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

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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

Geometry
- Range images
- Registration
- Surface generation

Texture
- Photographs
- Texture-geometry registration
- Texture map generation
- Texture processing
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:

- $a = \cos^{-1}(N_1 \cdot N_2) < \text{angle threshold}$
- $d = \max(|R_{12} N_1|, |R_{12} N_2|) < \text{distance threshold}$
Segmentation and 3-D Registration Lines
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

Range data (Geometry) + Images (Appearance) = Textured model
Shadows

Sun

Geometry (occluder)

Cast shadow

Image

Camera
Shadows as features

Geometry + Sun position

Shadows in 3D world

Image

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

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

Components

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

- Head tracker
- See-through head-worn display
- Glove
- Hand tracker
Accessing Virtual Artifacts - Interacting with Site
Thulamela Site, Kruger Park, South Africa
Unforeseen Problems
Scanning Under the Beobob Tree
Acknowledgements

- NSF grant IIS-0121239
- Stanford Archeology Center and Prof. Ian Morris for providing access to Monte Polizzo.
- Team that went to Monte Polizzo
  - Prof. Steven Feiner
  - Prof. Lynn Meskell
  - James Conlon, Benjamin Smith, Hrvoje Benko, Edward Ishak
- Alias Systems