



**HCU**

**HafenCity University  
Hamburg**

University for the Built Environment  
and Metropolitan Development

# **HAMBURG'S NEW UNIVERSITY**

Europe's first University for the Built Environment

**Thomas P. Kersten**

# **3D Point Clouds through Image-Based Low-Cost Systems**



# Outline of Presentation

- **Introduction**
- **Workflow**
- **Software Used**
- **Examples & 3D Comparison**
- **Conclusions & Outlook**



## Introduction

- Today, 3D recording of objects by standard techniques
- Alternative solution – camera based low-cost systems
- Different requirements for 3D models
  - ➔ reliable, precise, detailed, complete
  - ➔ geometric & visual quality, efficiency, data volume
- Photogrammetry & Computer Vision – model the world
- Automation in 3D modelling – the dream comes alive?



# Workflow

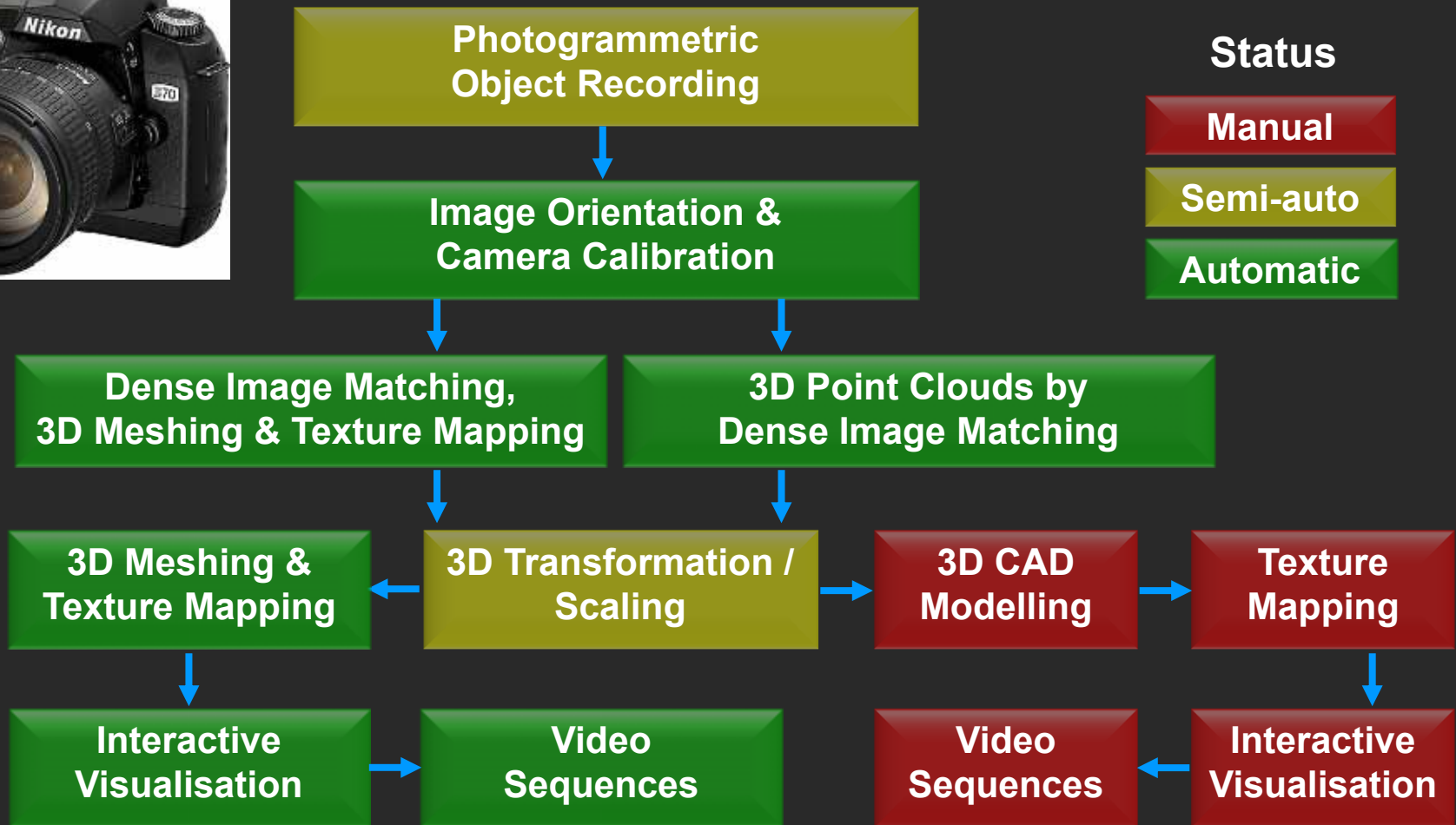


**Terrestrial laser scanner**  
~ € 80,000



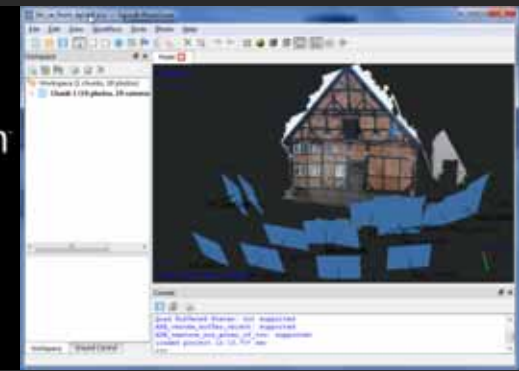
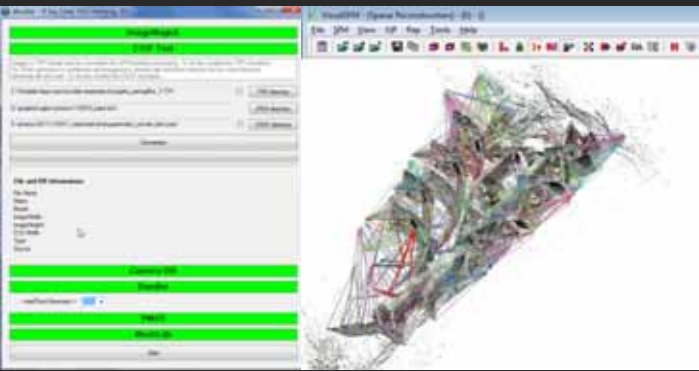
**Digital SLR camera**  
~ € 1,000

# Workflow



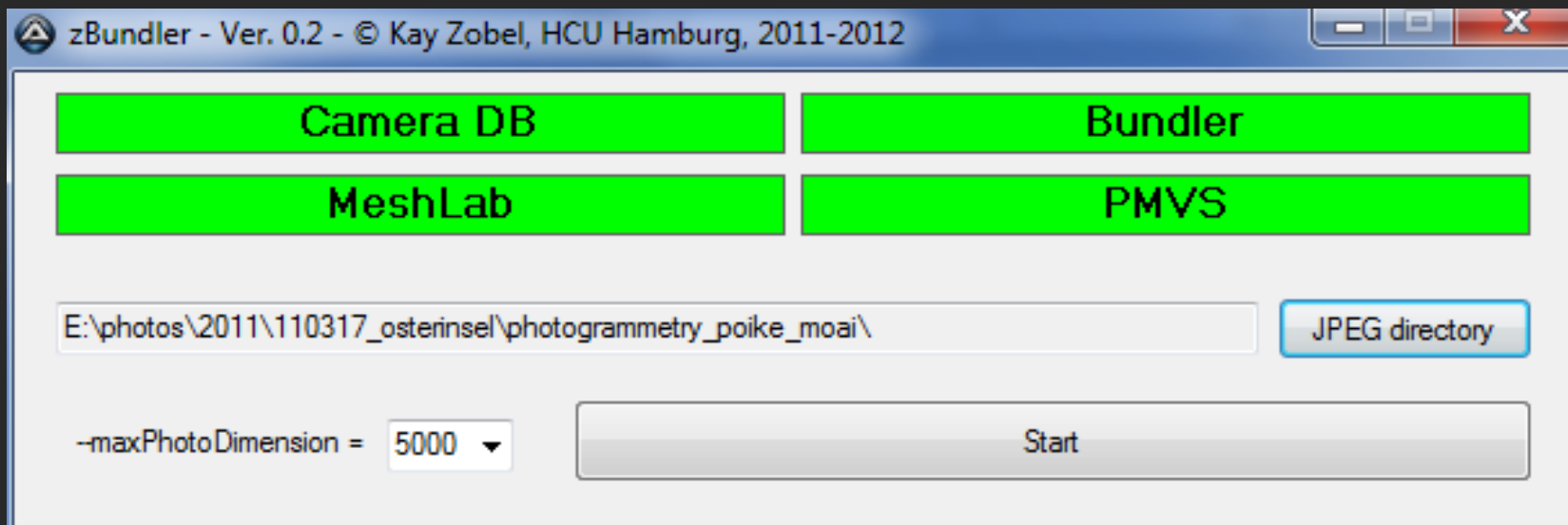
## Software used

- Open-source Software – Bundler & PMVS2
- Open-source Software – VisualSFM
- Webservice – Microsoft Photosynth
- Webservice – Autodesk Photofly | 123D Catch (beta)
- Low-cost software – Agisoft PhotoScan



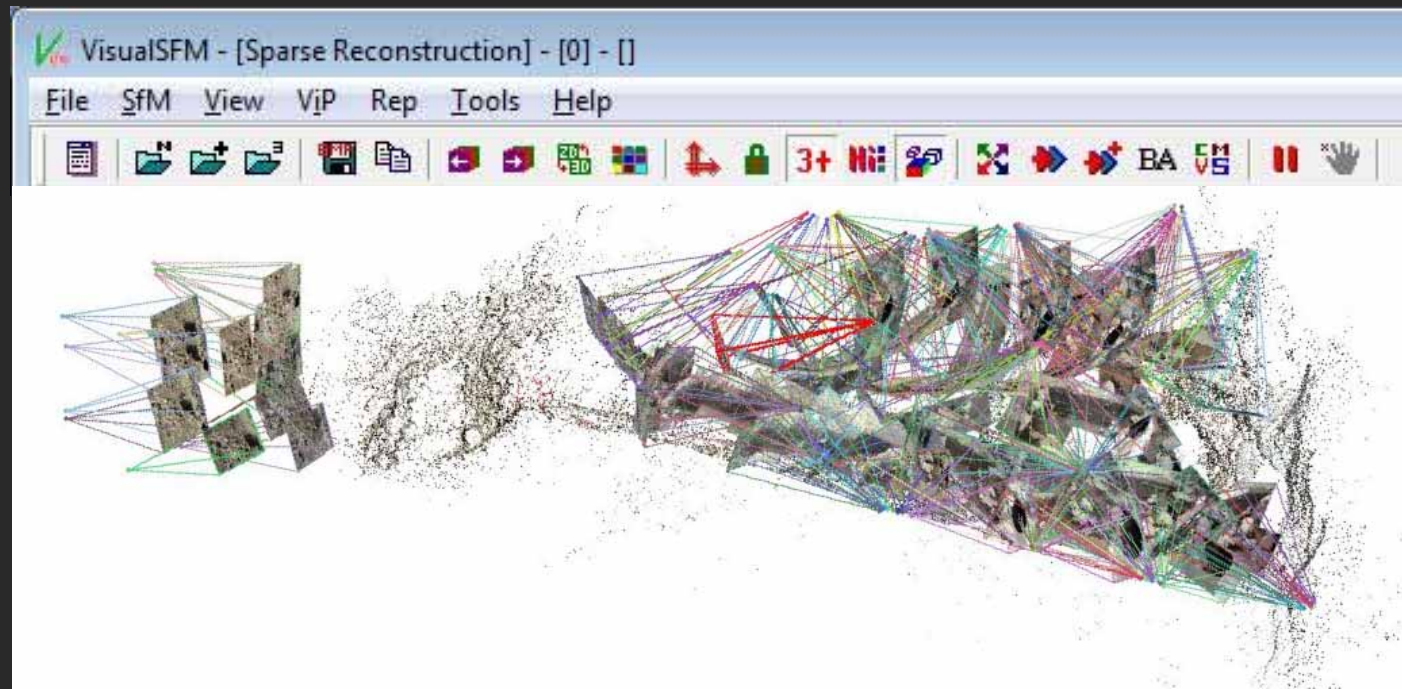
## Software used

- Bundler/PMVS2 (University of Washington, Seattle)
- Command-line based open-source software
- Automatic workflow with HCU graphical user interface
- Structure from Motion Algorithm (SIFT / RANSAC) & Dense Image Matching



## Software used

- Visual SFM (University of Washington, Seattle)
- Structure from Motion on Graphics Processing Unit
- Multicore bundle block adjustment
- Dense Image Matching by CMVS/PMVS2

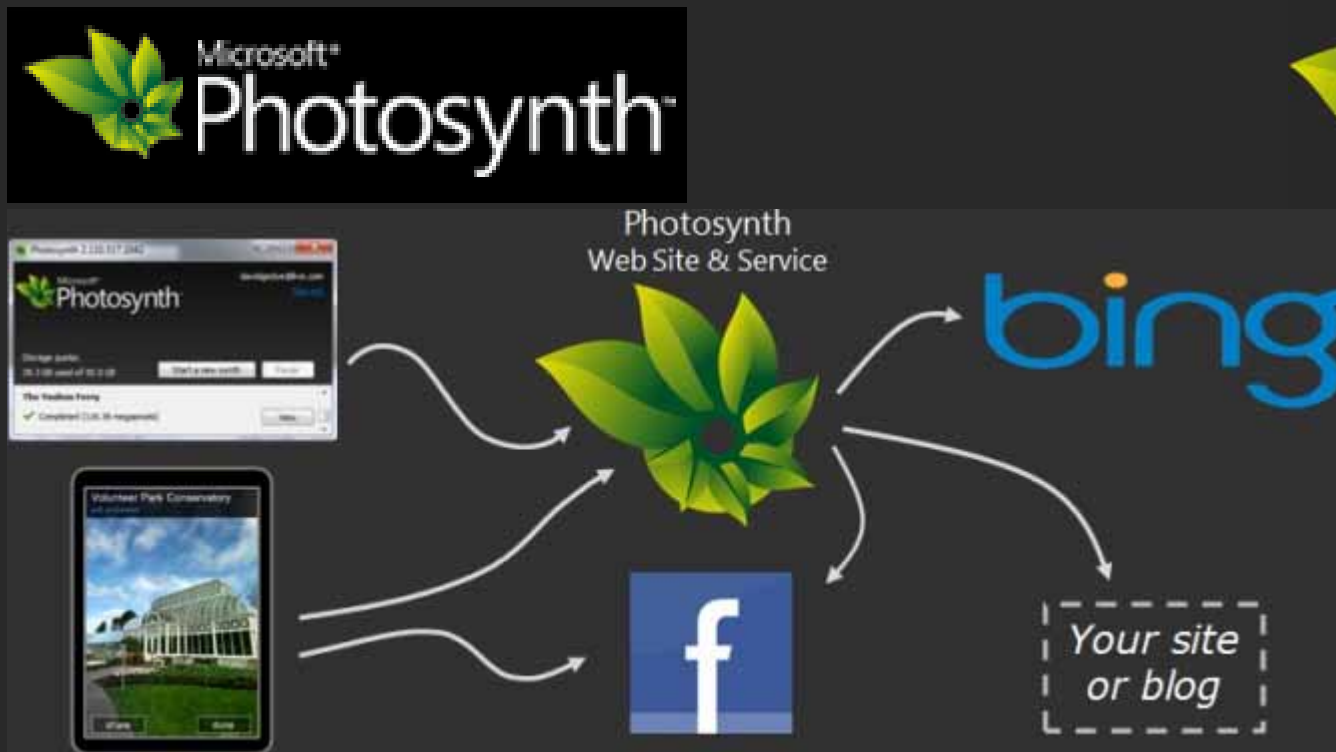




## Software used

- Webservice – Microsoft Photosynth
- Capture your world in 3D

<http://photosynth.net>



- Photosynth is a powerful set of tools for capturing and viewing the world in 3D. You can share these views with your friends on Facebook, publish them to Bing Maps, or embed them in your own Web site

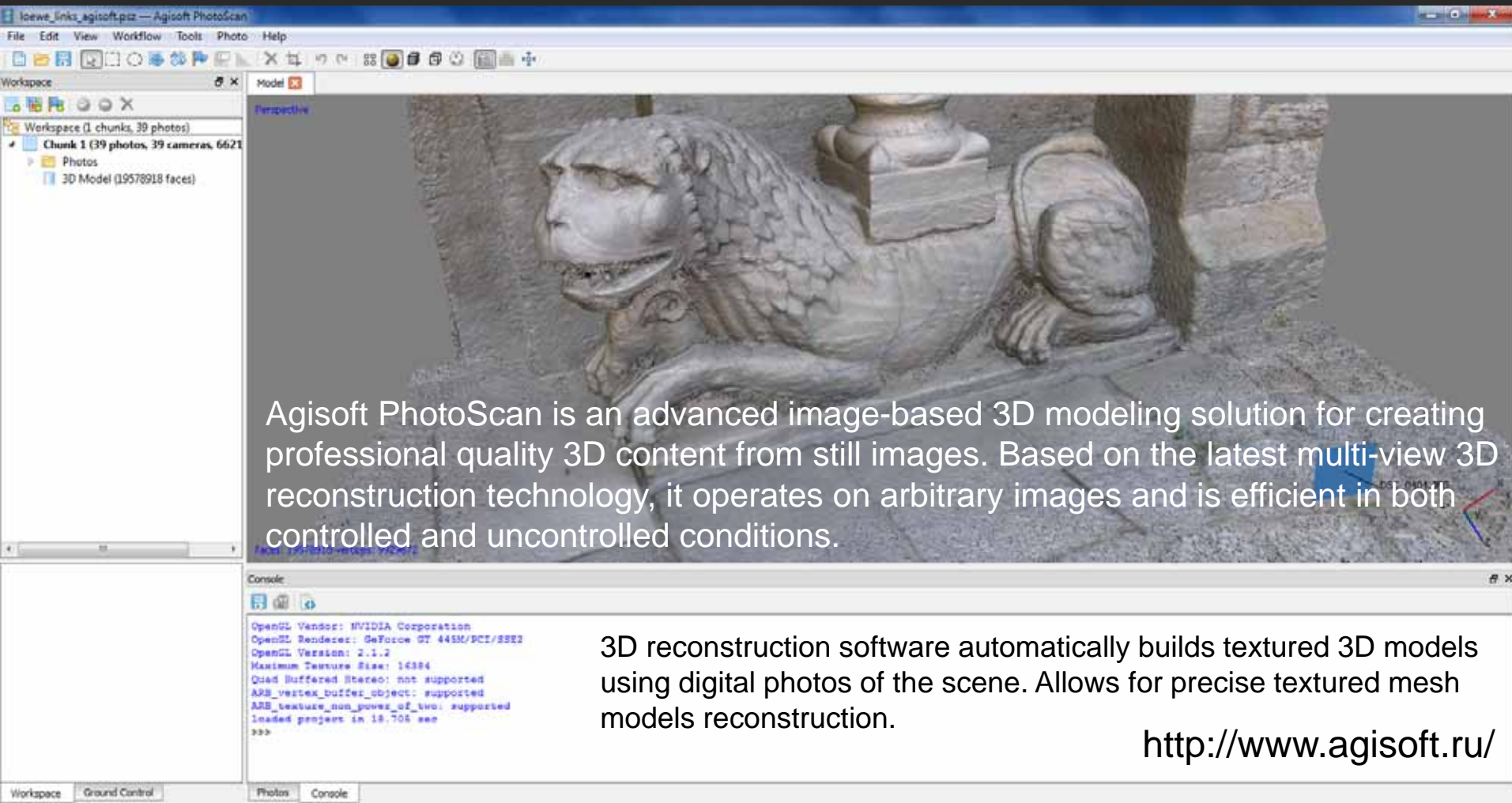
# Software used

- Webservice – Autodesk Photofly | 123D Catch (beta)



# Software used

## ■ Agisoft PhotoScan (Standard / Professional edition)

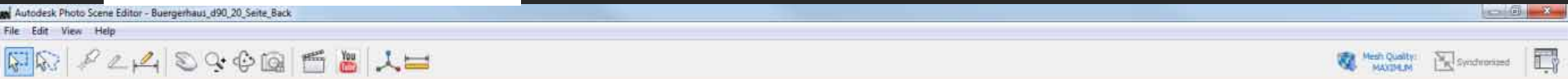


Agisoft PhotoScan is an advanced image-based 3D modeling solution for creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology, it operates on arbitrary images and is efficient in both controlled and uncontrolled conditions.

3D reconstruction software automatically builds textured 3D models using digital photos of the scene. Allows for precise textured mesh models reconstruction.

<http://www.agisoft.ru/>

# Software used



## Image acquisition configuration (example)

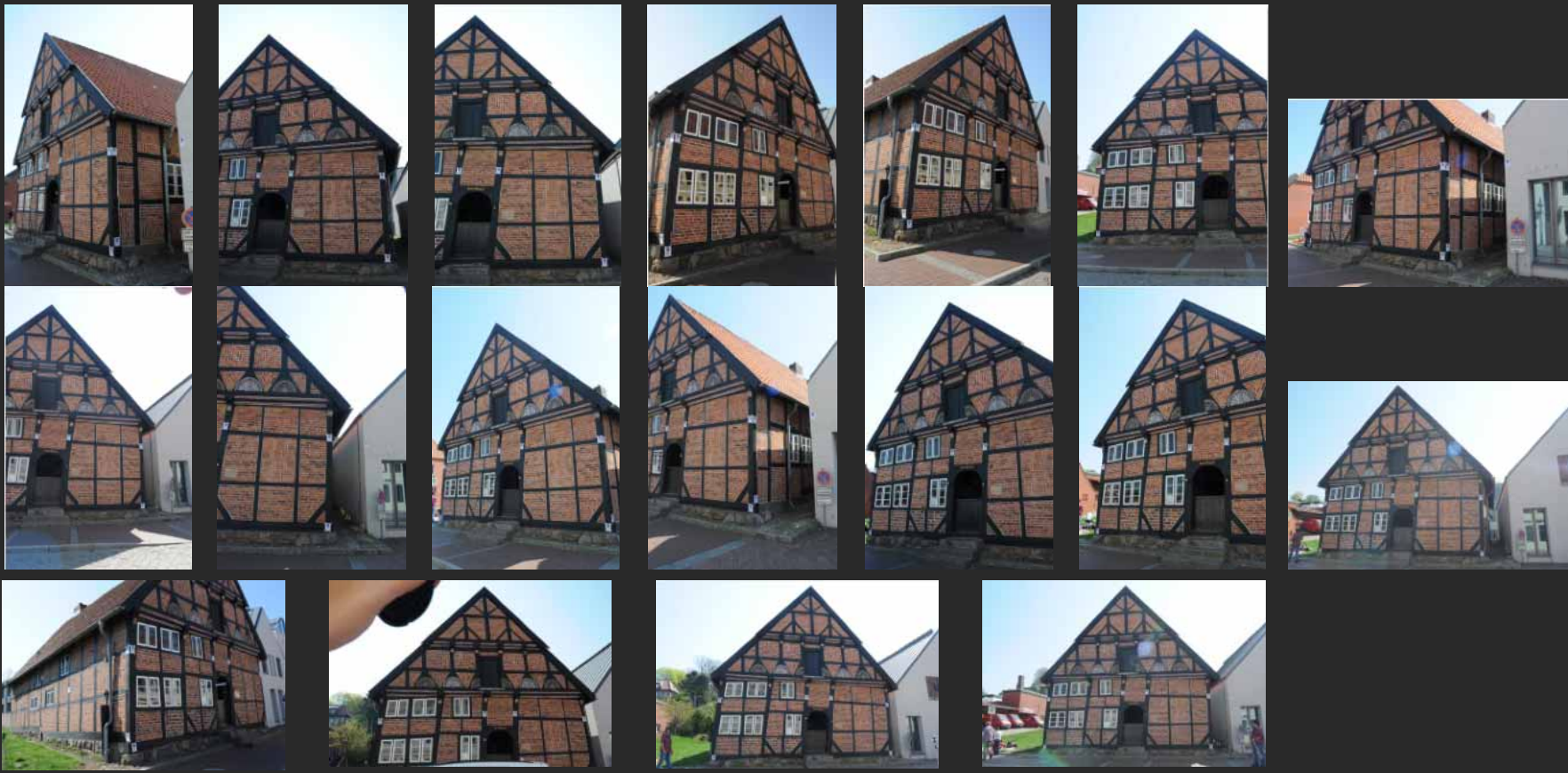


"Photo Scene Editor" of the town house in Bad Segeberg (Camera Nikon D90 with 18mm lens)



# Examples & 3D Comparison

- Object – Town house Bad Segeberg (front façade) from 1539/1606
- 19 images with Nikon D90 (4288 x 2848) using 20mm lens
- 3D comparison with laser scanning data from IMAGER 5006h

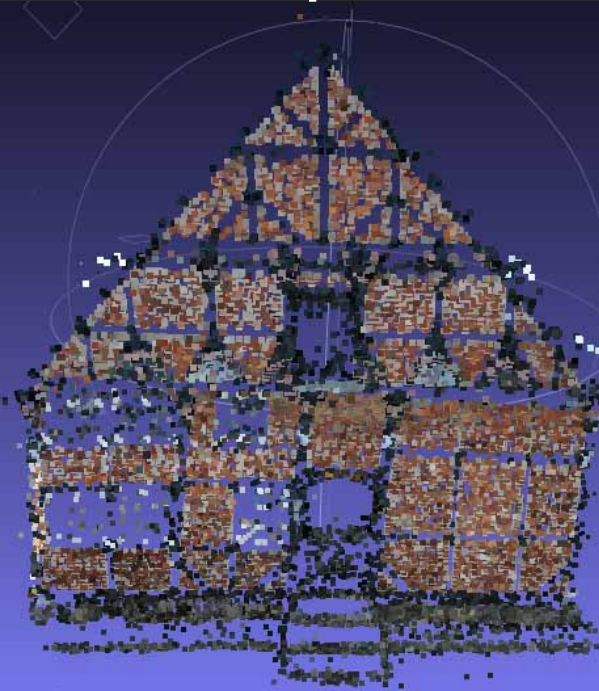


## Examples & 3D Comparison

- Object – Town house Bad Segeberg (front façade)
- Automatic generated point clouds & 3D meshes

### Photosynth

20.237 points



Vertices: 20237

### Bundler/PMVS2

1.016.874 points



Vertices: 1016874

### Photofly

272.350 points



Vertices: 272350  
Faces: 515447

## Examples & 3D Comparison

- Object – Town house Bad Segeberg (front façade)
- Automatic generated point clouds & 3D meshes

### VisualSFM

500.694 points



### PhotoScan

4.750.456 meshes



## Examples & 3D Comparison

- Object – Town house Bad Segeberg
- Automatic generated point clouds & 3D meshes

VisualSFM

10.005.361 meshes



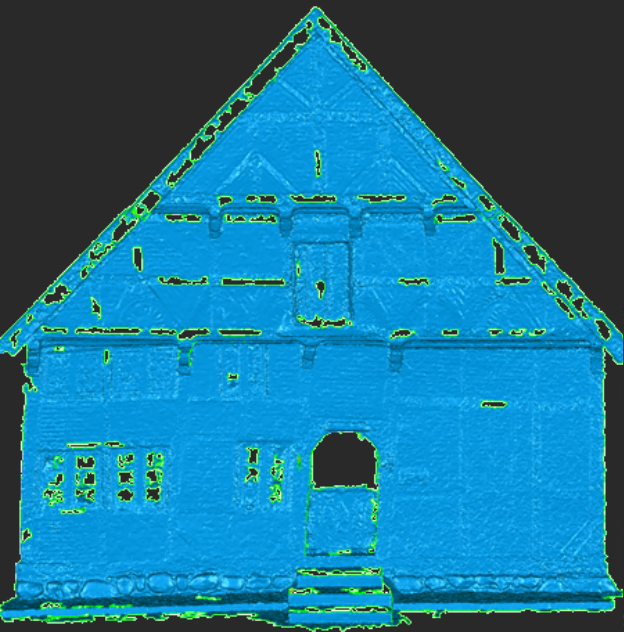


## Examples & 3D Comparison

- Object – Town house Bad Segeberg (front façade) from 1539/1606
- 19 images with Nikon D90 (4288 x 2848) using 20mm lens
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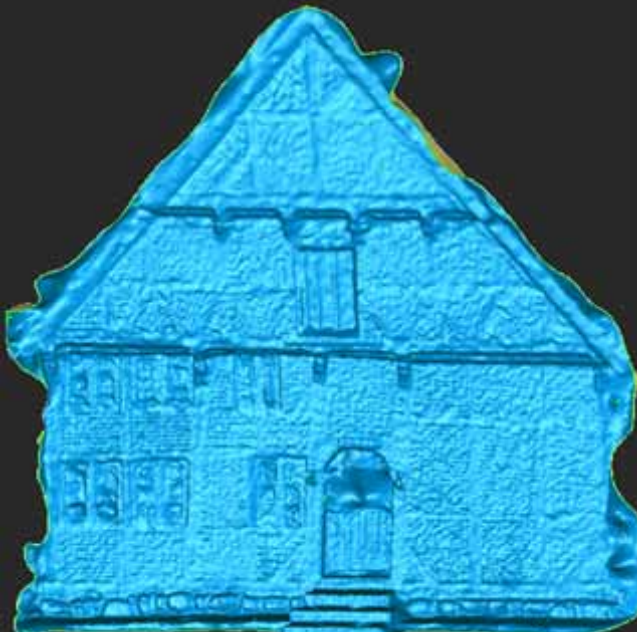
### Bundler/PMVS2

900.000 triangles  
5mm grid spacing



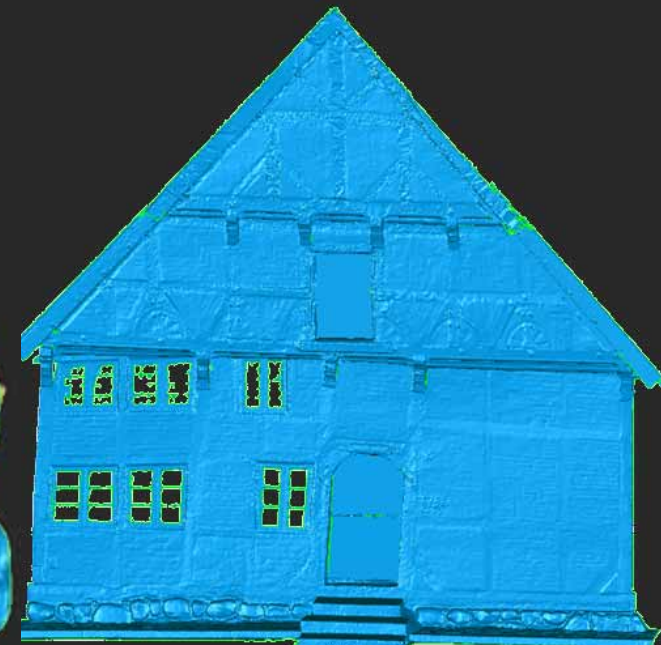
### Photofly

500.000 triangles



### IMAGER 5006h

2 Million triangles



## Examples & 3D Comparison

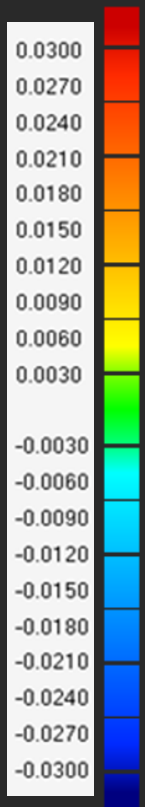
- Object – Town house Bad Segeberg
- Scaling of image-based data using distances in Geomagic
- Registration with ICP – Image-based data vs. range-based data



# Examples & 3D Comparison

- Object – Town house Bad Segeberg
- 3D comparison – Bundler/PMVS2 vs. IMAGER 5006h

Green object parts < 3mm

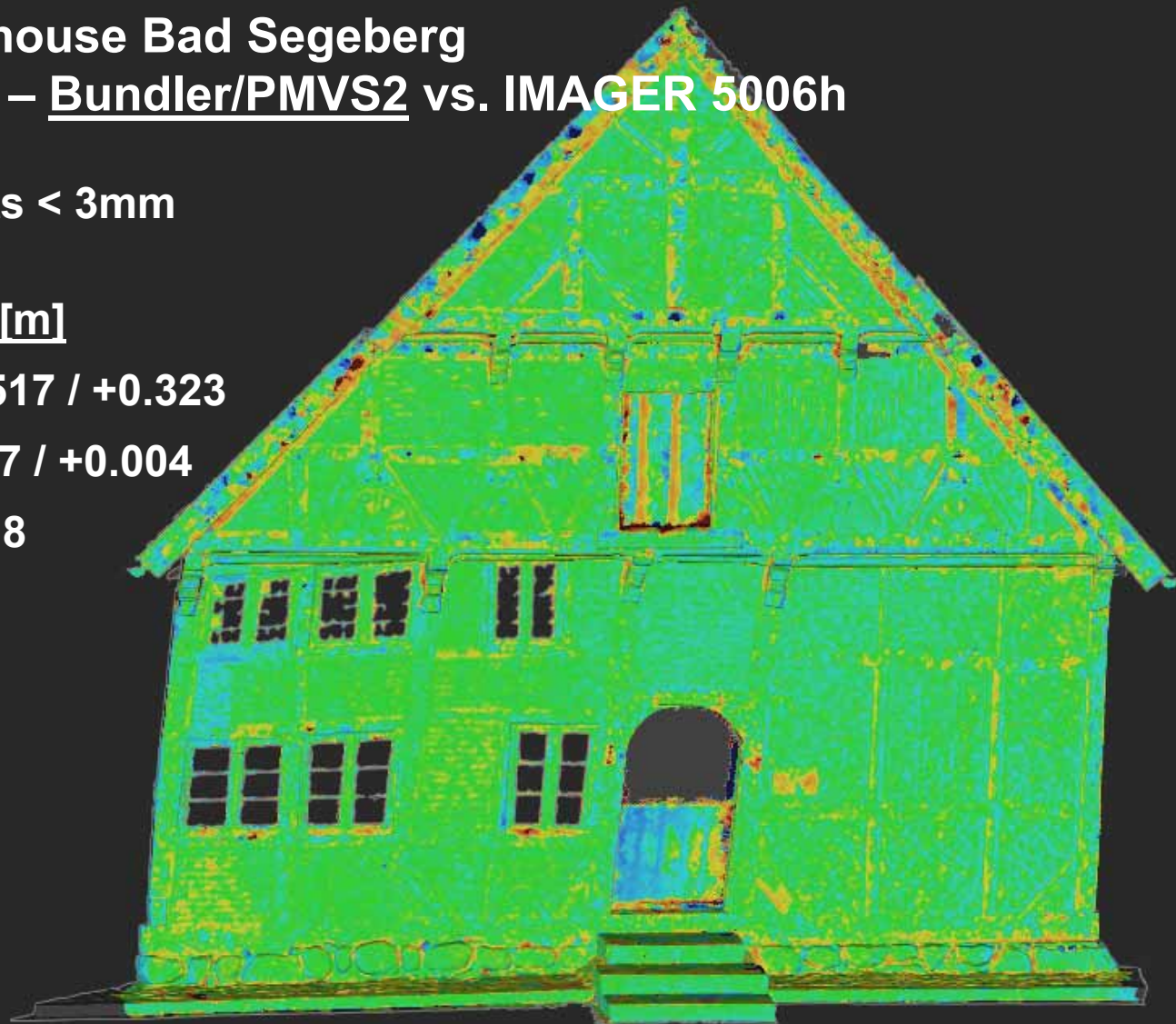


3D deviation [m]

Max. dev. -0.517 / +0.323

Av. dev. -0.007 / +0.004

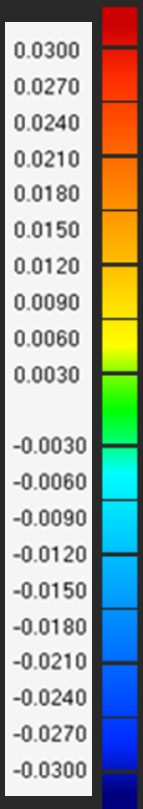
Std. dev. 0.018



# Examples & 3D Comparison

- Object – Town house Bad Segeberg
- 3D comparison – VisualSFM vs. IMAGER 5006h

Green object parts < 3mm

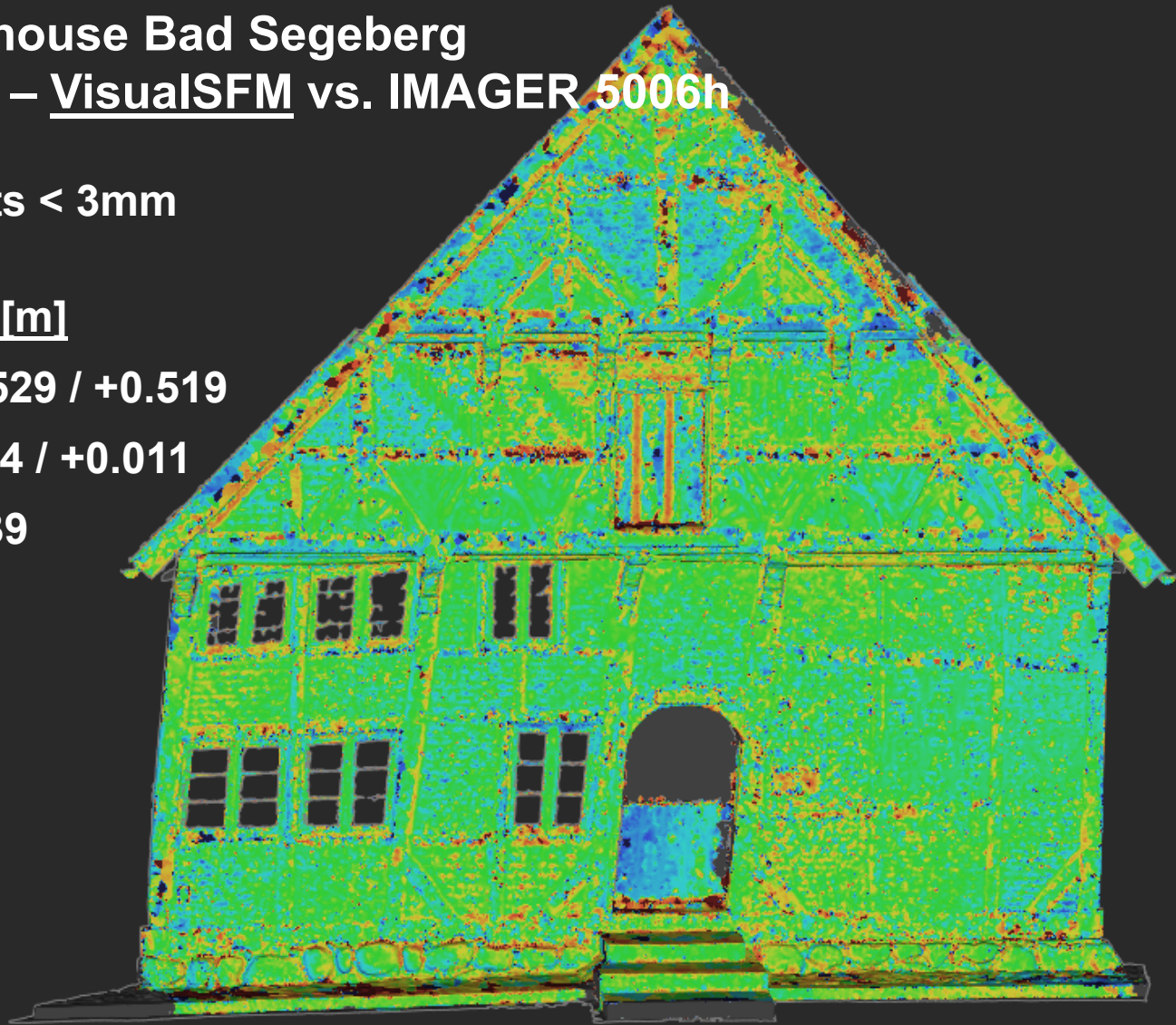


3D deviation [m]

Max. dev. -0.529 / +0.519

Av. dev. -0.014 / +0.011

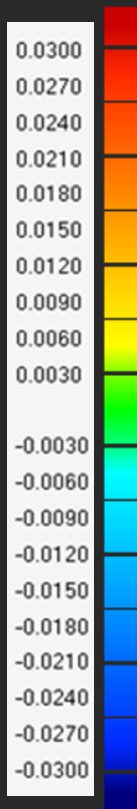
Std. dev. 0.039



# Examples & 3D Comparison

- Object – Town house Bad Segeberg
- 3D comparison – Autodesk Photofly vs. IMAGER 5006h

Green object parts < 3mm

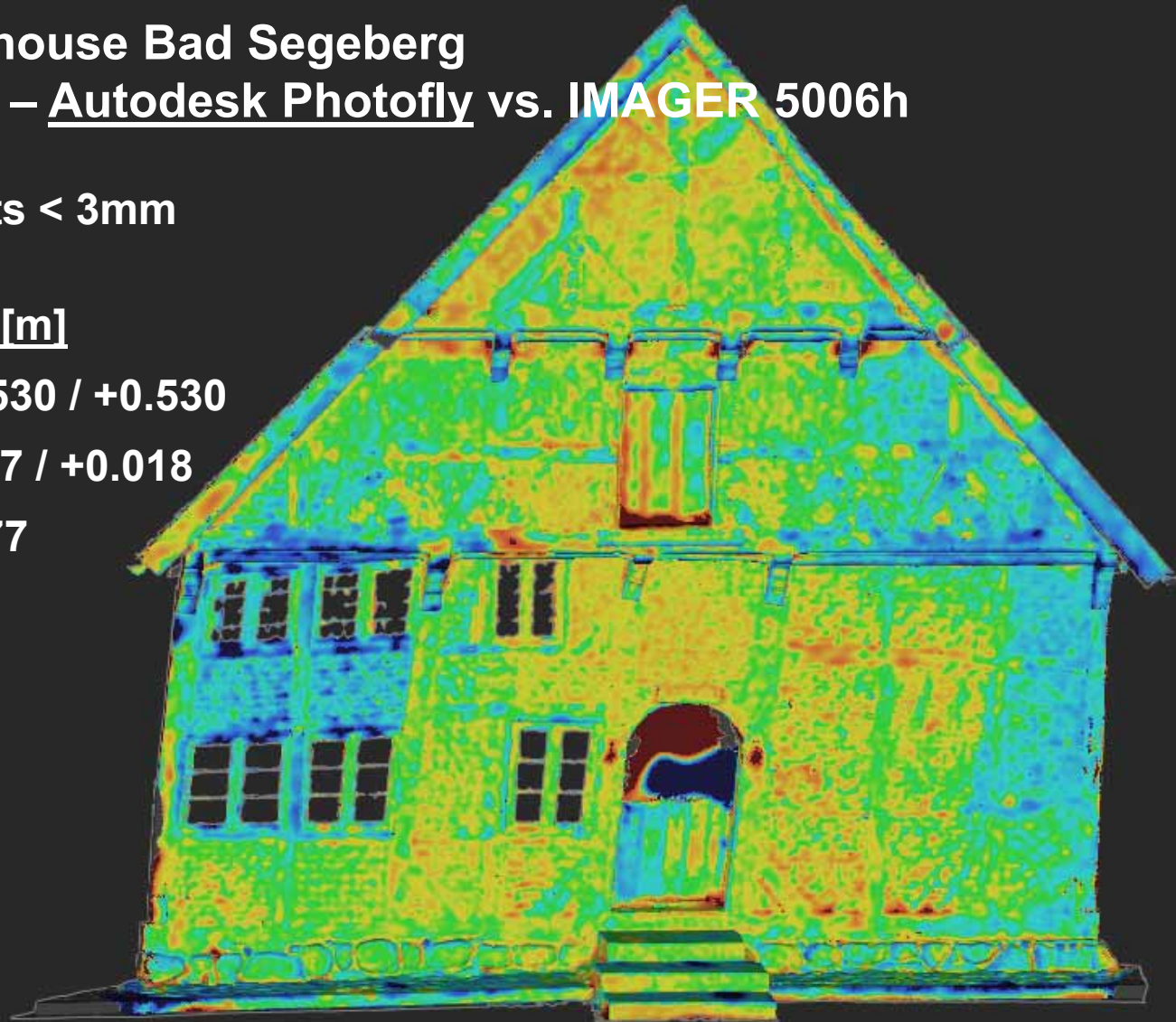


3D deviation [m]

Max. dev. -0.530 / +0.530

Av. dev. -0.037 / +0.018

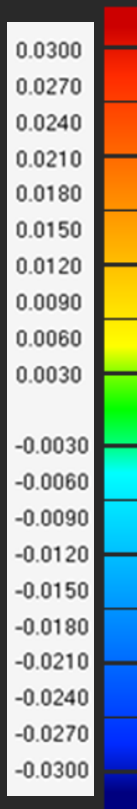
Std. dev. 0.077



# Examples & 3D Comparison

- Object – Town house Bad Segeberg
- 3D comparison – Agisoft PhotoScan vs. **IMAGER 5006h**

Green object parts < 3mm

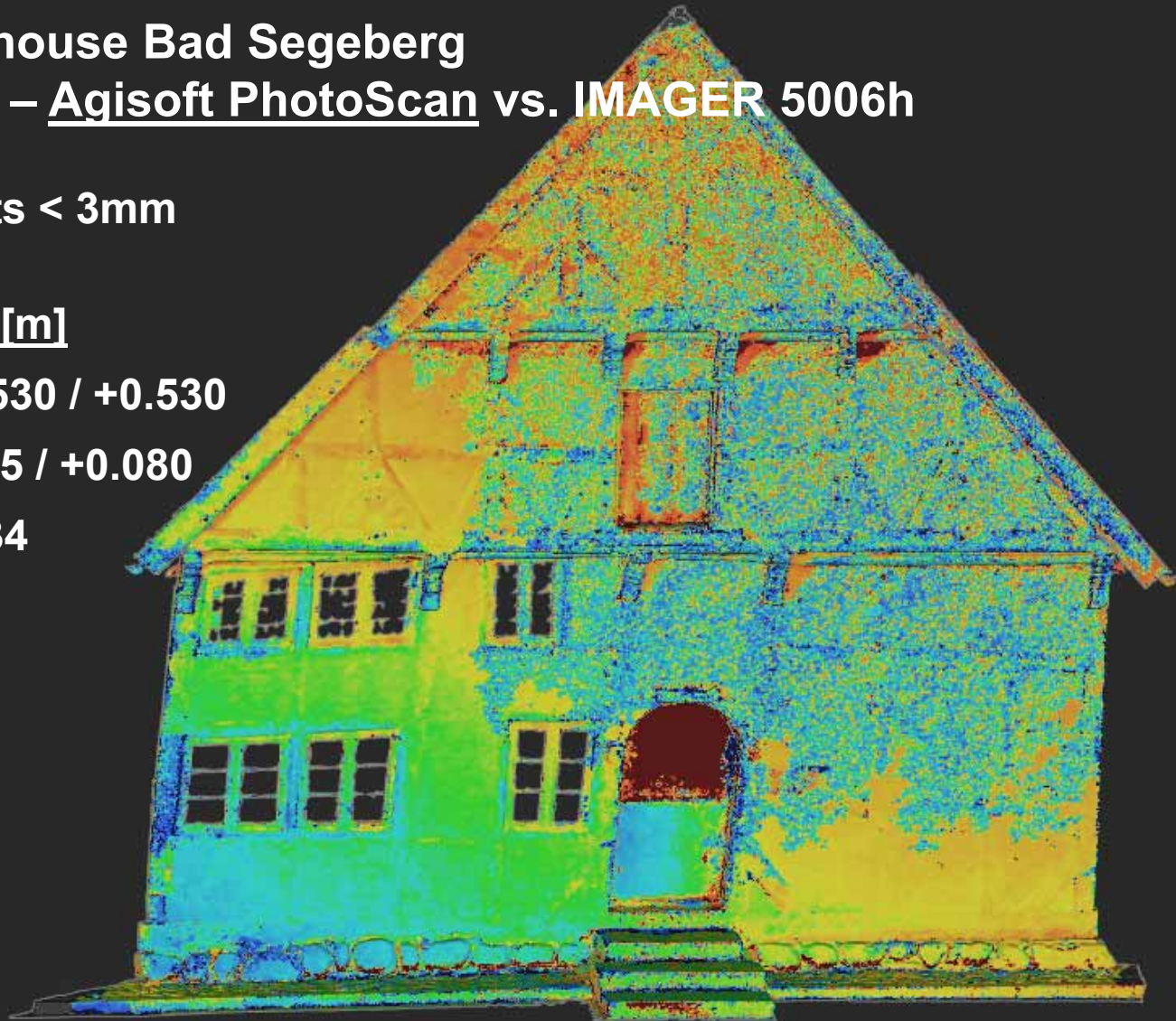


3D deviation [m]

Max. dev. -0.530 / +0.530

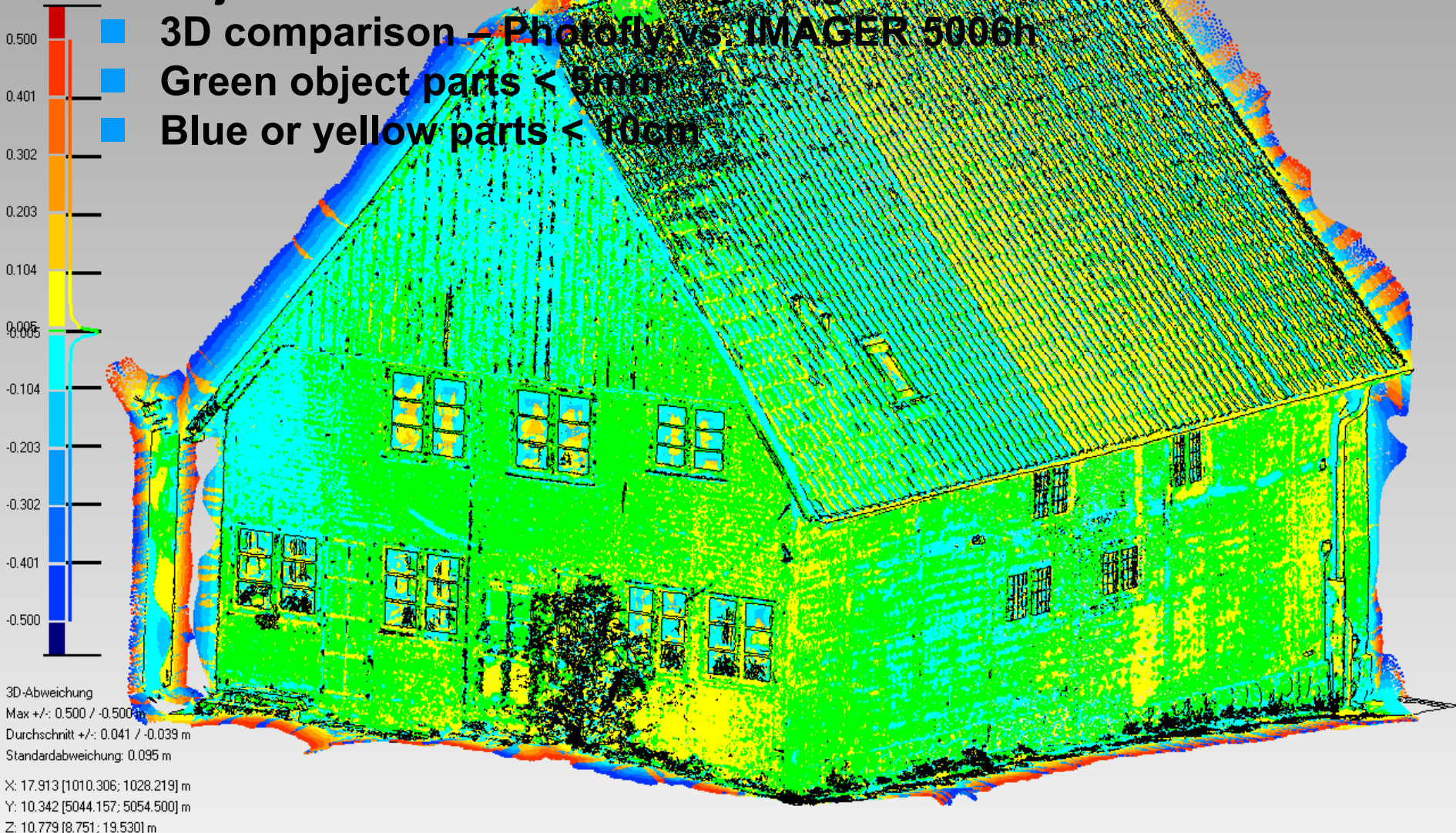
Av. dev. -0.075 / +0.080

Std. dev. 0.134



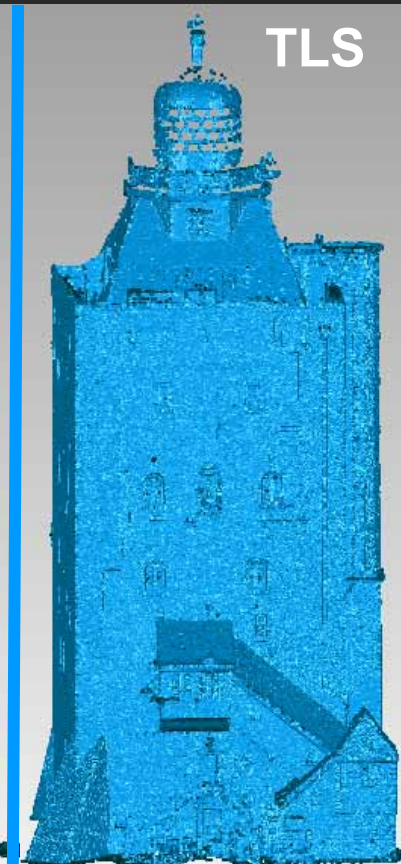
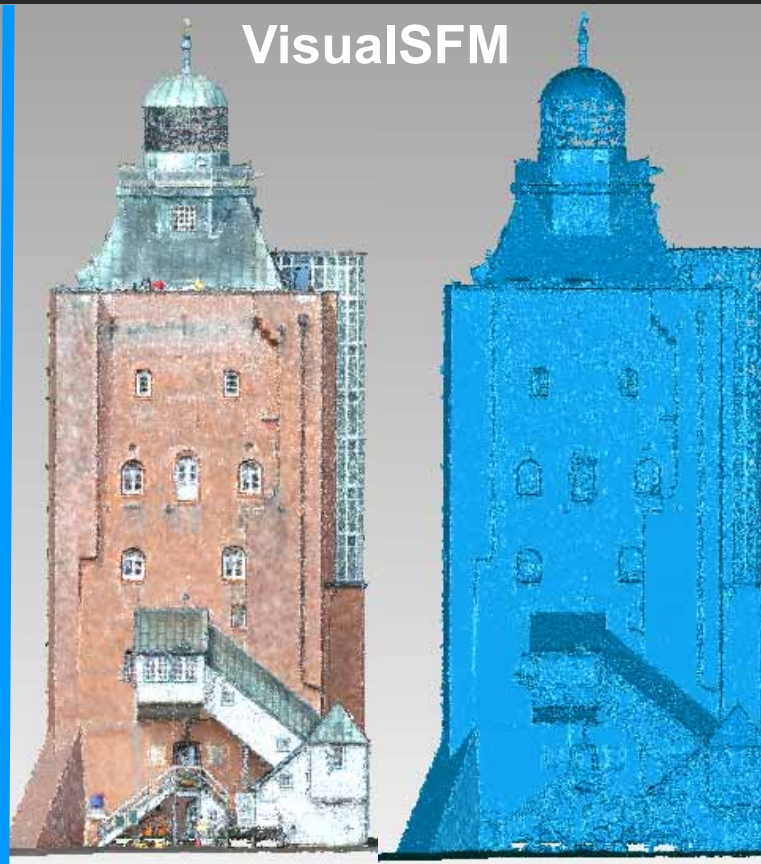
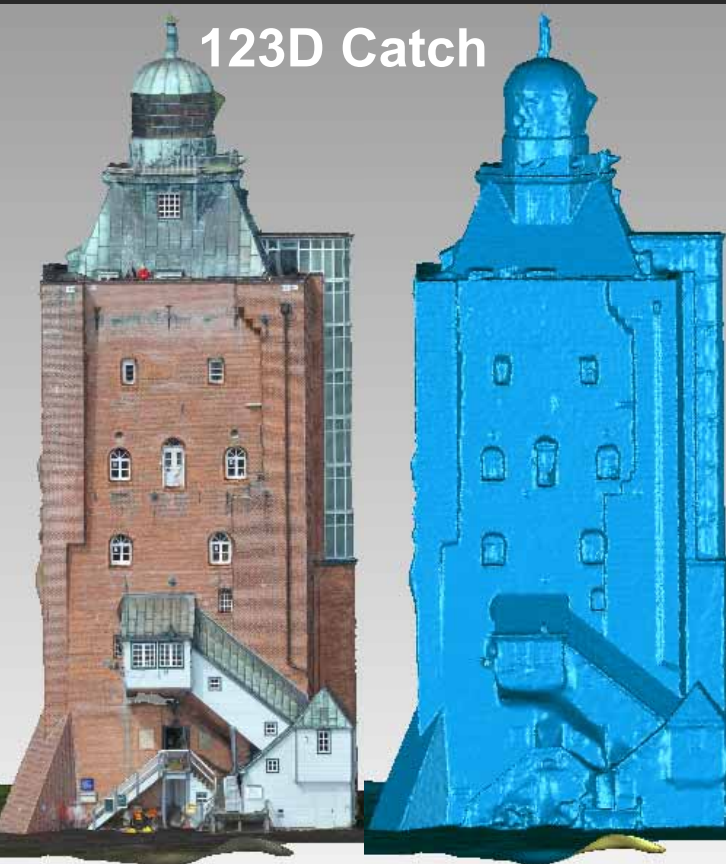
# Examples & 3D Comparison

- Object – Town house Bad Segeberg
- 3D comparison – Photofly vs. IMAGER 5006h
- Green object parts < 5mm
- Blue or yellow parts < 10cm



## Examples & 3D Comparison

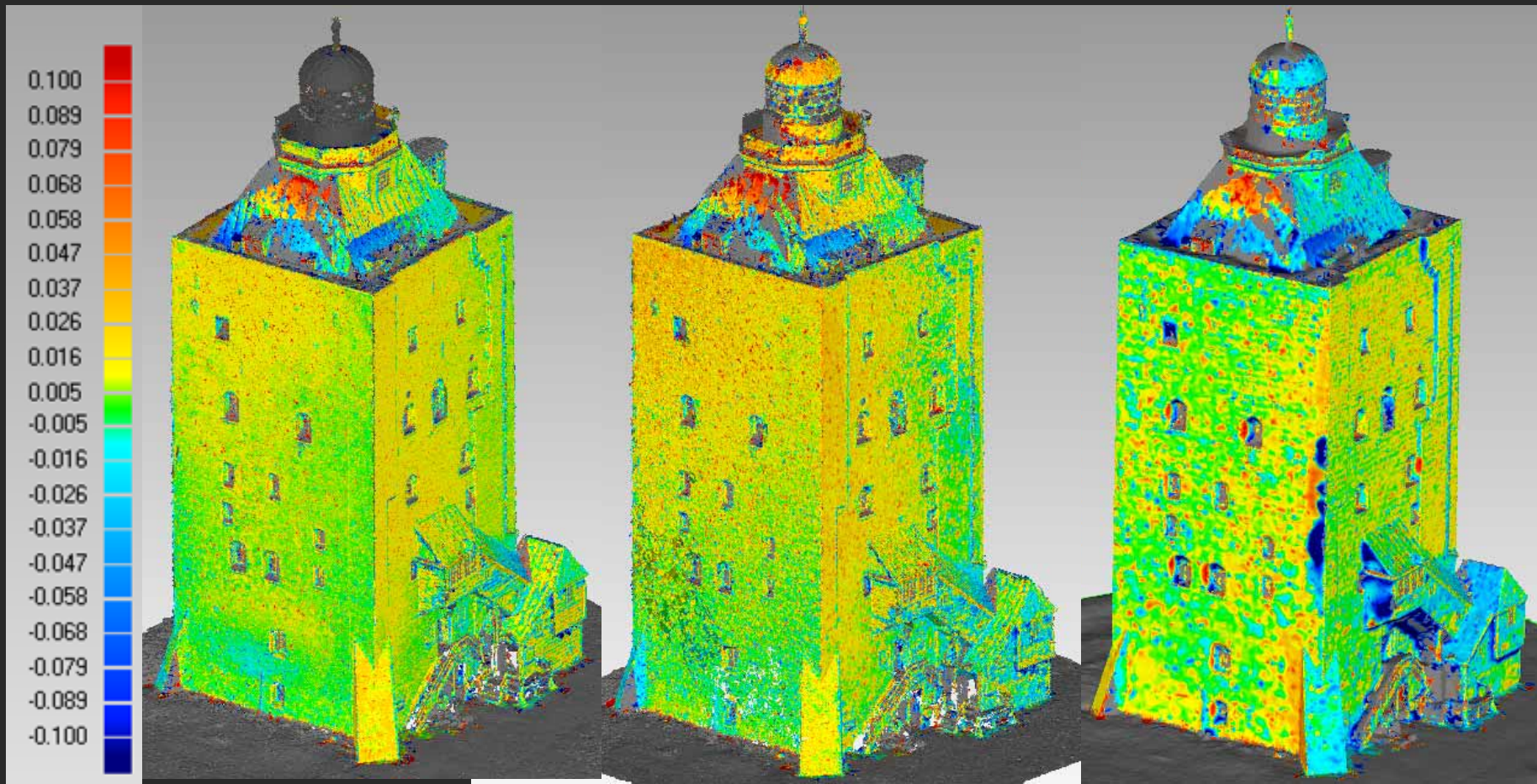
- Object – Lighthouse Neuwerk (Hamburg)
- Fotos – Helicopter Nikon D3 (85 mm) | 94 images
- Fotos – Ground Nikon D40 (18 mm) | 24 images





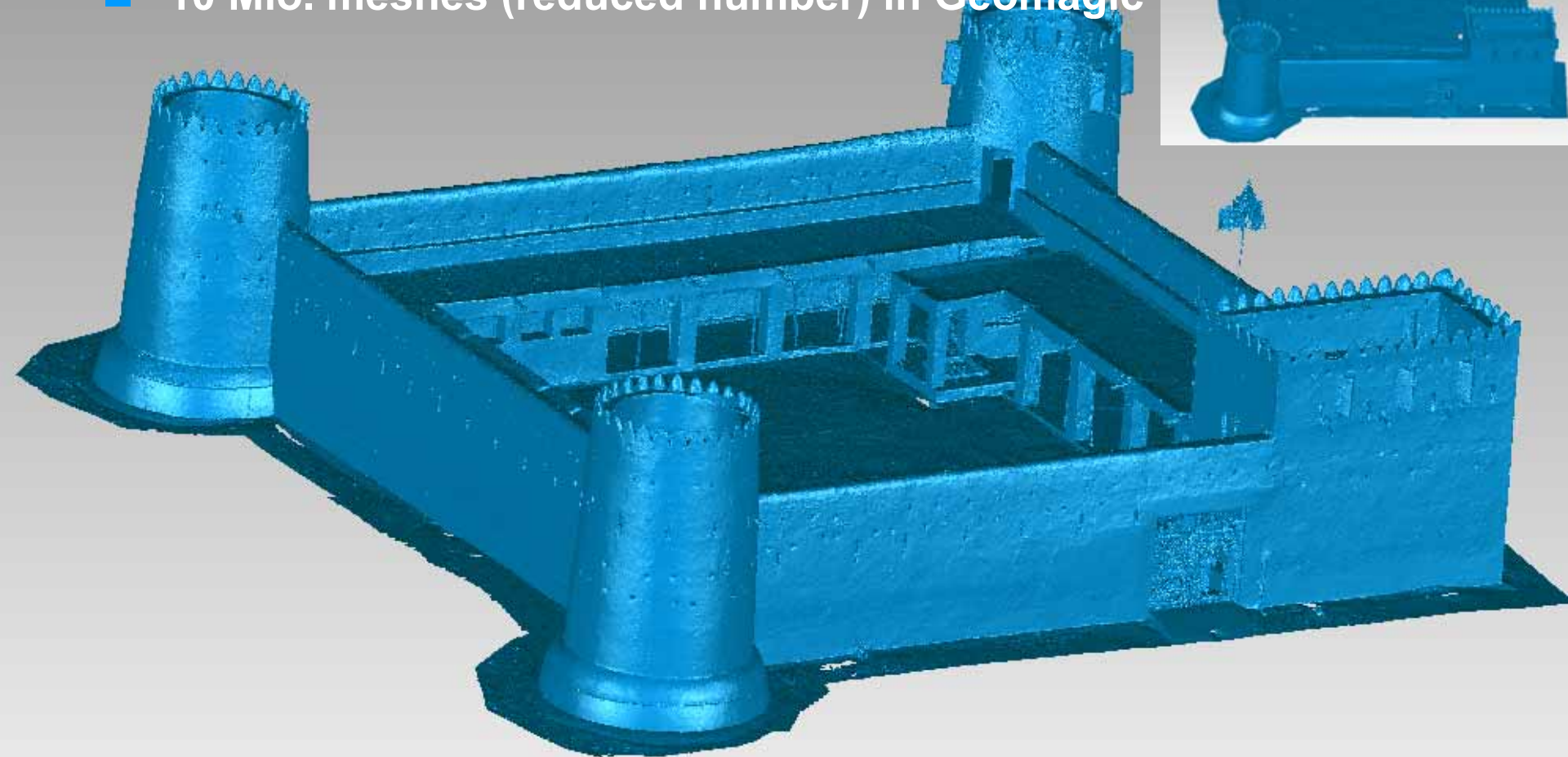
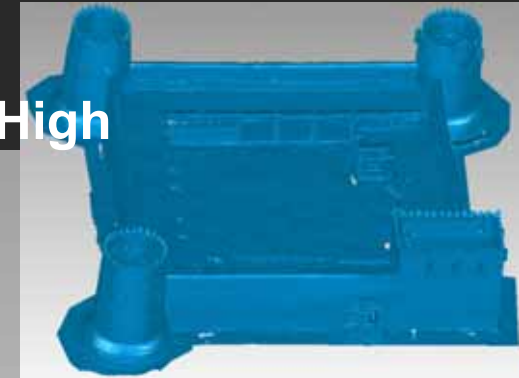
# Examples & 3D Comparison

- Object – Lighthouse Neuwerk (Hamburg)
- 3D comparison – meshes vs. reference data (Trimble GS101) – Bundler/PMVS2, VisualSFM, 123D Catch Beta



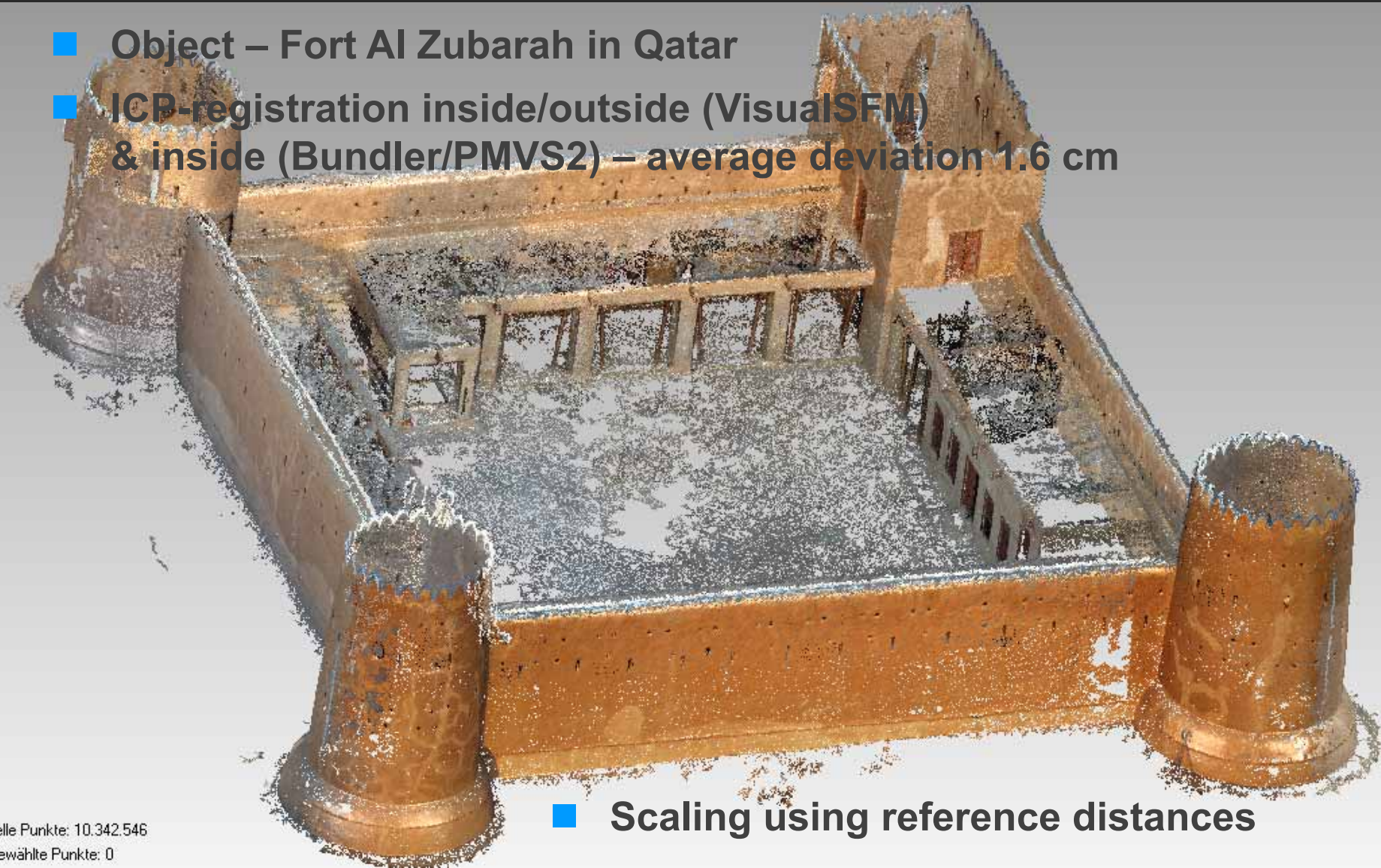
## Examples & 3D Comparison

- Object – Fort Al Zubarah in Qatar
- Scanner Z+F IMAGER 5006h – Scan resolution High
- 10 Mio. meshes (reduced number) in Geomagic



# Examples & 3D Comparison

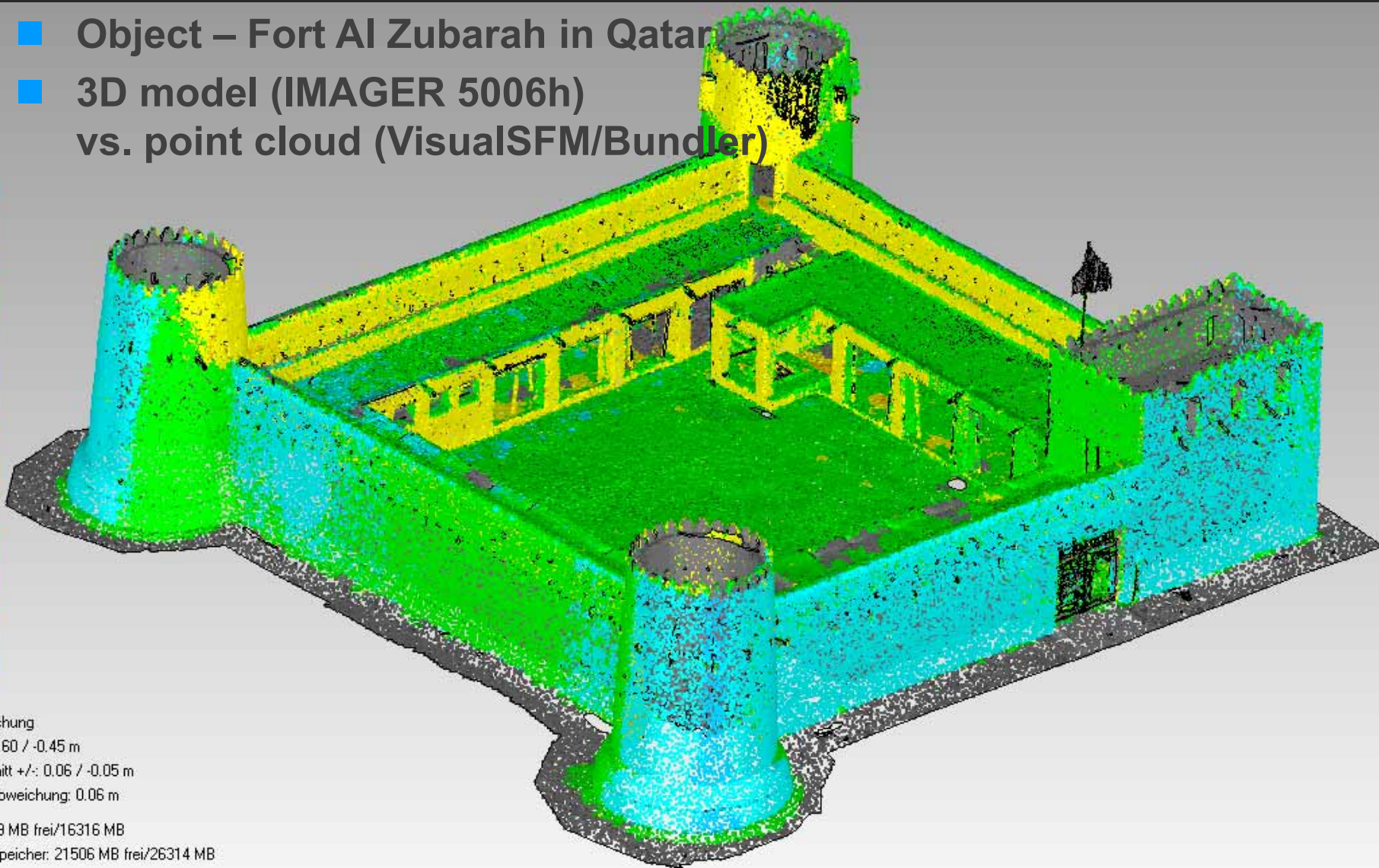
- Object – Fort Al Zubarah in Qatar
- ICP-registration inside/outside (VisualSFM)  
& inside (Bundler/PMVS2) – average deviation 1.6 cm



- Scaling using reference distances

# Examples & 3D Comparison

- Object – Fort Al Zubarah in Qatar
- 3D model (IMAGER 5006h)  
vs. point cloud (VisualSFM/Bundler)



3D-Abweichung  
Max +/-: 0.60 / -0.45 m  
Durchschnitt +/-: 0.06 / -0.05 m  
Standardabweichung: 0.06 m  
RAM: 8319 MB frei/16316 MB  
Virtueller Speicher: 21506 MB frei/26314 MB

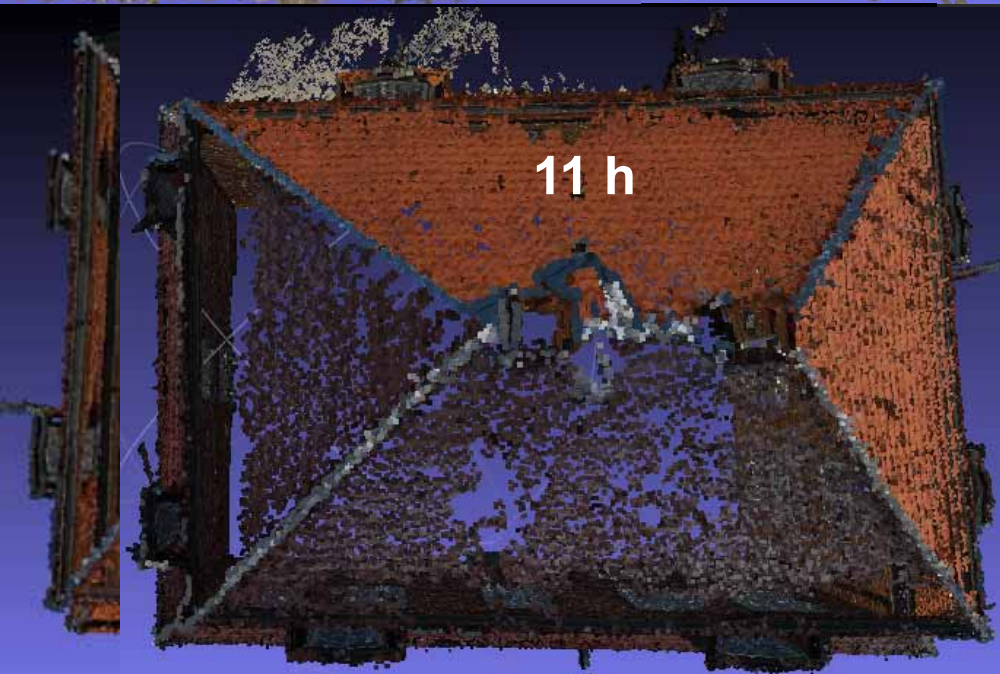
Visual SFM



Bundler/PMVS2



Autodesk 123D Catch



11 h

Vertices: 1641872  
Faces: 0  
VC

Bundler/PMVS2



# Examples & 3D Comparison

Autodesk Photofly

Bundler/PMVS2

Microsoft Photosynth



- Figure in the Zwinger Palace Dresden
- 15 images with camera Nikon D90 with 28mm lens

FOV: 60  
FPS: 12.8

Vertices: 155697  
Faces: 285669  
VC VT FC WT

FOV: 60  
FPS: 22.1

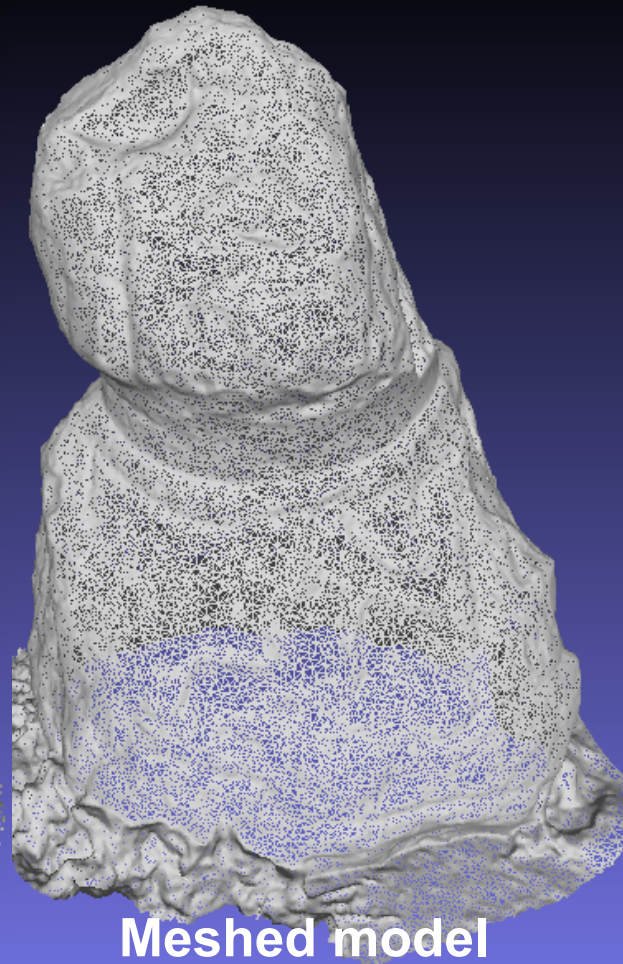
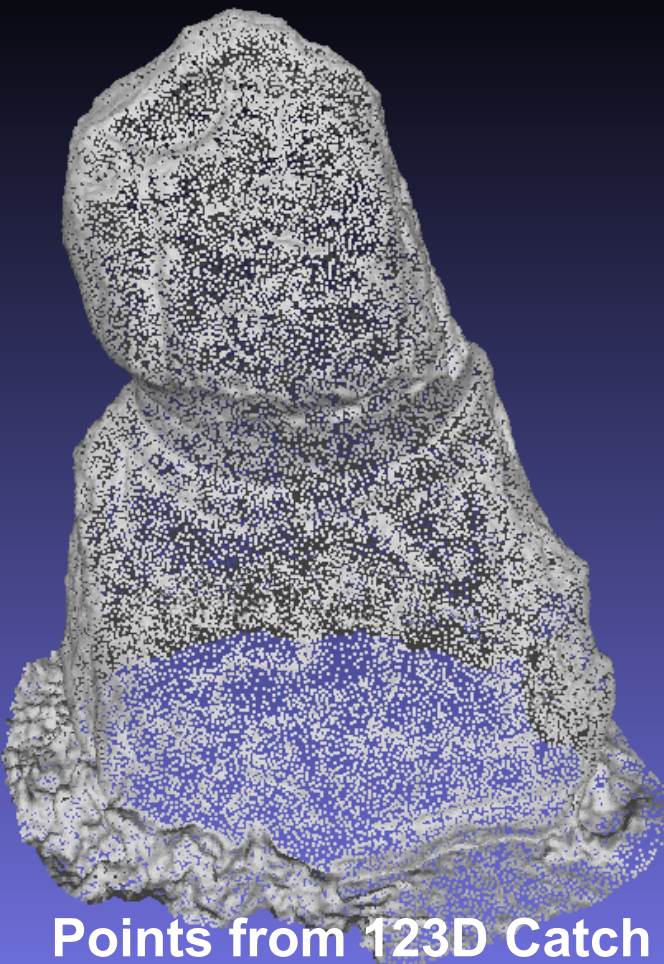
Vertices: 917965  
Faces: 0  
VC

FOV: 60  
FPS: 62.9

Vertices: 18553  
Faces: 0  
VC

## Examples & 3D Comparison

- Small moai from Poike (Easter Island)
- 27 images with Nikon D70 (3008 x 2000) using 35mm lens





## Examples & 3D Comparison

- **Moai Vaihu – 3D comparison  
terrestrial laser scanning system vs. image-based system**
- **51 photos – Nikon D70 (1458 x 2193) with 35mm lens**
- **Generation of 3D meshes with Geomagic**

IMAGER 5006 (2009)  
700.000 meshes

Bundler/PMVS2 (2011)  
1.6 Million meshes

123D Catch Beta (2011)  
445.000 meshes





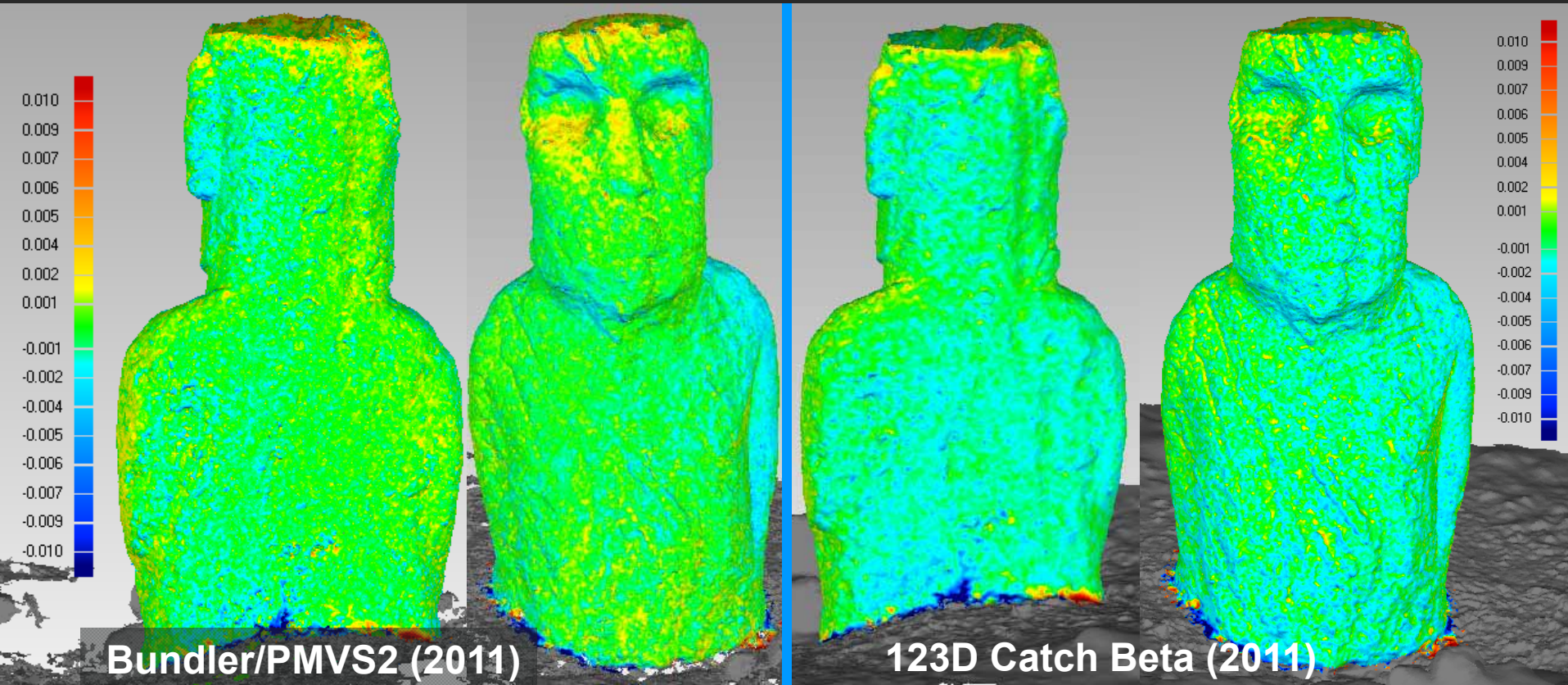


# Examples & 3D Comparison

- Moai Vaihu – 3D comparison range-based vs. image-based systems

Average deviation 0.8mm  
Maximum deviation 44.5mm

Average deviation 1.4mm  
Maximum deviation 44.5mm



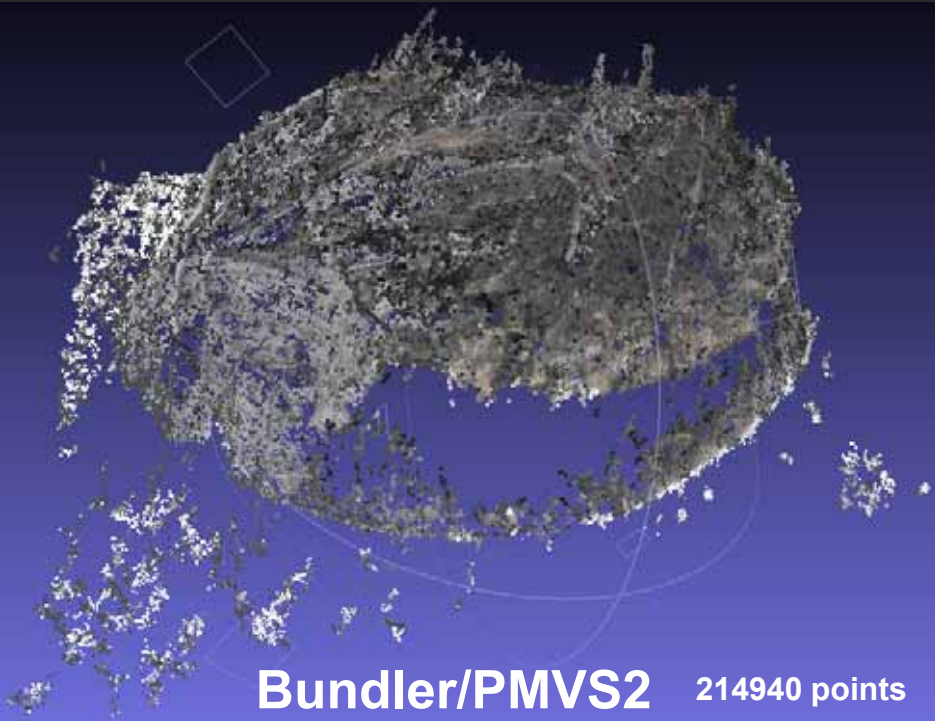
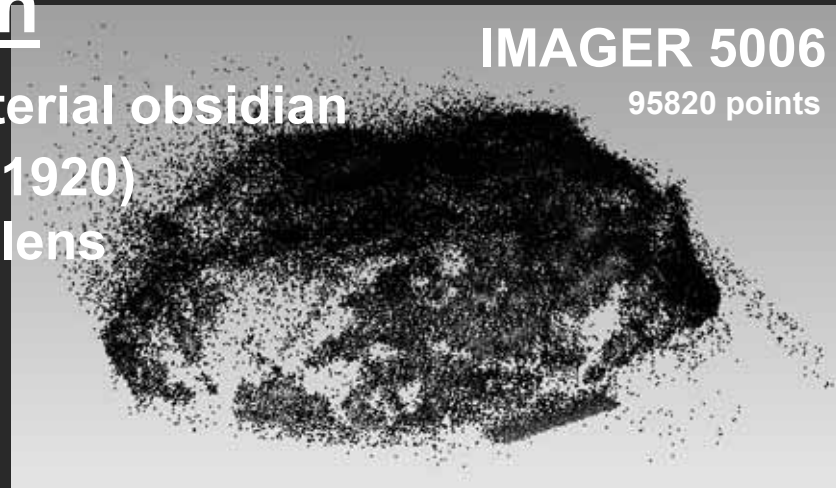


## Examples & 3D Comparison

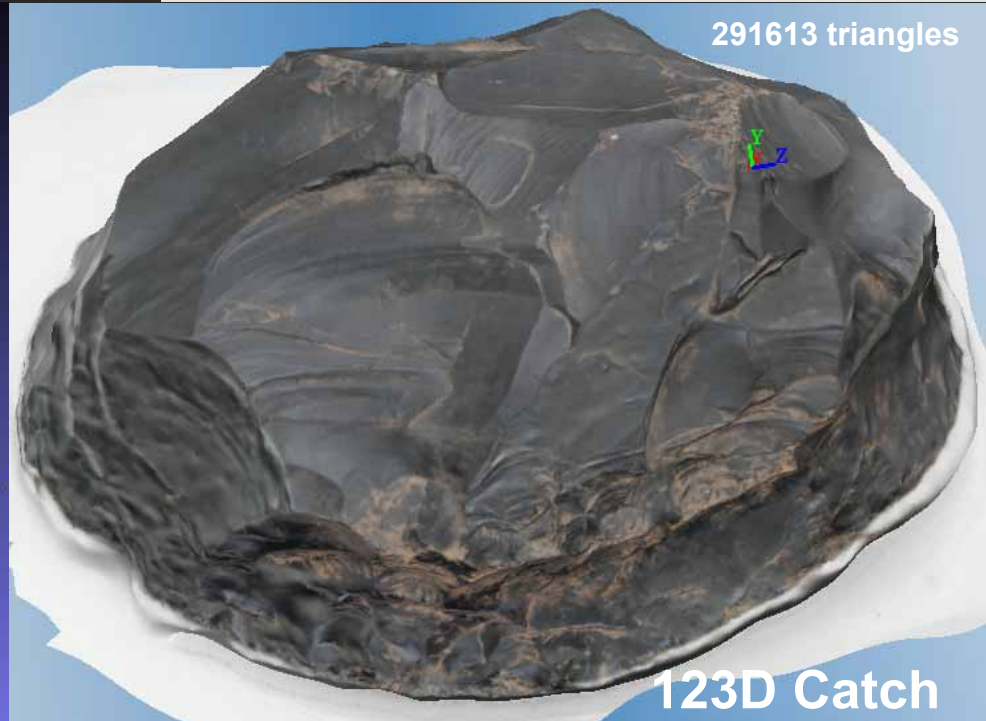
- Eye of a moai (Easter Island) – material obsidian
- Cameras – Pentax Optio X (2560 x 1920) & Nikon D80 (3872 x 2592) / 50mm lens
- Laser scanning & bundler/PMVS2 failed – noisy point cloud

**IMAGER 5006**

95820 points



**Bundler/PMVS2** 214940 points



291613 triangles

**123D Catch**

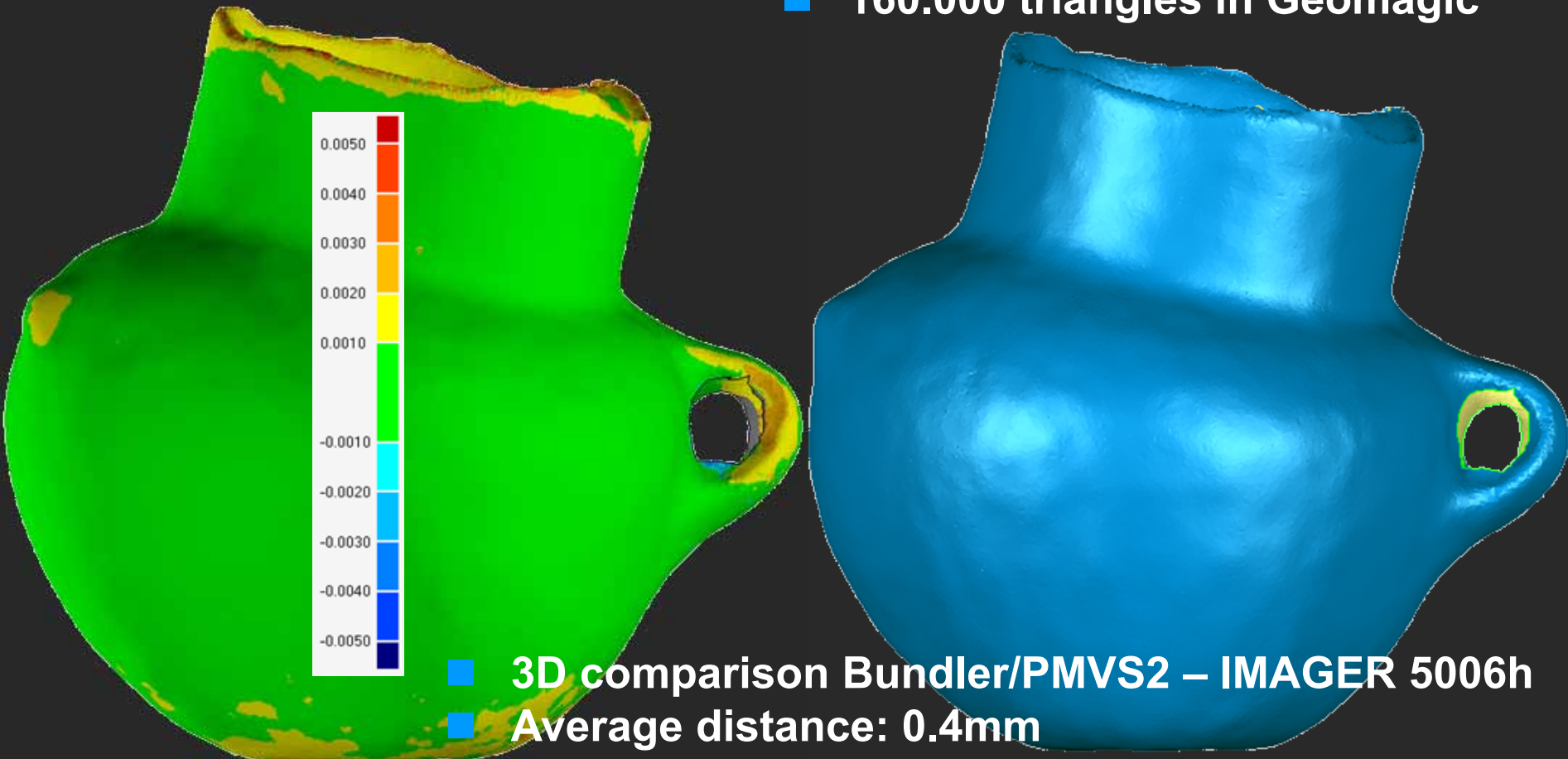
## Examples & 3D Comparison

- Pottery (ceramic) from Yeha (Ethiopia), ca. 20cm height & 15cm diameter
- Camera Nikon D40 (3008 x 2000) with 34mm lens
- Bundler/PMVS2 – two parts (top 54 images & bottom 30 images)



## Examples & 3D Comparison

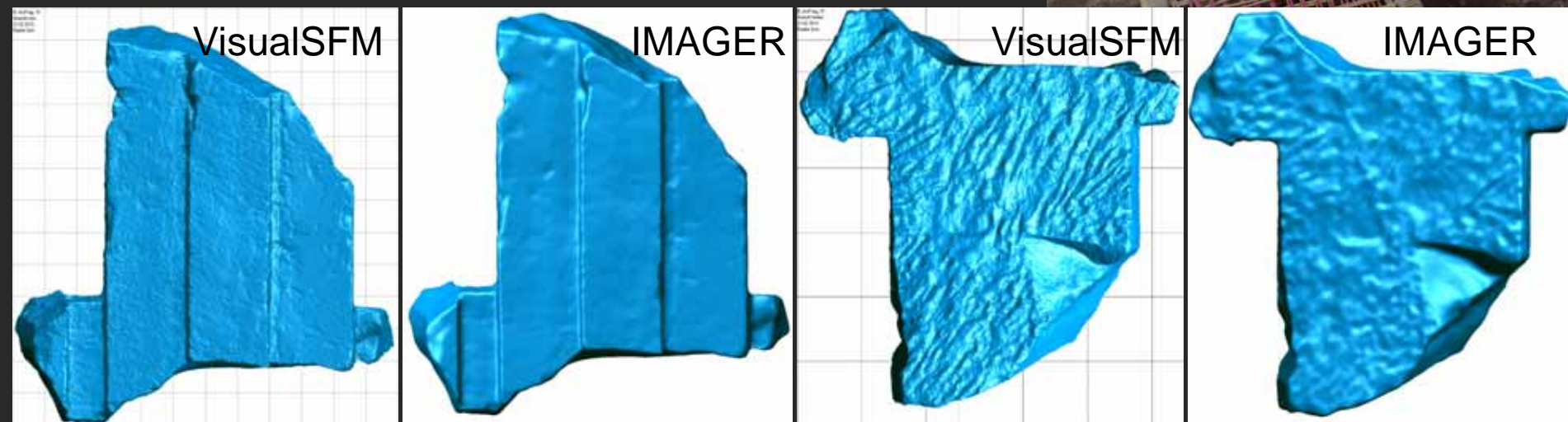
- Pottery (ceramic) from Yeha (Ethiopia)
  - 9 scans with IMAGER 5006h (Z+F)
  - 160.000 triangles in Geomagic



## Examples & 3D Comparison

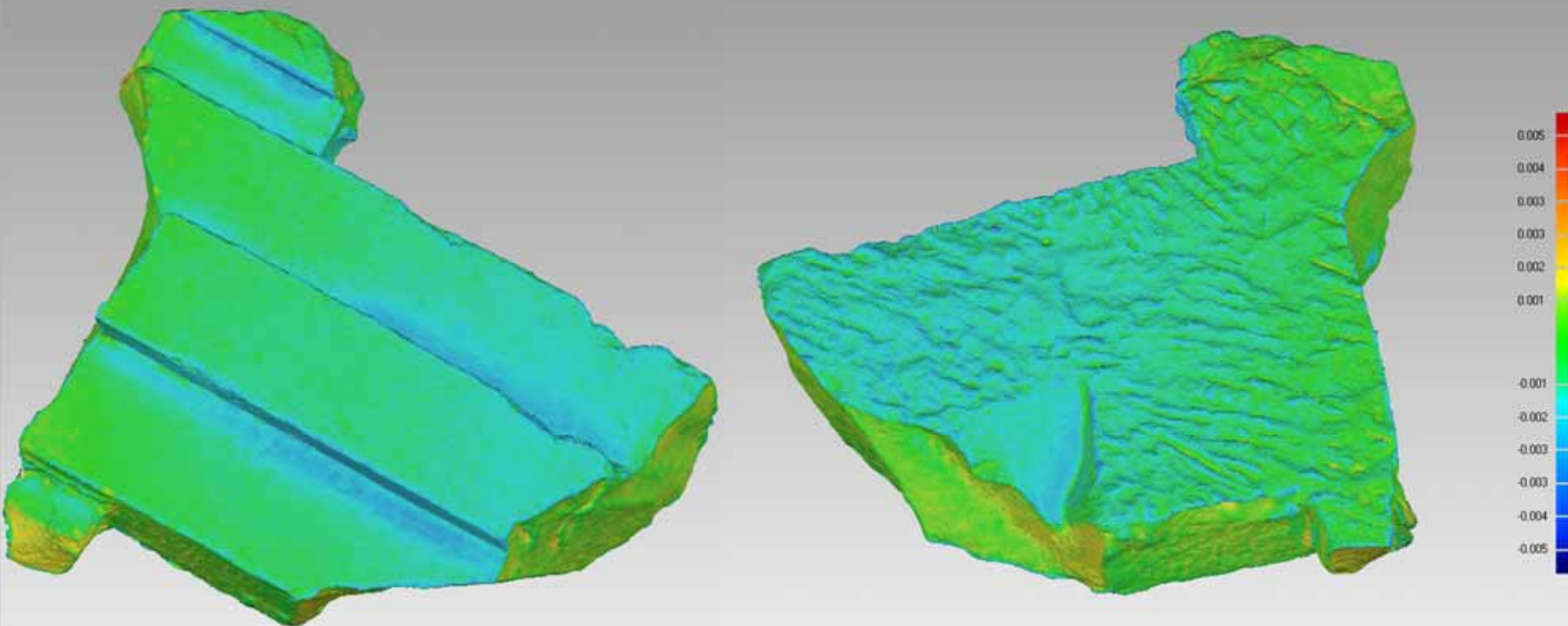
- Architectural fragments from Yeha (Ethiopia)
- Nikon D90 (Nikkor 24mm lens) – 33 photos front | 25 photos rear
- VisualSFM – ca. 110 min + ca. 90 min  $\approx$  3.5 min/photo

- Results from matching show more details  
– scanned data is more smoothed



## Examples & 3D Comparison

- Architectural fragments from Yeha (Ethiopia)
- 3D comparison – VisualSFM vs. IMAGER 5010
- Most parts better < 1mm



## Conclusions & outlook

- Camera based object recording – fast & flexible & low cost
- Quality factors – photo scale, illumination & object texture
- Quality of points clouds from dense matching comparable to TLS
- Quality of points clouds from dense matching for CAD modelling
- High computer performance necessary for desktop processing
- Data processing using GPU necessary for fast results ⇒ future
- Web services save user's resources – but data privacy?
- Increasingly more software packages available on the market
- Further investigations in quality control with reference data



Lighthouse of Neuwerk (1310 A.D.)  
Oldest existing building of Hamburg

**Thank you  
for your attention!**