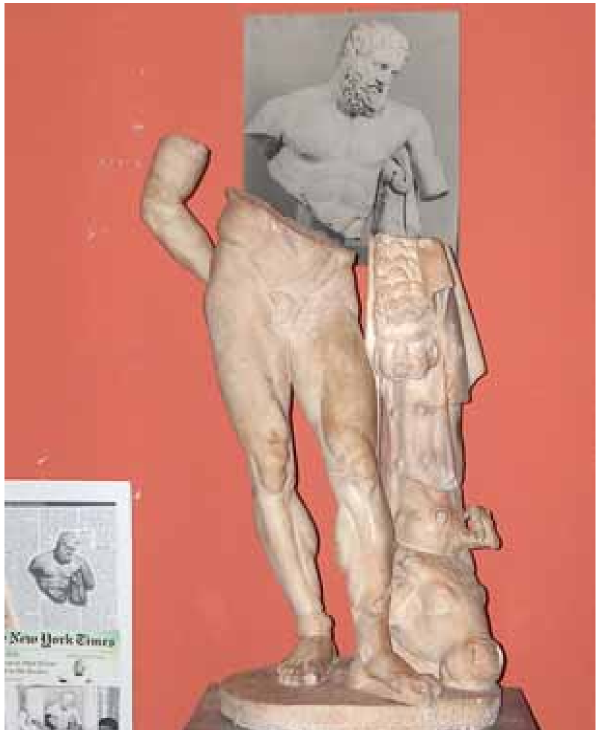

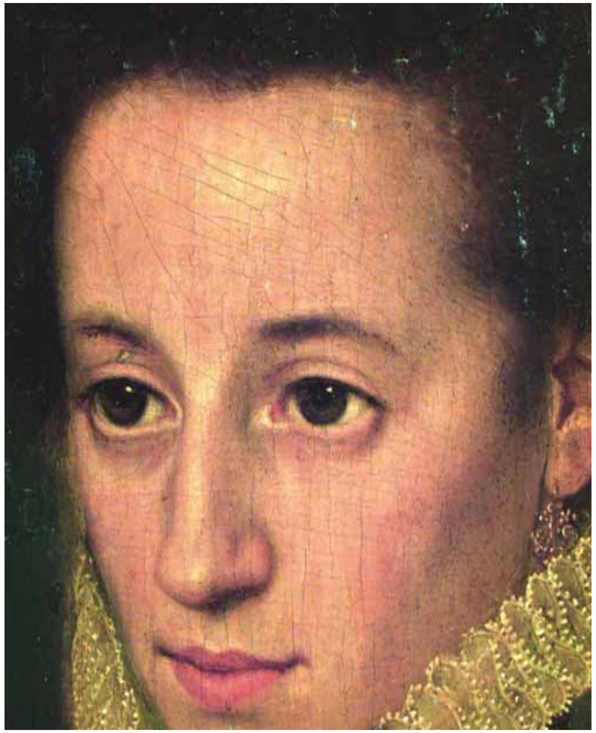

# HIGH DEFINITION 3D-SCANNING OF ARTS OBJECTS AND PAINTINGS

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[3]Centre de Rcherche et de Restauration des Musées de France, France

# Why 3D modeling of Cultural Heritage objects?
# Case of lost or damage

Buddha of Bamiyan, Afghanistan:

<u>Before March 2001:</u>
- 53 m high
- tallest representation of a standing Buddha
- niche full of frescos

<u>After March 2001:</u>
- empty niche
- no more frescos
- risk of collapse

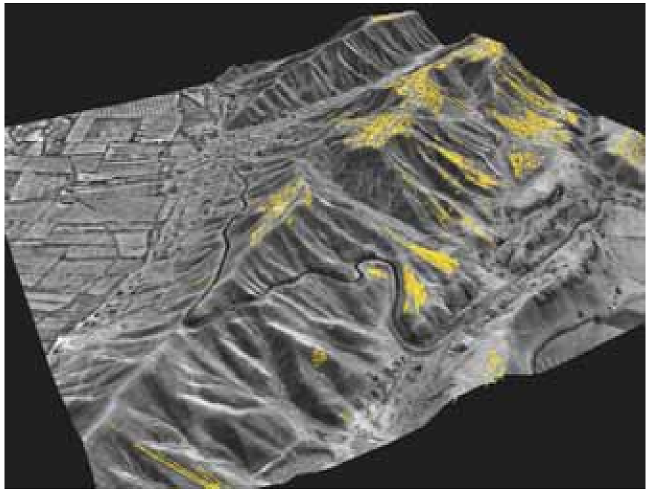
3D modeling from old images

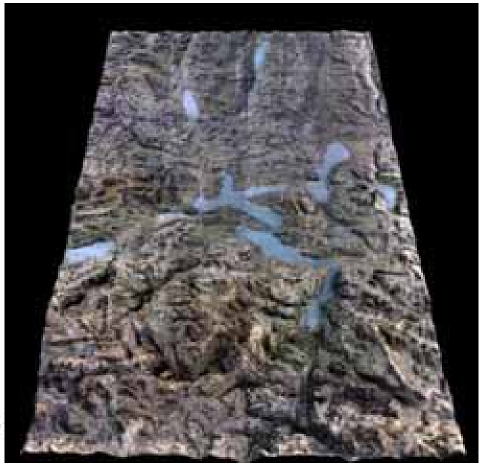
# Why 3D modeling of Cultural Heritage objects?
## Case of physical replica

# Why 3D modeling of Cultural Heritage objects?

....

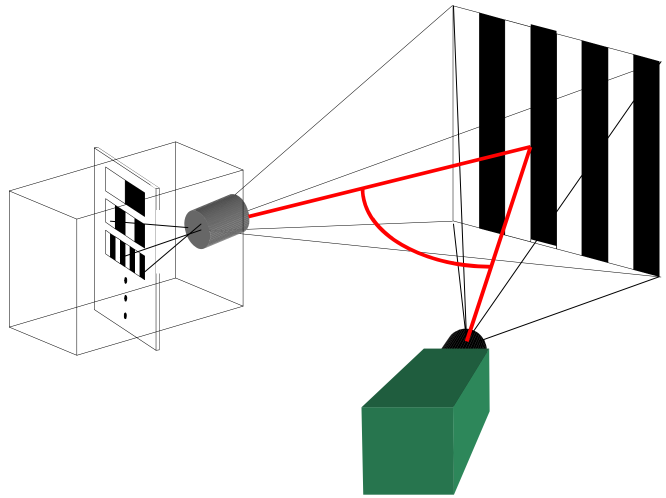
- Documentation
- Education resources
- Interaction without risk of damage
- Virtual tourism and virtual museums
- Maintenance
- ...





# 3D modeling of Cultural Heritage objects

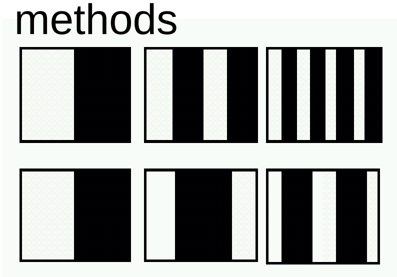
## Active Sensors - Coded Structural Light System



- Projecting a set of known patterns onto the object
- Grabbing the images with the a camera
- Correspondence problem solved by system calibration parameters & known geometry of the patterns (*decodification*)

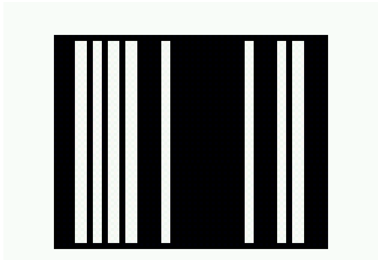
<u>Time-multiplexing</u>

- Binary codes
- n-ary codes
- **Gray code + phase shifting**
- Hybrid methods



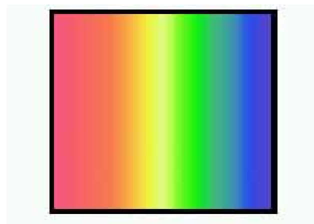
<u>Spatial codification</u>

- Non-formal codification
- De Bruijn sequences
- M-arrays



<u>Direct Codification</u>

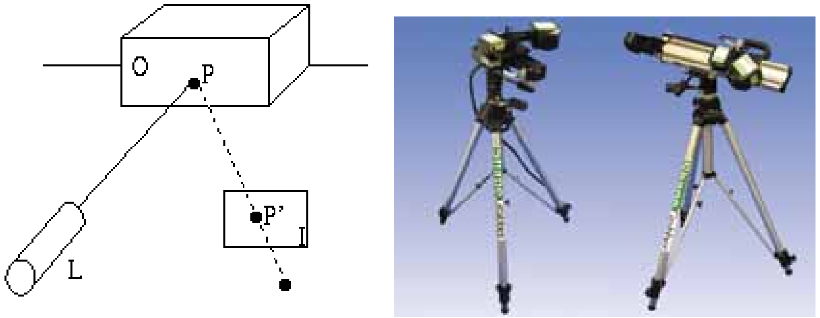
- Grey levels
- Color



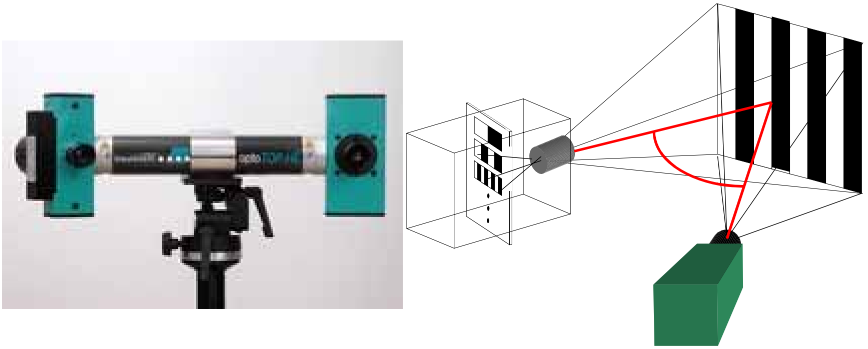
*Salvi et al., 2003*

# 3D modeling of Cultural Heritage objects
## Active Sensors – Triangulation based systems

| Triangulation based systems | Laser light | Coded structured light |
|---|---|---|
| Weight and price | Identical | Identical |
| Speed | | Faster |
| Sensitivity to ambient light | Less | |
| Speckle noise | | Less |
| Penetration into object surface | | No |
| Imaging for texture mapping | | Yes |
| Depth of view | Larger | |
| Eye safety | | Better |




**Laser light**



**Coded structured light**

# The 3D modeling work

**Goal:**

Generation of precise digital model for visualization, documentation and possible physical replica production

- Herakles statue
- ca 1 m height
- Antalya Museum

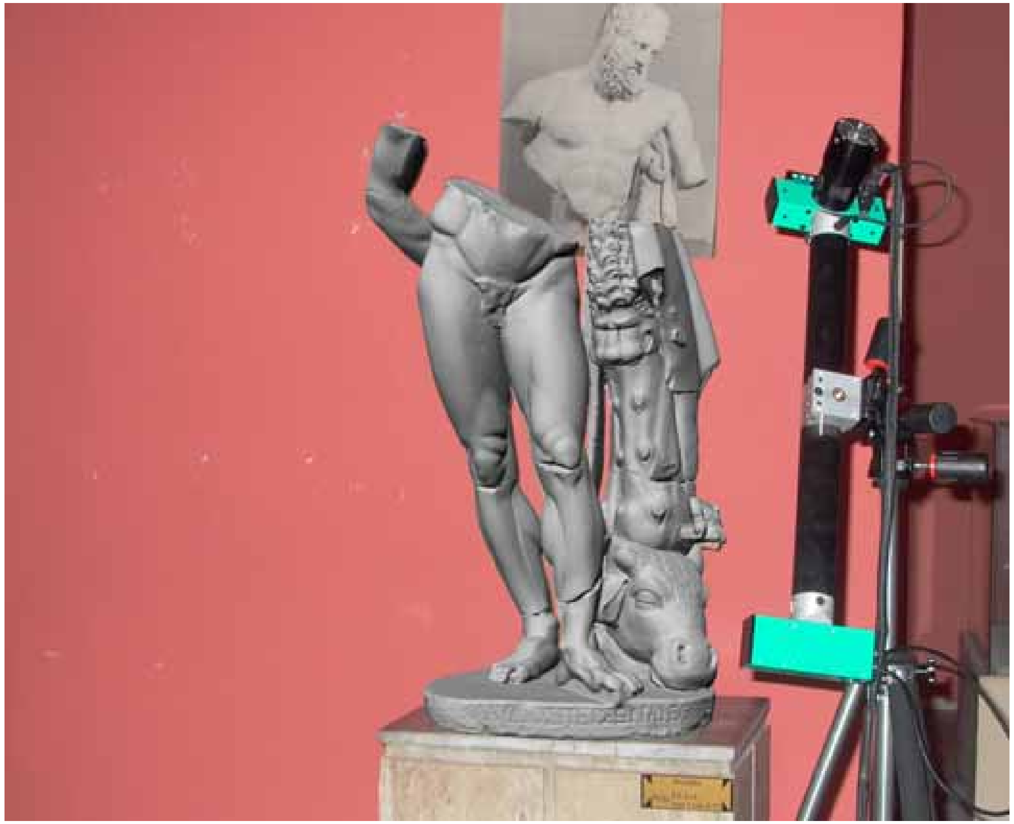
- Khmer head
- ca 30 cm height
- Rietberg Museum, Zurich

- Lady Praying
- 20x30 cm
- Louvre Museum, Paris

# Active Sensors: Breuckmann systems



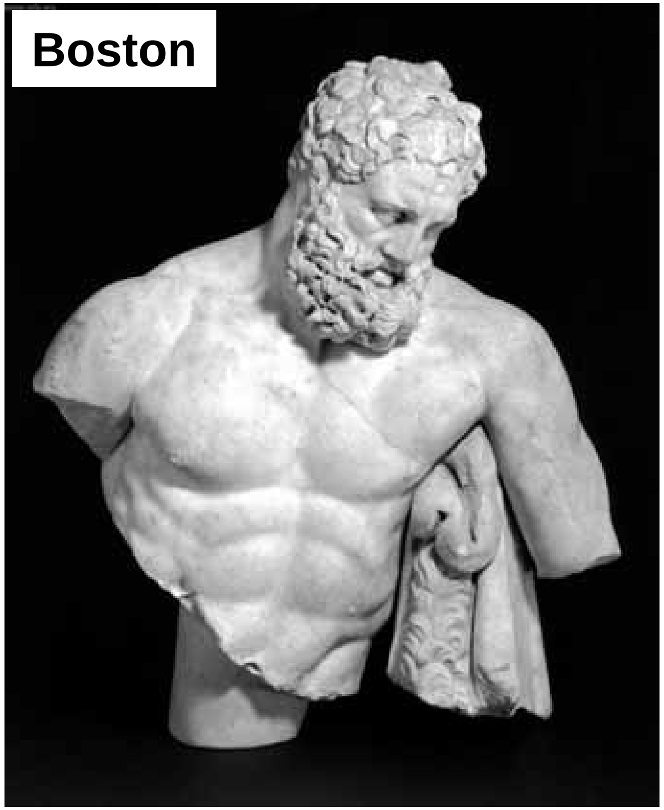
| | optoTOP-HE | optoTOP-SE (3) | triTOS (3) |
|---|---|---|---|
| Field of View (mm) | 480x360 | 400x315 | 80x60 |
| Depth of View (mm) | 320 | 260 | 40 |
| Acquisition time (sec) | **<1** | **<1** | **<1** |
| Weight (kg) | 2-3 | 2-3 | 2-3 |
| Digitization (points) | 1280x1024 (1) | 1280x1024 | 1280x1024 |
| Base length (mm) | 600 | 300 | 50 |
| Triangulation angle (deg) | $30^0$ | $30^0$ | $30^0$ |
| Projector | 128 order sinus patterns | 128 order sinus patterns | 128 order sinus patterns |
| Lamp | 100W halogen | 100W halogen | 100W halogen |
| Lateral resolution (µm) | ~350 | ~300 | ~60 |
| Feature accuracy (relative) | 1/15000 | 1/10000 | 1/10000 |
| Feature accuracy (µm) | **~45** | **~50** | **15** |



**3D modeling of the Weary Herakles statue**

**http://www.photogrammetry.ethz.ch/research/herakles/**

# The Weary Herakles Statue - Story


- Marble statue of the Greek demi-god Herakles (2nd c.AD).
- Copy of the original bronze statue of famous sculptor Lyssipos of Sicyon (4th c.BC)
- Broken in two parts.
- The upper half, seen in the USA in the early 1980s (Boston Museum of Fine Arts).
- The lower half, excavated in Perge (Antalya, TR) in 1980 by Prof. J. Inan, (now in the Antalya Museum).

# The Weary Herakles Statue - Story

- According to Turkish law, Turkish antiquities state property since Ottoman times 1906.
- The Turkish government asked the upper half.
- The Boston MFA refused the petition, saying that:

"the statue may have broken in ancient times and the upper torso may have been taken from Turkey before the year 1906".

# Aim of the Project


**The Aim**

- To record and model both the lower and the upper part and
- **bring these partial models together in the computer**,
- so that at least there the complete statue could be seen, appreciated and analyzed.

- The lower part in the Antalya Museum was scanned in September 2005.

- Access to the upper part in the Boston MFA was denied.

**The Project**

In cooperation with

ETH Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology Zurich

breuckmann

info(+)TRON "Birlikte Geleceği Yaratıyoruz"

# Data Acquisition

- Digitization in the Antalya Museum in September 2005

- Breuckmann optoTOP-HE coded structural light system


# Scanning in the Antalya Museum

- Breuckmann optoTOP-HE system
- 1 ½ days on site work with 67 scans (56+11)
- Each scan 1.25M points
- Totally 83.75M points

preparation

scanning

# Scanning in the Antalya Museum

optoTOP-HE, very flexible system

# Postprocessing Workflow

- Registration (LS3D)
  - + Pairwise registration
  - + Global registration
- Point cloud editing (Geomagic Studio 6)
  - + Cropping the Area Of Interest
  - + Noise reduction
  - + Down-sampling
- Surface triangulation and editing (Geomagic Studio 6)
- Texture Mapping (VCLab's 3D Scanning Tool, CNR, Pisa)
- Visualization (PolyWorks 9.0.2)

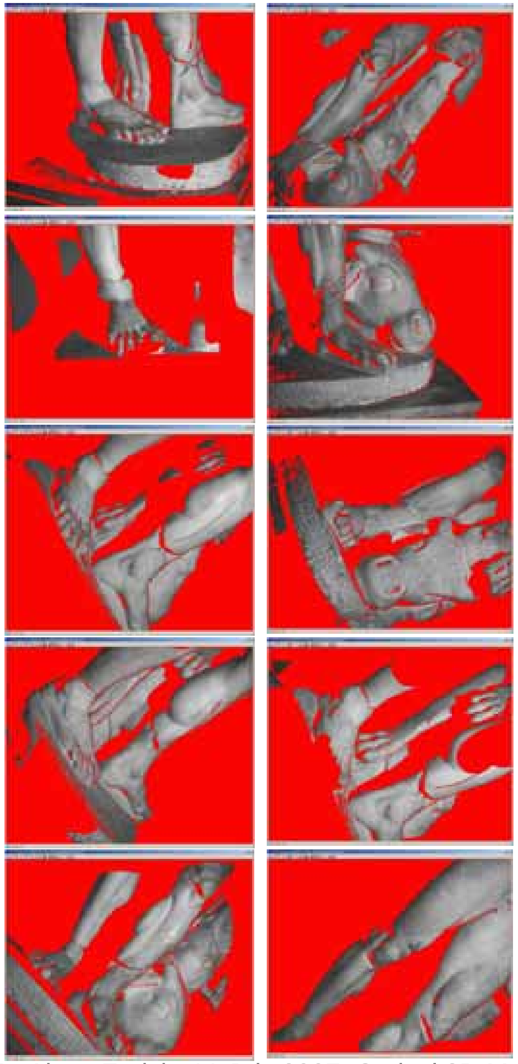
# Registration – Pairwise registration

- 234 consecutive pairwise LS3D matching. The average sigma naught is **81 microns**.

Example: Registration of 1st and 2nd scans
Note: 3x3 down-sampling for better visualization

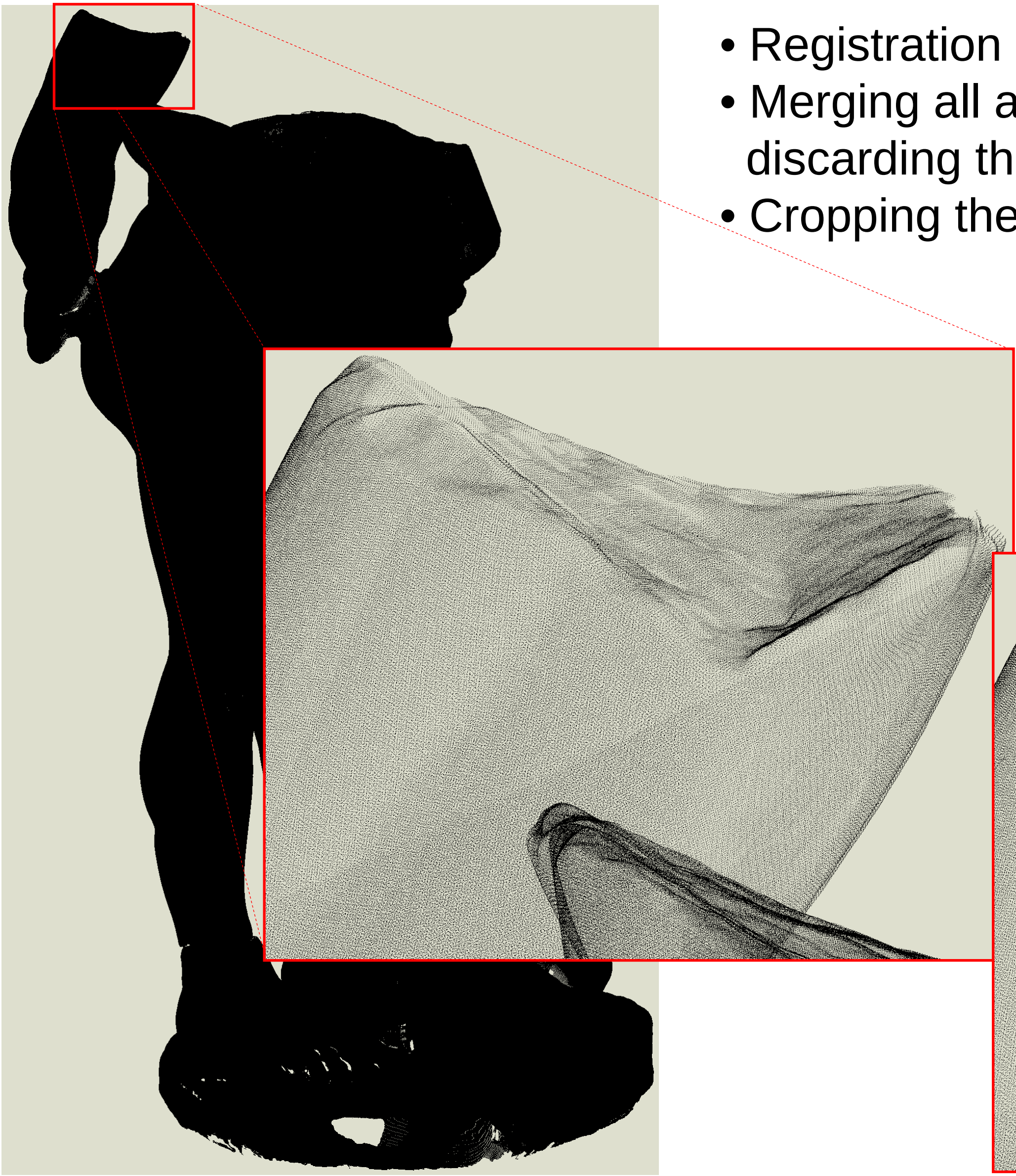
# Registration – Global registration

- Global registration with the block adjustment by independent models solution
- Sigma naught **47 microns**, in agreement with the system specifications



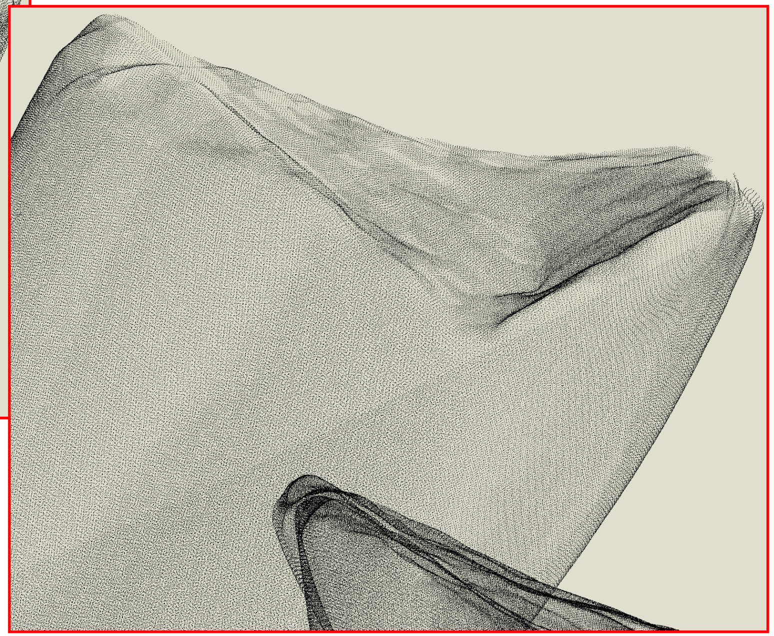
Example: Registration of first 10 scans
Note: 3x3 down-sampling for better visualization

# Point Cloud Editing – Noise reduction

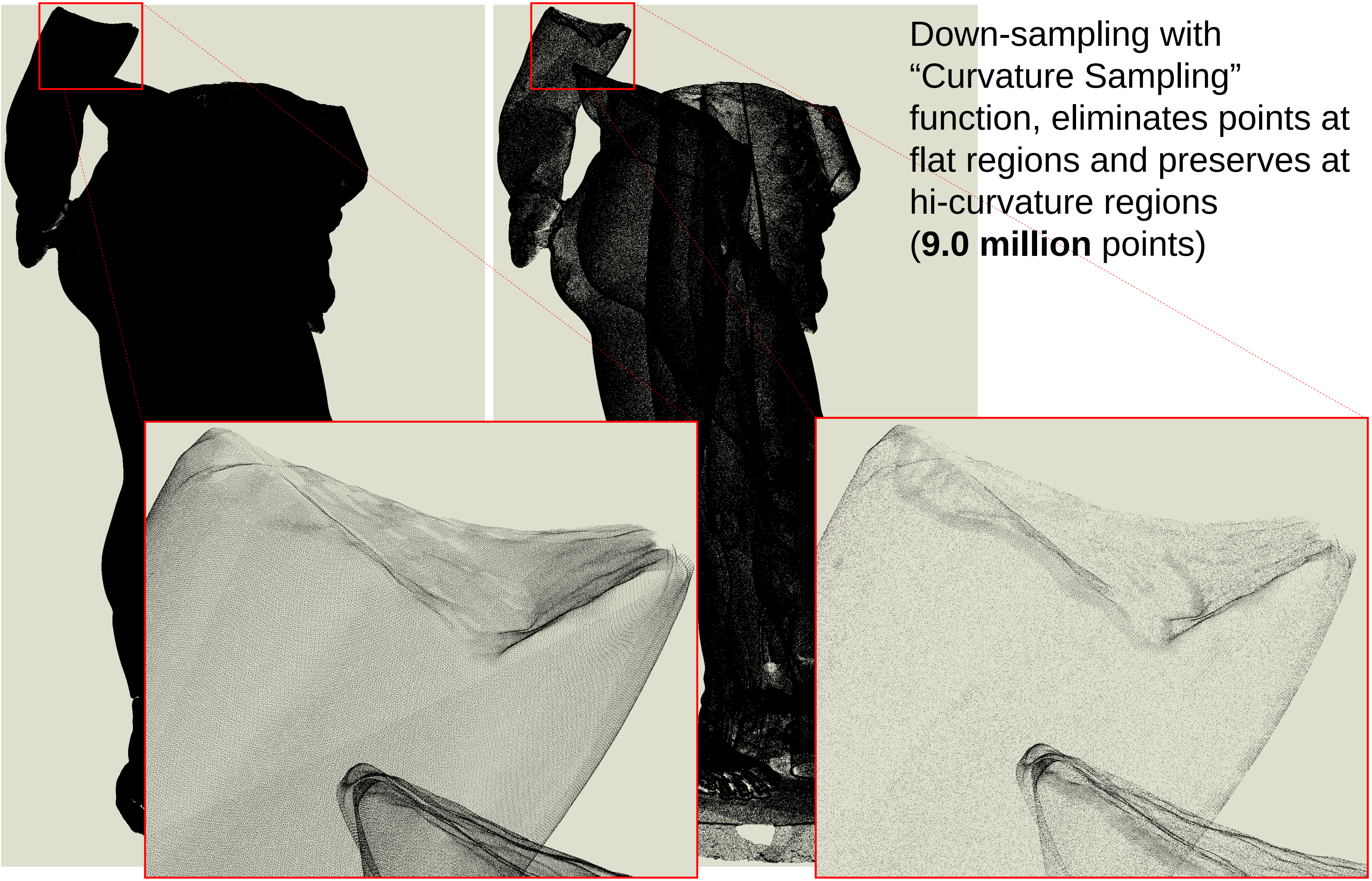


- Registration (ALL= 83.75M = **87.8 million** points)
- Merging all as one XYZ file, discarding the NODATA points (**36.2 million** points)
- Cropping the AOI (**33.9 million** points)

- Noise reduction with “Reduce Noise” function (medium level)



# Point Cloud Editing – Down-sampling

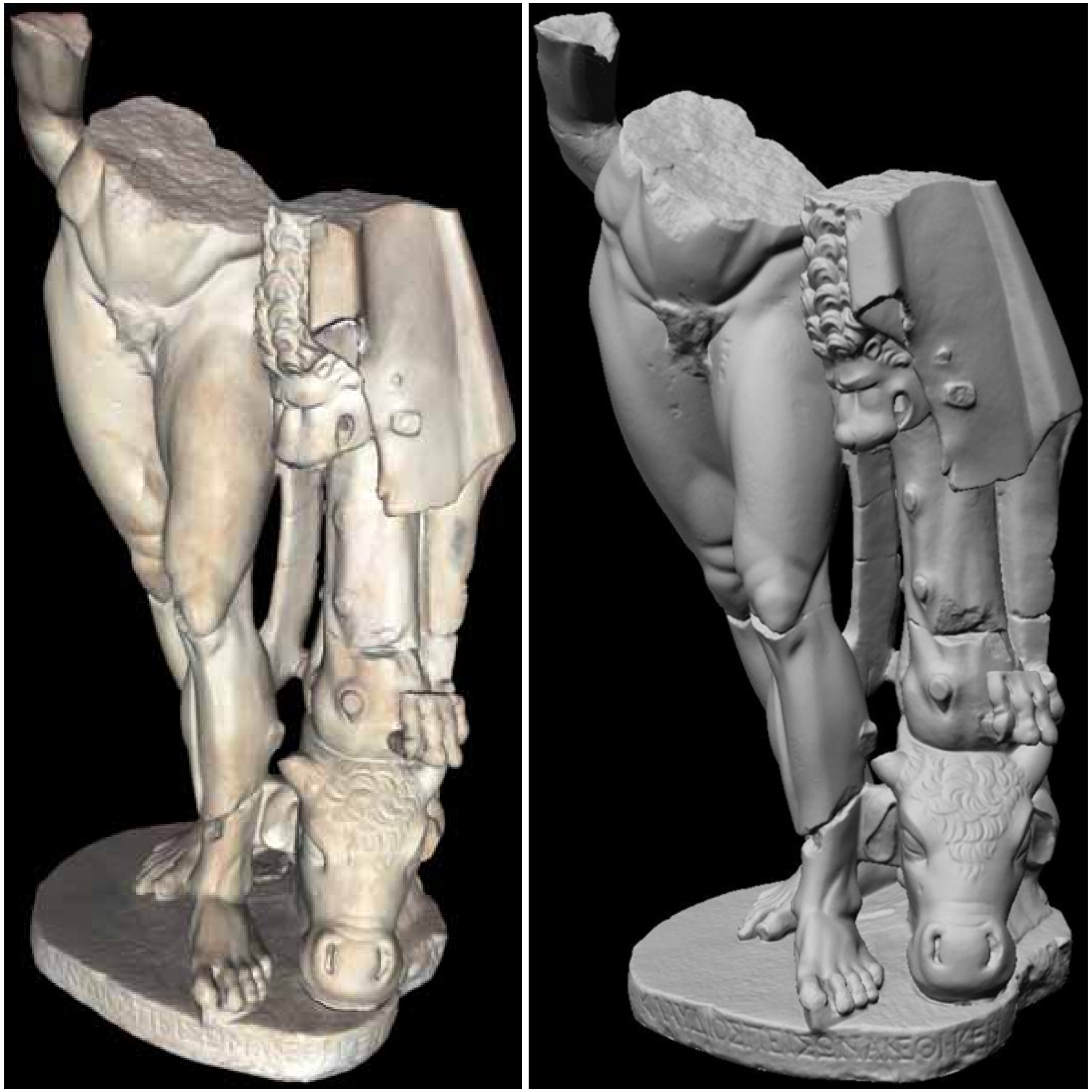


Down-sampling with "Curvature Sampling" function, eliminates points at flat regions and preserves at hi-curvature regions (**9.0 million** points)

# Surface Triangulation and Editing

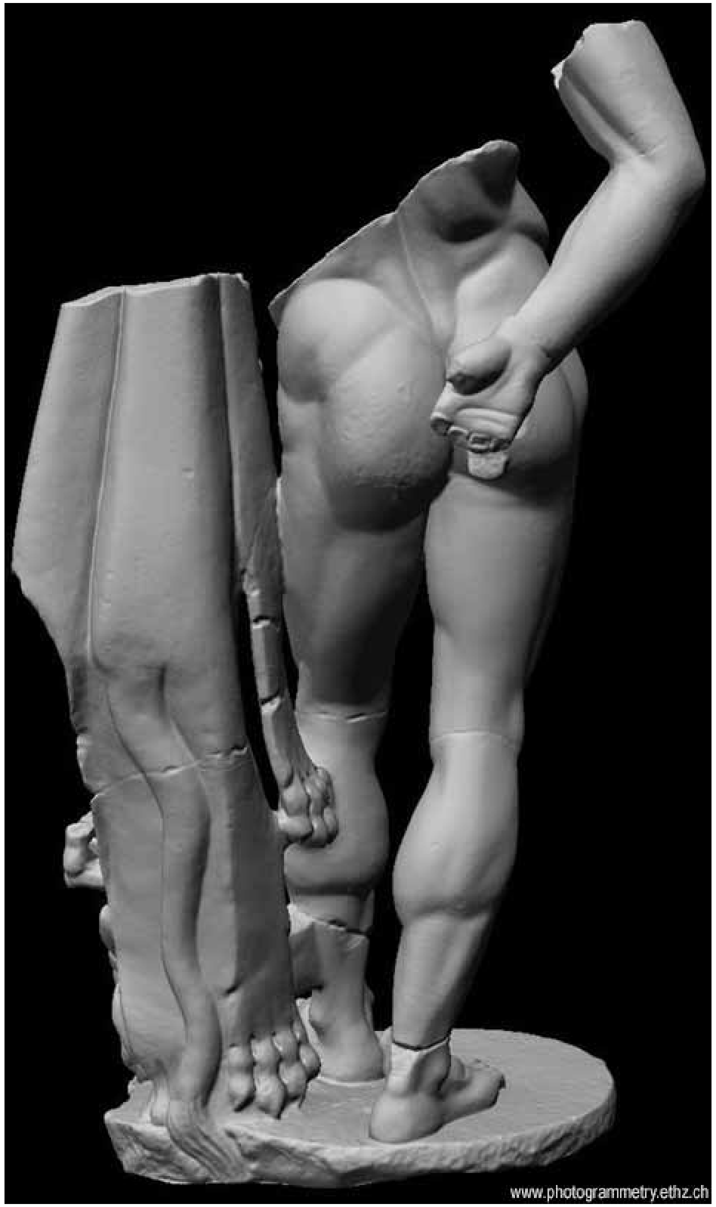
- Finally **9.0 million points => 5.2 million triangles**
- Memory problems with Geomagic if greater number of target triangles, e.g. 10 million
- Data holes due to complexity & inner concave parts
- Filling the holes is the most tedious step of the project

# Texture Mapping



- Leica Digilux1, 4Mpixel CCD camera
- The Veawer module of VCLab‘s 3D Scanning Tool (ISTI-CNR, Pisa, Italy)

## Visualization – (gray shaded)


- Better lighting & shading with PolyWorks IMView.

# Visualization

Back projection of the 3D model into image space

**http://www.photogrammetry.ethz.ch/research/herakles/**

# Gained experiences

- The coded structural light system is a mature technology and allows high resolution documentation of cultural heritage objects.
- The hardware component, optoTOP-HE worked well.
- Editing the surface is the most tedious step of the whole modeling pipeline. Need for sophisticated algorithms & software.
- Texture mapping is not fully available in either software.

**http://www.photogrammetry.ethz.ch/research/herakles/**

# Result


**http://www.photogrammetry.ethz.ch/research/herakles/**

# 3D Modeling of a Khmer Head

http://www.photogrammetry.ethz.ch/research/khmer/

# The Khmer head project

- Bodhisattva Head
- Cambodia - Khmer period
- Bayon style, $12^{th}$-$13^{th}$ a.c.
- 28 cm in height
- Sandstone
- Collection of Rietberg Museum, Zurich

# The Khmer head project – Data acquisition

- Data acquisition: 3-4 hours on site work
- Breuckmann OptoTOP-SE coded structural light system
- 18 scans, each scan 1.3 million points (totally 23.6 million points)

# The Khmer head project – Data processing

**Point cloud registration**

- 52 Pairwise registration with the Least Squares 3D Surface Matching (LS3D) method + global registration (final **28 microns** sigma0 value)

**Surface generation & editing**

**Geomagic Studio**

Importing the point clouds
Point cloud merging
Defining the AOI
Noise reduction
Down sampling
Surface triangulation
Surface editing

**PolyWorks**

Importing the point clouds
Surface triangulation
Surface merging
Defining the AOI
Surface editing

**Texture mapping & visualization**

# The Khmer head project – Data processing

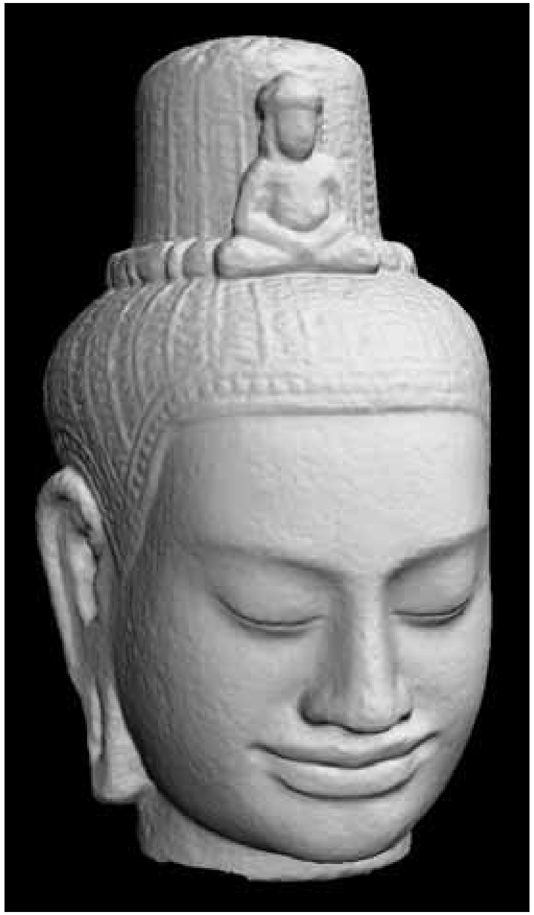
## Geomagic Studio

• Full automatic import functionality

• Import
& merge all the pointclouds
& noise reduction
& pointcloud down-sampling

• Surface triangulation: fully 3D and automatic, limited user interaction

• Preserve the high frequency details of the object geometry successfully by considering all points in one processing sweep



# The Khmer head project – Data processing

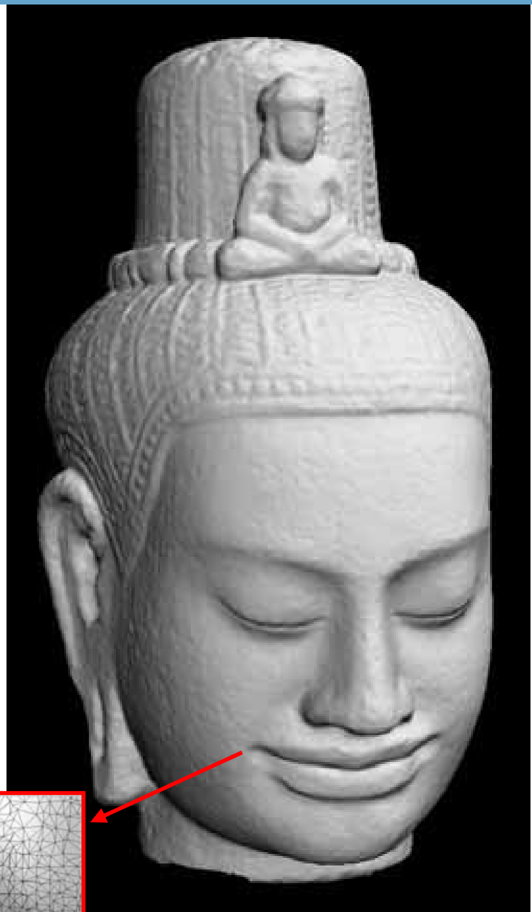
## PolyWorks

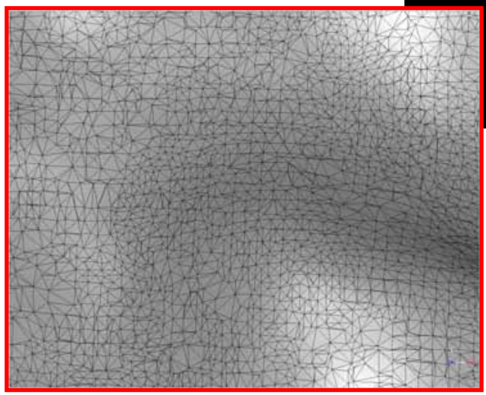
• Data import is not automatic

• Each pointcloud individually imported,
subsequently converted to surface by 2.5D triangulation.
Each pointcloud interactively rotated to the viewing angle of the data acquisition instant.
+ Advantage: less topological errors
-Disadvantage: partial processing, not one processing sweep

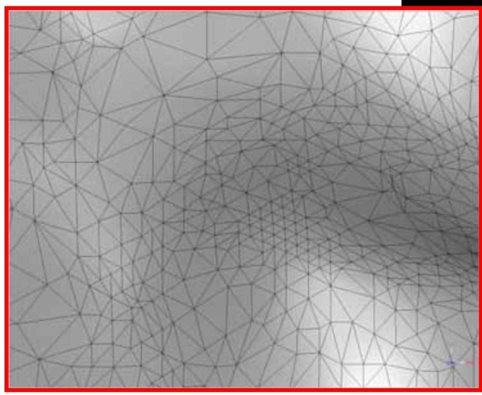
• Merge individual 2.5D surface → 3D manifold
• Noise reduction

# The Khmer head project – Data processing





**Geomagic Studio**
3.9 million triangles



**PolyWorks**
0.6 million triangles

# The Khmer head project – Data processing

| | PolyWorks | Geomagic |
|---|---|---|
| Data import | Manual | Automatic |
| Triangulation | | |
| Type | 2.5D | 3D |
| Optimality | Better | |
| Detail preservation | | Better |
| Topological correctness | Better | |
| Automatisation | | Better |
| Editing capabilities | | Better |
| Performance | Better | |
| Visualization | Better | |
| User friendliness | | Better |
| Stability | Better | |

PolyWorks 9.0.2

Geomagic Studio 6

# The Khmer head project – Texture mapping & Viz

- Special illumination to avoid shadows
- Diffuse reflection
- Texture mapping,
in-house developed (by T. Hanusch)

# The Khmer head project – Texture mapping & Viz

Grey shaded model

Texture mapped model

# The Khmer head project – Texture mapping & Viz

Picture

3D model

# Lady Praying project

# Lady Praying project

- **Task**: high resolution digitization of Lady Praying painting, ca. 60 micron point spacing

- FOV of triTOS sensor adapted to the task,
ca. 15-20 micron feature accuracy

- 25 scans

- OPTOCAT used for post-processing

- In spite of ~100 micron depth difference, successful alignment by OPTOCAT.

# Lady Praying project

Shaded view of the 3D model

Z-coordinate magnified by a factor of 50

# Conclusions

- Coded structural light systems are a good solution for fast and precise object recording and modeling

- Hardware component worked properly with all the surface material (marble, sandstone, painting)

- Reached accuracy (ca 15-50 micron) might be not necessary in some archaeological applications

- Recovered 3D digital models useful for documentation or physical replica

- Employed modeling Software produced reasonable results
but any of them is not fully superior to others
=> multiple software should be used as the optimum solution!

**Thank you for your attention!**

**http://www.photogrammetry.ethz.ch**