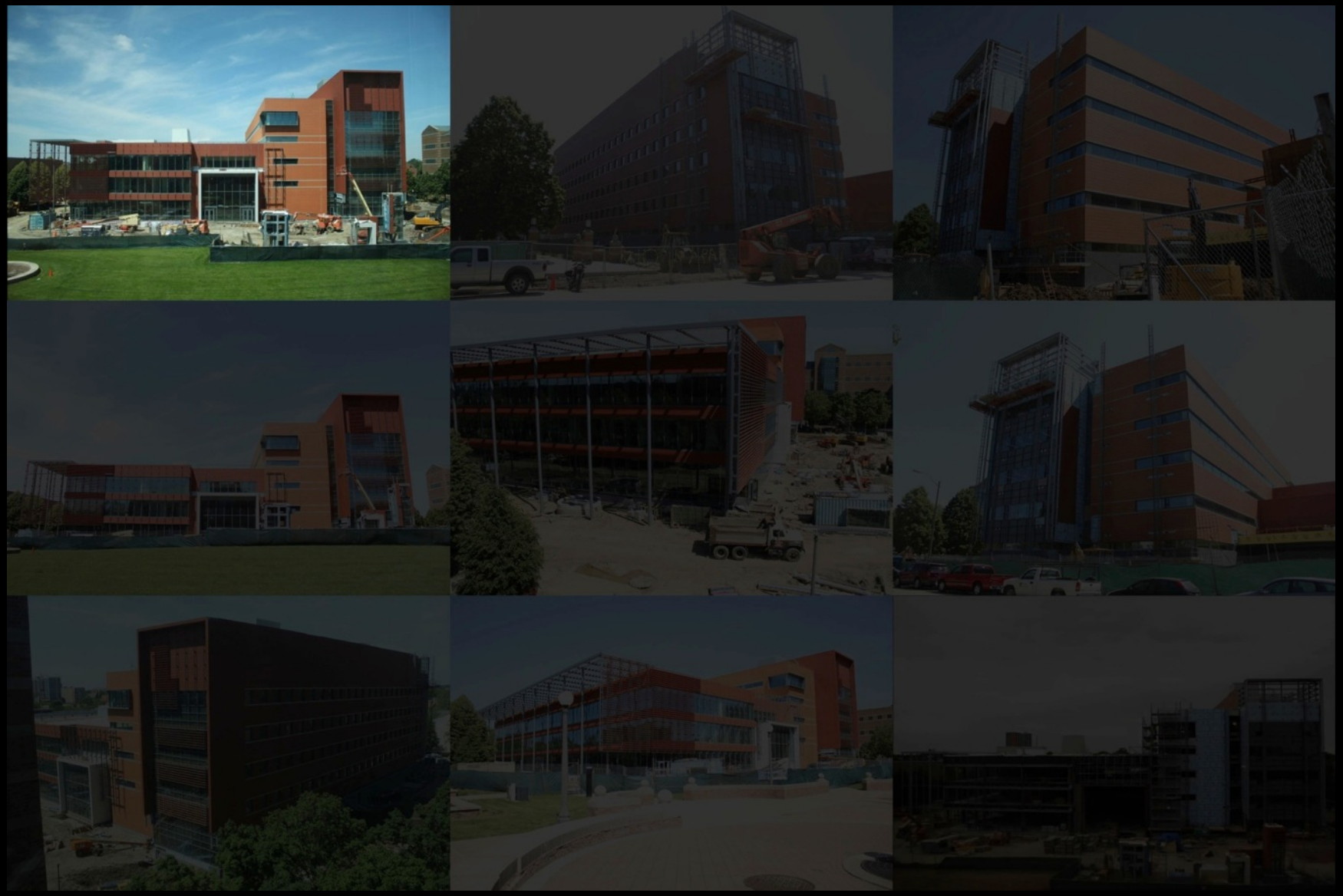

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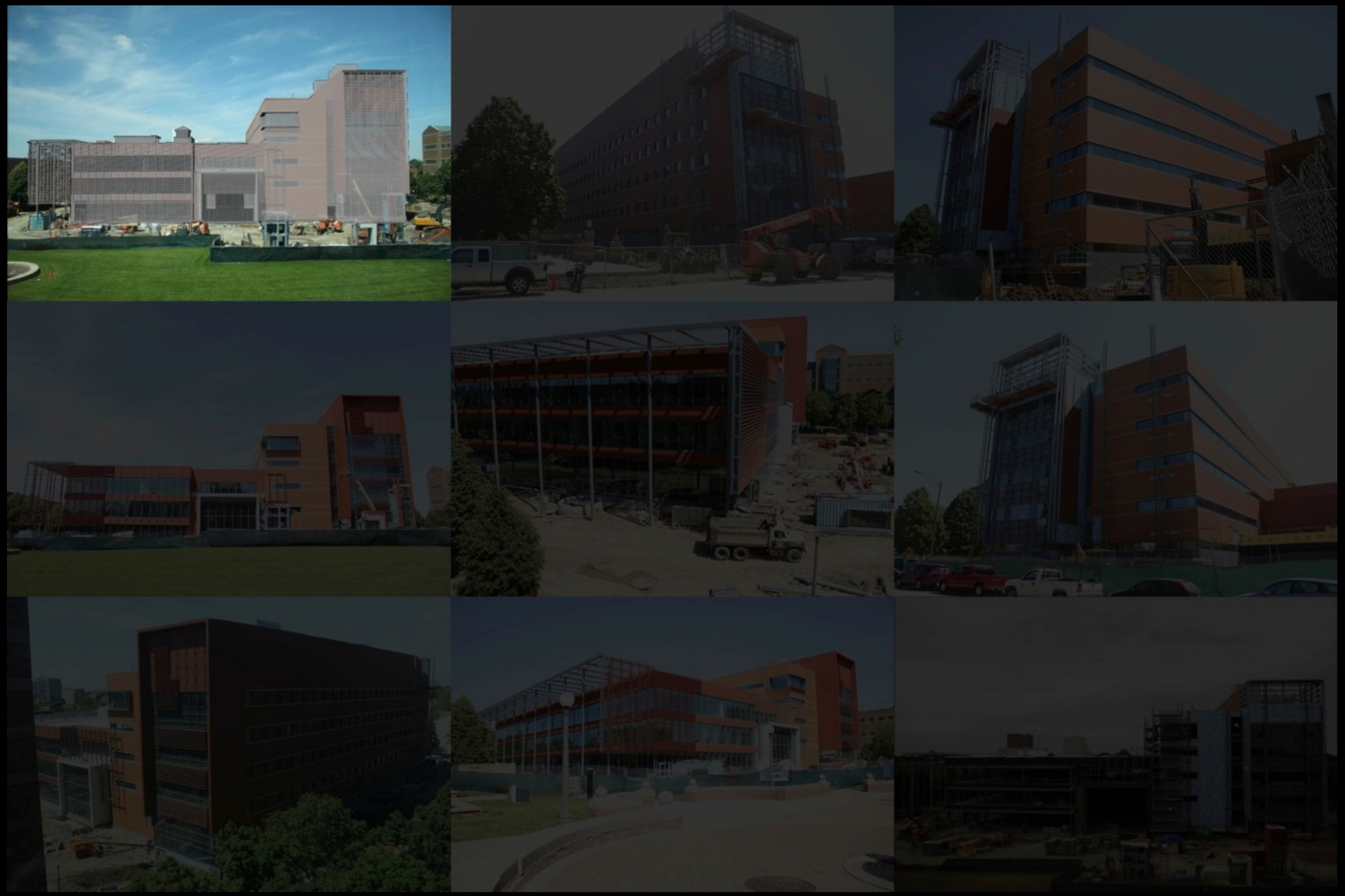

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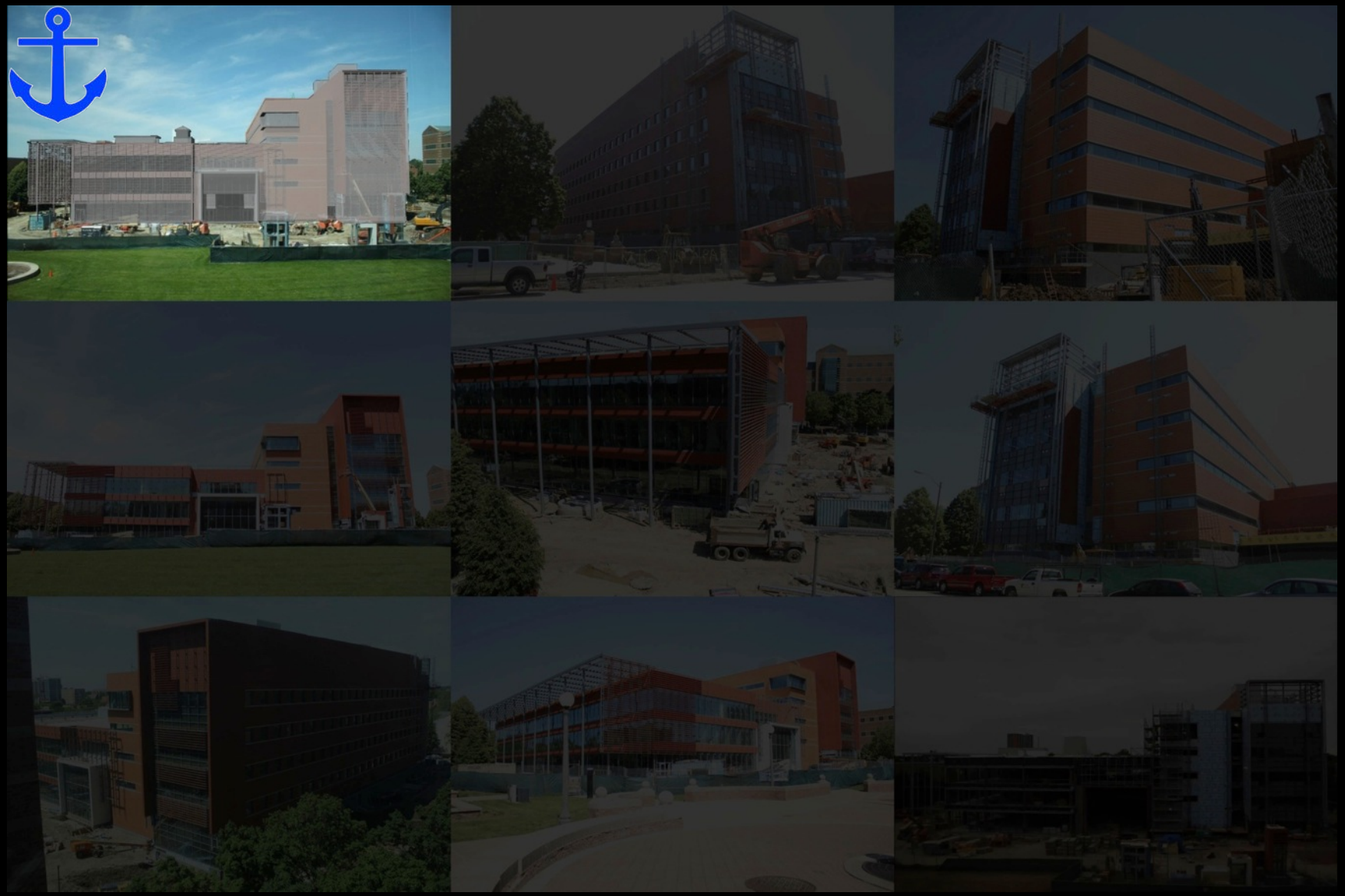

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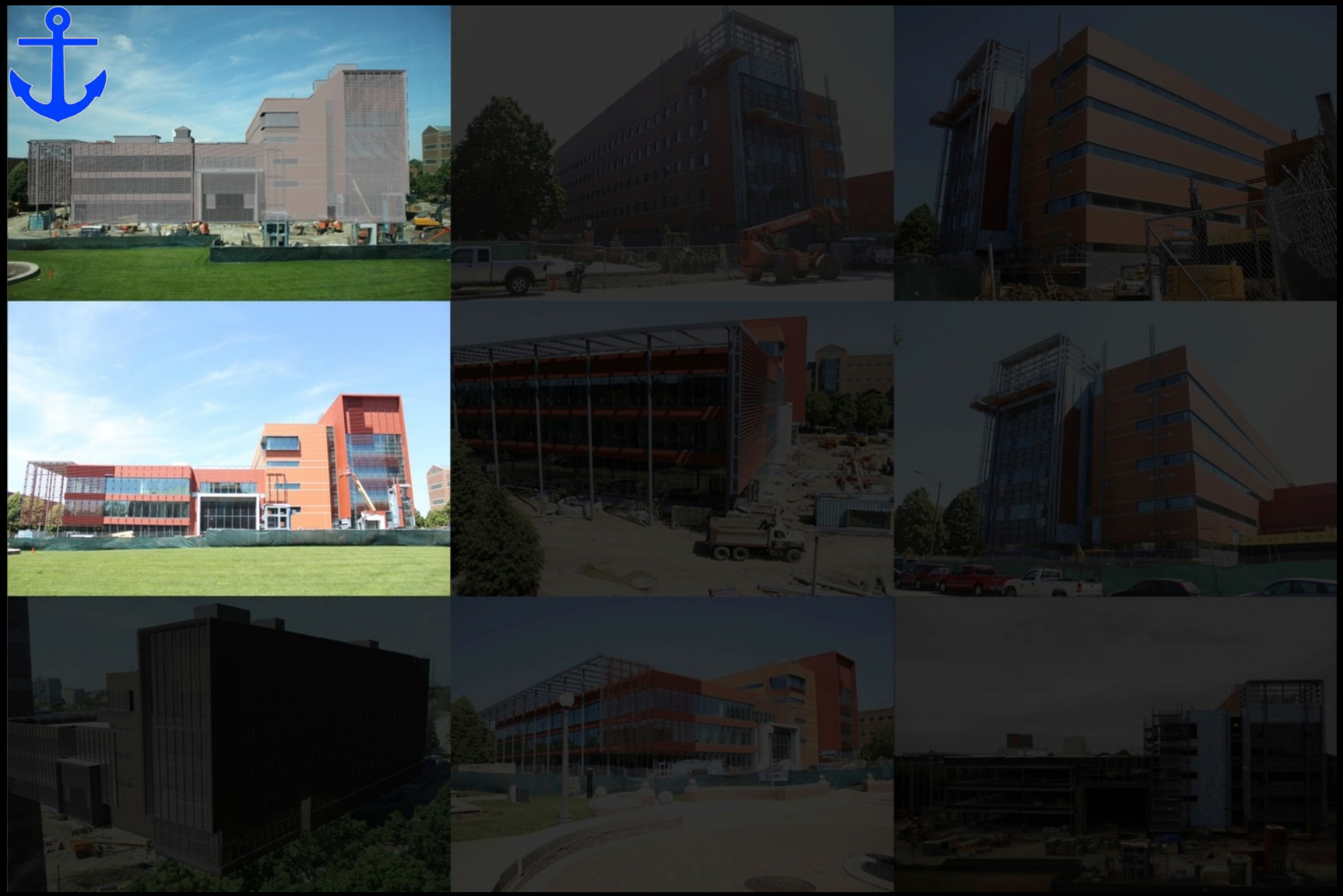

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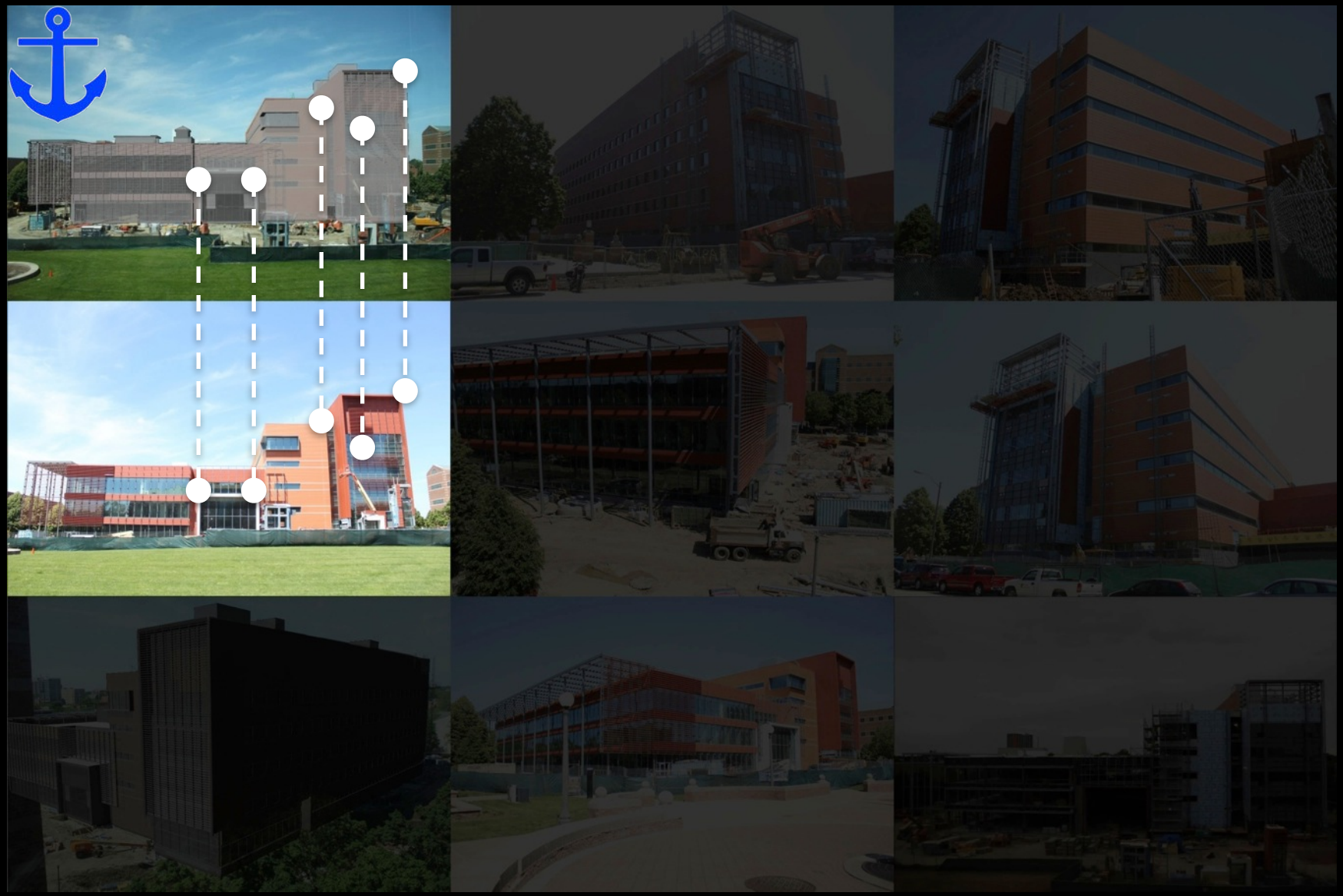

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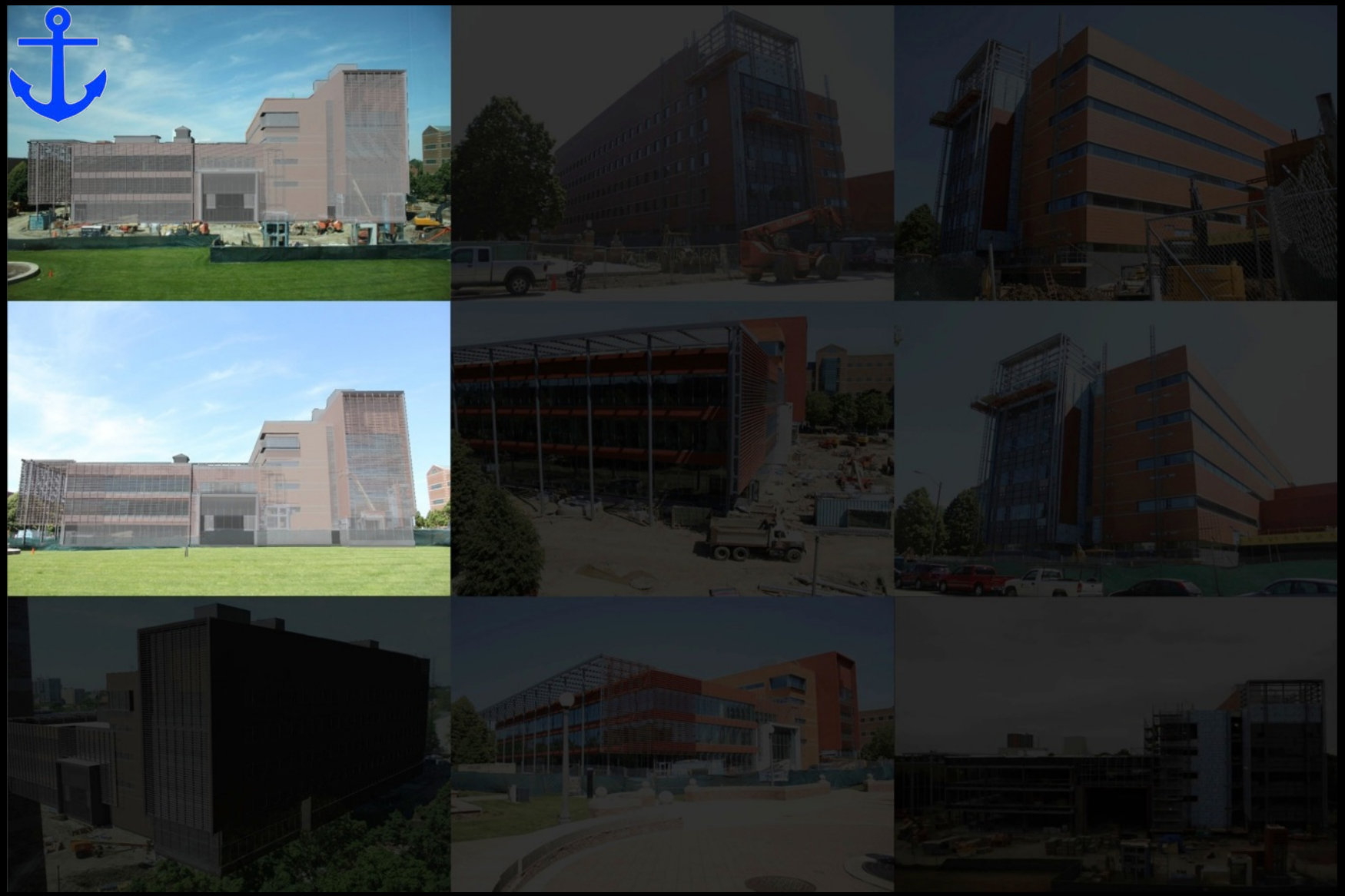

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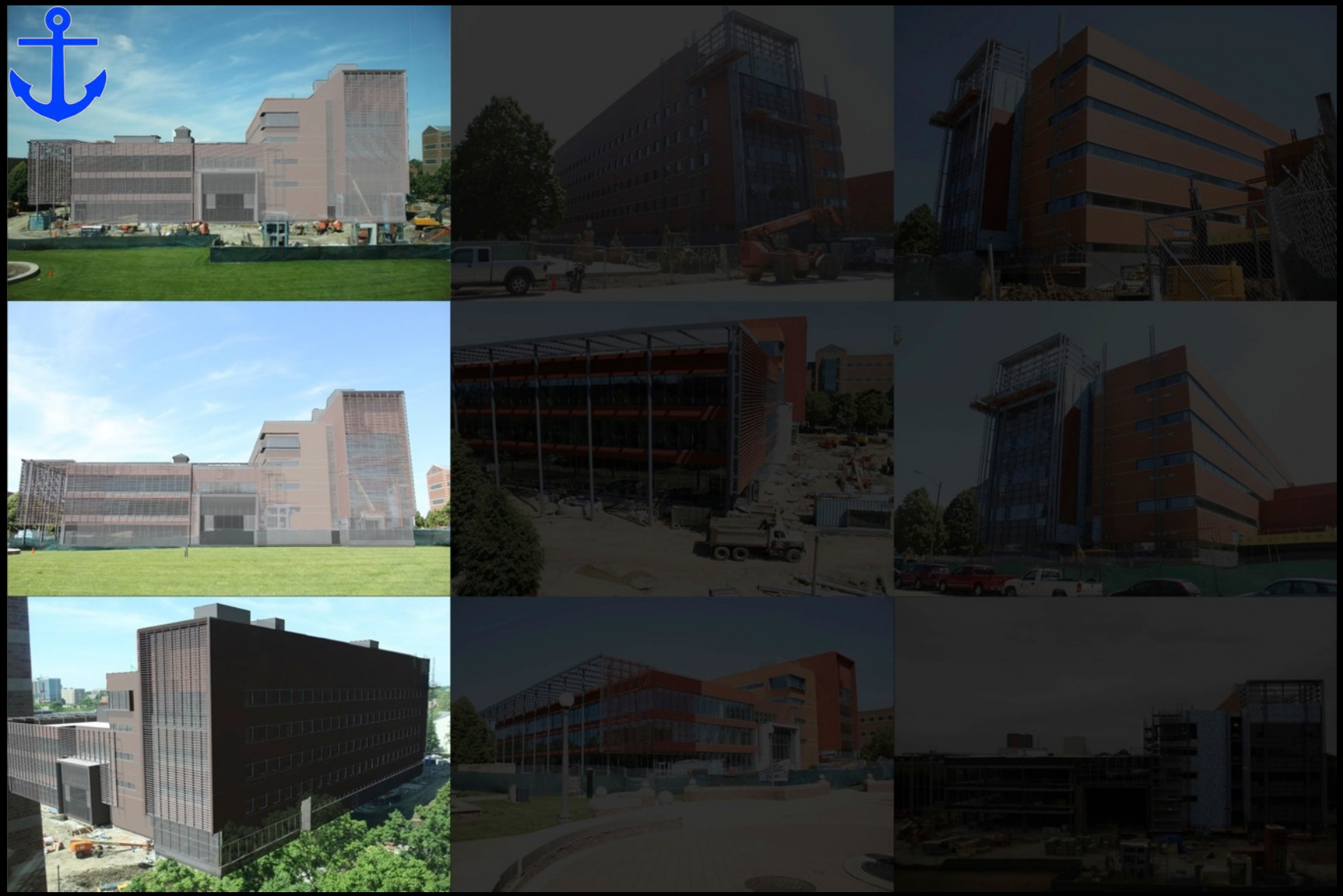

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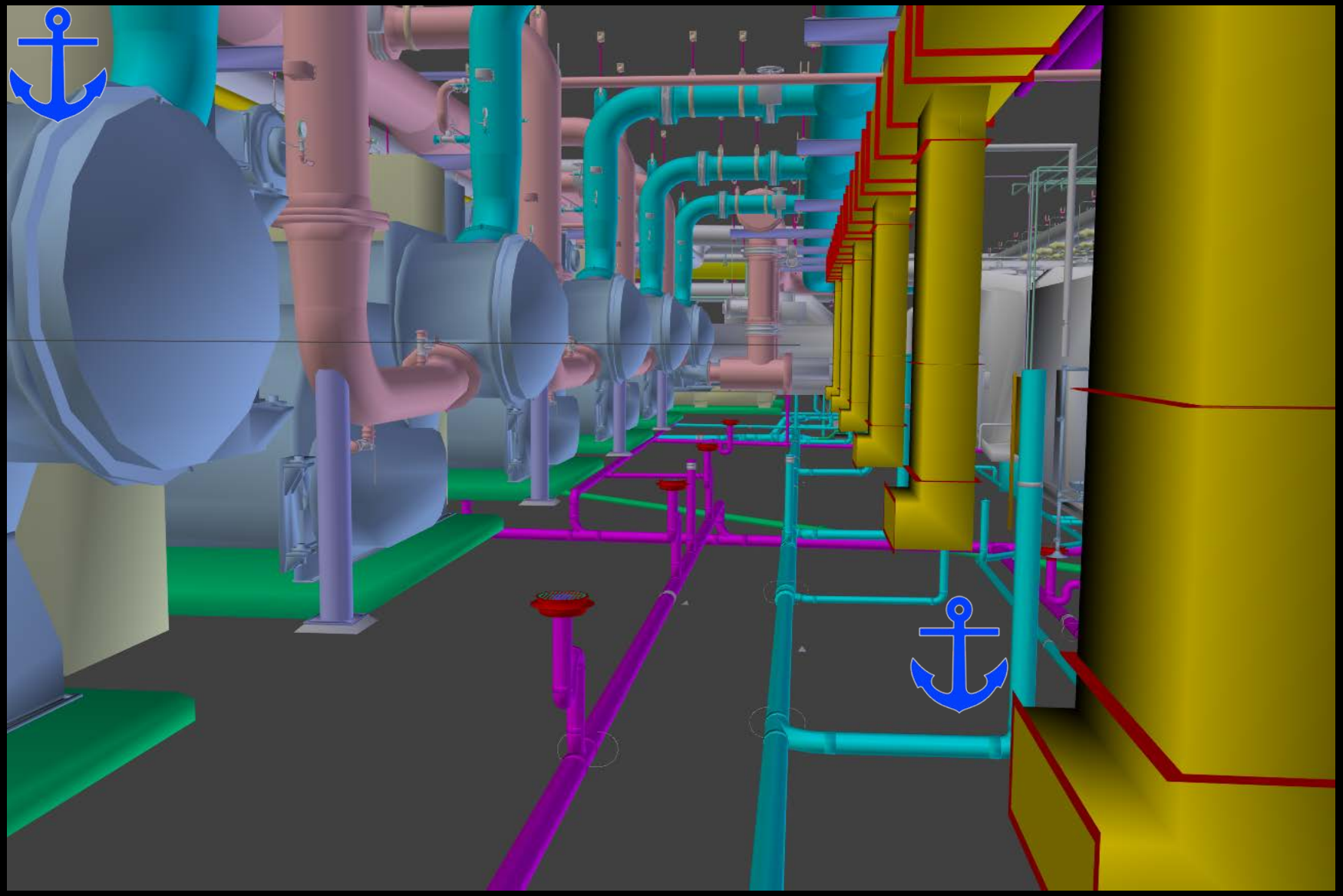
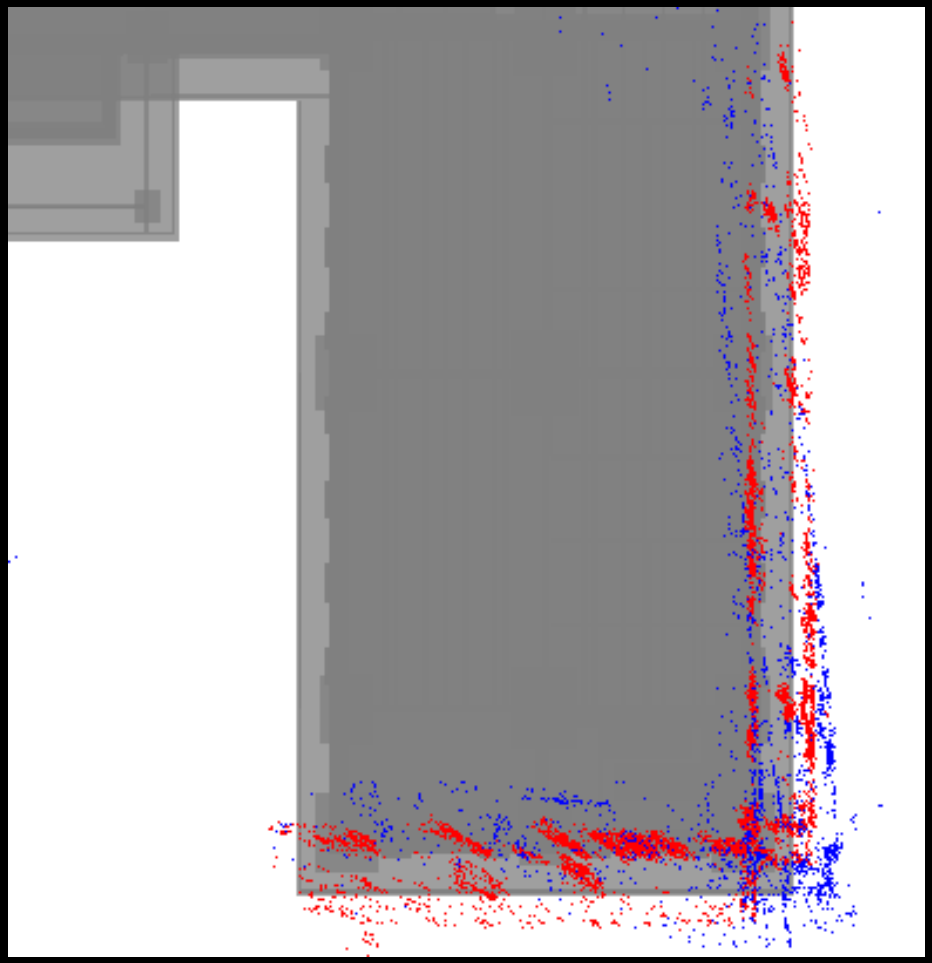


Comparisons to Existing SfM Methods

	Construction datasets		Middlebury datasets	
	Ours	Photosynth*	Ours	Photosynth*
Rotation error (degrees)	**0.74**	4.23	**2.47**	3.31
Translation error (meters)	**0.50**	2.18	**0.06**	0.19

* https://code.google.com/p/visual-experiments/

Comparisons to Existing SfM Methods



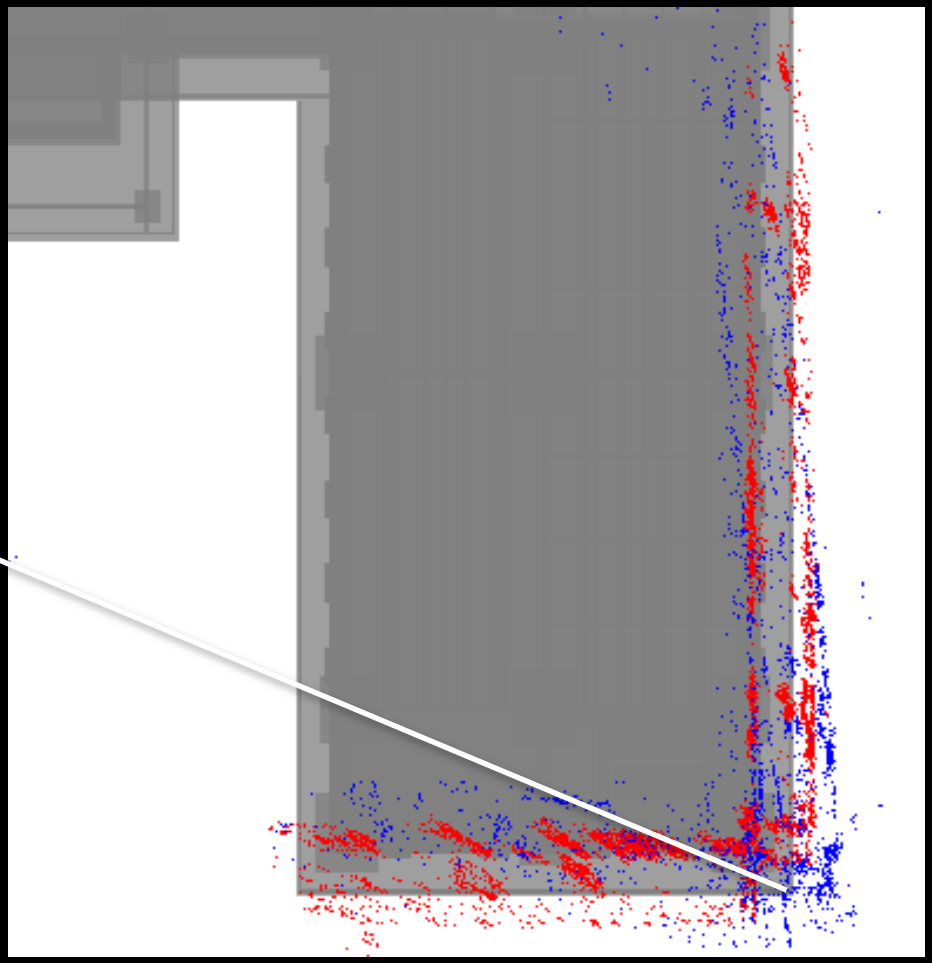
Visual SfM* reconstruction

Our reconstruction

Constraints help prevent drift

*[Wu et al. 2011, 2013]

Comparisons to Existing SfM Methods



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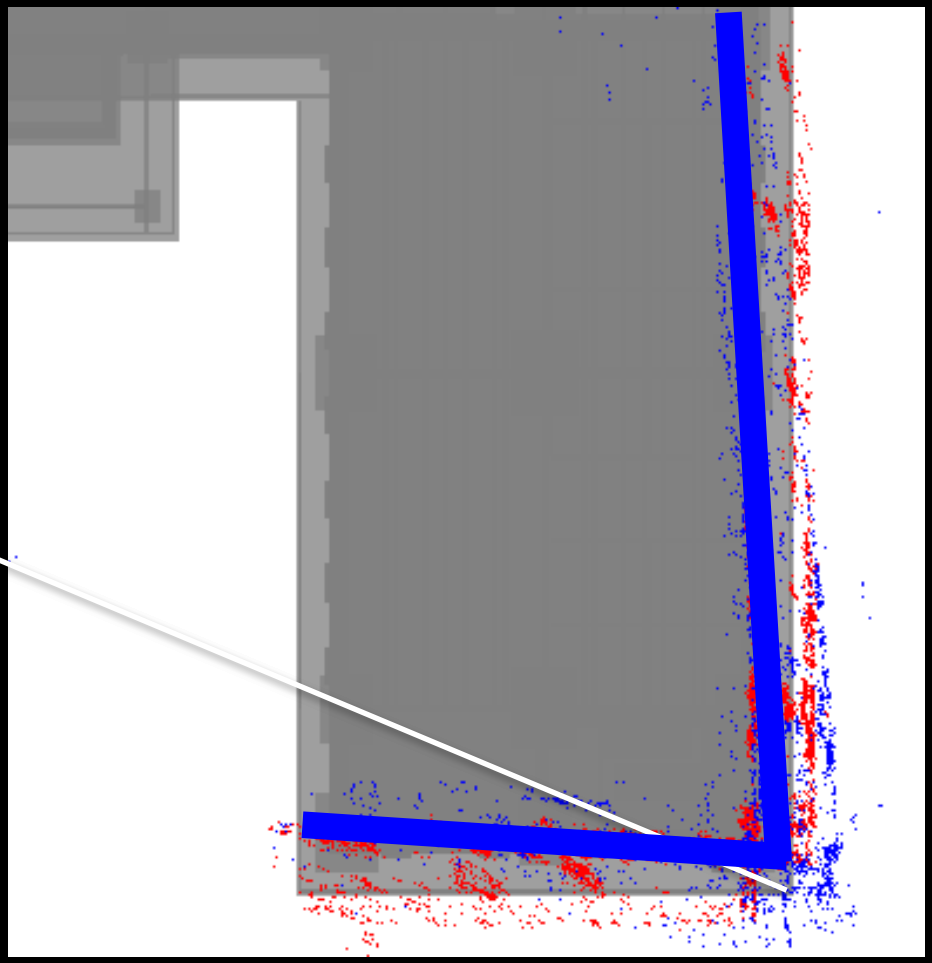

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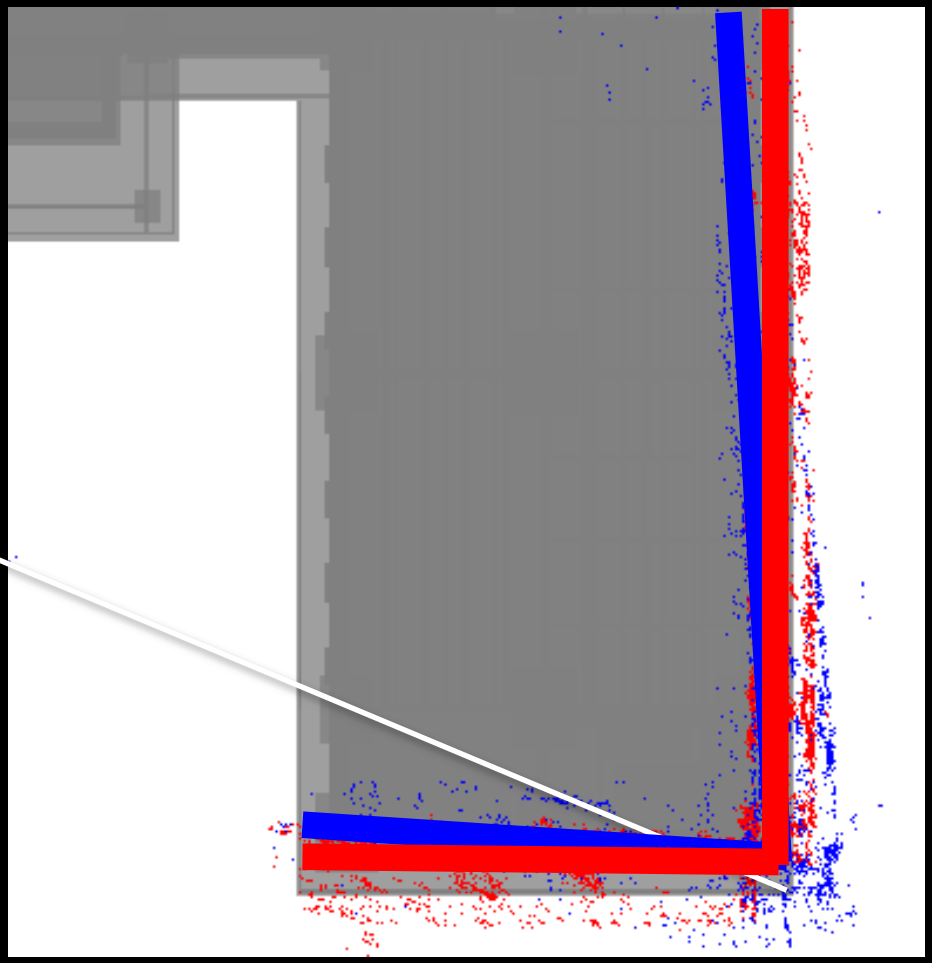

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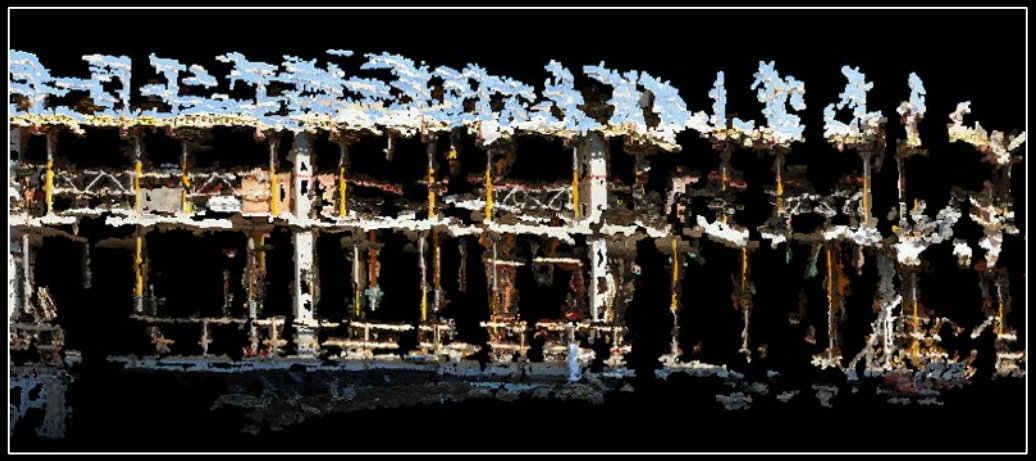

Visual SfM reconstruction

More accurate and complete reconstructions

ConstructAide Preprocessing

- Creating 4D image sequences
  - Easy if time-lapse data exists
  - Possible otherwise
- Detecting occlusions
  - Static and dynamic occlusions handled differently
- Extract rendering information from BIM

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Unordered Image Sets to Time-lapses

Unordered Image Sets to Time-lapses

Before time-lapse conversion

Unordered Image Sets to Time-lapses

Unordered Image Sets to Time-lapses

Before time-lapse conversion

Unordered Image Sets to Time-lapses

After time-lapse conversion

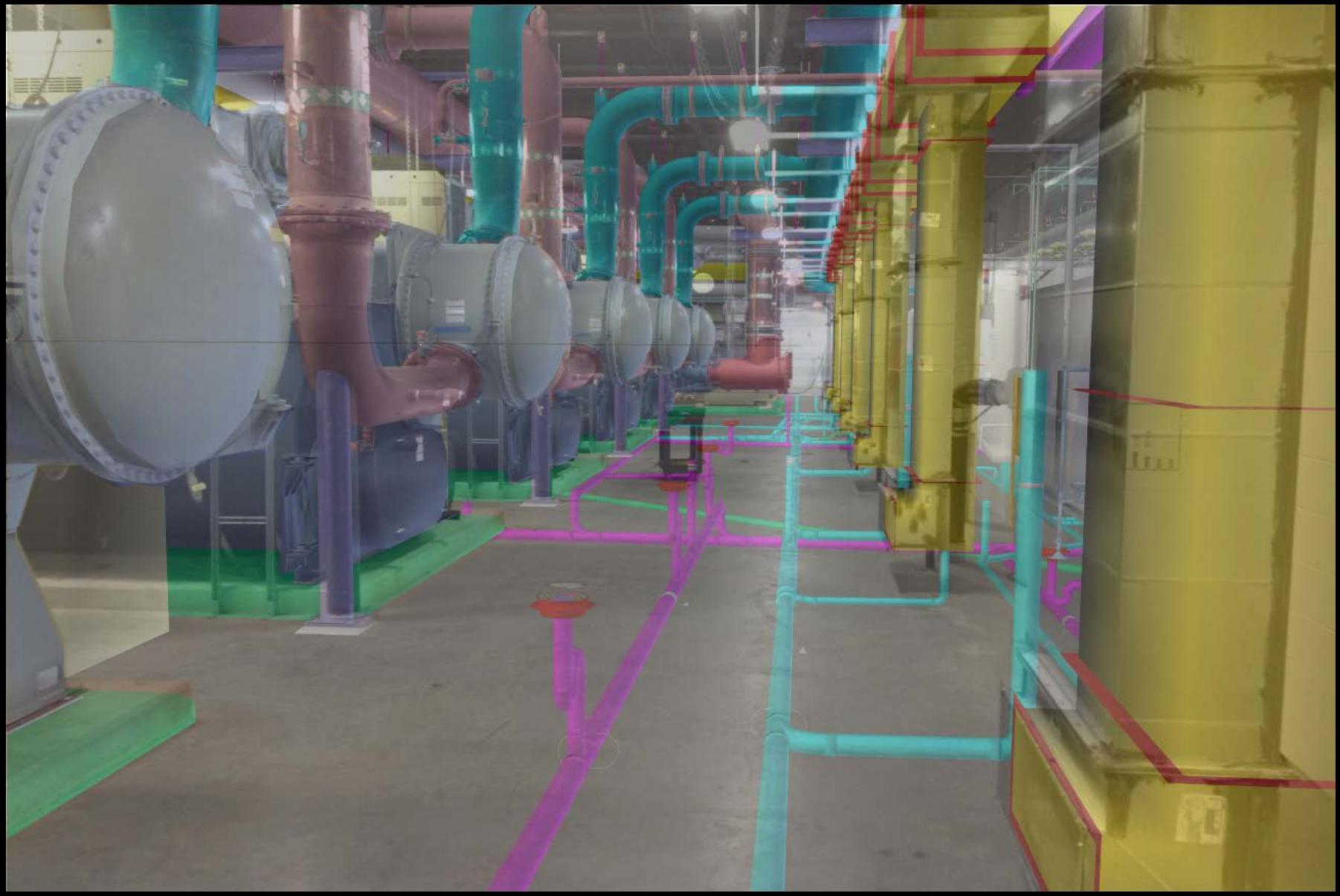
Unordered Image Sets to Time-lapses

Unordered Image Sets to Time-lapses

Unordered Image Sets to Time-lapses

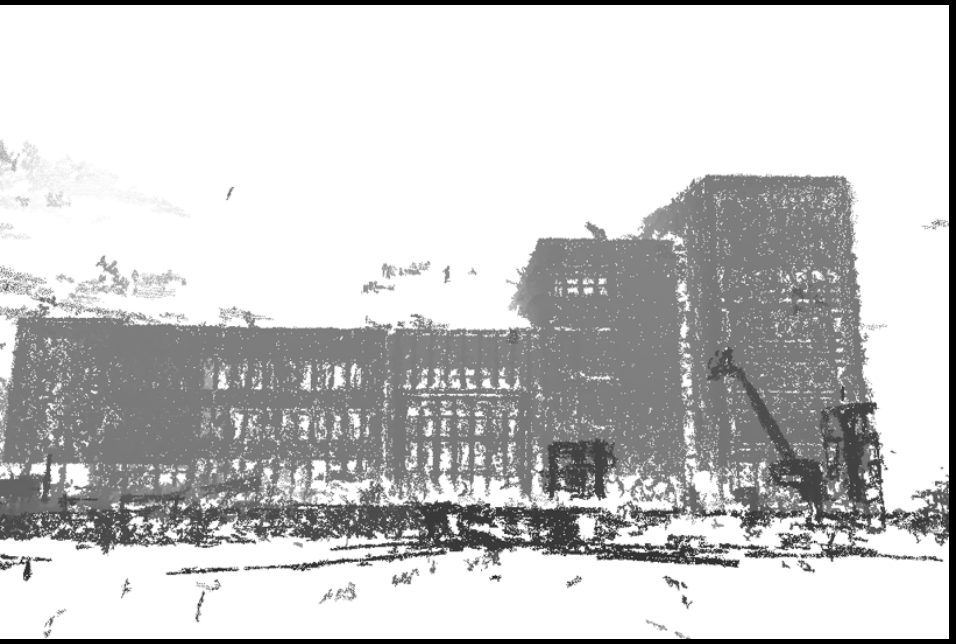
Detecting Static Occlusions

Detecting Static Occlusions

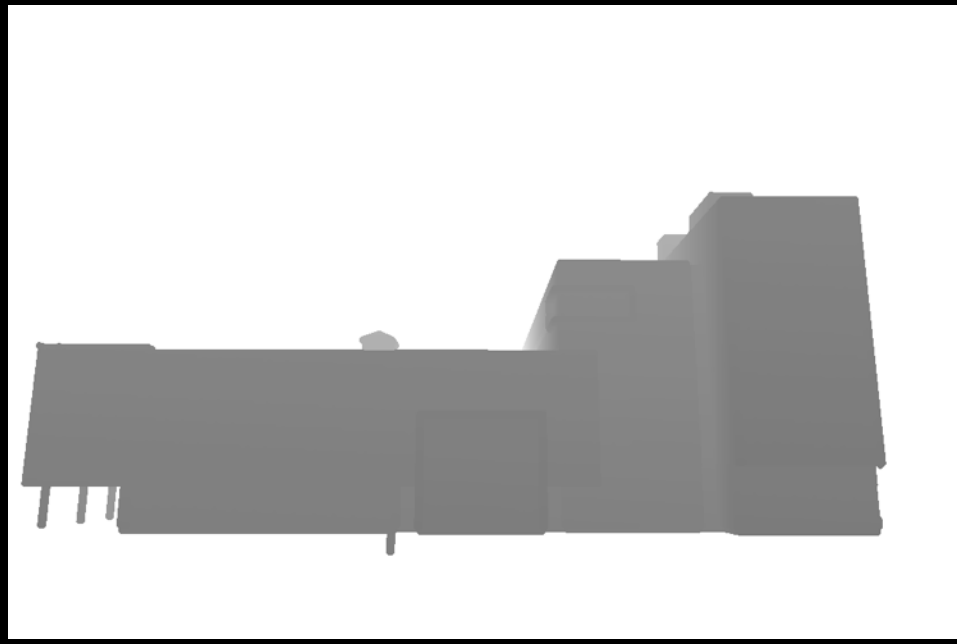


Detecting Static Occlusions

SfM point cloud



Mesh



1) Compare mesh and point cloud geometry
2) Keep points that deviate from mesh values
3) Smooth remaining points based on image

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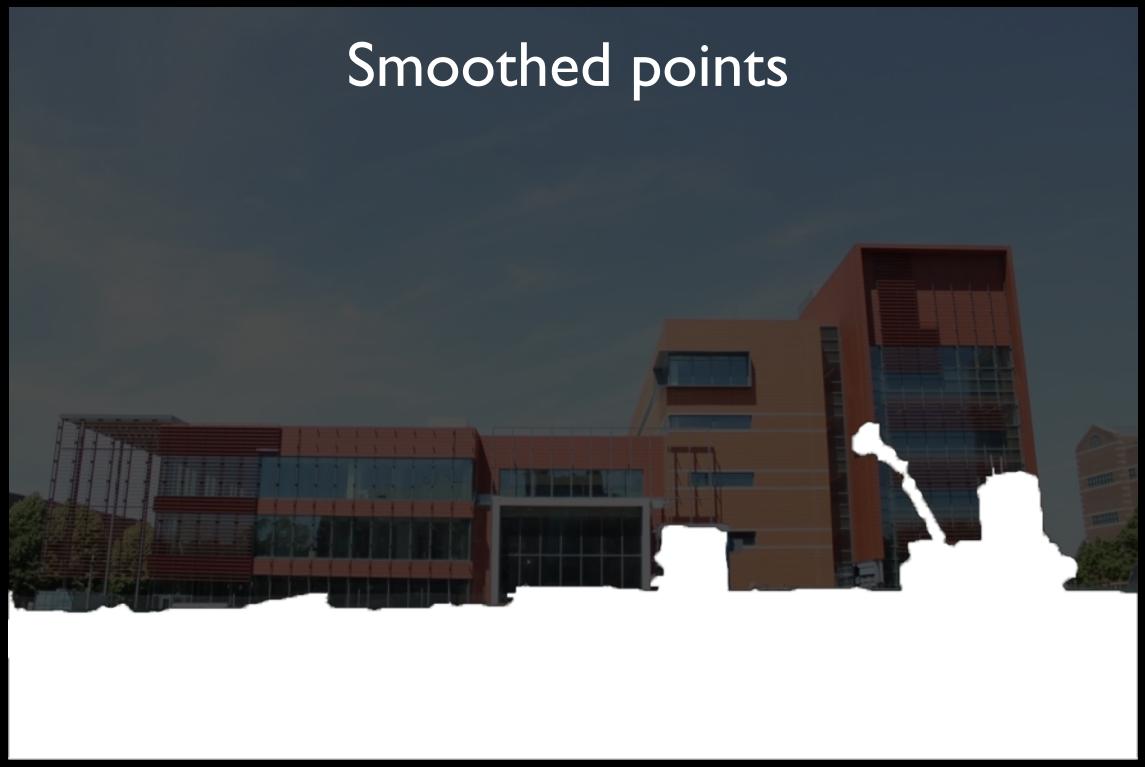

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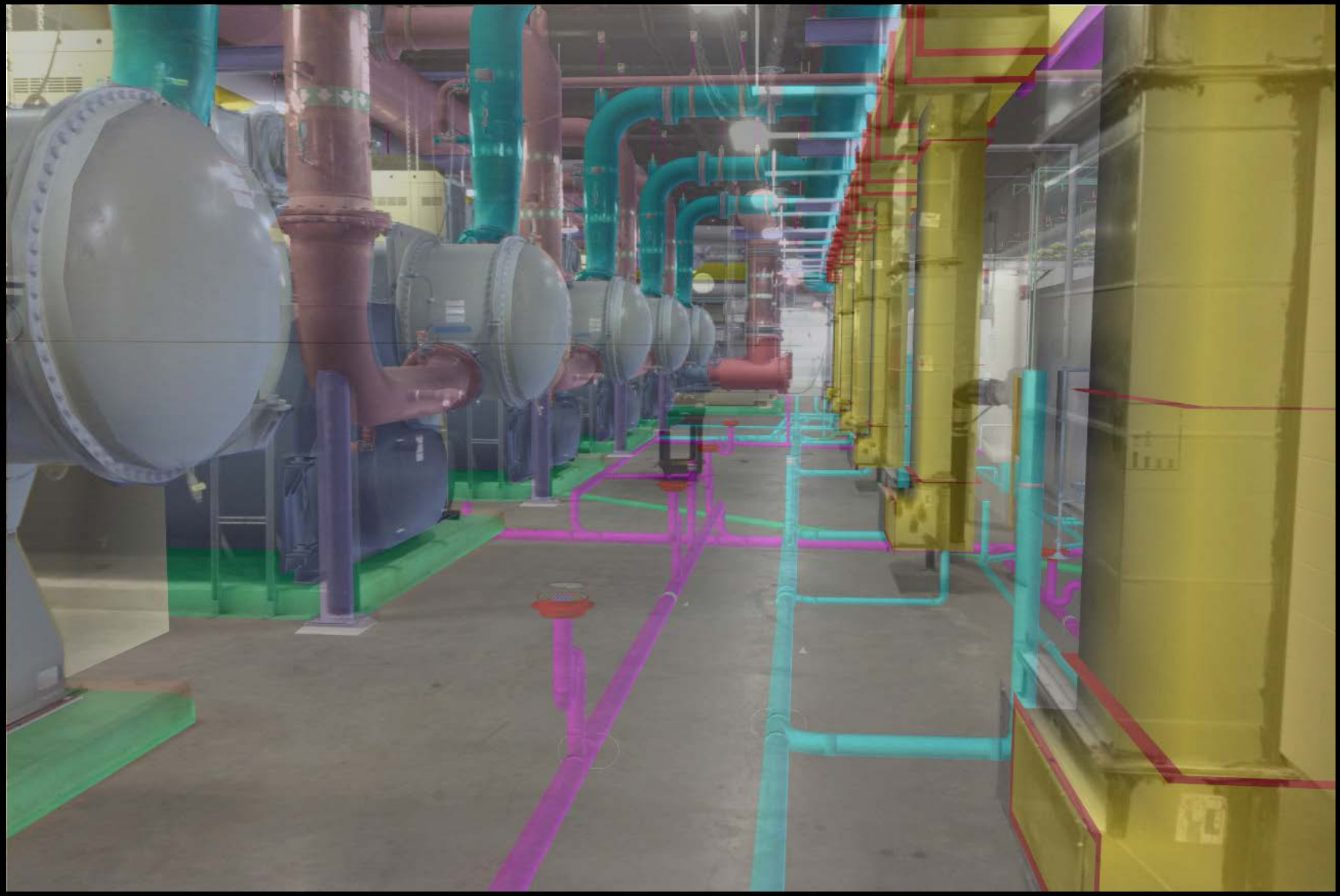

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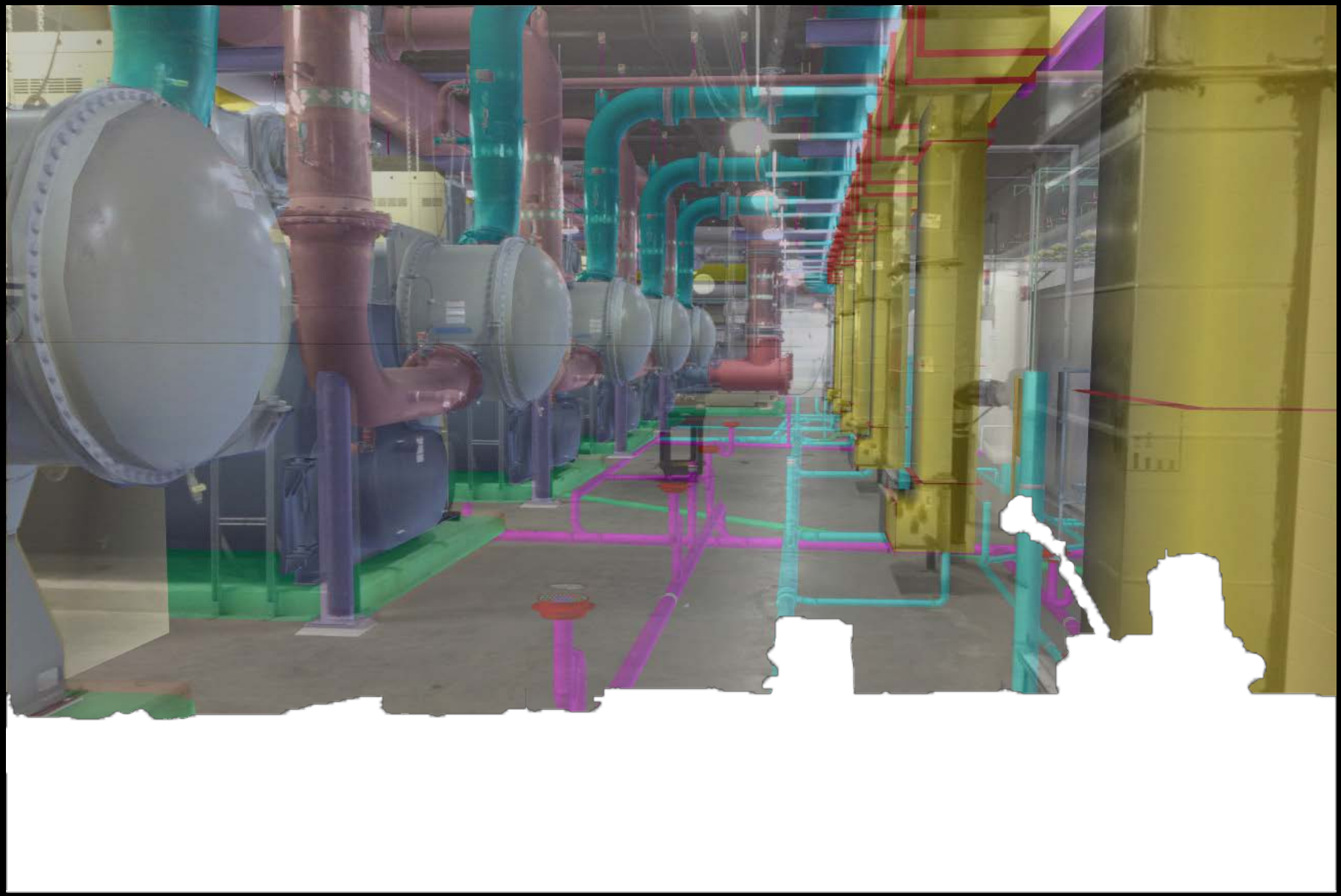


Detecting Static Occlusions

Detecting Dynamic Occlusions

Input A

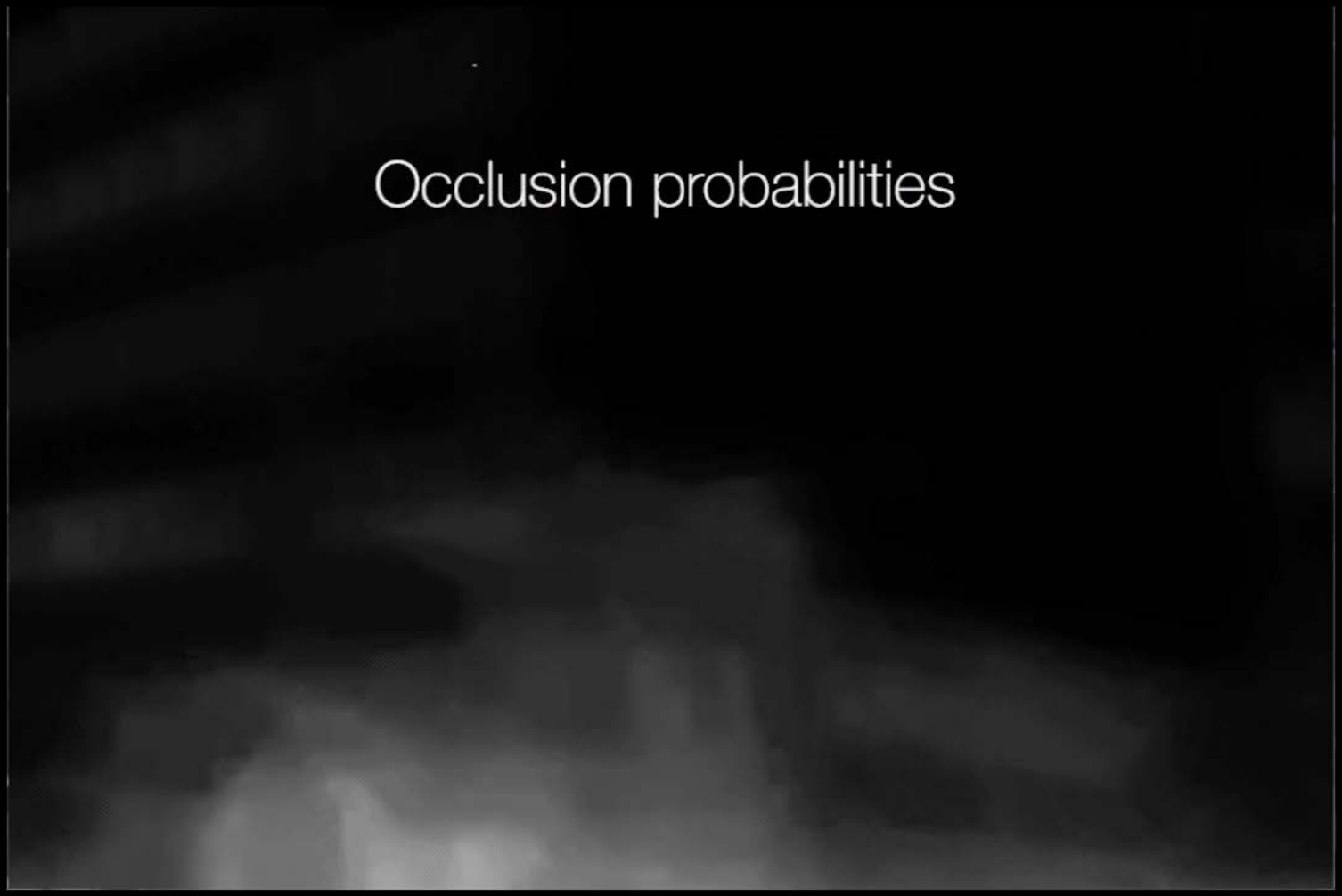
Input B

Detecting Dynamic Occlusions

Input A

Aligned Input B

Detecting Dynamic Occlusions



Detecting Dynamic Occlusions

Detecting Dynamic Occlusions

Detecting Dynamic Occlusions

Putting BIM to Work

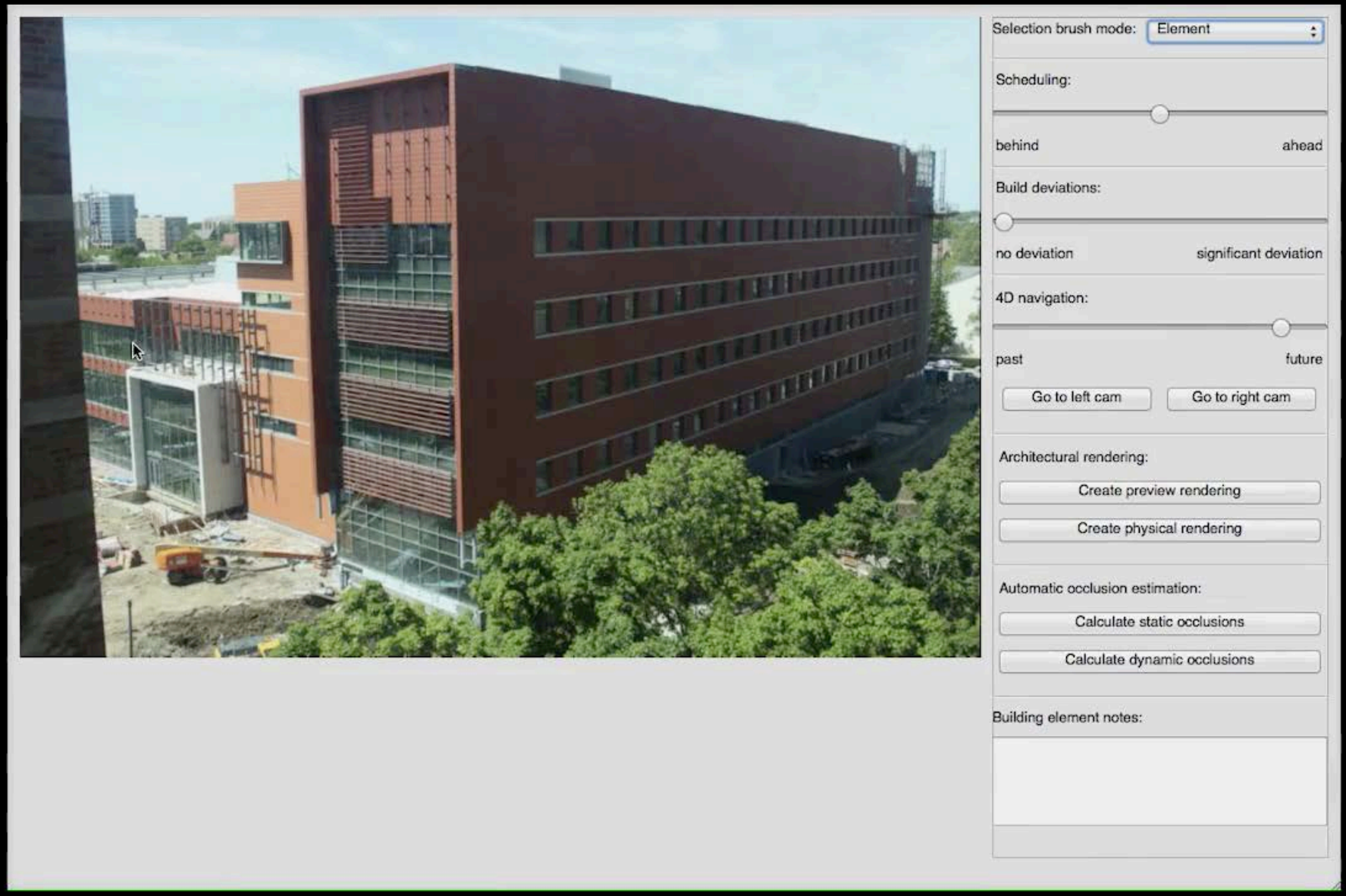
- BIM data contains
  - Per-element material information
  - GPS and timing data
- From this we synthesize
  - Mesh component hierarchy for user selection
  - Material models for off-the-shelf renderers
  - Lighting information

Selection Tools

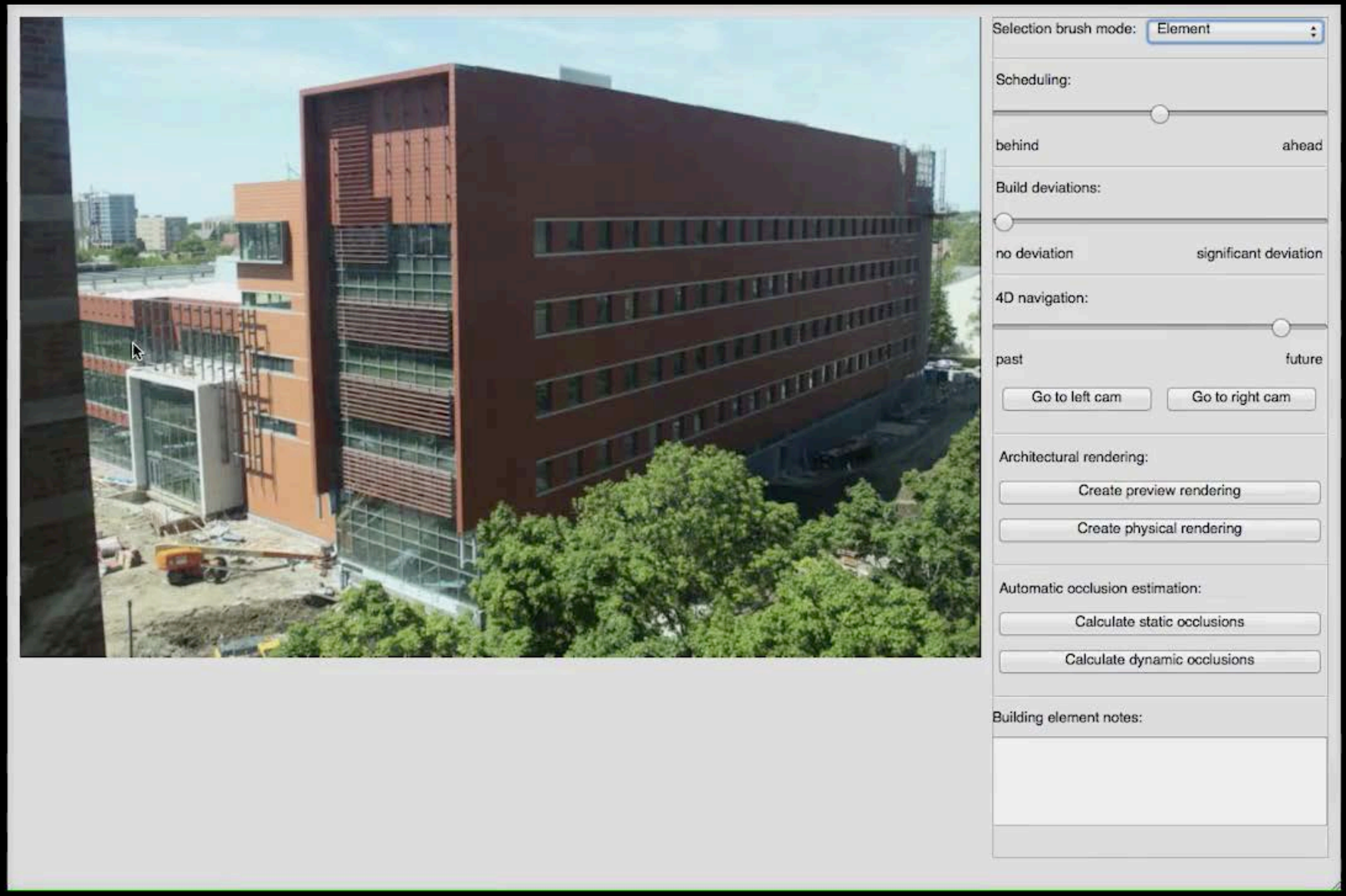
Selection Tools

Selection Tools

Performance Monitoring



Performance Monitoring



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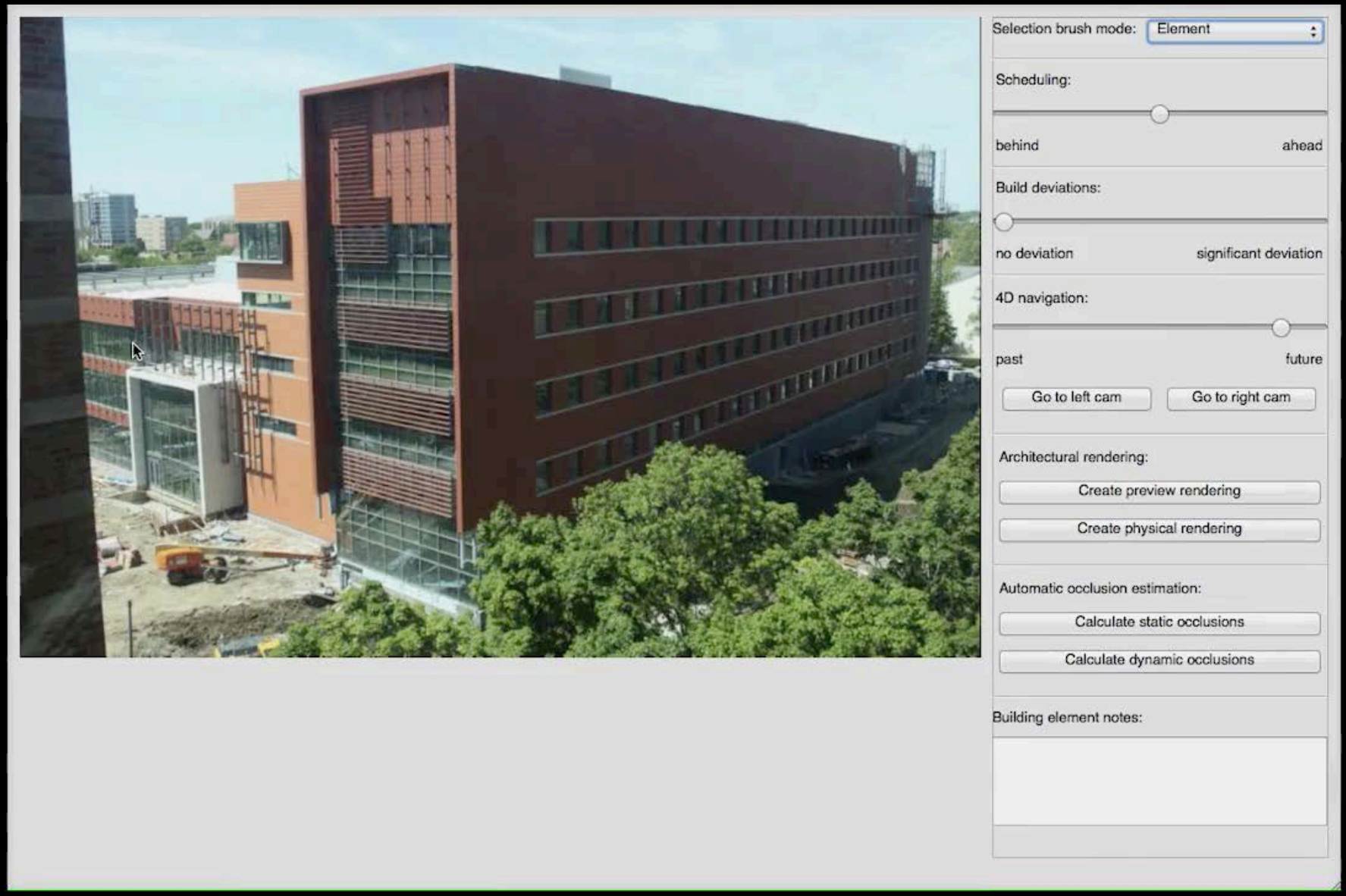
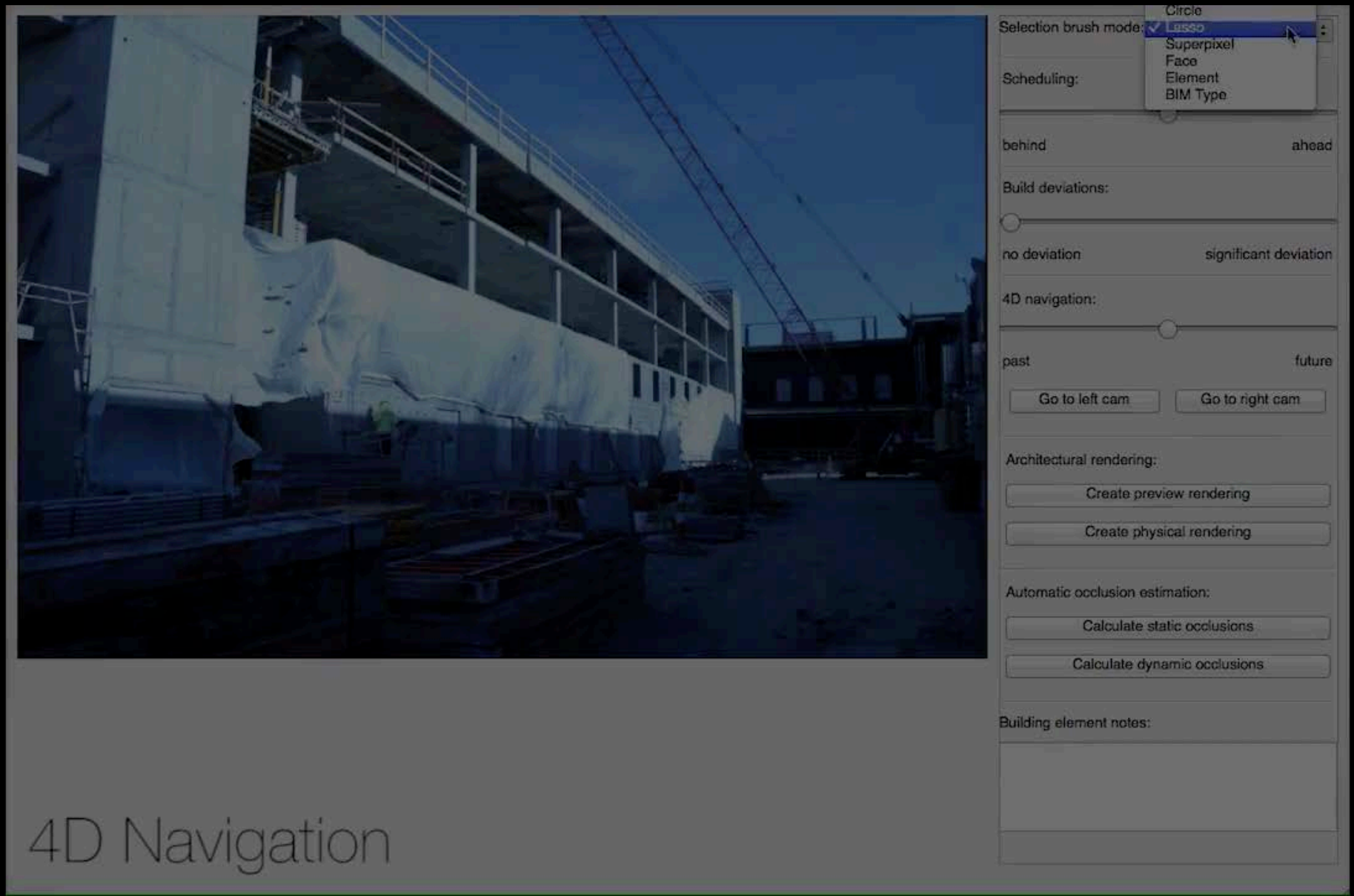


Querying Previous/Future Information



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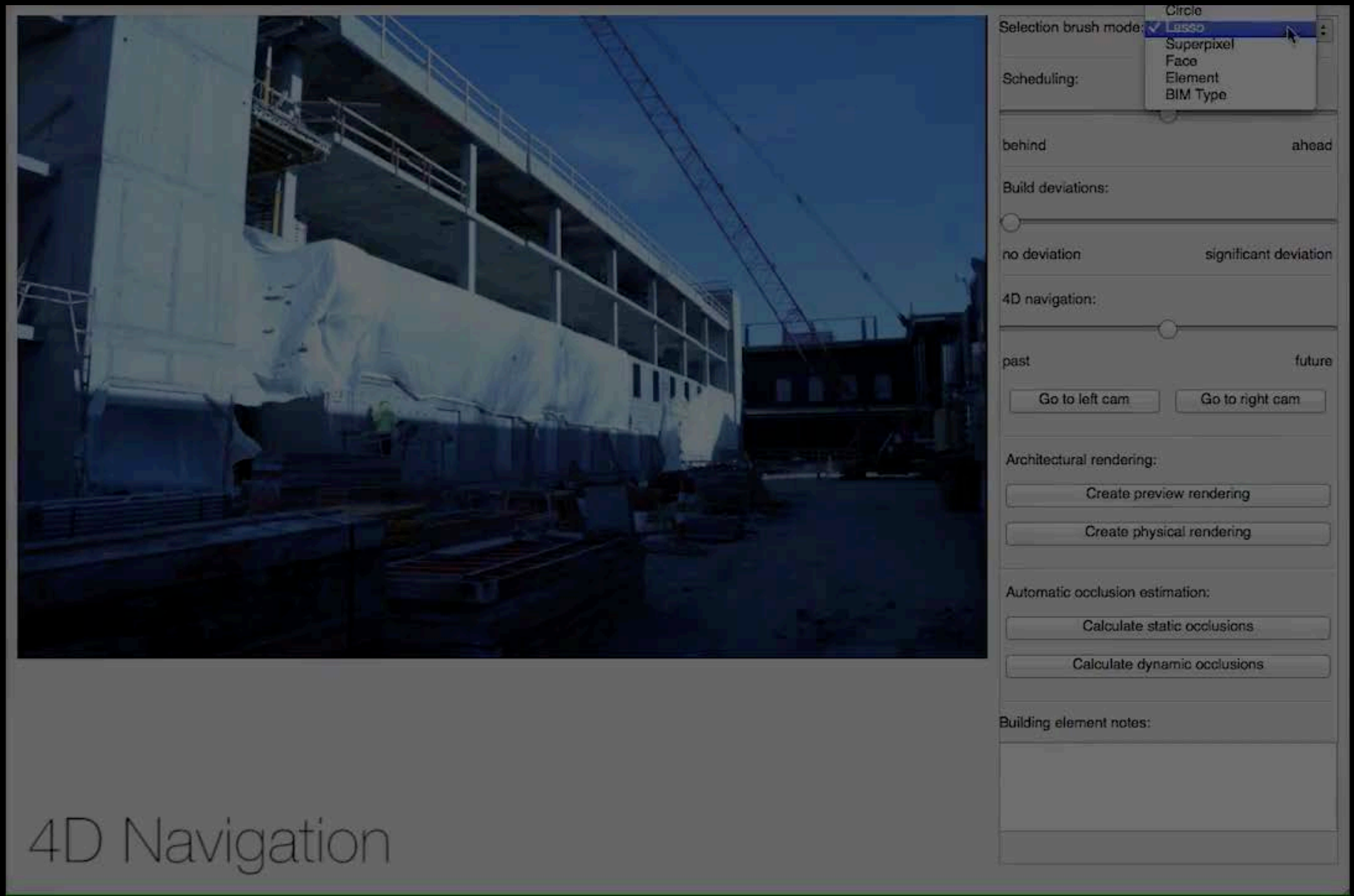

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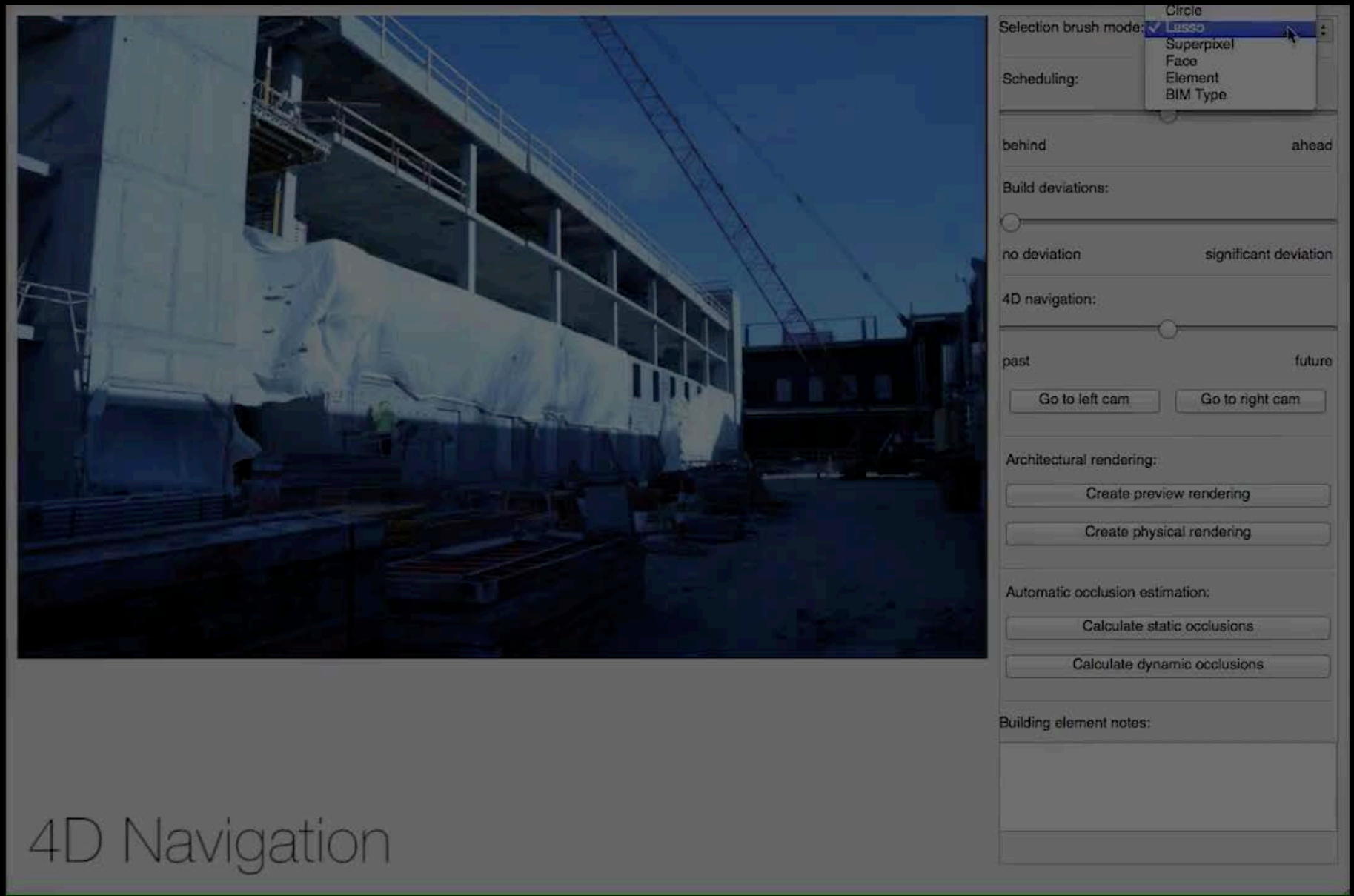

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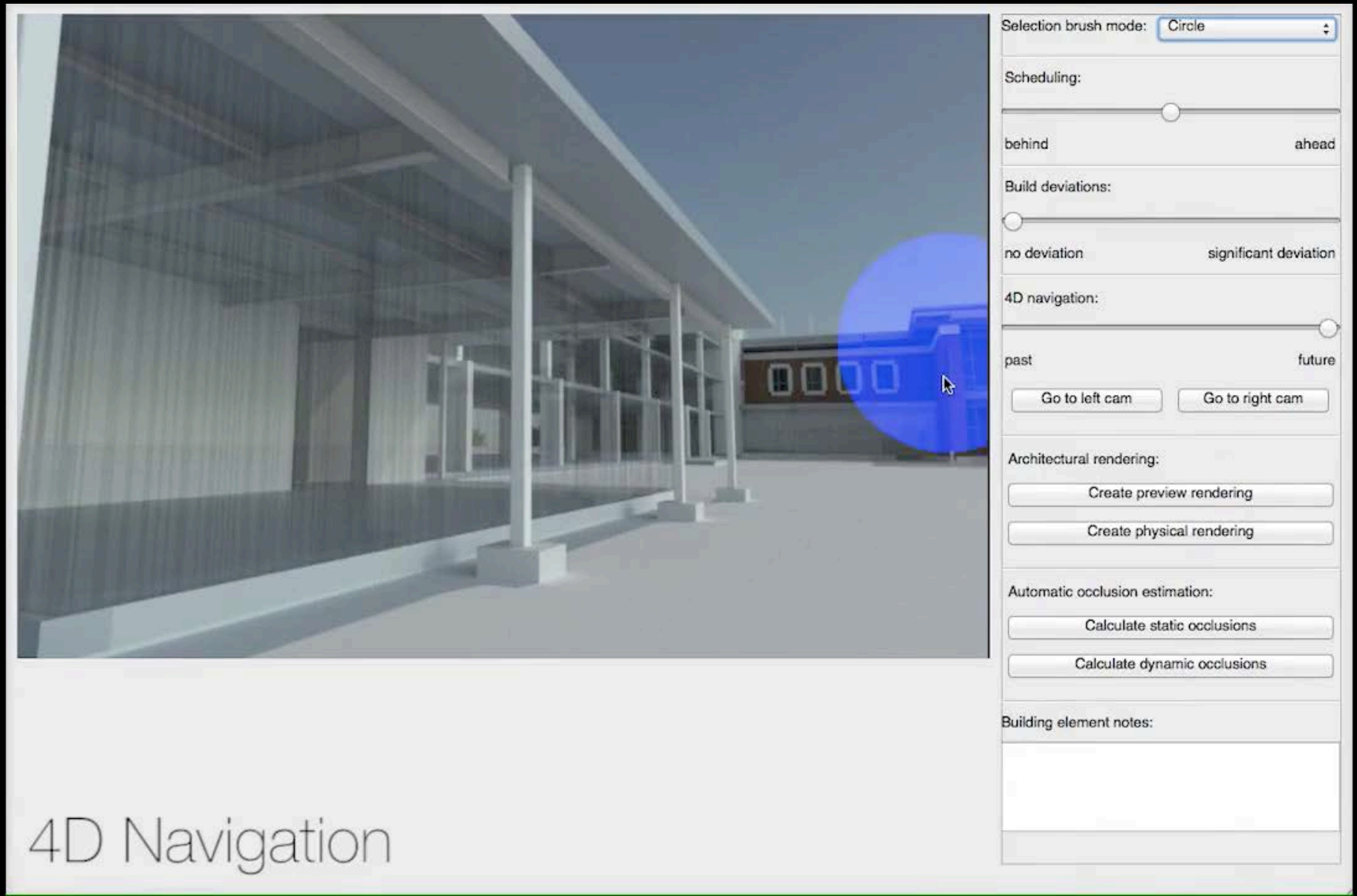

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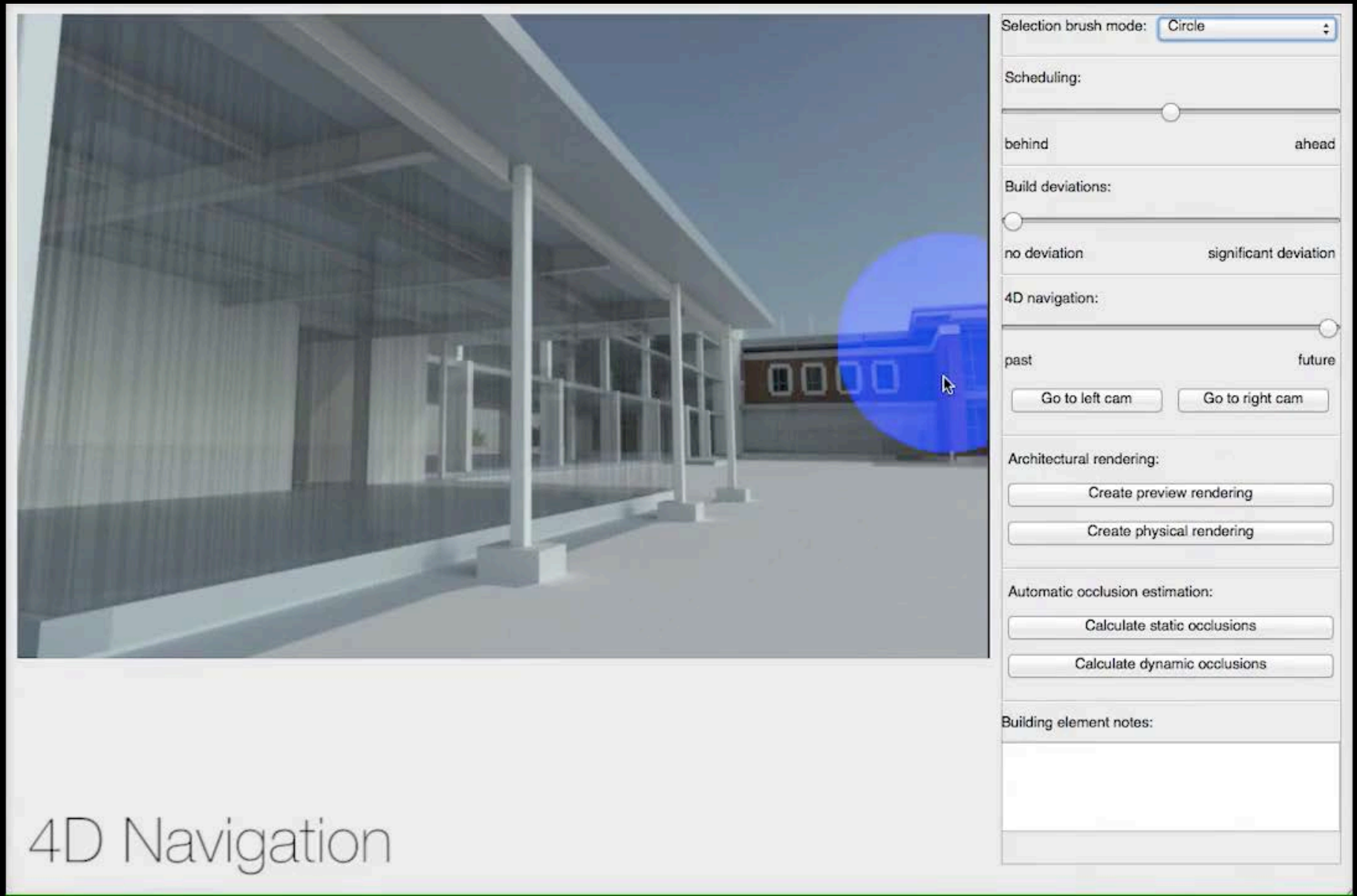

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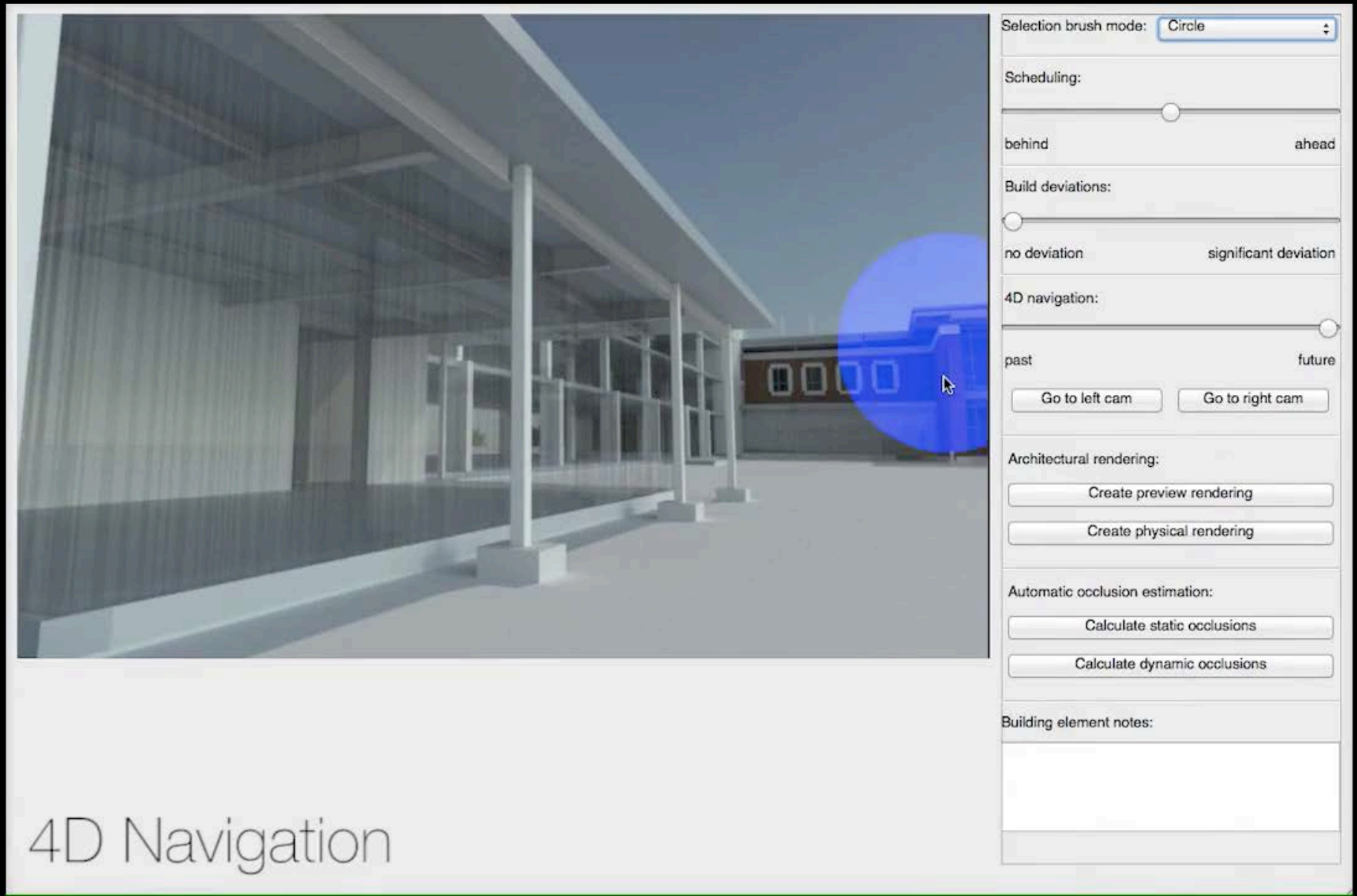

Modifying Occluding Segments

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Putting BIM to Work

- BIM data contains
  - Per-element material information
  - GPS and timing data
- From this we synthesize
  - Mesh component hierarchy for user selection
  - Material models for off-the-shelf renderers
  - Lighting information

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Architectural Visualization

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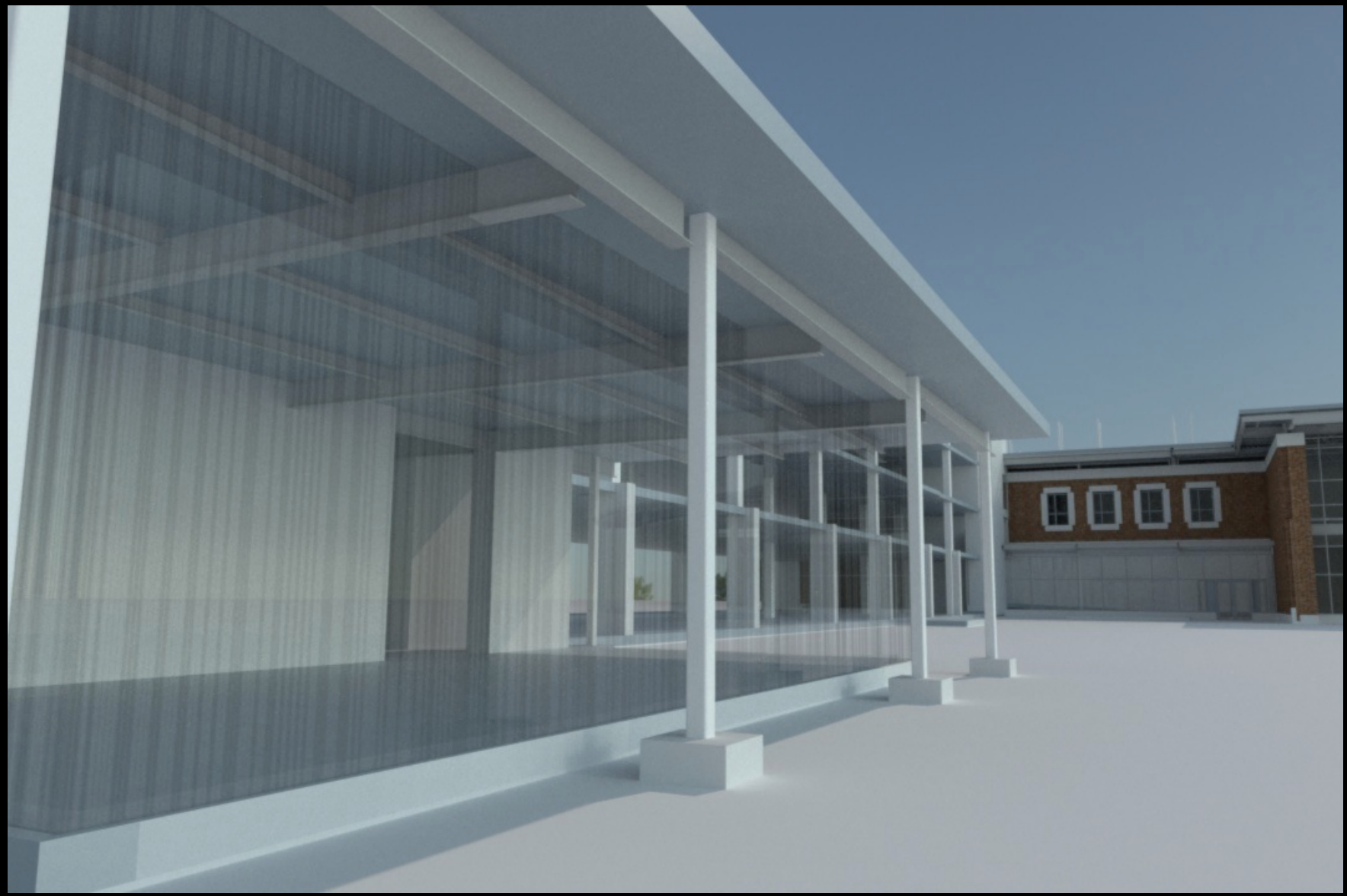

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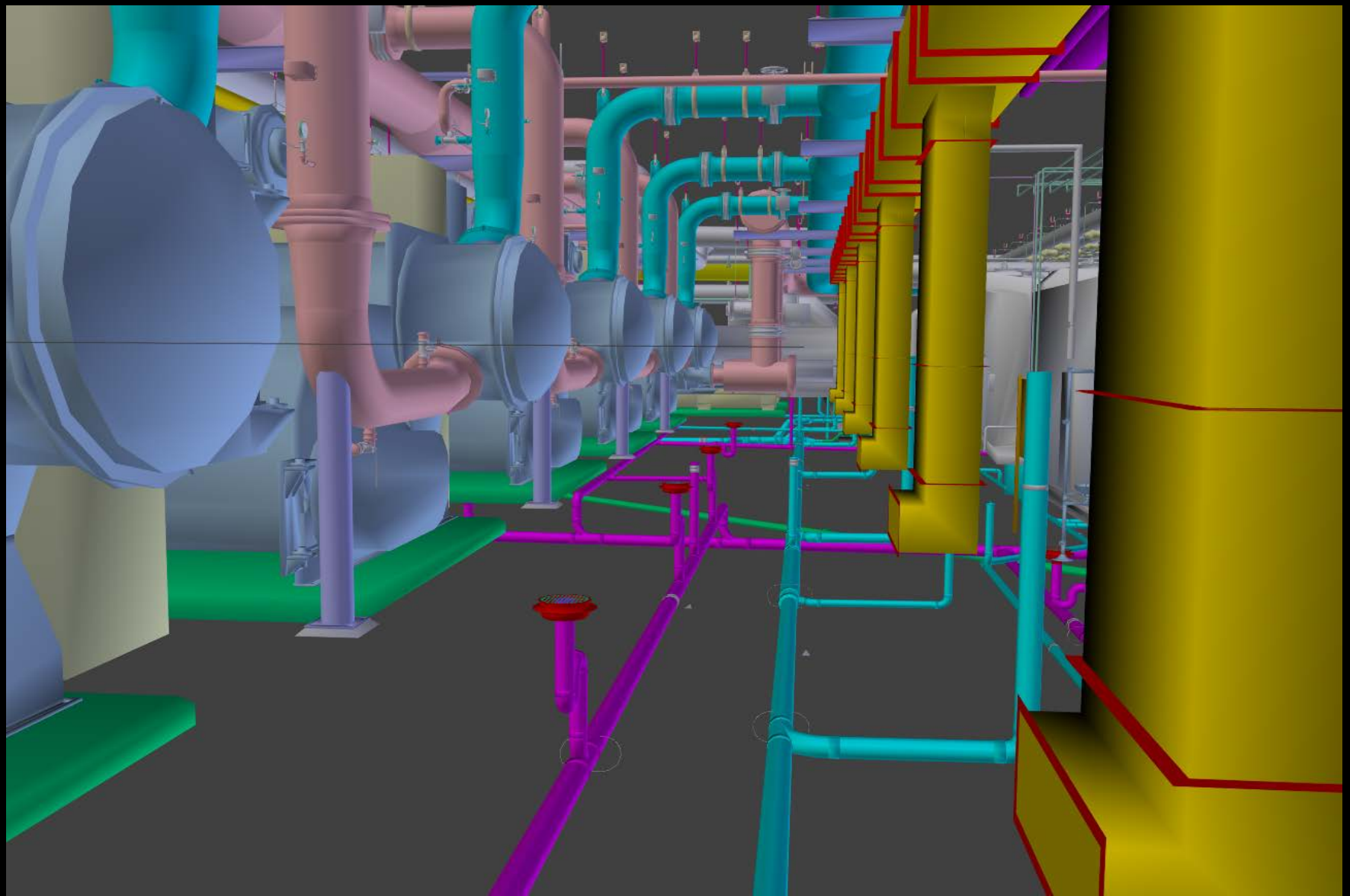

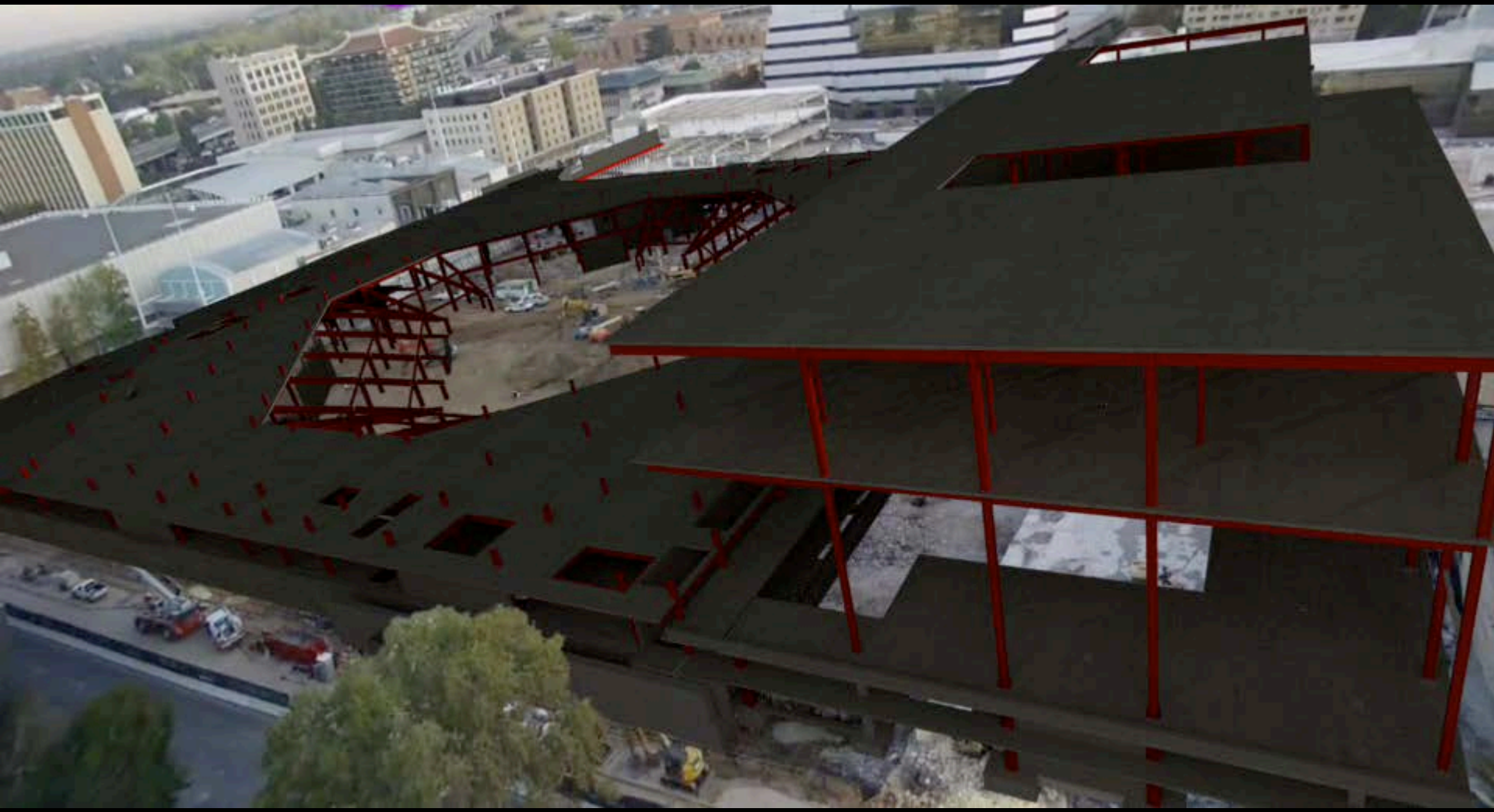

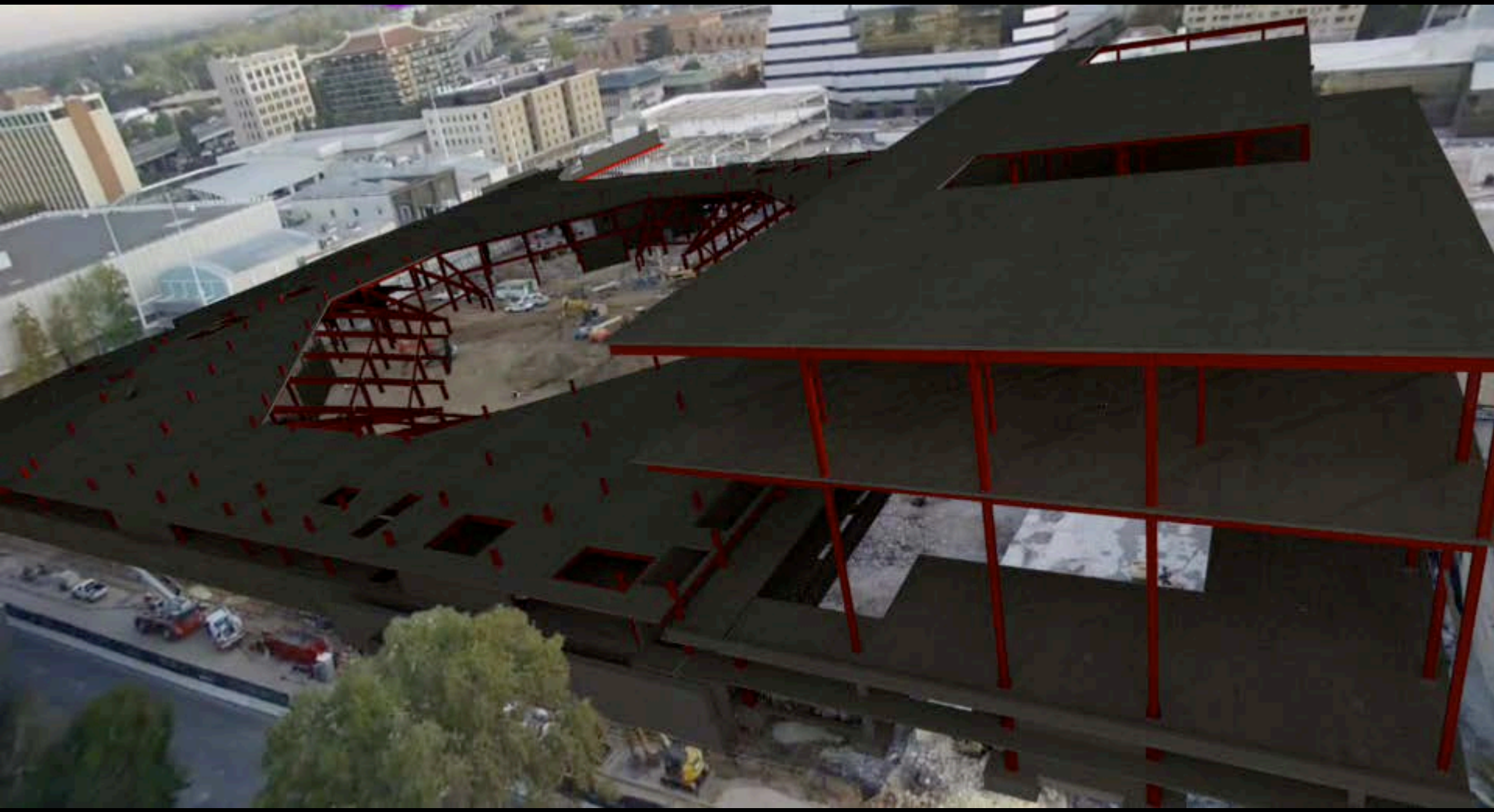

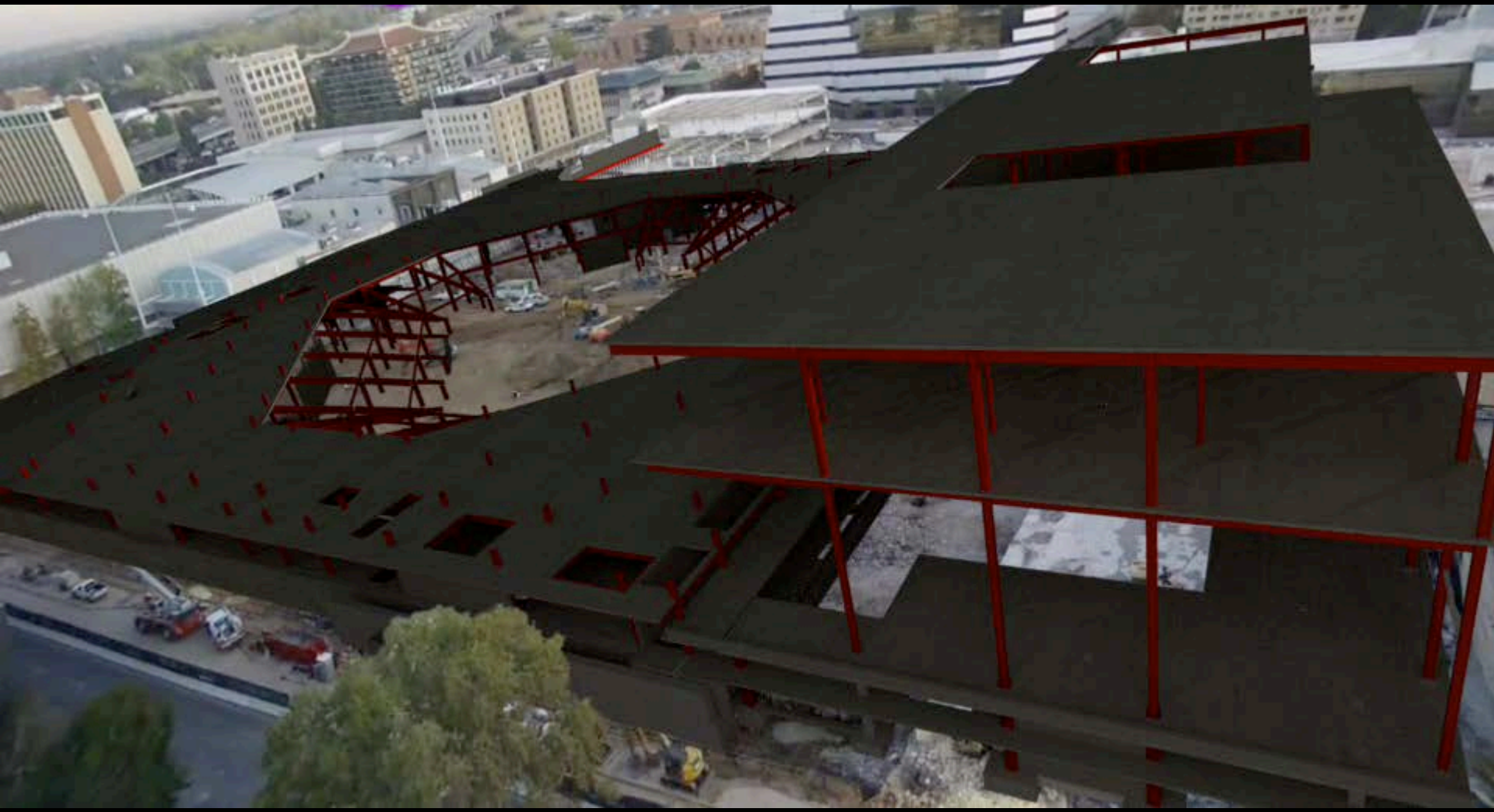

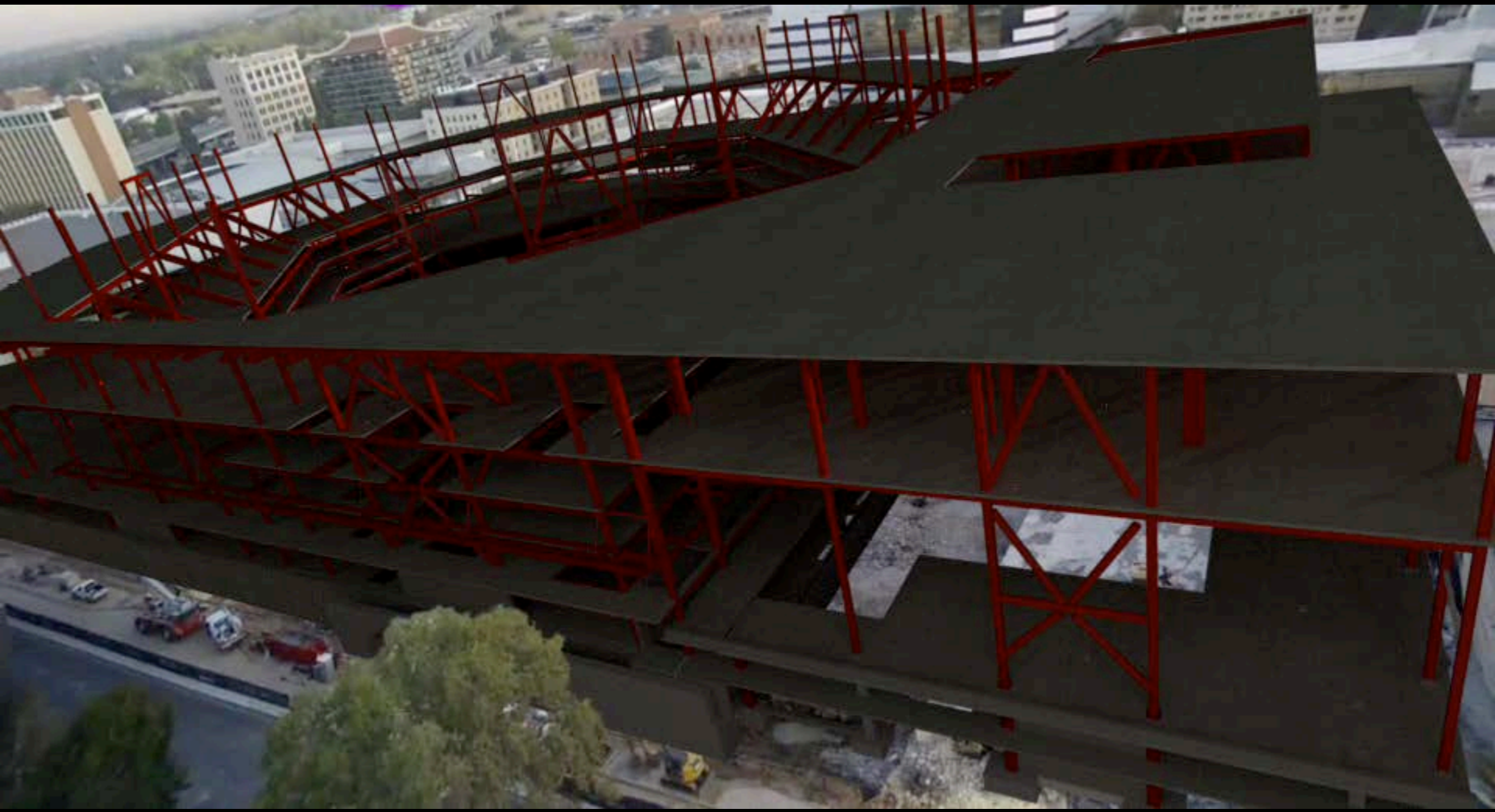

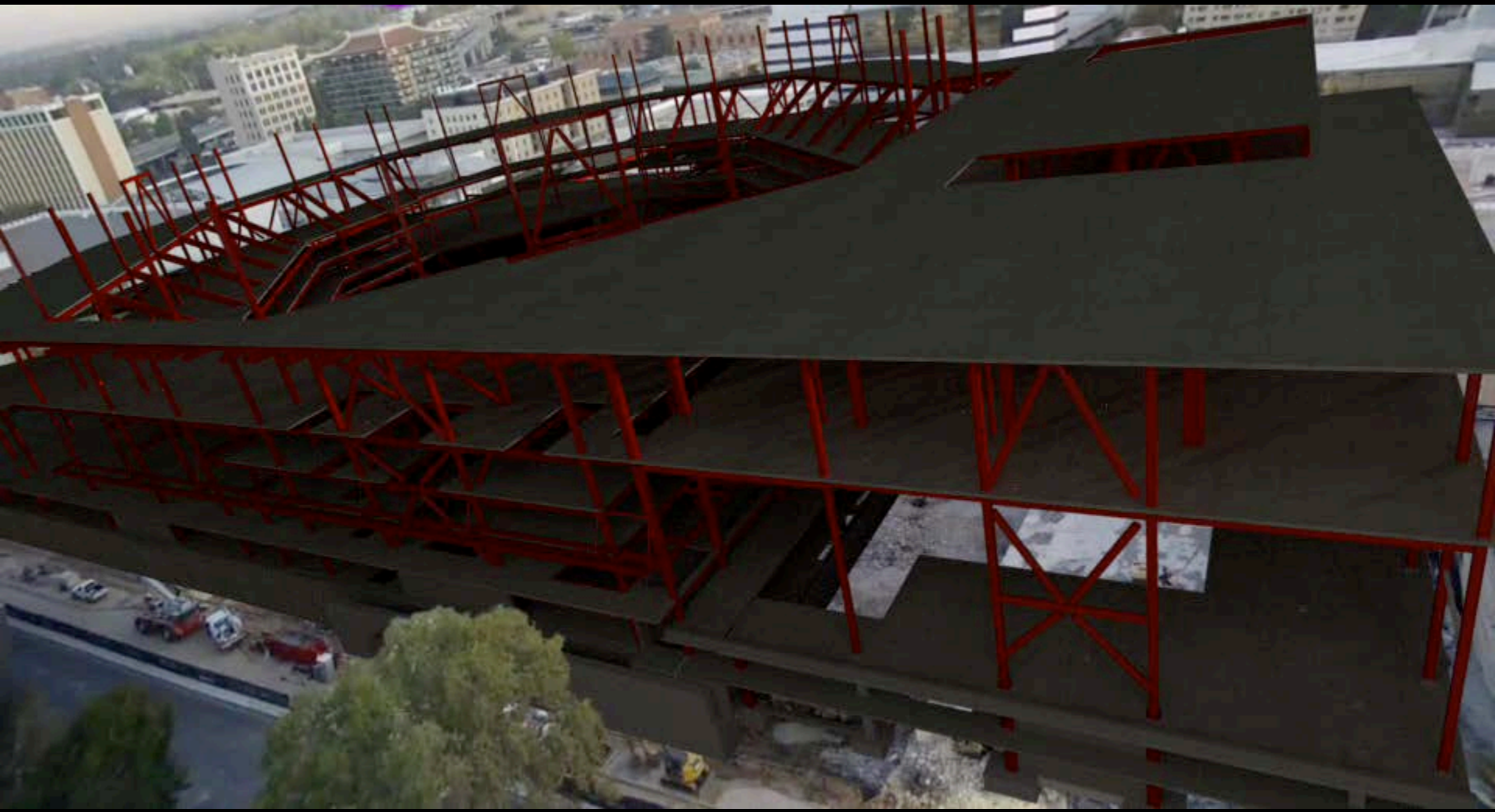

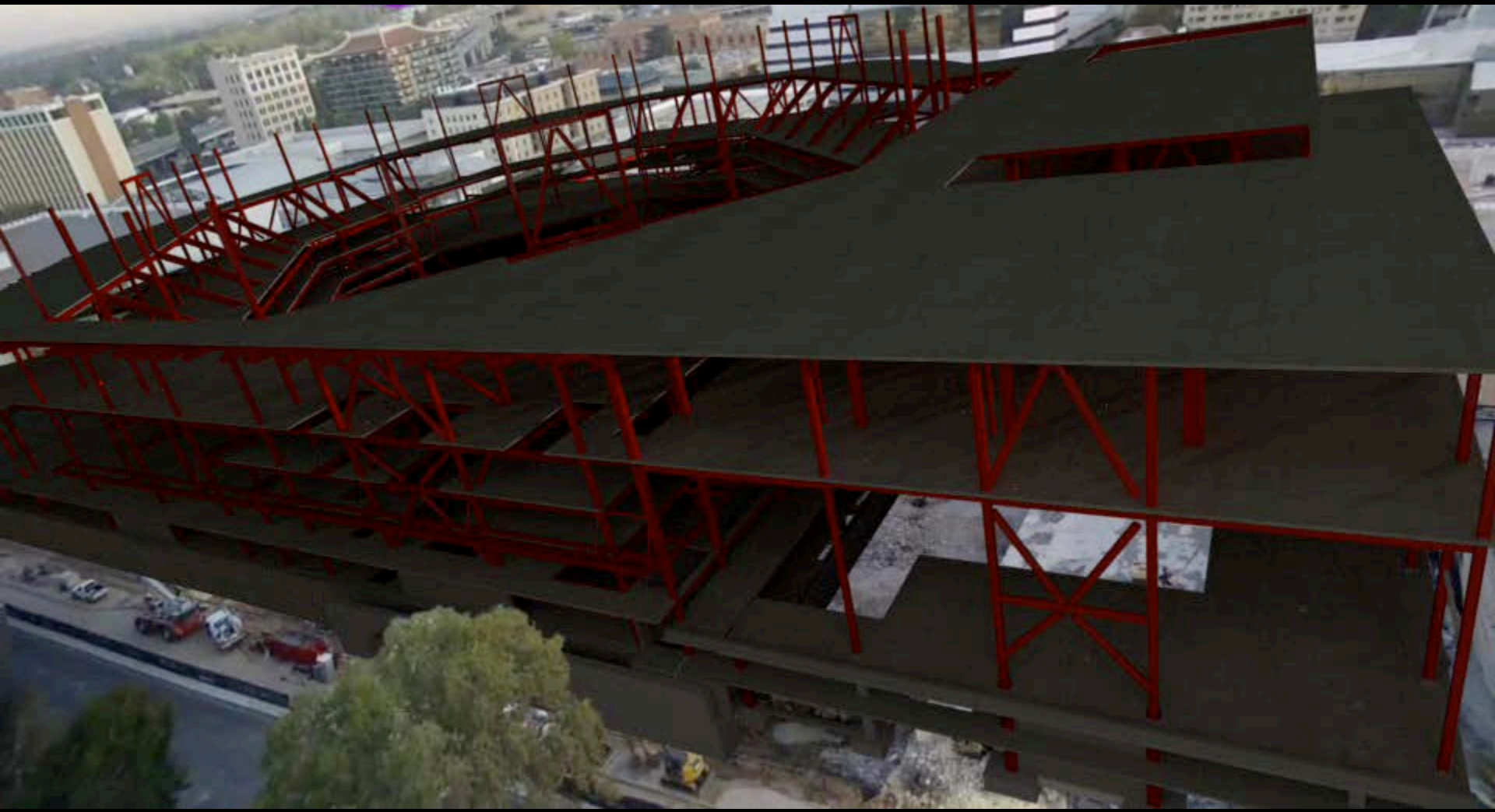

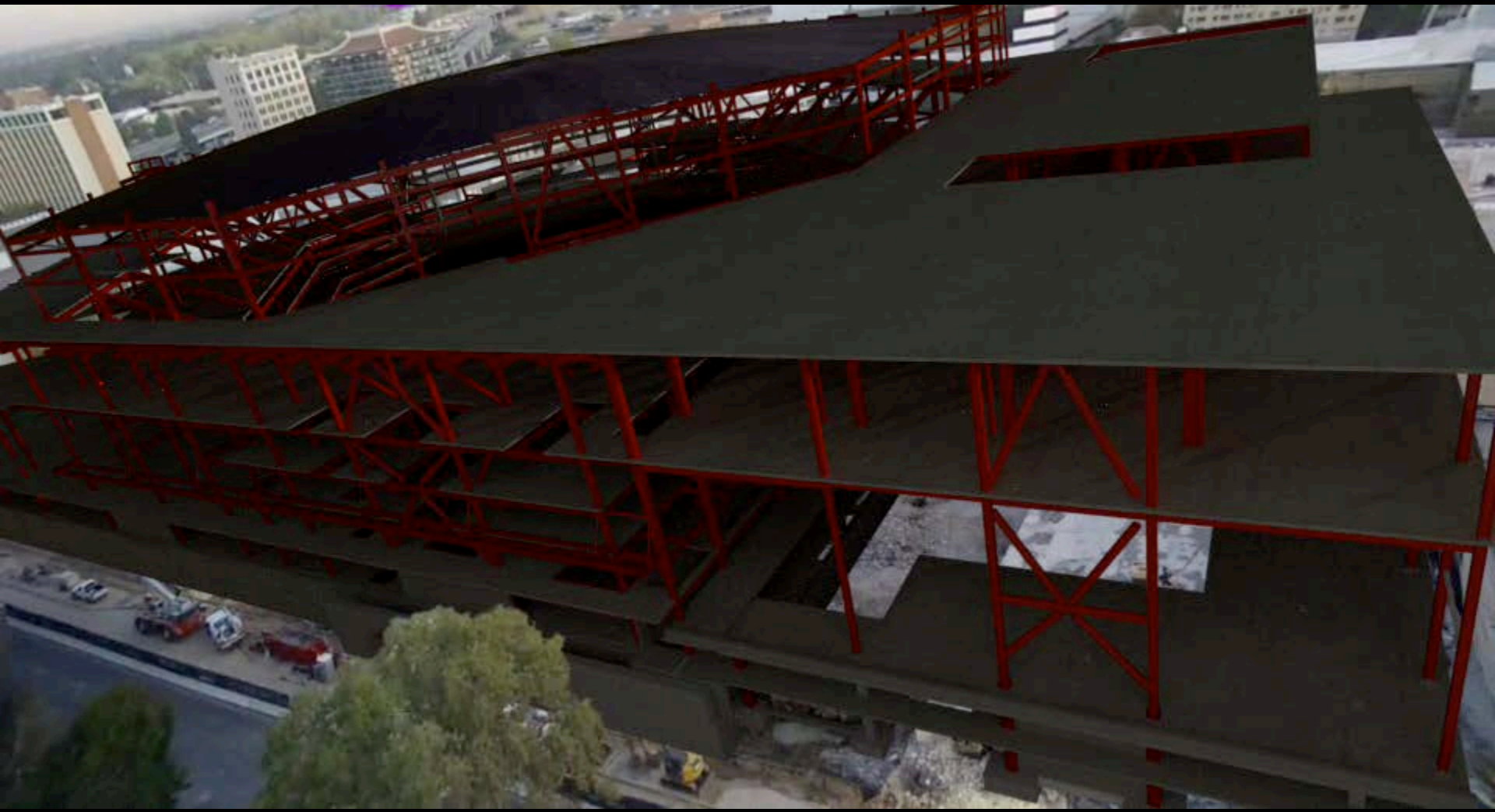

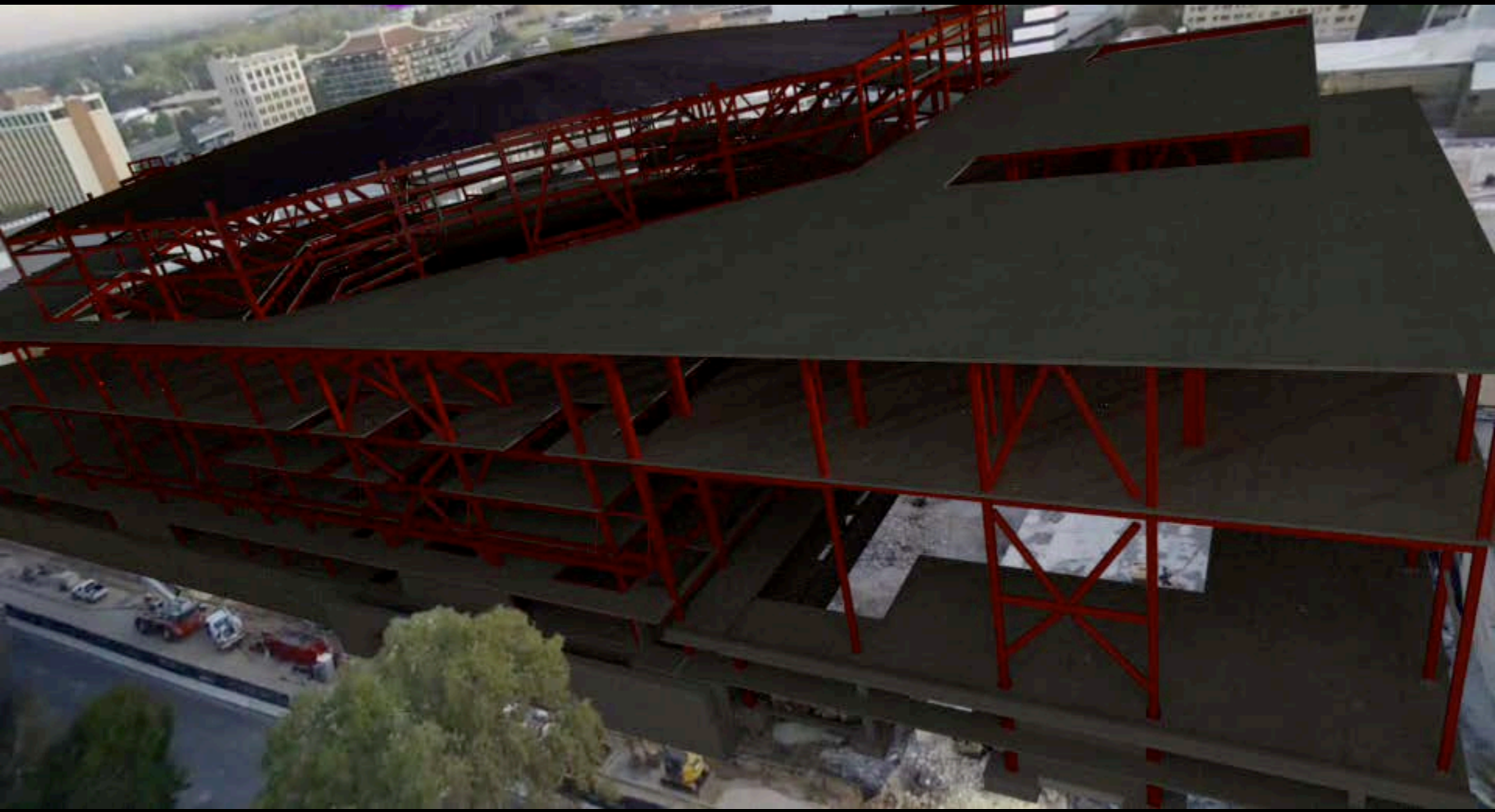

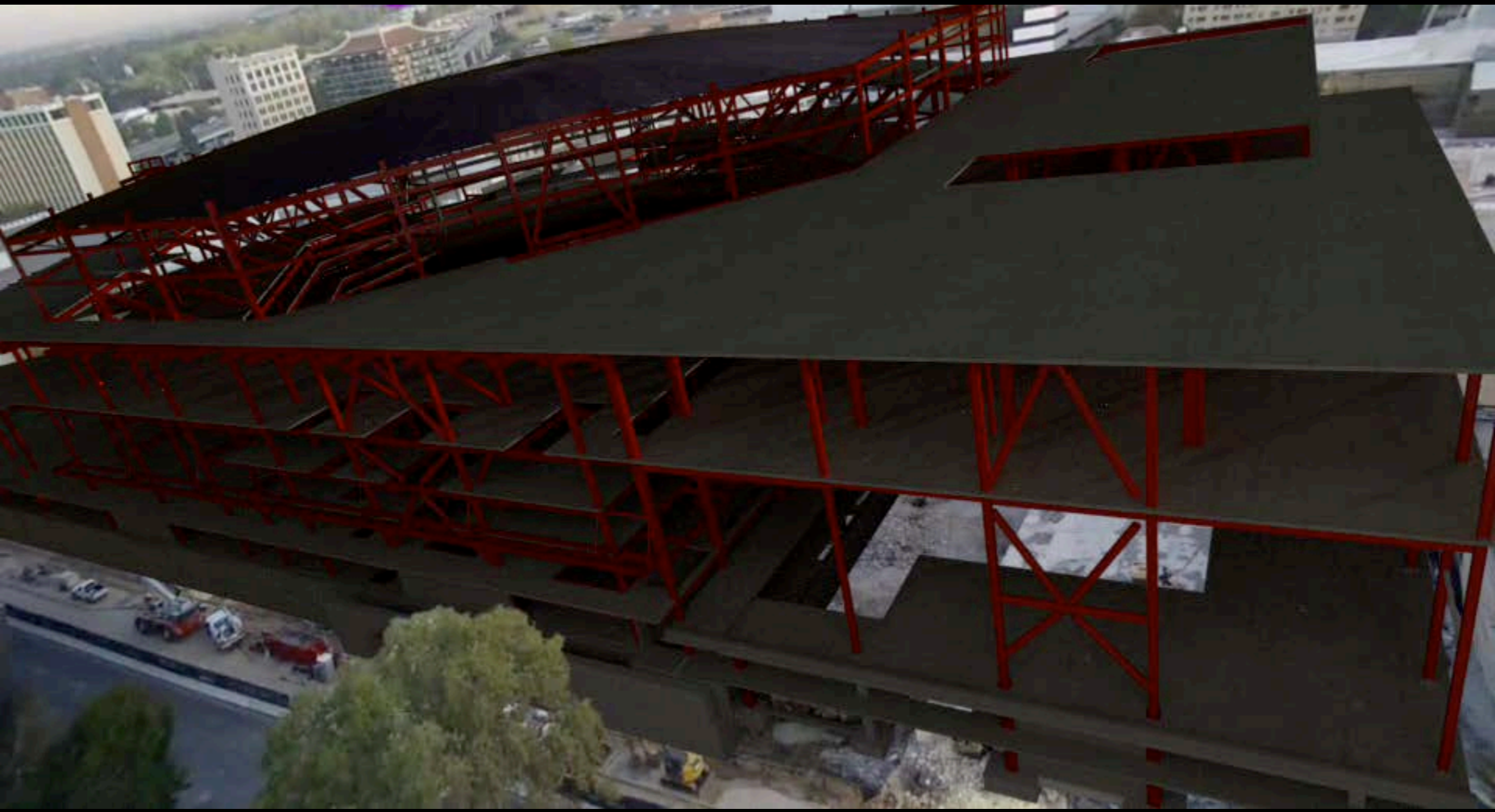

Material Selection and Adjustment

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Indoor Results

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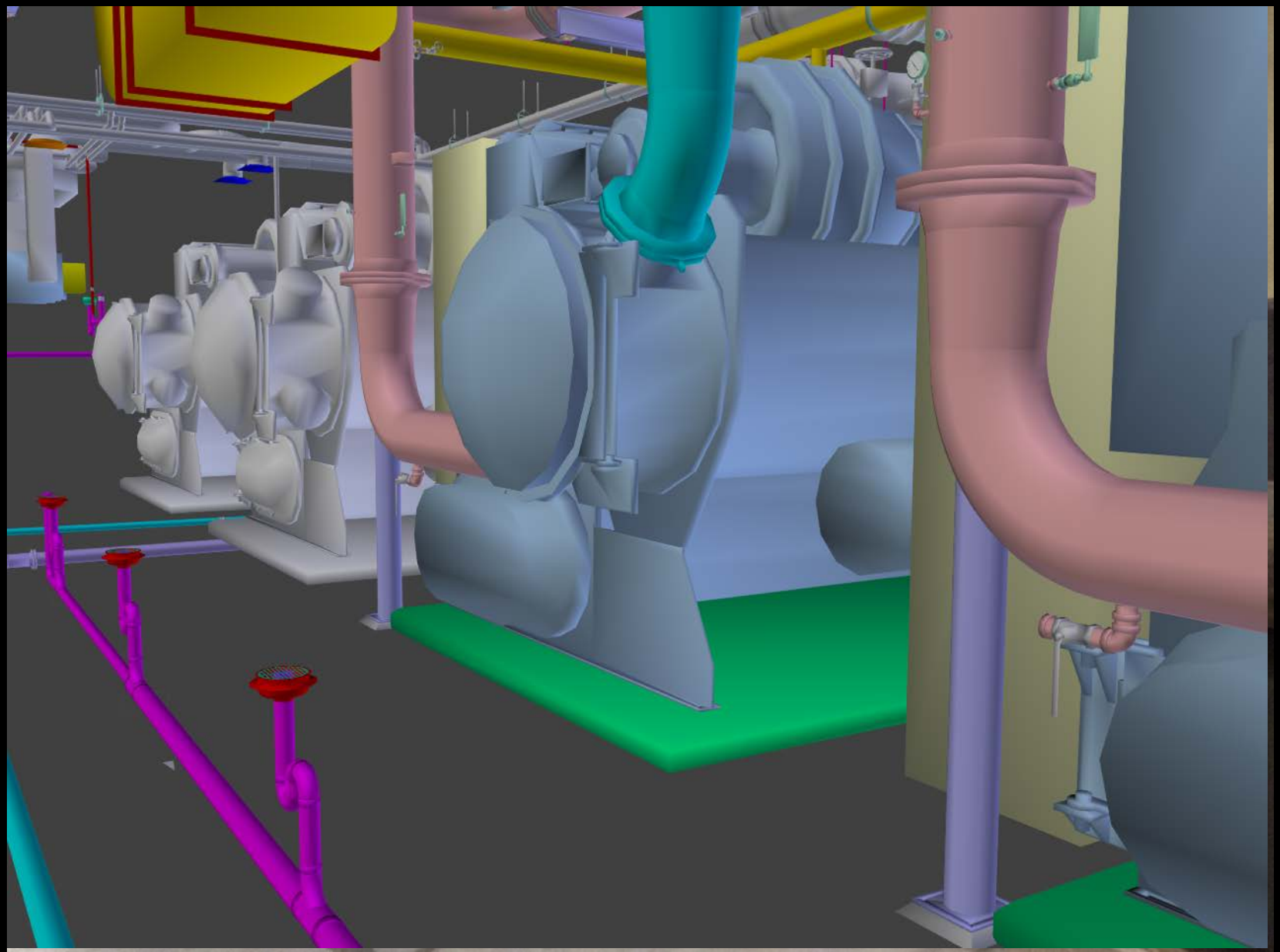

Indoor Results

Aerial Results

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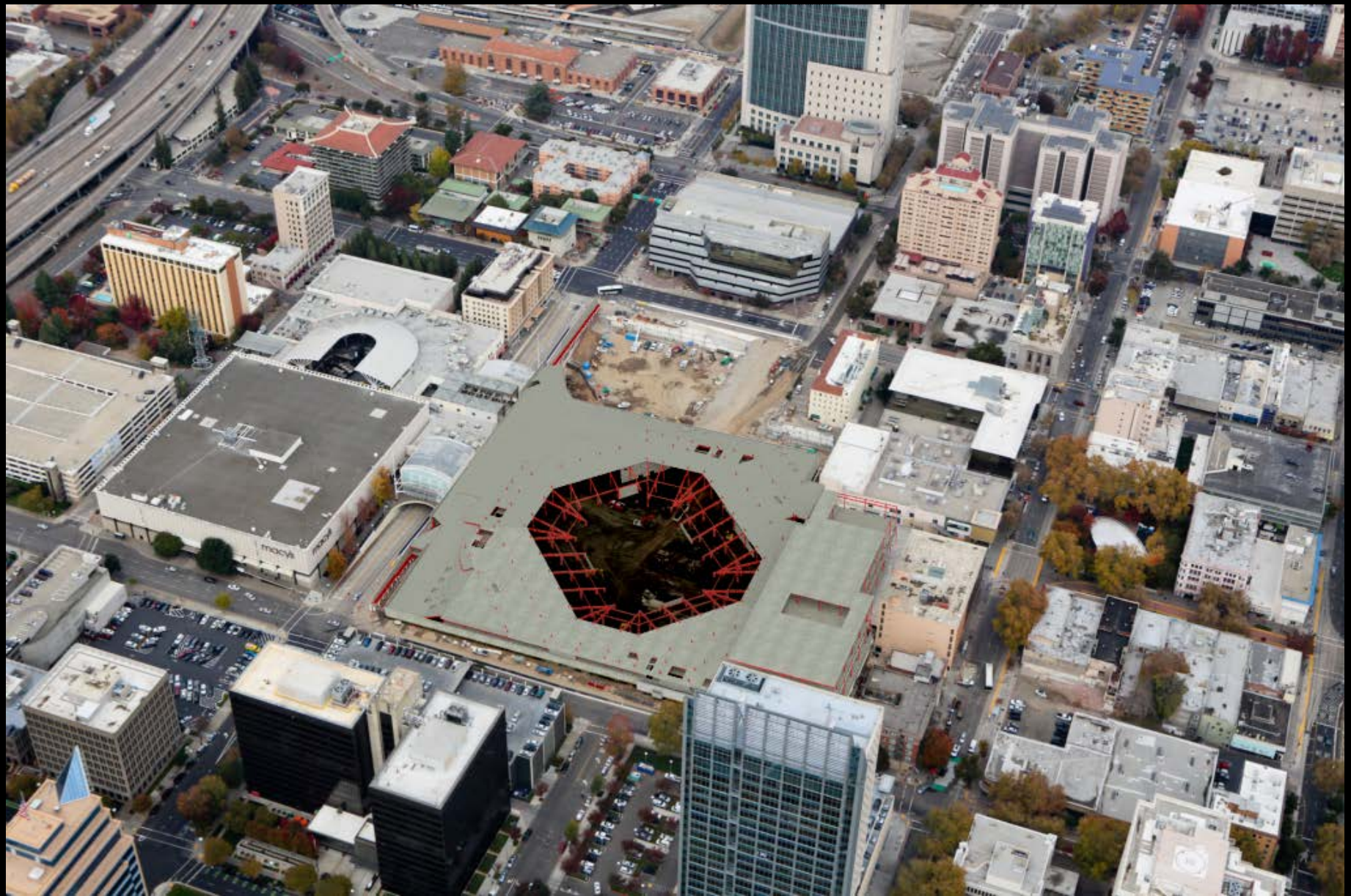

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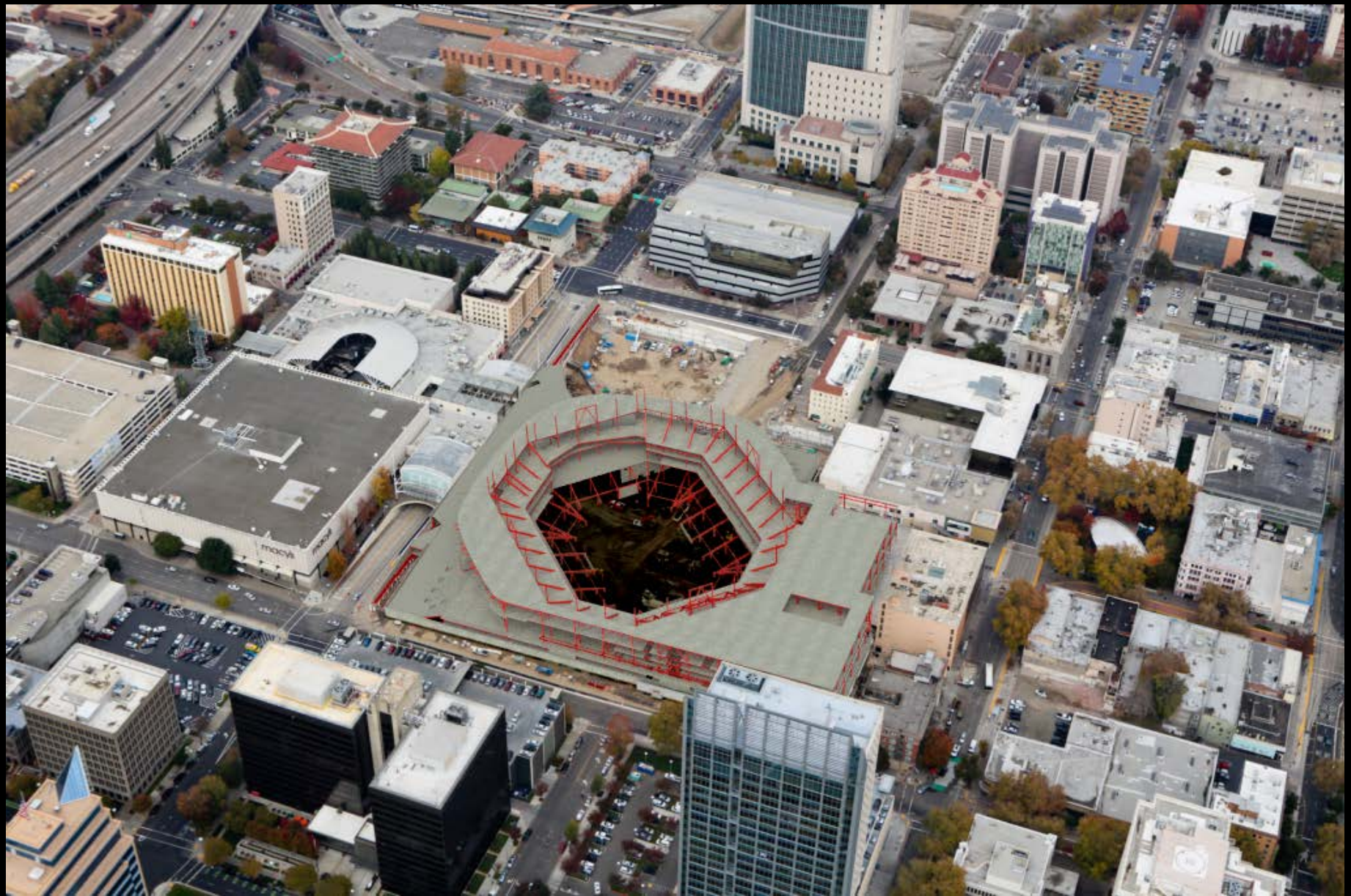
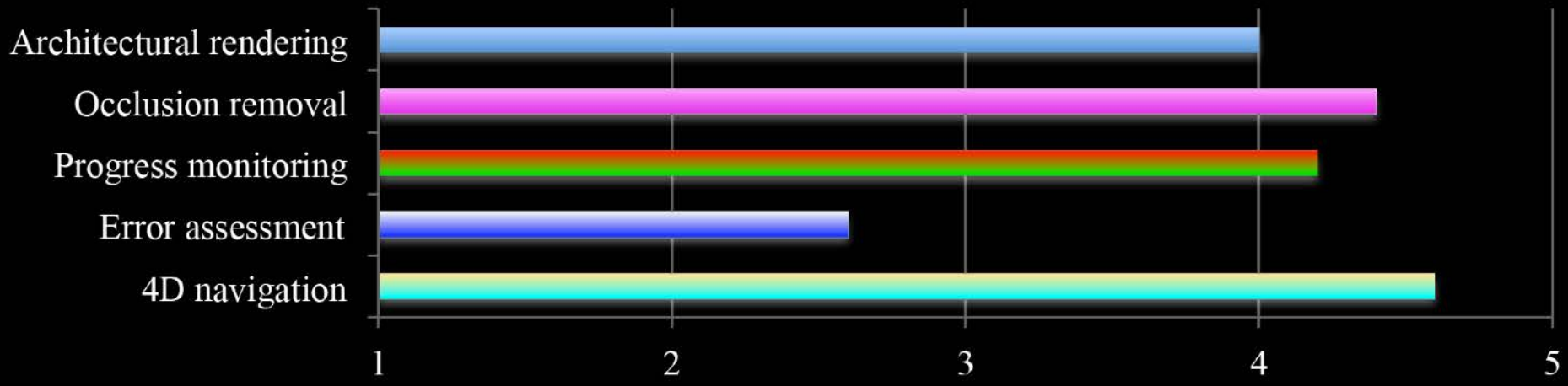


Aerial Results

Domain Expert Responses

"Rate the usefulness of the following tools" (Likert scale, 5 = excellent)



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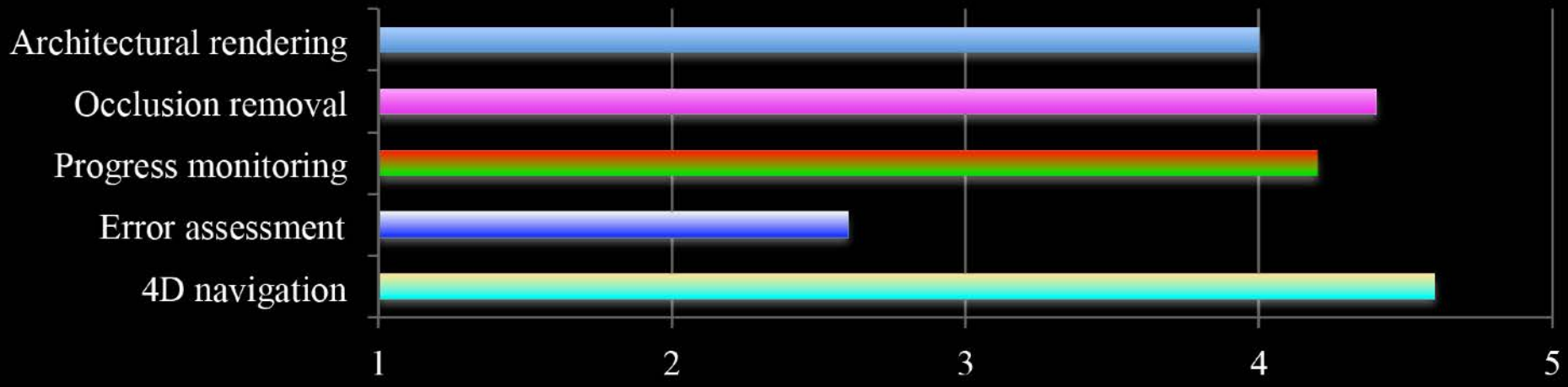

Quotes from users:

- "Existing methods are highly subjective and based on judgment and experience"
- "Space-time navigation is very useful for assessing/verifying contractor claims."
- "Automatic progress and error assessment would be nice."

Recap

- ConstructAide facilities everyday construction monitoring tasks
  - 4D navigation through photos
  - Architectural visualization
  - Progress and performance monitoring
- Rendering, occlusion, and time-lapse information are synthesized automatically from BIM + photos
- Constrained SfM works well when user input is available

Future Work

- Mobile, real time implementation for field use (in progress)
- Comprehensive user study
- How to better incorporate mesh in SfM?
  - Automatic registration [Aubry et al. 2014]