Columbia University
Robotics Group

Computational Tools for Modeling, Visualizing and Analyzing Historic and Archaeological Sites

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Interdisciplinary project with overall goal of bringing new digital technologies and methods to Archaeology & Historic Preservation

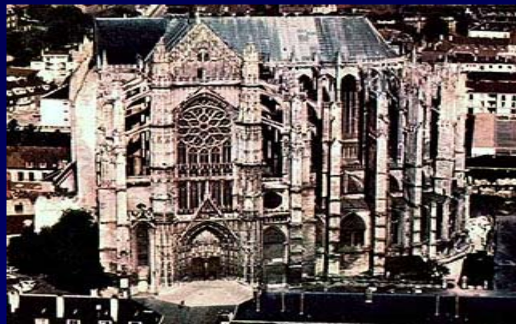
- Build accurate above-ground site models.
- Image below-ground data, merge with above-ground models
- Database technology to catalogue and access a site
- Visualization systems that integrates above-and below-ground models, images, text, web-based resources to annotate the physical environment.
- Developing an educational interface that will permit remote access to the models

www.cs.columbia.edu/~allen/ITR

Interdisciplinary Team

- Peter Allen(PI), Computer Science
- James Conlon, Media Center for Art History
- Steven Feiner, Computer Science
- Lynn Meskell, Anthropology
- Stephen Murray, Art History and Archaeology
- Kenneth Ross, Computer Science
- Roelof Versteeg, Environmental Engineering

Sites



France

South Africa

Egypt

Sicily

New York

Cathedral St. Pierre, Beauvais, France

Modeling the Cathedral

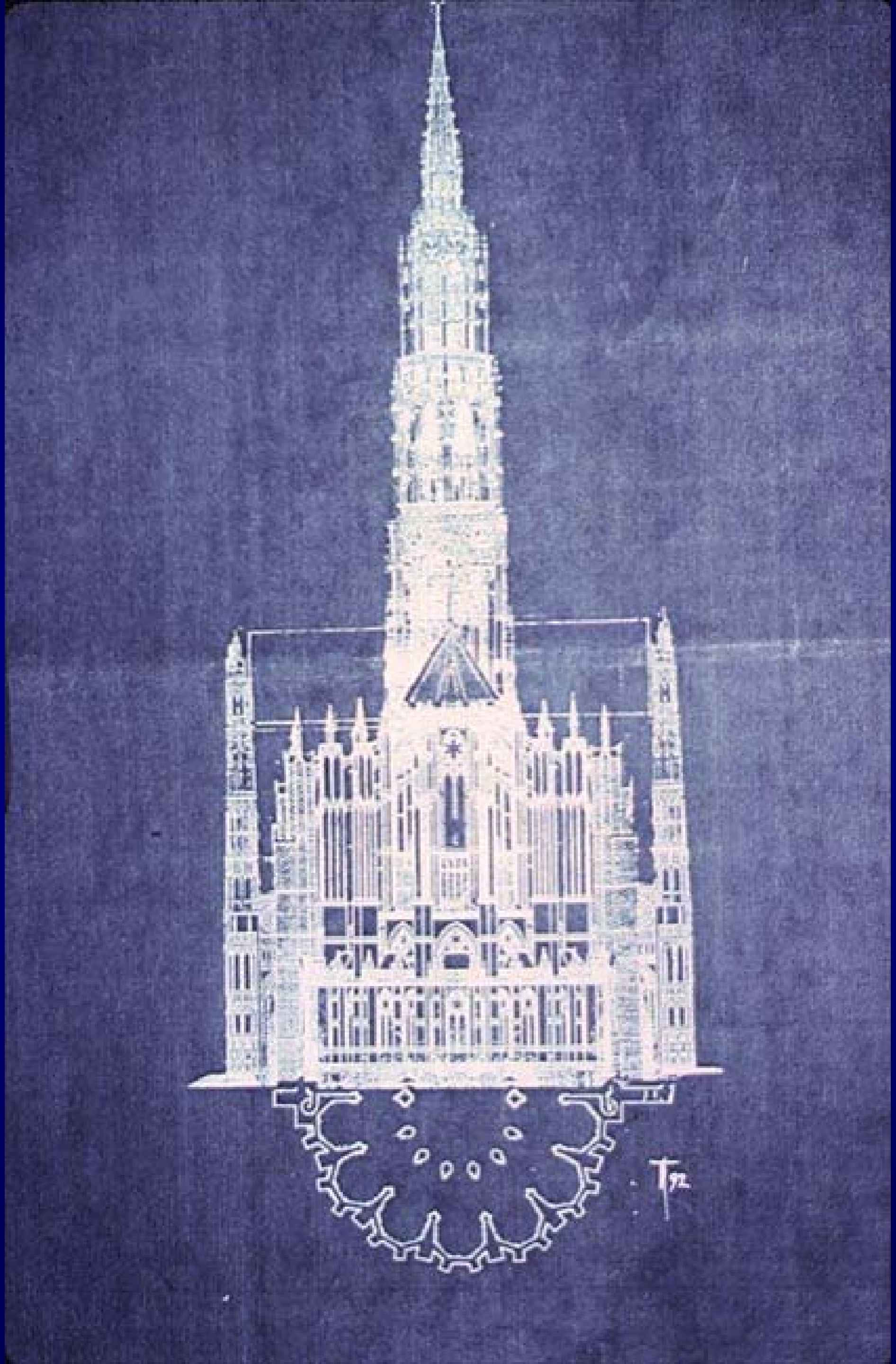
Goals:

- Cathedral on the World Monuments Fund's Most Endangered List.
- Create 3-D model to examine weaknesses in the building and proposed remedies
- Establish baseline for condition of Cathedral
- Visualize the building in previous contexts
- Basis for a new collaborative way of teaching about historic sites, in the classroom and on the Internet.

History: 1200 - 1600

- Commissioned in 1225 by Bishop Milon de Nanteuil
- Only the choir and transepts were completed - choir in 1272
- In 1284 part of the central vault collapsed
- Area where the nave and façade would be is still occupied by the previous church constructed just before 1000.
- Completed in 16th century, the transept was crowned by an ambitious central spire that allowed the cathedral to rival its counterpart in Rome.
- The tower collapsed on Ascension Day in 1573.

Rendition of original central spire



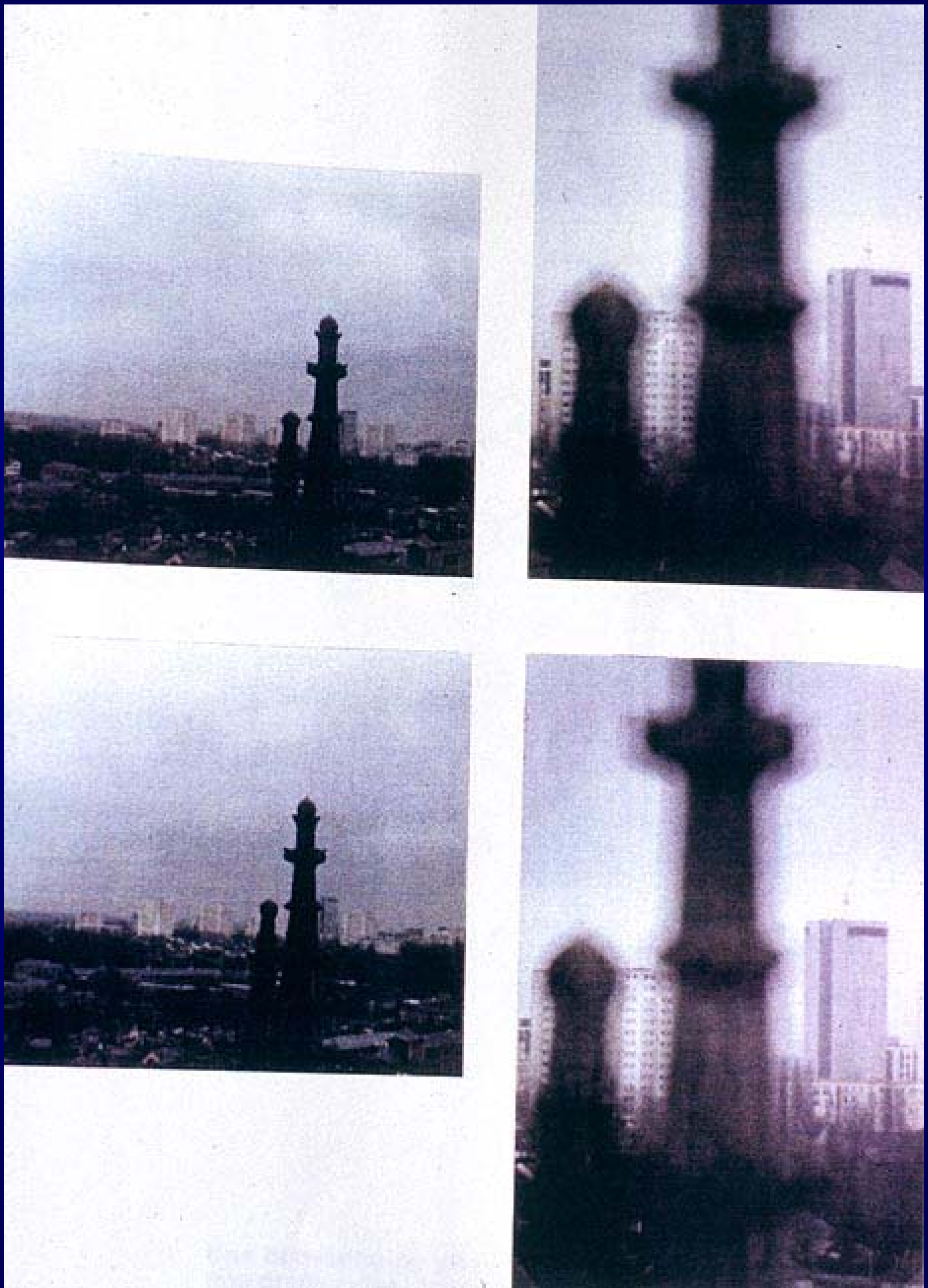
History: 20th Century

- Cathedral survived intense incendiary bombing that destroyed much of Beauvais in WW II.
- Between 1950-80 many critical iron ties were removed from the choir buttresses in a damaging experiment.
- Temporary tie-and-brace system installed in the 1990s may have made the cathedral too rigid, increasing rather than decreasing stresses upon it.
- There continues to be a lack of consensus on how to conserve the essential visual and structural integrity of this Gothic wonder.

Problems with the Structure

- Wind Oscillation from English Channel winds
- Strange inner and outer aisle construction – can cause rotational moments in the structure
- Leaking Roof, foundation is settling
- Built in 3 campaigns over hundreds of years with differing attention to detail

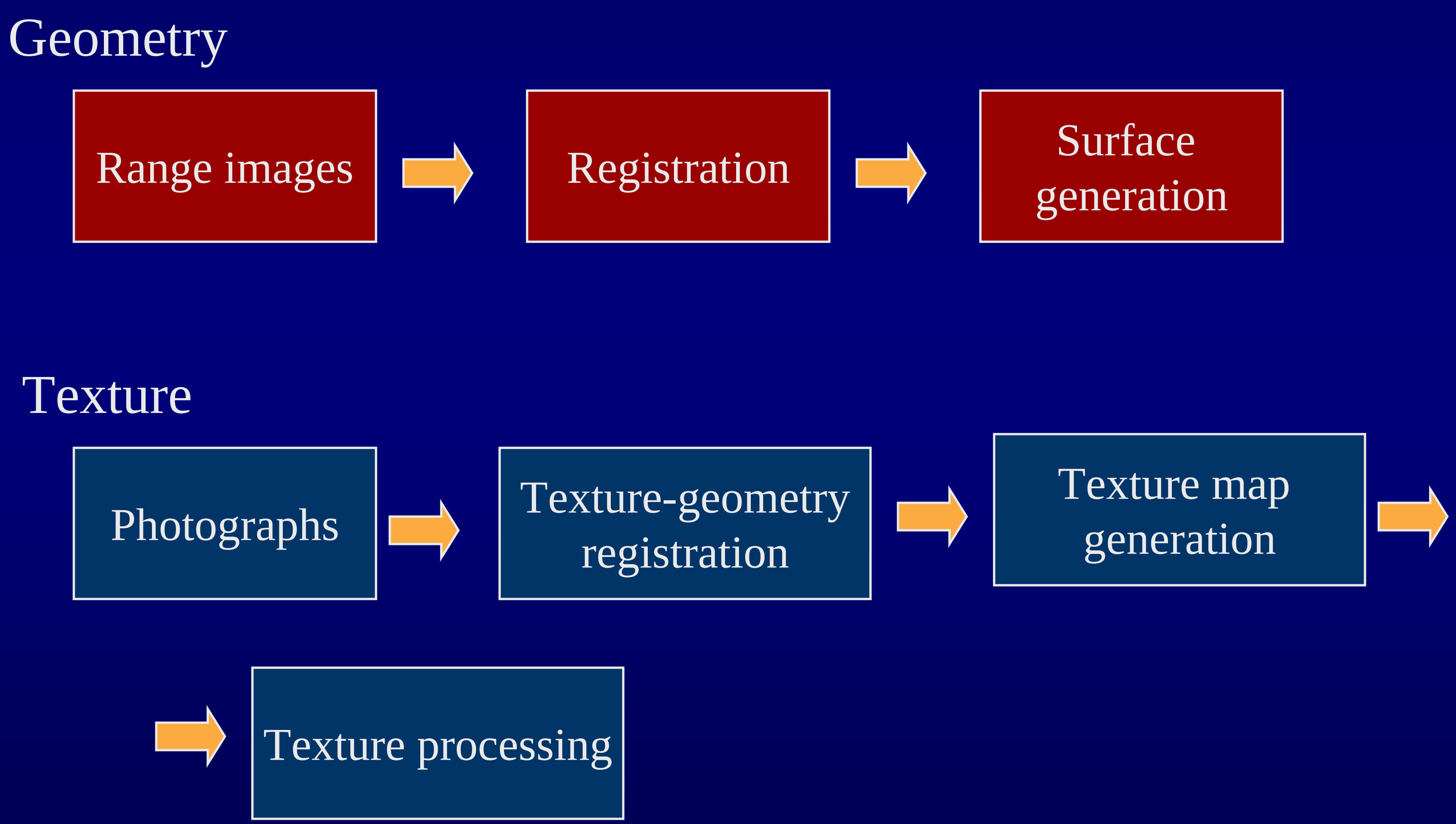
Time-Lapse Image - Spire Movement Due to Wind



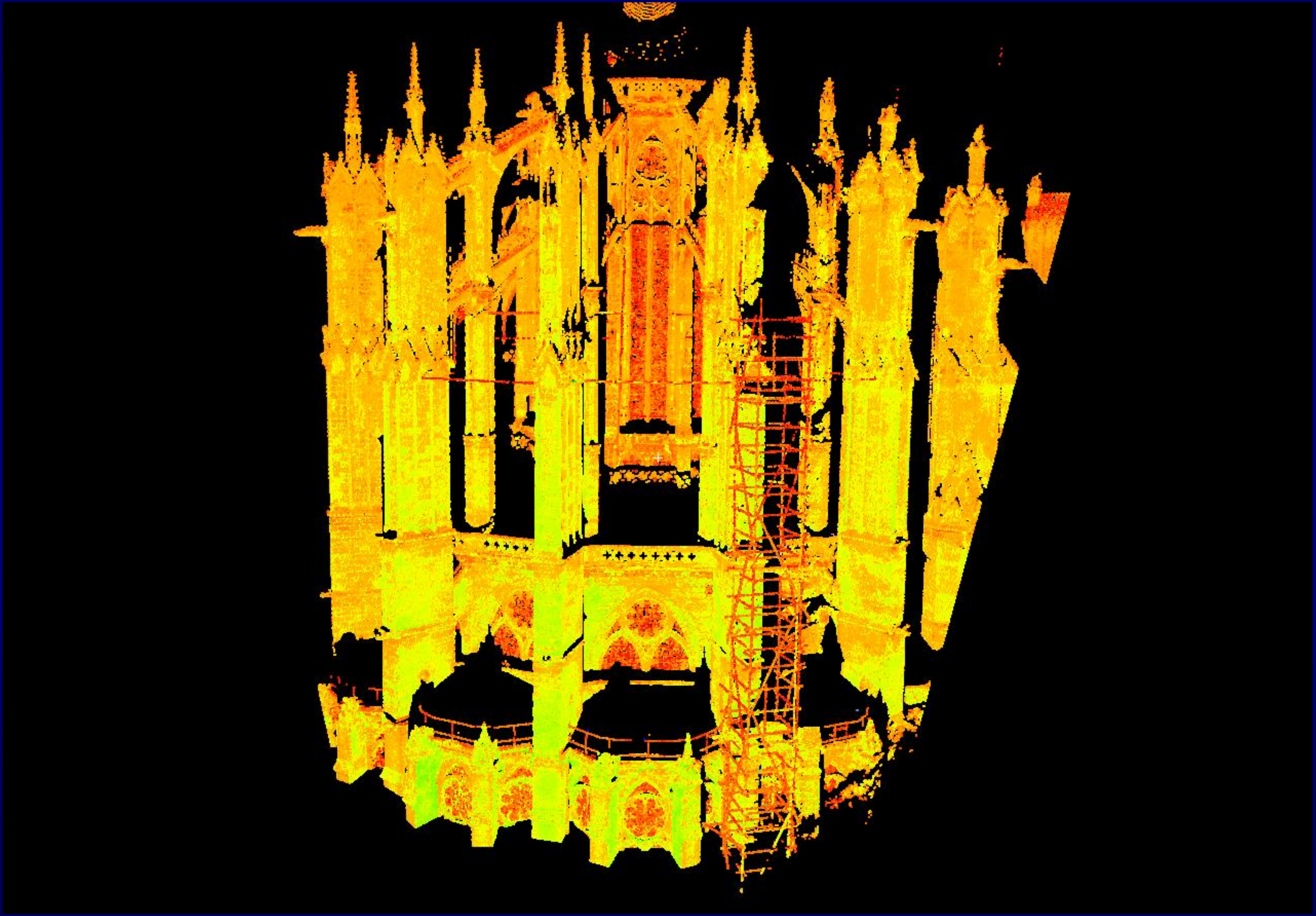
Technical Challenges

- Create Global and coherent geometric models: handle full range of geometries
- Reducing data complexity
- Registration of MANY million point data sets
- Range and intensity image fusion

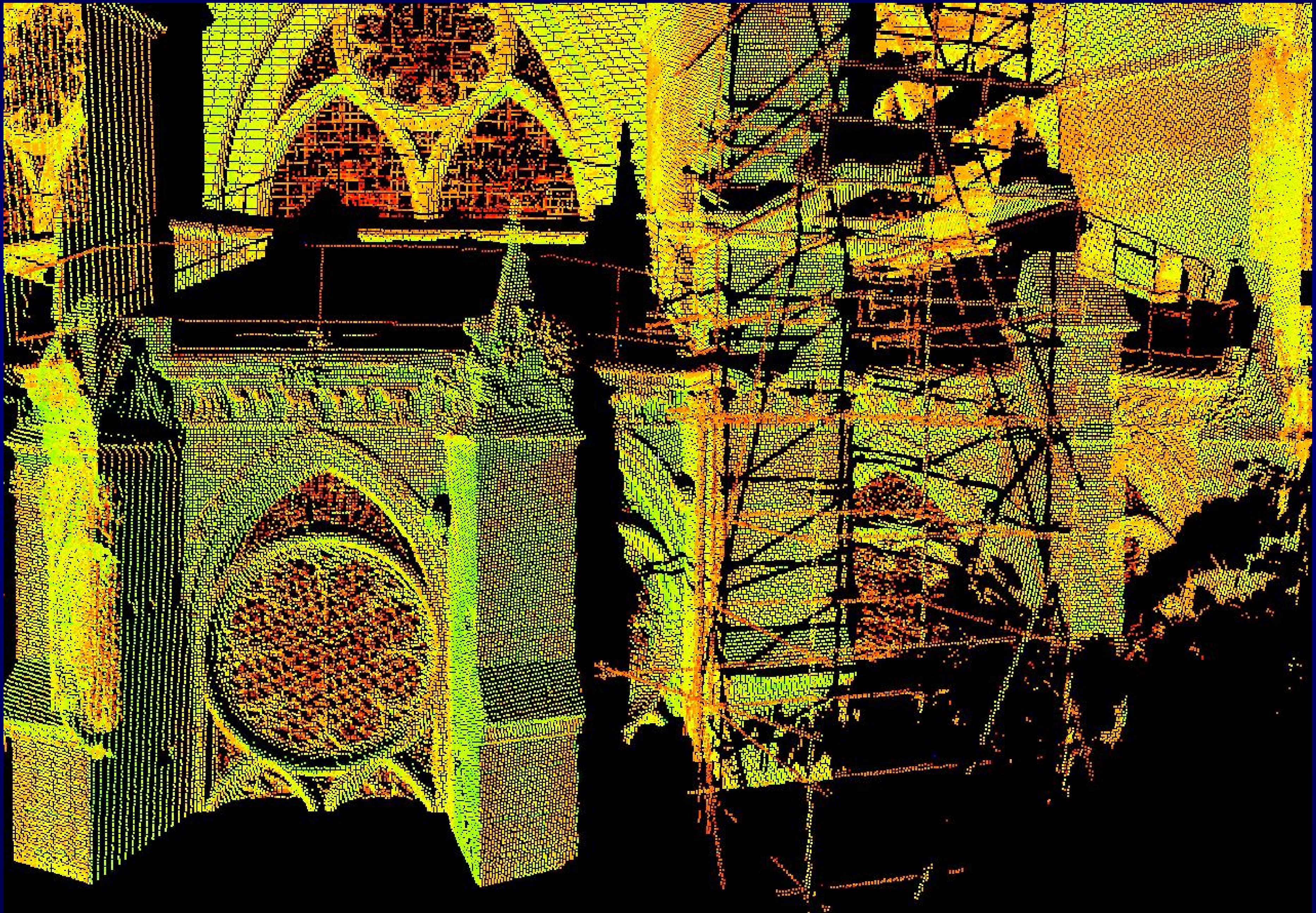
The 3D modeling pipeline



Exterior: Raw Range Scan



Beauvais: Scan Detail



Range Registration

3 Step Process:

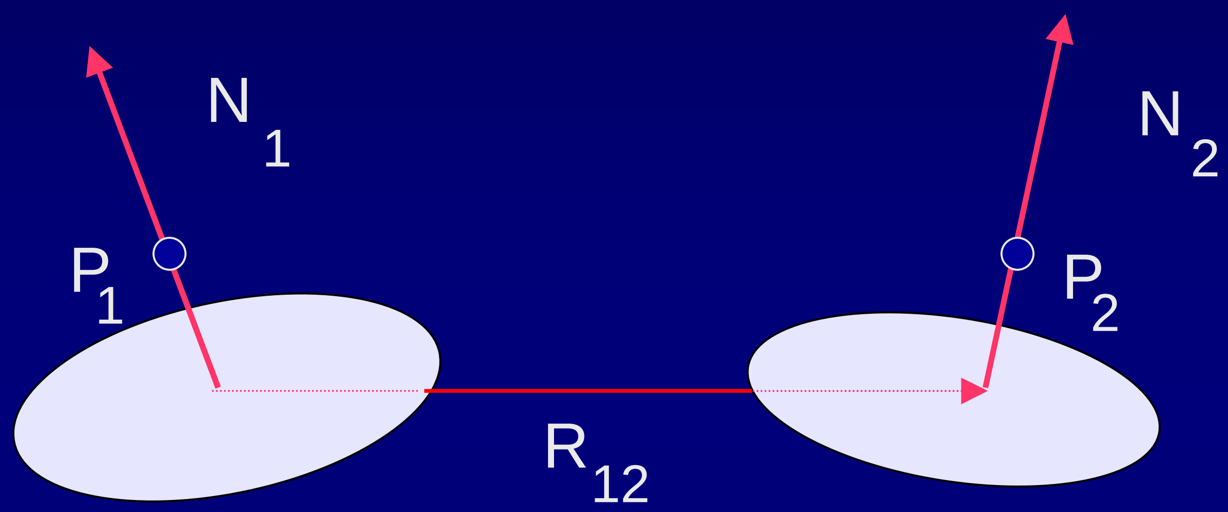
1. Pairwise registration between overlapping scans. Match 3D lines in overlapping range images.
2. Global registration using graph search to align all scans together.
3. Multi-scan simultaneous ICP registration algorithm (Nishino et. al.)

Produces accurate registration.

Segmentation Algorithm

- Creates reduced data sets (~80%).
- Fit local plane to neighborhood of range points.
- Classify range points: planar, non-planar, unknown.
- Merge into connected clusters of co-planar points.
- Identify boundaries of planes.
- Used to find prominent linear features for matching.

Local Planarity Comparison

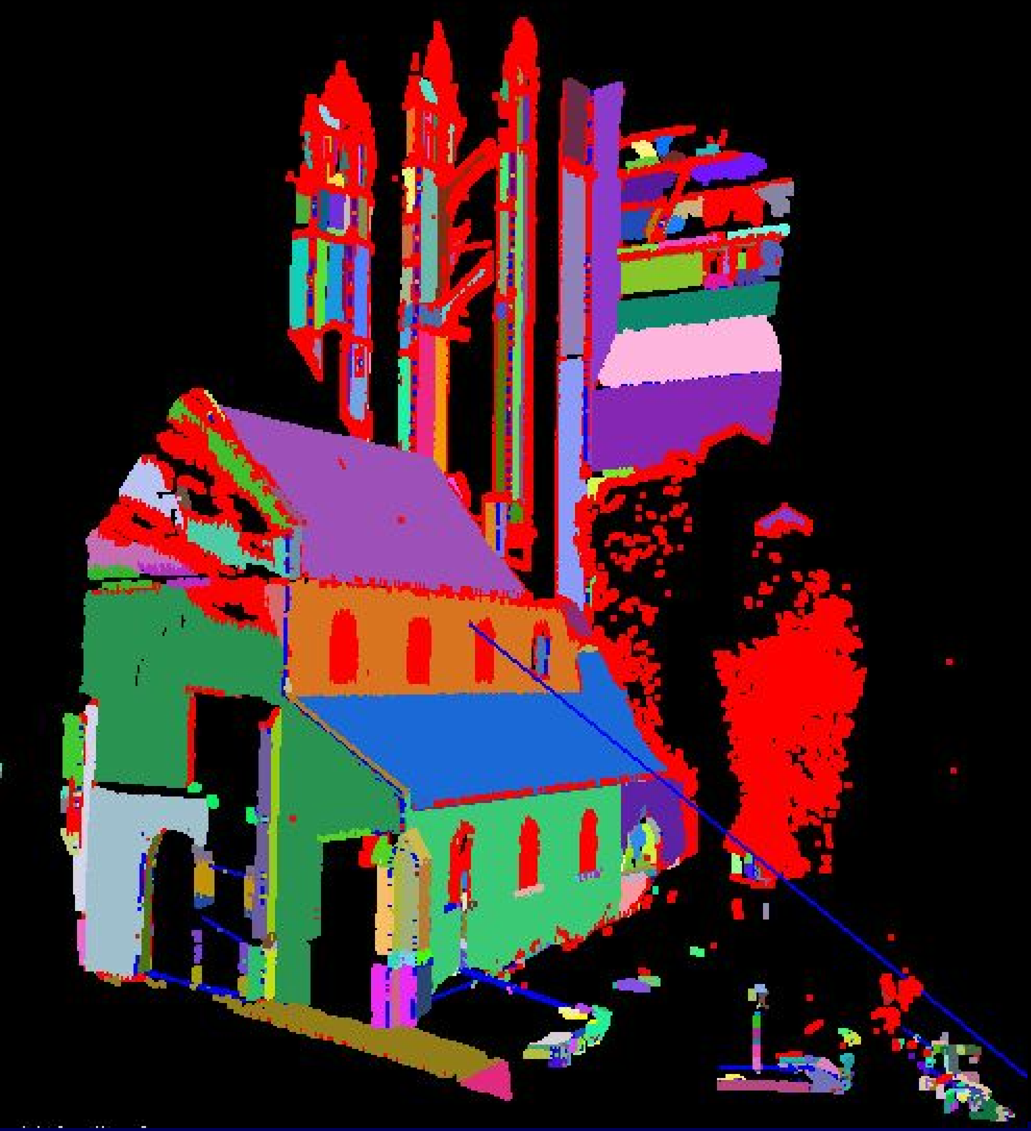


Patches fit around points P1 and P2

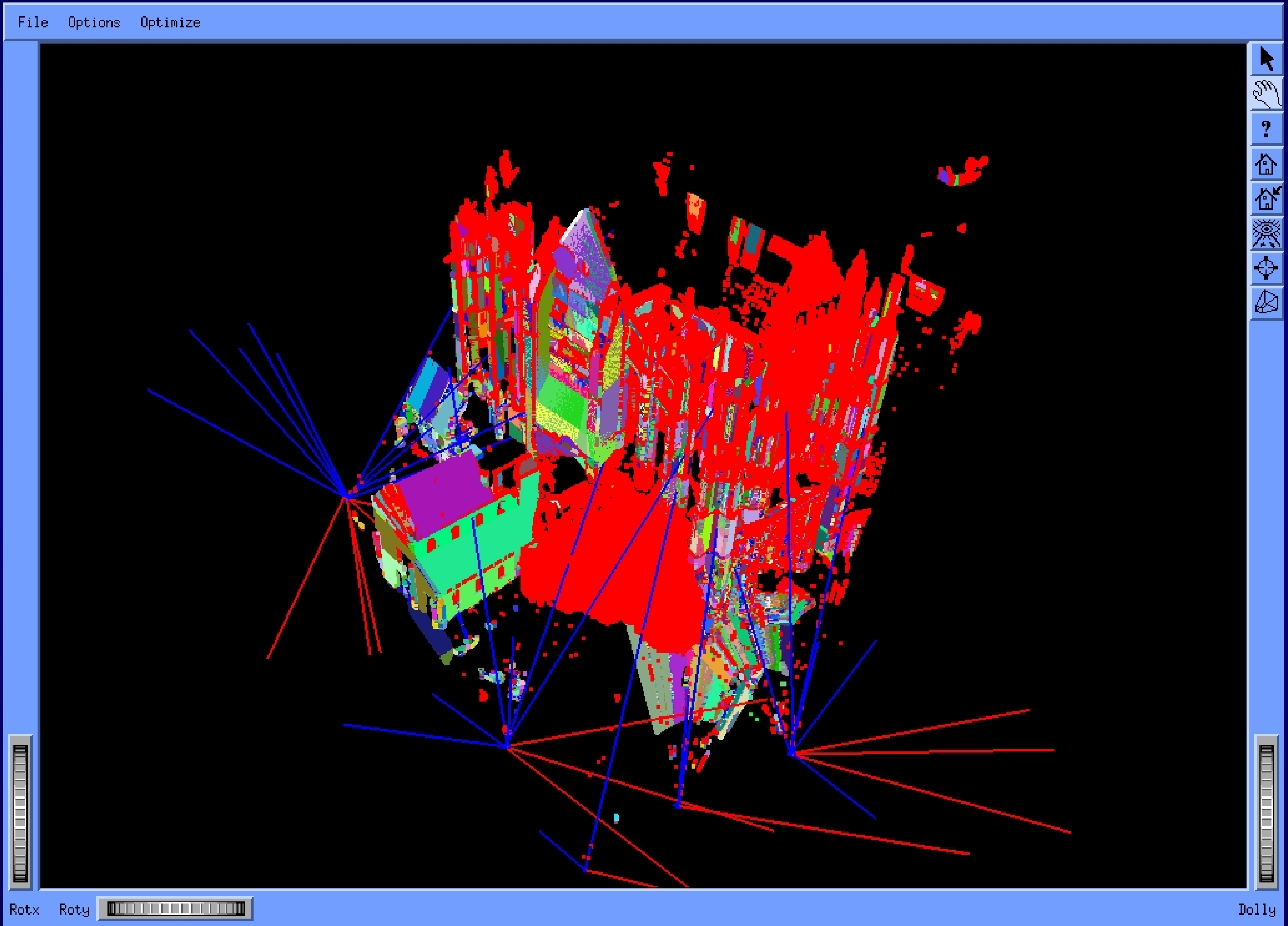
P1 and P2 are **coplanar** if:

- $a = \cos^{-1}(N_1 \cdot N_2)$ < angle threshold
- $d = \max(|R_{12} N_1|, |R_{12} N_2|)$ < distance threshold

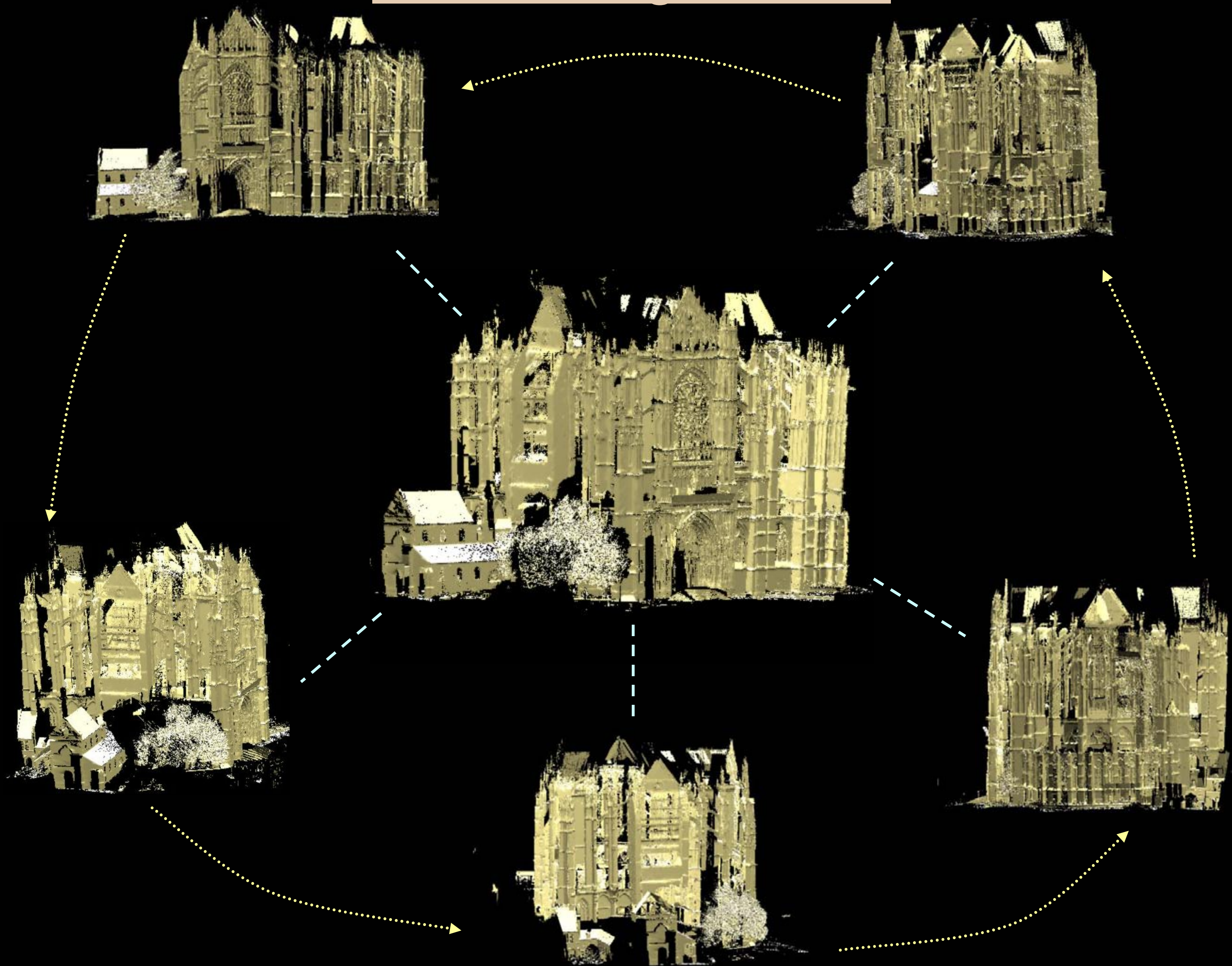
Segmentation and 3-D Registration Lines



Registered Scans – Beauvais Cathedral

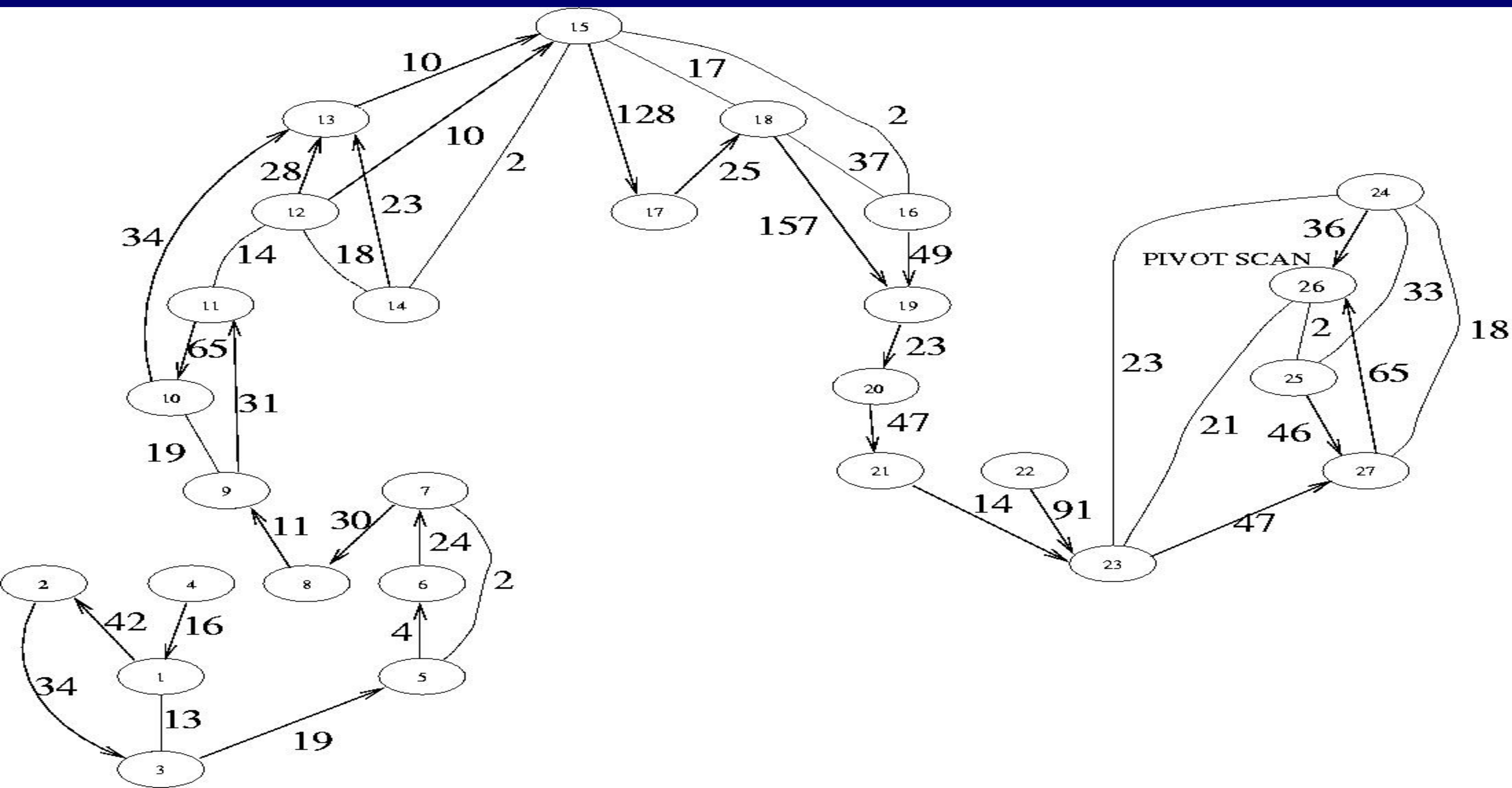


Global Registration

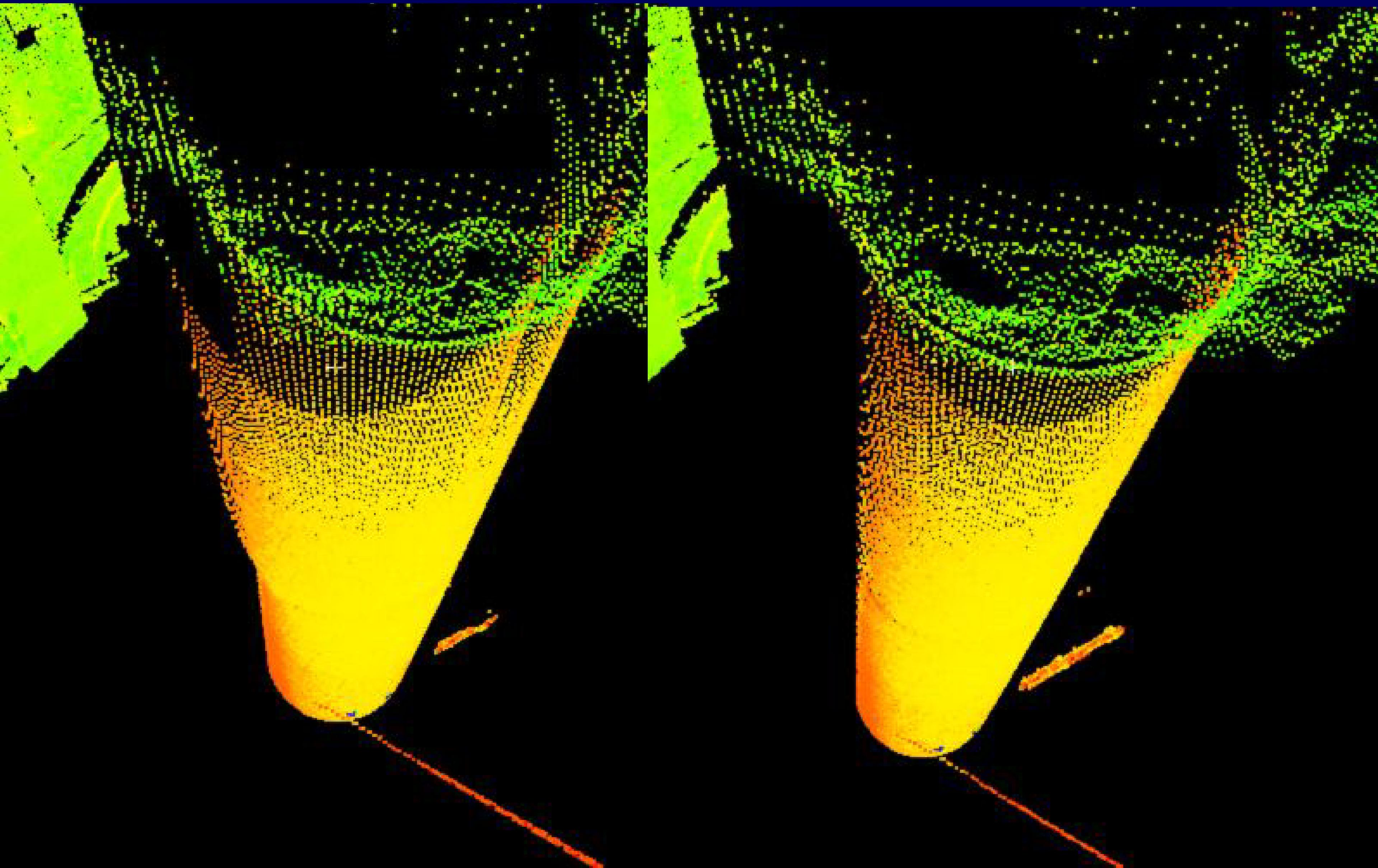


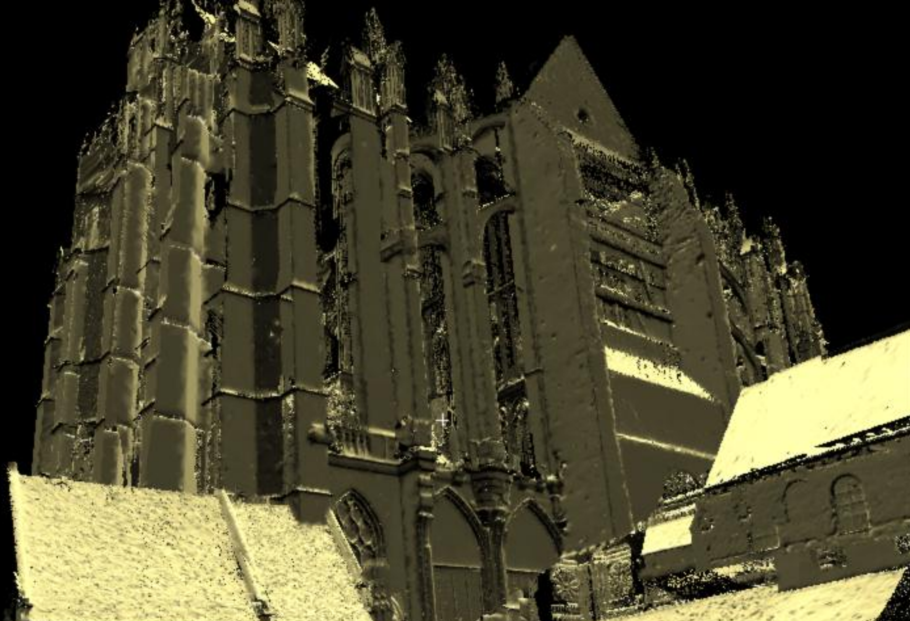
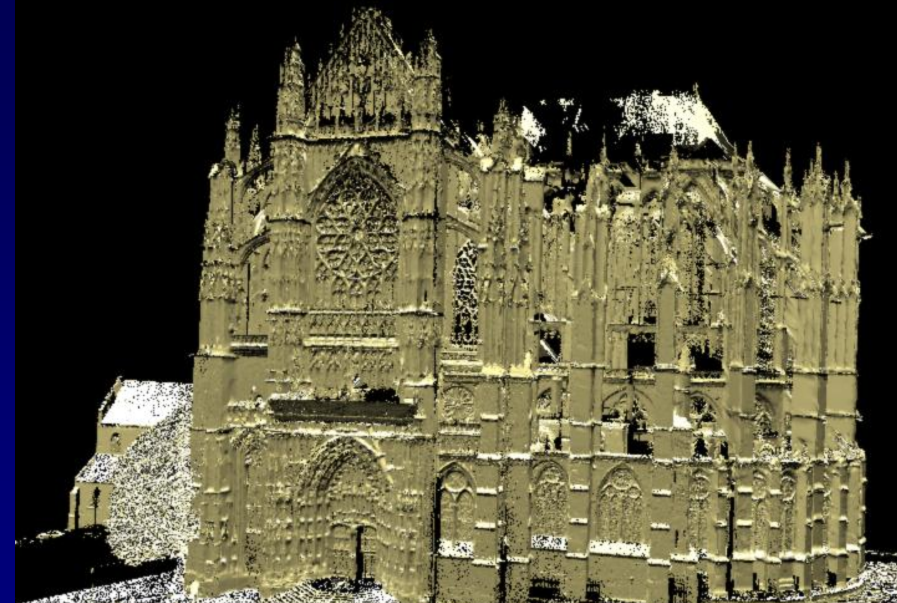
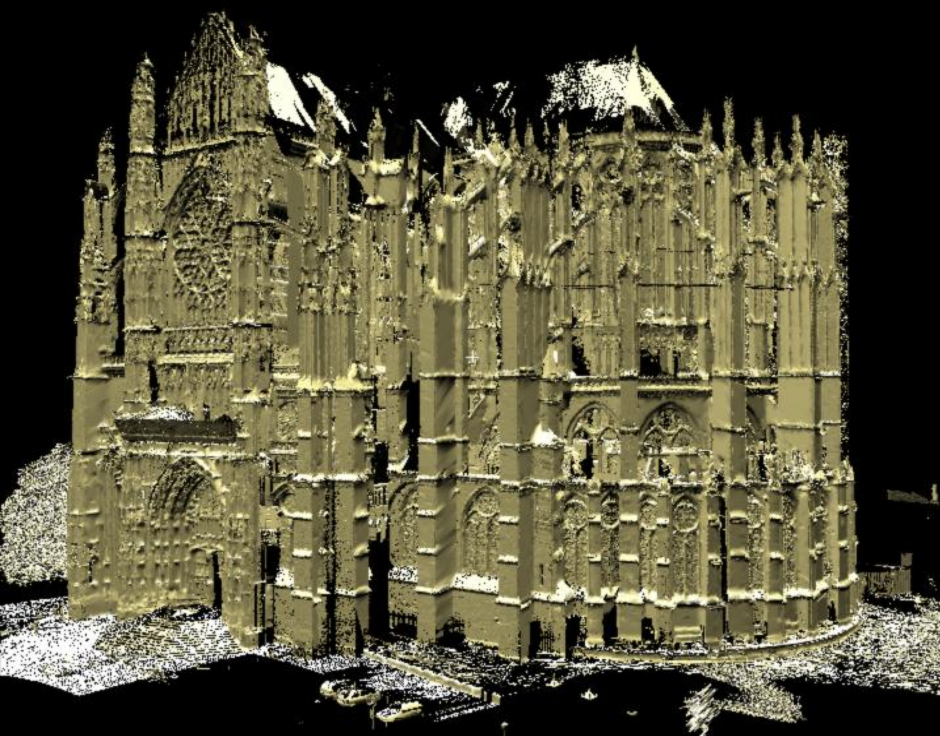
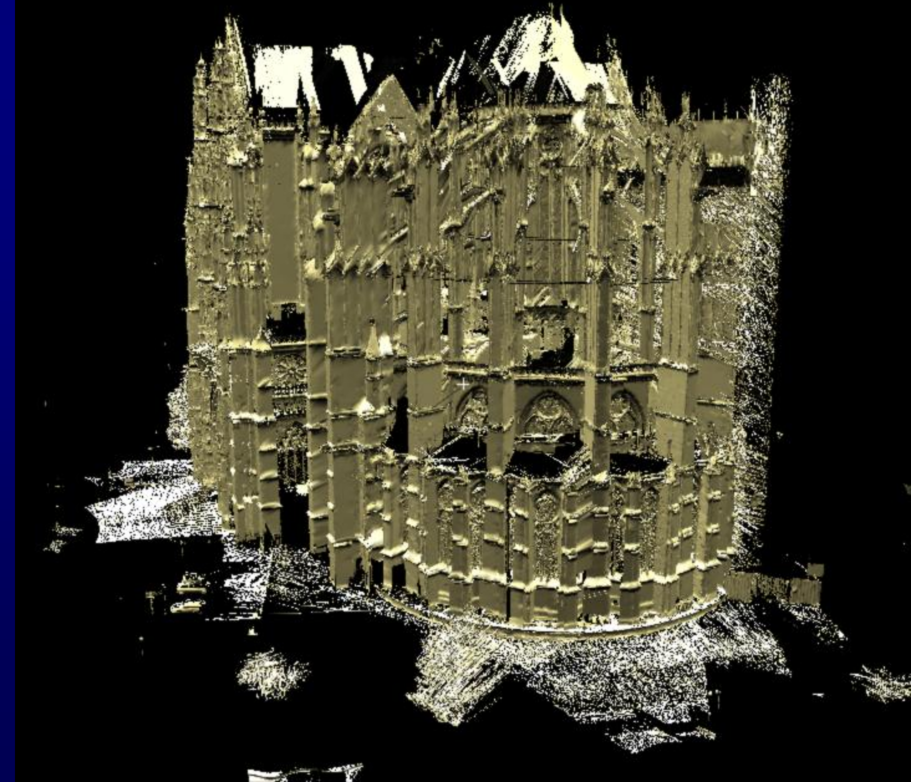
Graph Search Global Registration

- Create weighted graph of scans. Edges of graph are confidence in finding correct registration between pairs of scans
- Confidence (cost) is number of correctly aligned lines after applying registration (R,T)
- Global Registration: find max-cost path from pivot scan to each scan

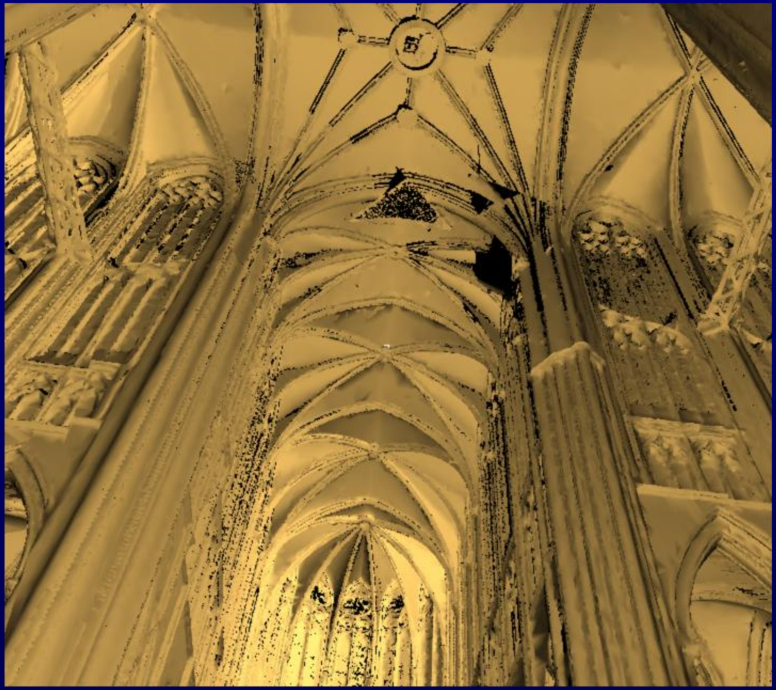


Final ICP Registration

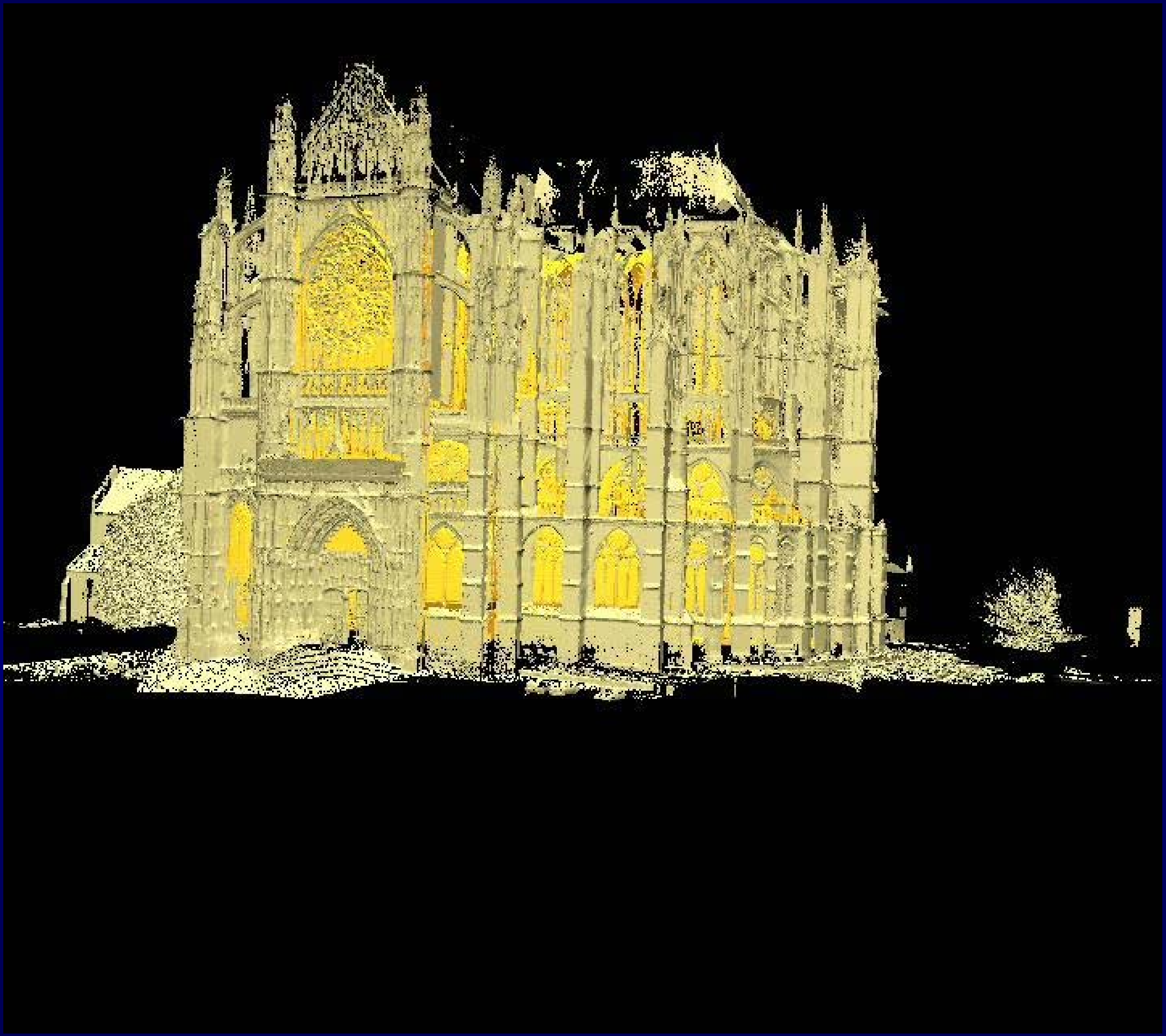







Beauvais Cathedral Model: Fly-Thru



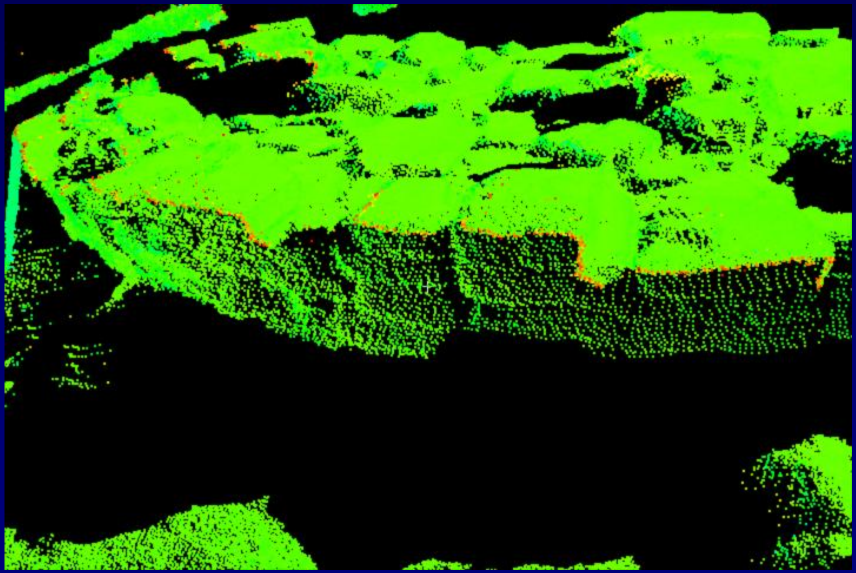
Excavation on Monte Polizzo, Sicily

Sicily: Modeling Goals

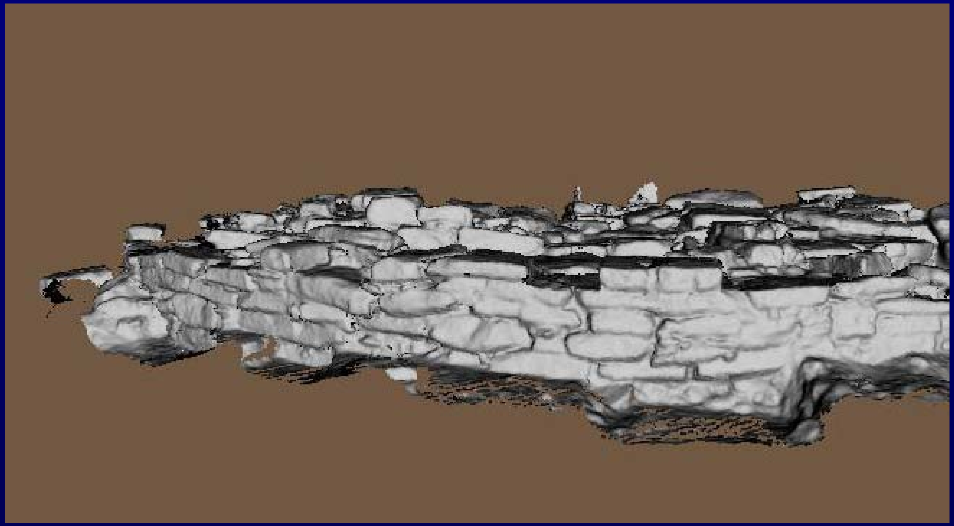
- Archaeological excavation is a destructive and physically “unreconstructable” process
- Need to preserve as much data as possible for analysis
- Most analysis/interpretation happens off-site after digging when the real 3D environment is missing
- Encourage Archaeologists to go ``Digital’’
- Goals:
  - Create complete 3D record of excavation process with range scans and 2-D images
  - Gather multimedia data from site: images, video, audio, 3D panoramic images
  - Develop collaborative immersive visualization environment for analyzing data off-site

3D Model Acquisition

Registration target placement



Laser scan

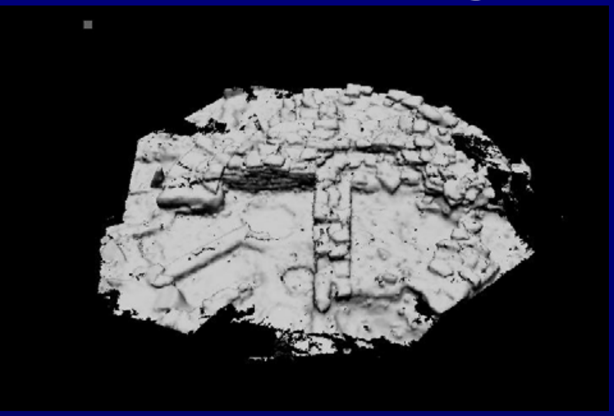


Volumetric Model

Texture Mapping with images

Motivation

- To create photo-realistic 3D models of historic sites using range scans and images



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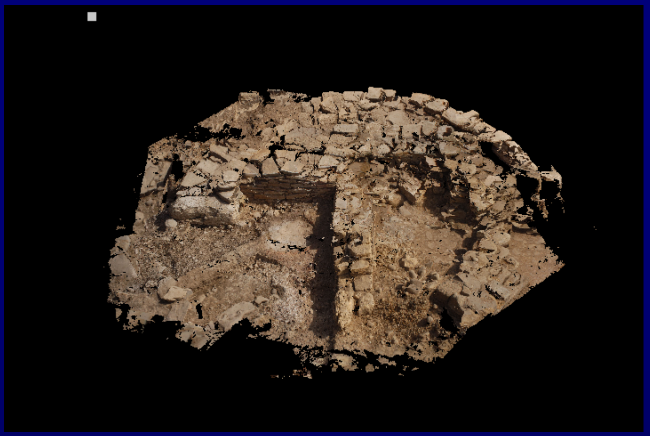
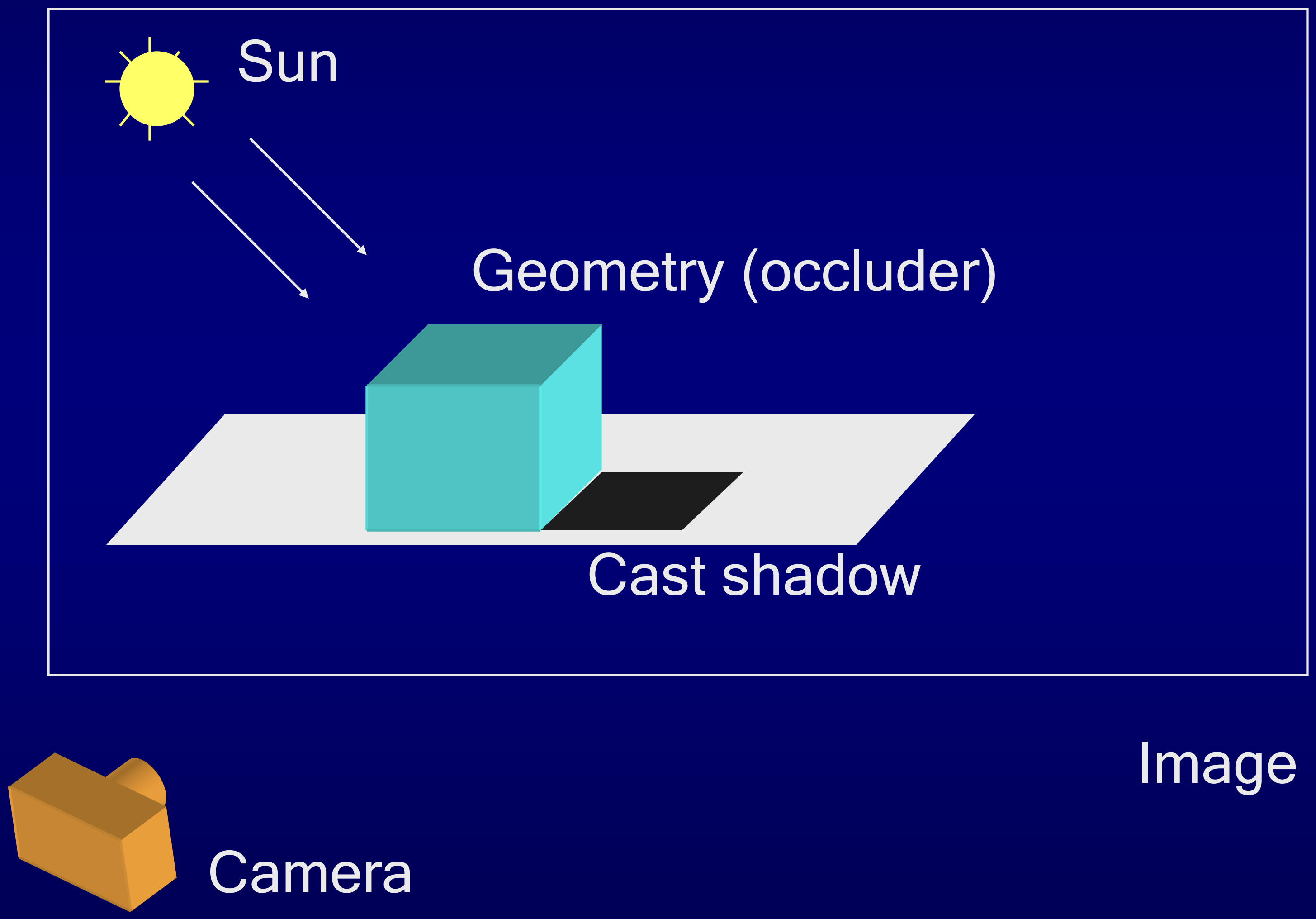


Range data
(Geometry)

Images
(Appearance)

Textured model

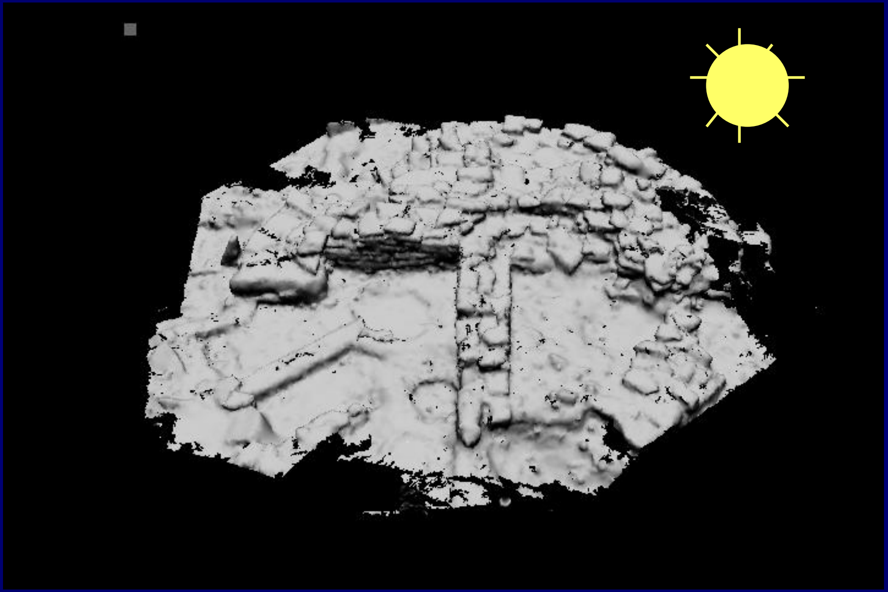
Shadows



Shadows as features

Geometry + Sun position

Image

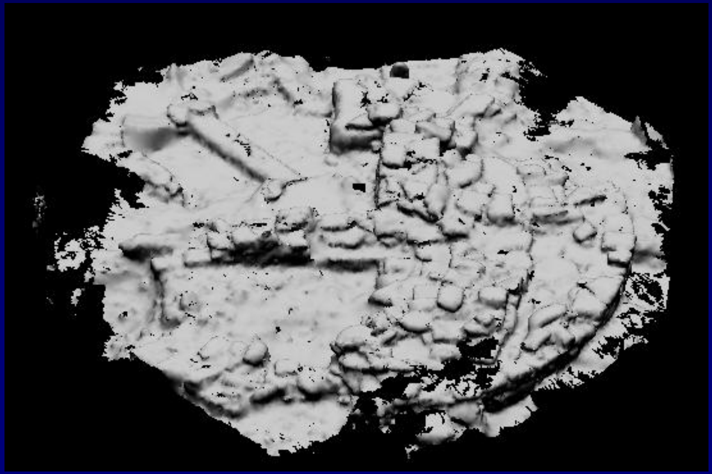


Shadows in 3D world

Shadows in 2D image

Match and compute image registration

Shadow match with texture mapping



Rendering of the model seen from the sun

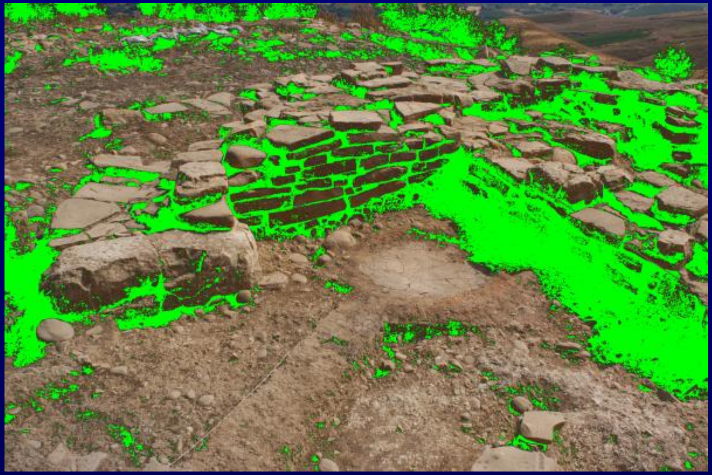
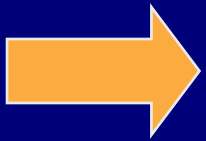
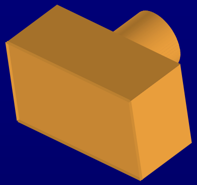


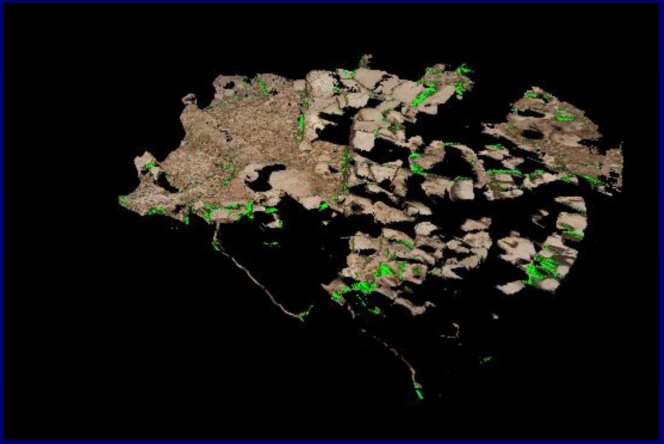
Image with shadows masked in green



Texture mapping



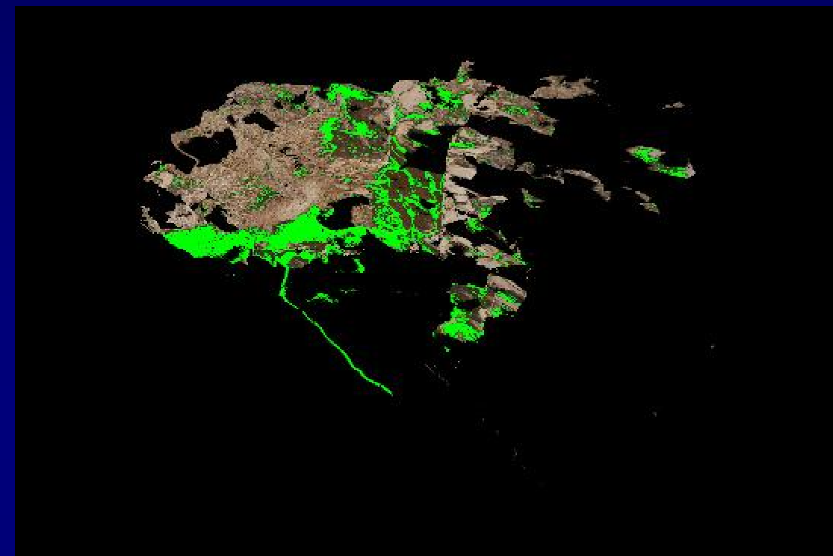
Texture camera (image to model registration)



Textured version of the model as seen from the sun

Shadow match with texture mapping

Shadow pixels = 127
Good match.



Shadow pixels = 1875
Bad match.

Algorithm

Given an initial camera position, find a new one that minimizes the number of shadow pixels.

Results

- Applied method to 10 of the 13 images of our model

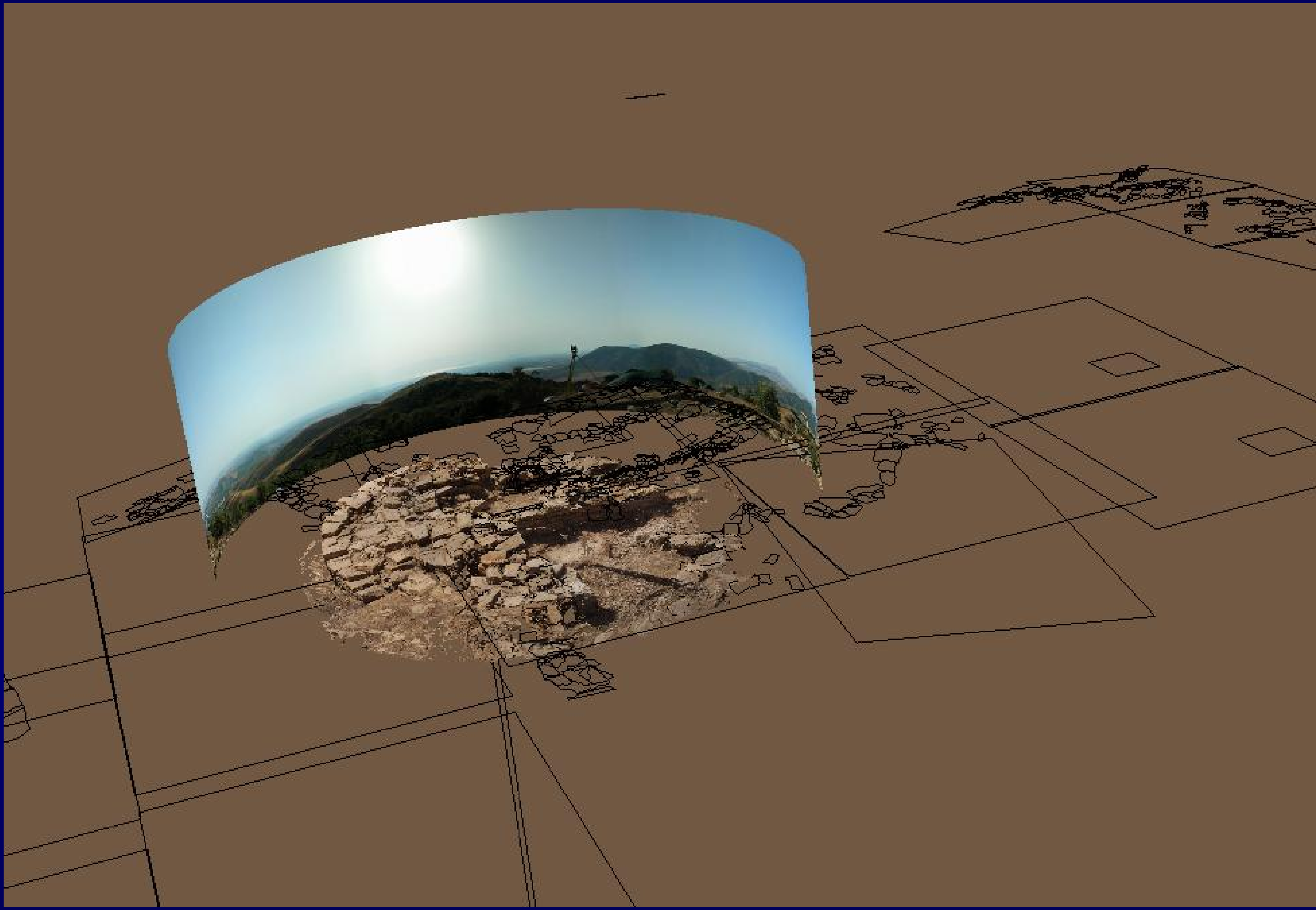
Before

After

Site Model, Mt. Polizzo

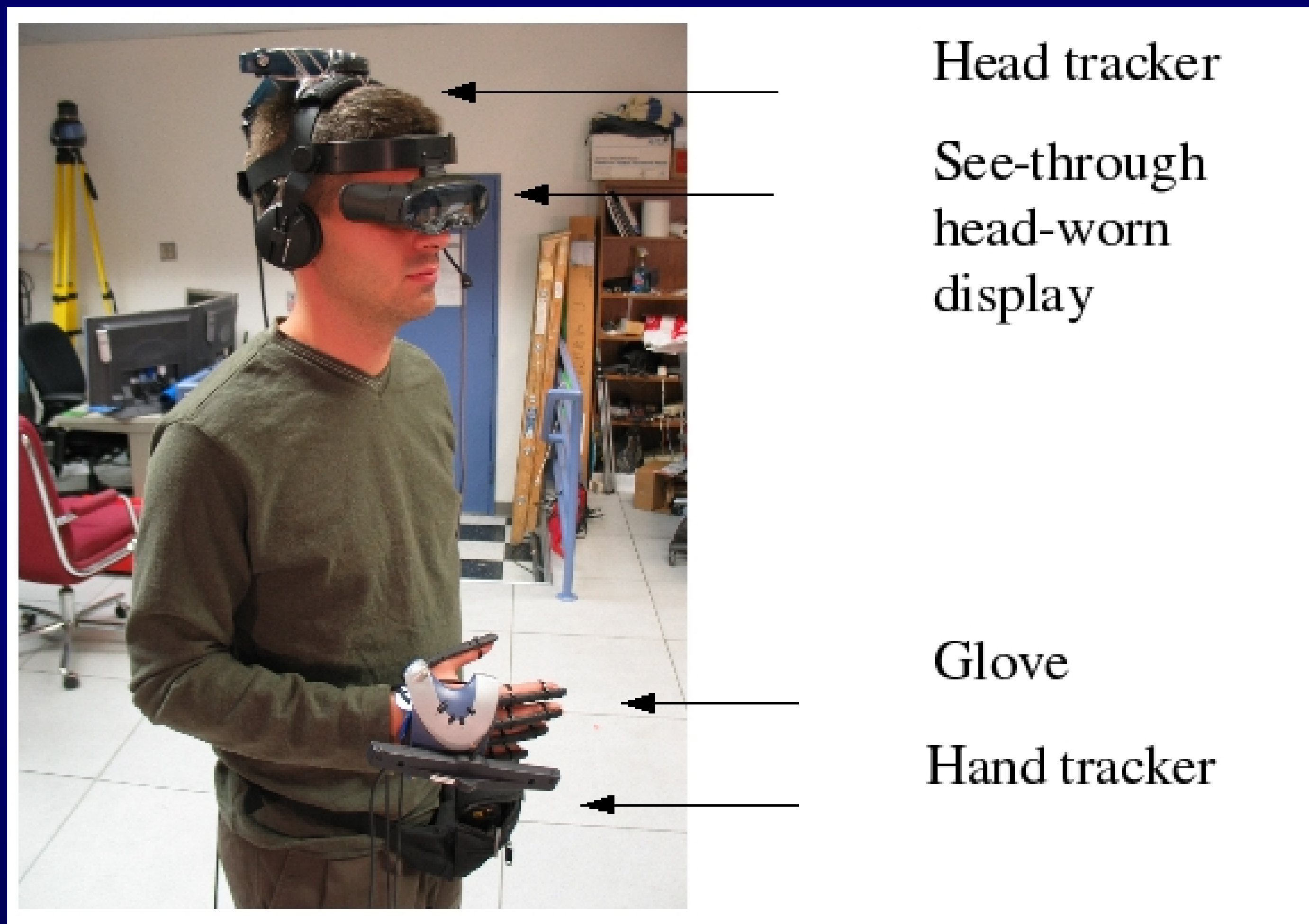
<u>Components</u>

1. Model: 15 registered scans
2. Texture mapping
3. Cylindrical Panorma
4. GIS site survey



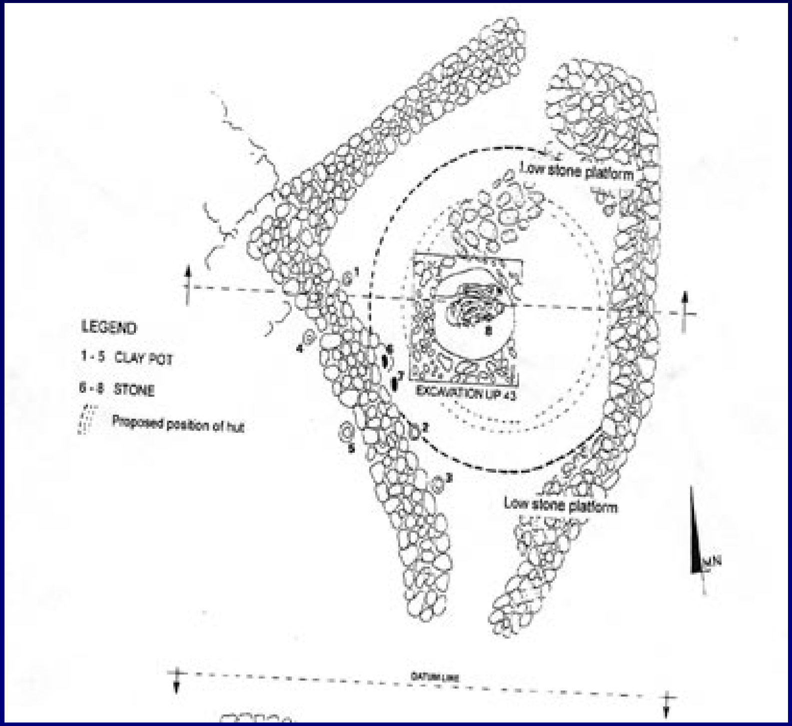
Site Model: Flythrough

Augmented Reality Collaborative Visualization of the Site Model



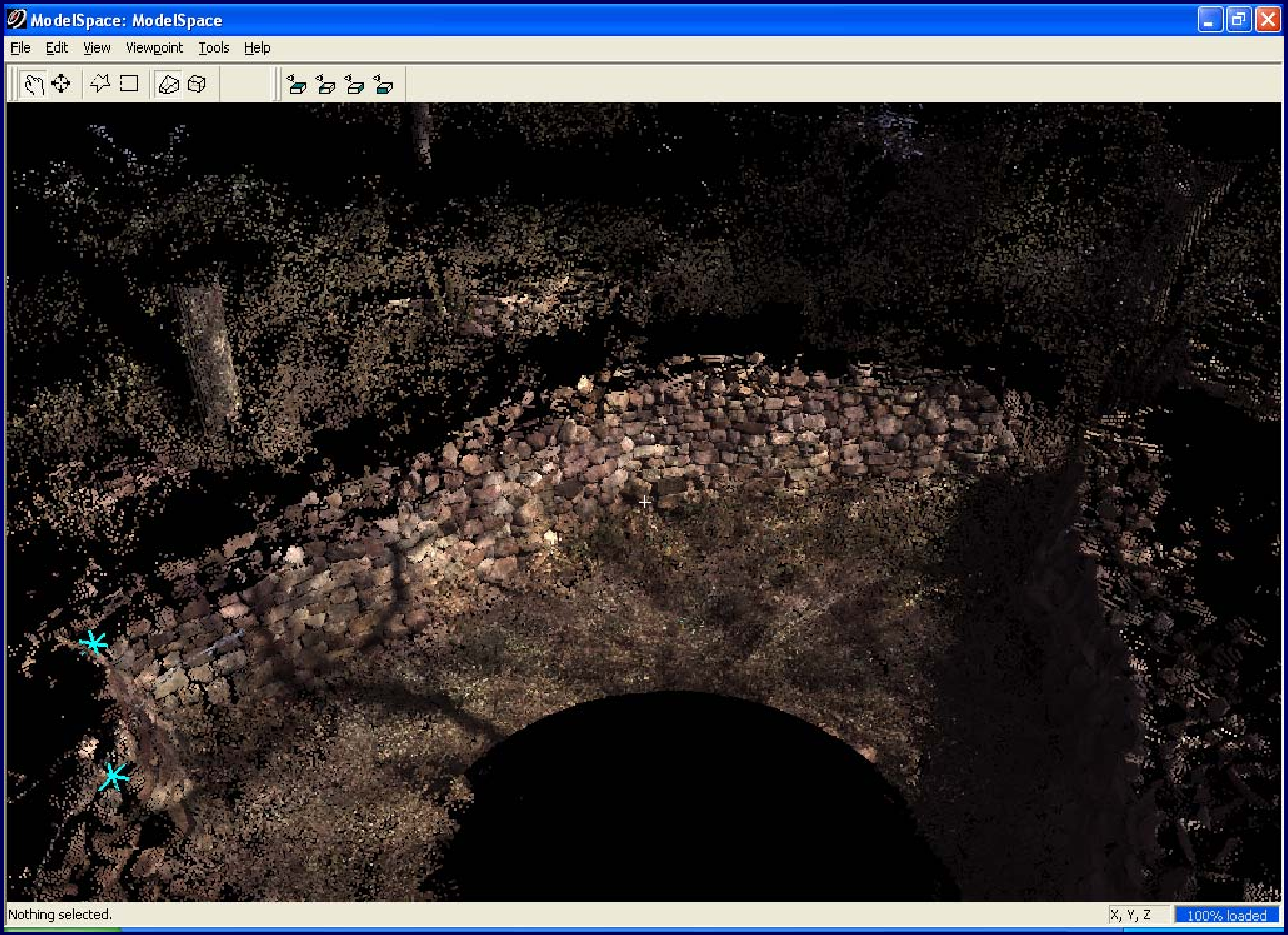
Accessing Virtual Artifacts – Interacting with Site

Thulamela Site, Kruger Park, South Africa



Unforeseen
Problems

Raw Laser Scan



Scanning Under the Beobob Tree

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- NSF grant IIS-0121239
- Stanford Archeology Center and Prof. Ian Morris for providing access to Monte Polizzo.
- Team that went to Monte Polizzo
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