

# Grafica 3D per i Beni Culturali

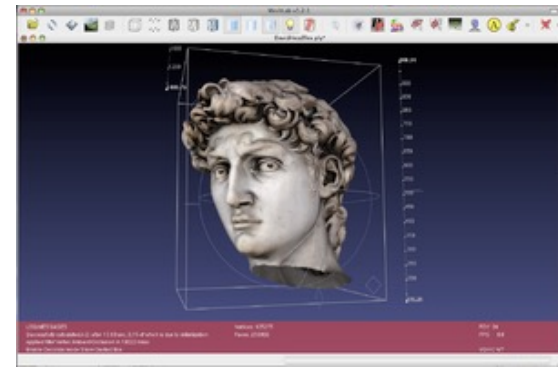
DIGITAL TOOLS FOR HUMANISTS SUMMER SCHOOL 2021



Paolo Cignoni - Marco Potenziani  
ISTI – CNR Pisa - Italy

# Chi sono?

- Research Director @ ISTI – CNR
  - teaching UniPi – Fondamenti di Graf. 3D
- Che facciamo al VCLab del ISTI-CNR?
  - Computer graphics,
  - 3D scanning and 3D printing
  - Collaborating with CH institutions for 3D scanning and CG projects since 1997
  - Created MeshLab!





# Che vi raccontiamo

- CG e CH

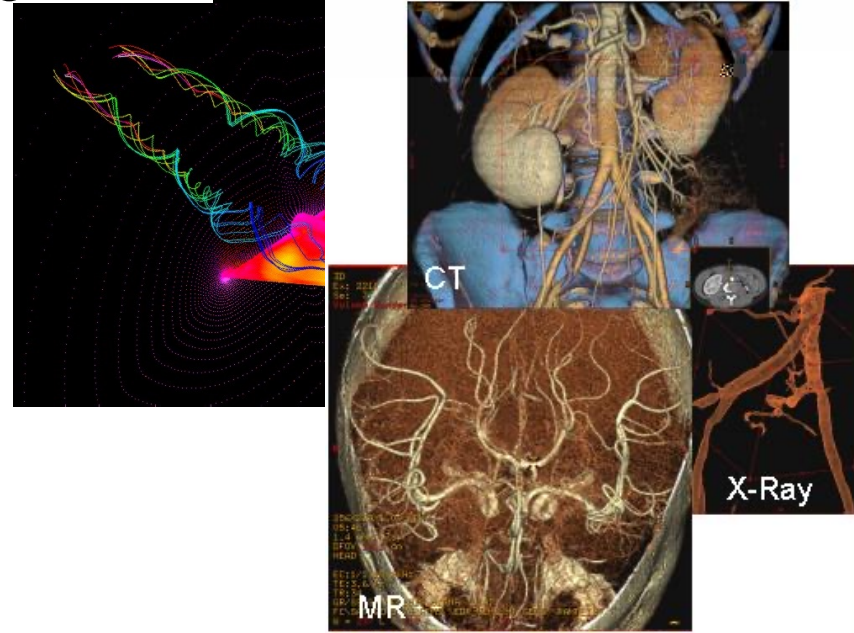
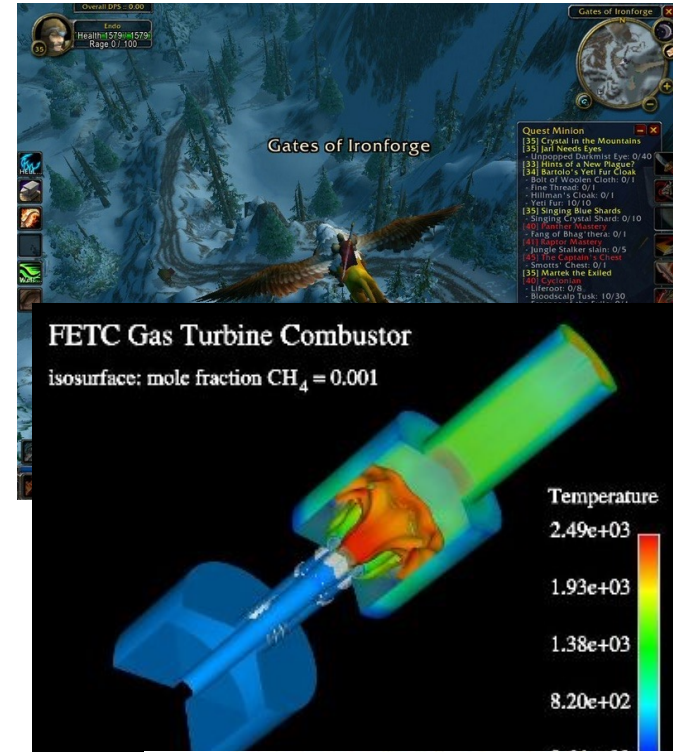
- Ovvero:

*Come e Cosa fare con il 3D  
per il mondo dei beni culturali*

- Asset creation for CH
- Why and How CG for CH
- 3D printing for CG
- How to publish 3D on the Web,  
tools and practices – 3DHop/nexus/etc

# Computer Graphics

- Entertainment Industry
  - *Visual effects*
  - *Games*
- Scientific Visualization
- Manufacturing industry
  - e.g. Computer Aided Design
- Medicina
  - supporto alla diagnosi
  - telechirurgia
  - simulazioni



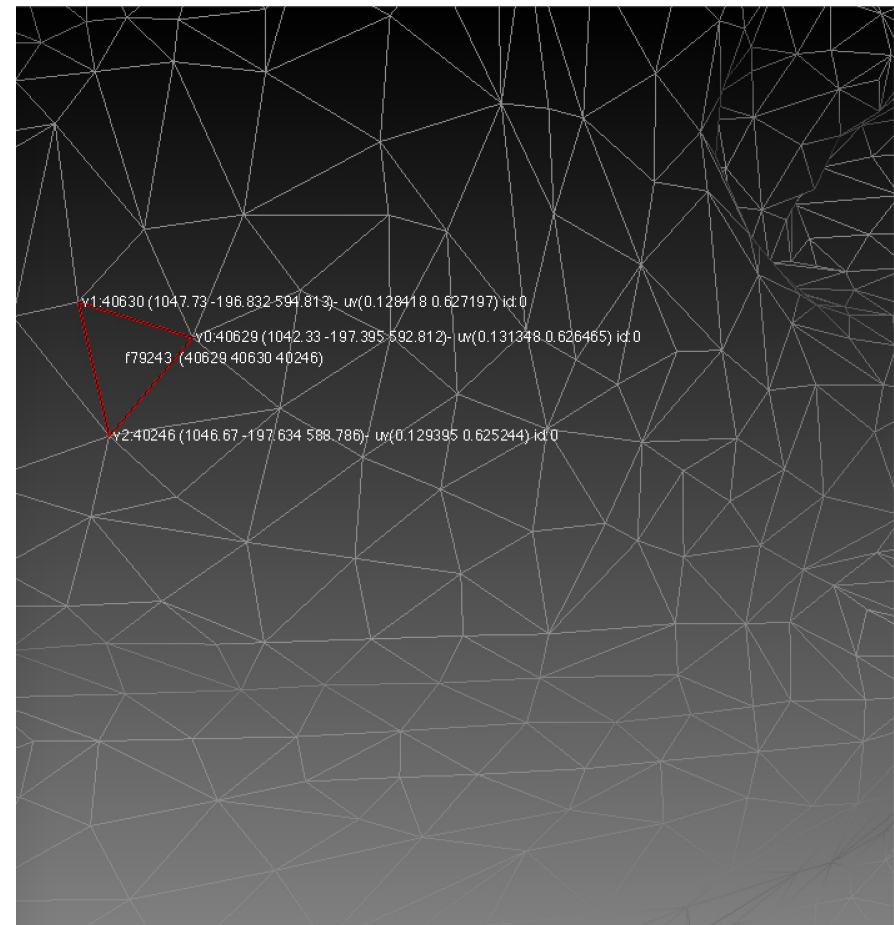
# Computer Graphics

- Entertainment Industry
  - *Visual effects*
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- Scientific Visualization
- Manufacturing industry
  - e.g. Computer Aided Design
- Medicina
  - supporto alla diagnosi
  - telechirurgia
  - simulazioni
- **Cultural heritage**
  - **Documentazione**
  - **Supporto all'analisi**
  - **Monitoring**
  - **Supporto al restauro**



# 3D Models

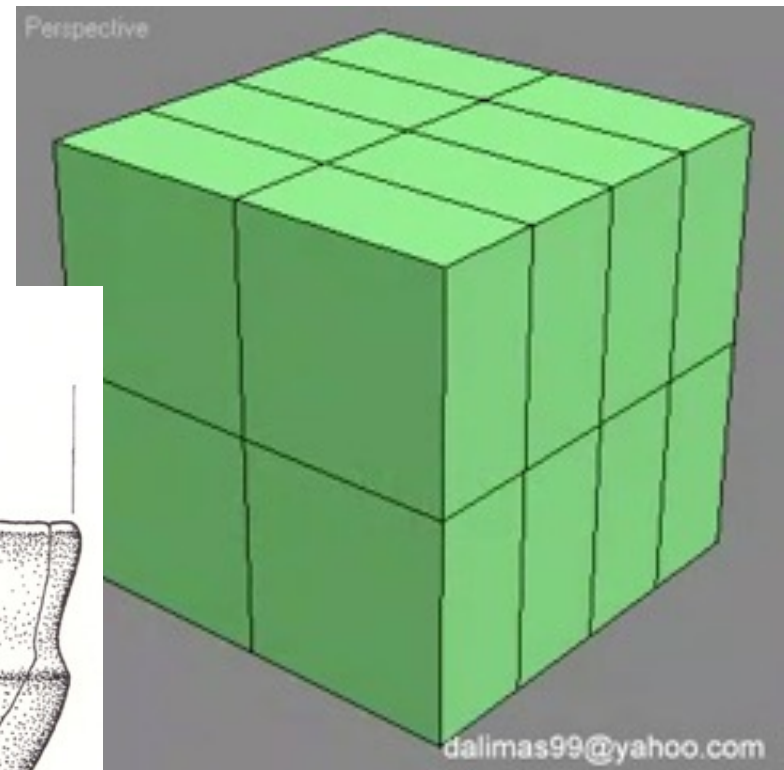
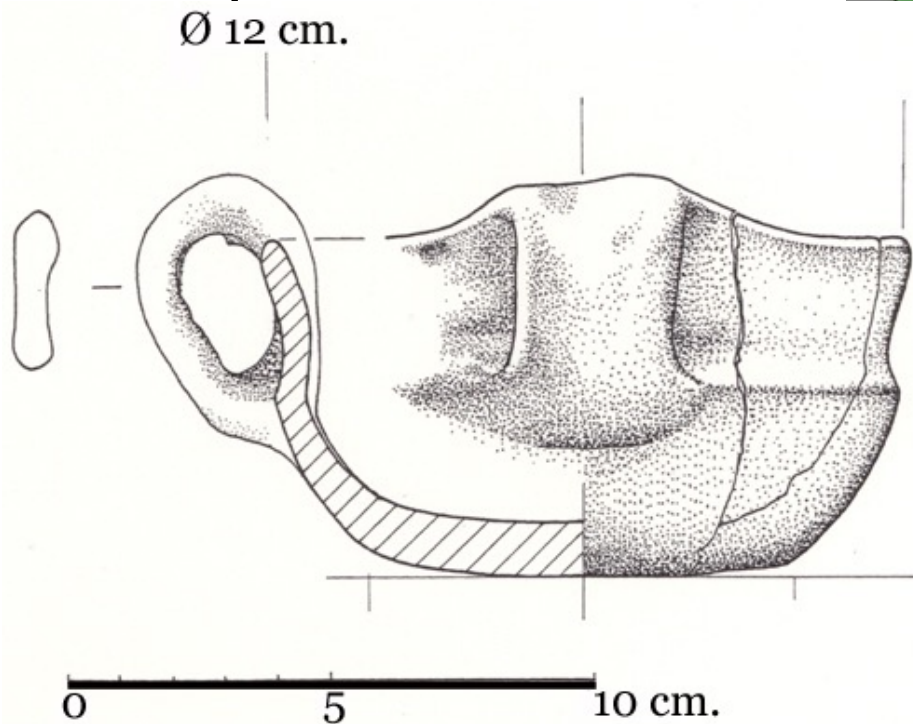
- Cosa c'è dietro ad un'immagine di sintesi?





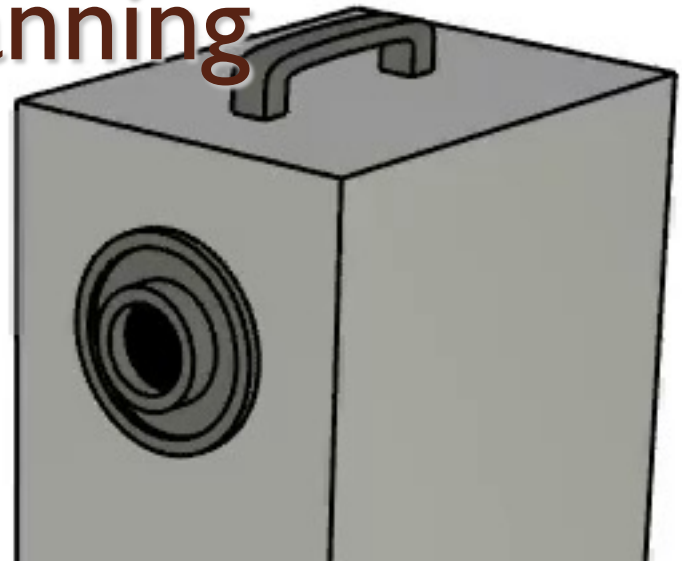
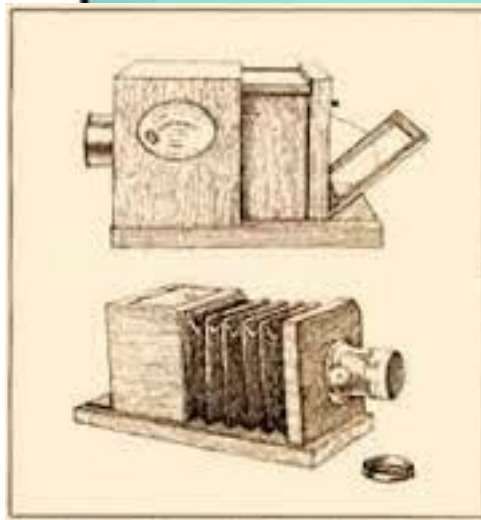
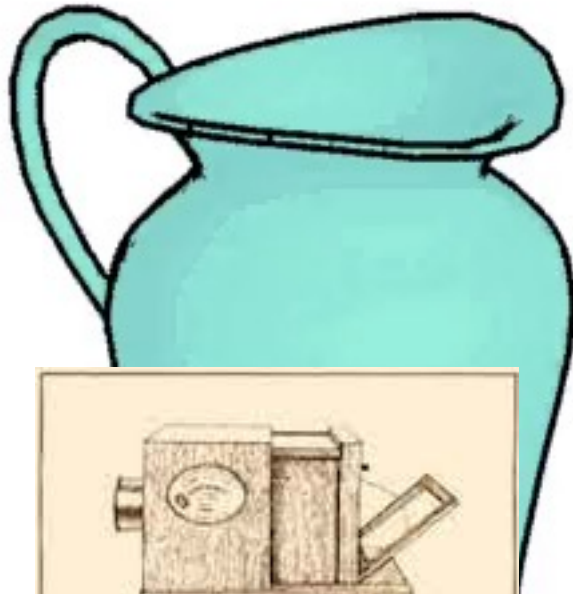
# Modeling

- The creation of 3D models
- Hand made
  - By artist



# Modeling: 3D scanning

- Automatic:  
like photo





# Modelling vs. Scanning

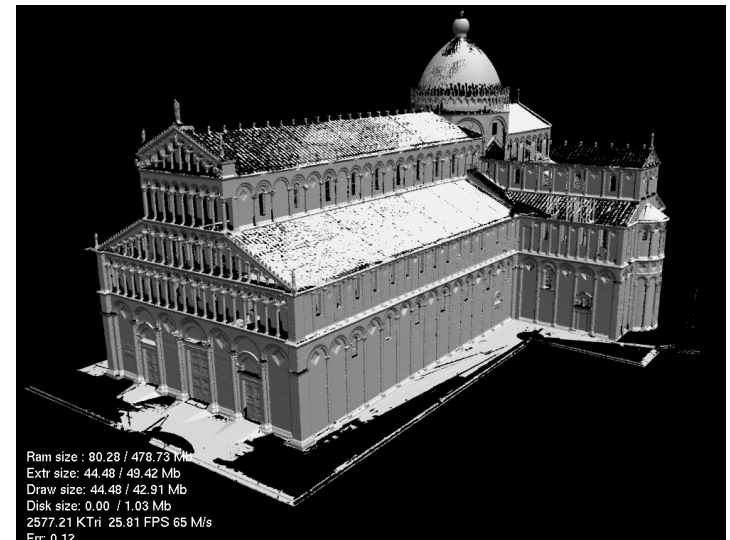
- **Modelling**

- Manual process [copyist]
- Unknown accuracy
- complete, nice model



- **Scanning**

- Semi-automatic process [photography]
- Accuracy can be estimated
- Incomplete 3D model (holes, missing parts)



# Modeling vs Scanning

- Why Scanning?
  - Documentation!
  - Basis for reconstruction
  - Basis for clean assets
- Why Modeling
  - Reconstruction hypothesis
  - Reusable Assets
    - (for dissemination/entertainment)



# Why 3D scanning

Photos +  
photo manipulation/painting

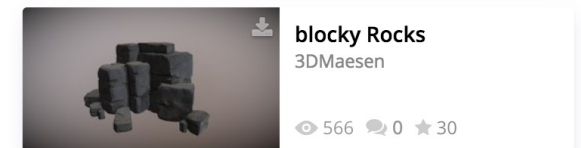
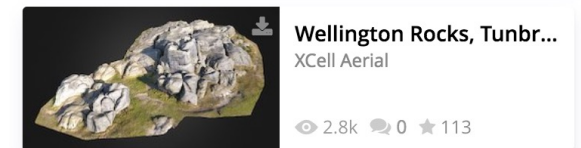
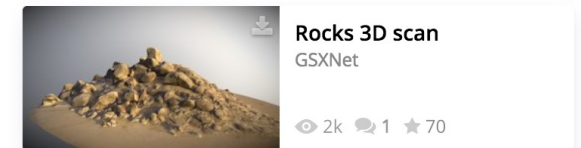
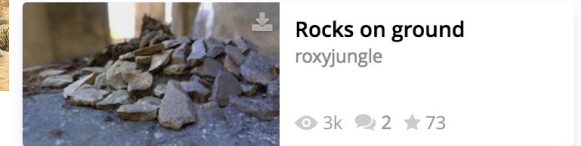
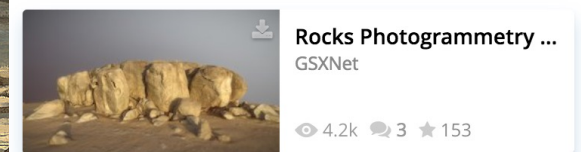
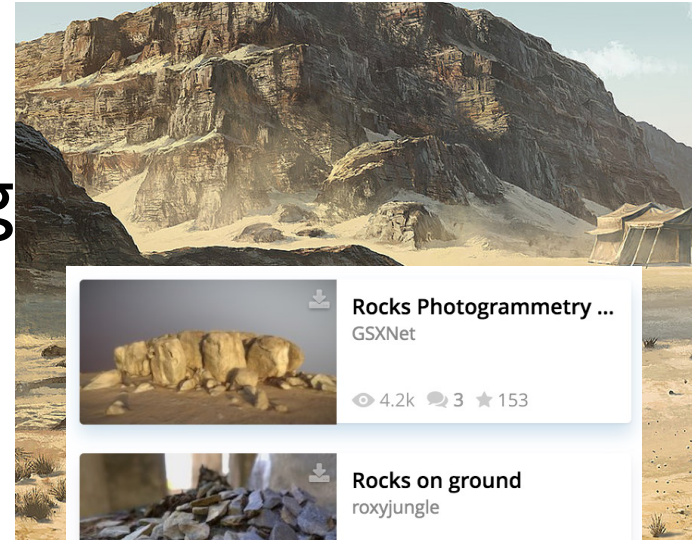


Digital matte painting

3D scanning +  
3D sculpting / 3D Painting



Nice 3D assets

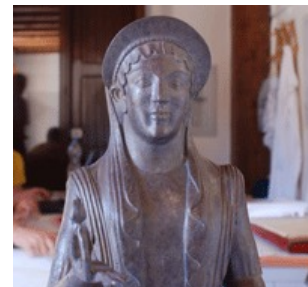
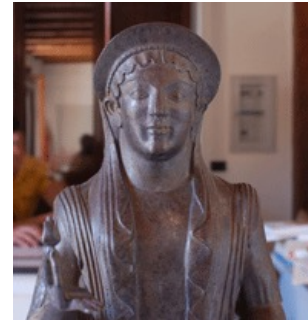


# 3D Scanning HowTo

- Many different techs
  - Active/Passive
  - Laser/structured lights/lidar/etc.
- Photogrammetry (aka 3D from photo) is a rising star
  - Cheap
  - Good appearance
  - Getting better and better

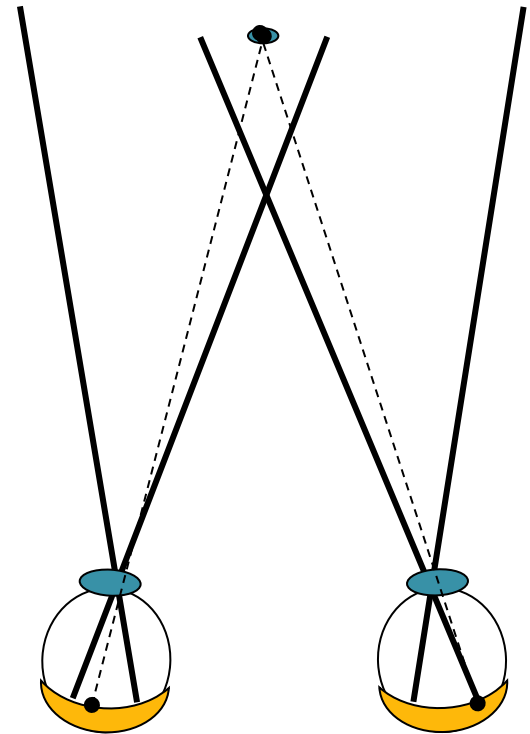
# 3D from photo: SW options

- Major players
- **Agisoft MetaShape**
  - Powerful/versatile/costly
- **RealityCapture**
  - Very fast / flexible licensing/EPIC bought it
- Free stuff
  - **Alicevision/MeshRoom /MicMac/openmvs**  
Slower much harder to be used. Sim



# How does it work?

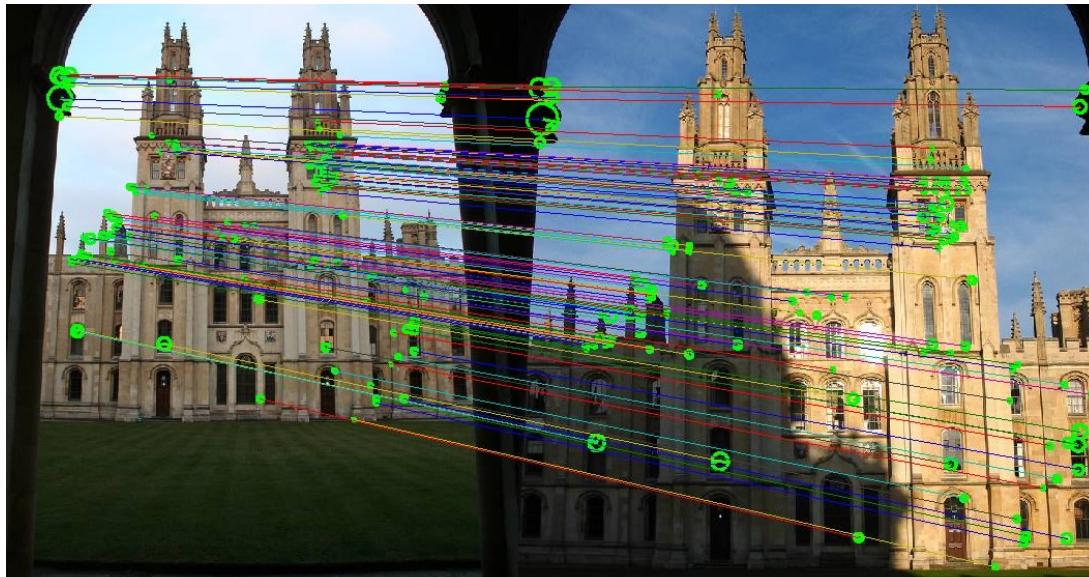
- We do perceive the environment three-dimensionality thanks to our **stereo vision** AND the perspective projection that occurs in our eyes..
- Using the geometric laws of this two phenomena we can reconstruct the 3D geometry of the scene





# Yes, but how does it *really* work?

- The entire process is based on finding matches between images.
  - *Matches are couple of visually similar points on the image that should hopefully be the same point in the world.*

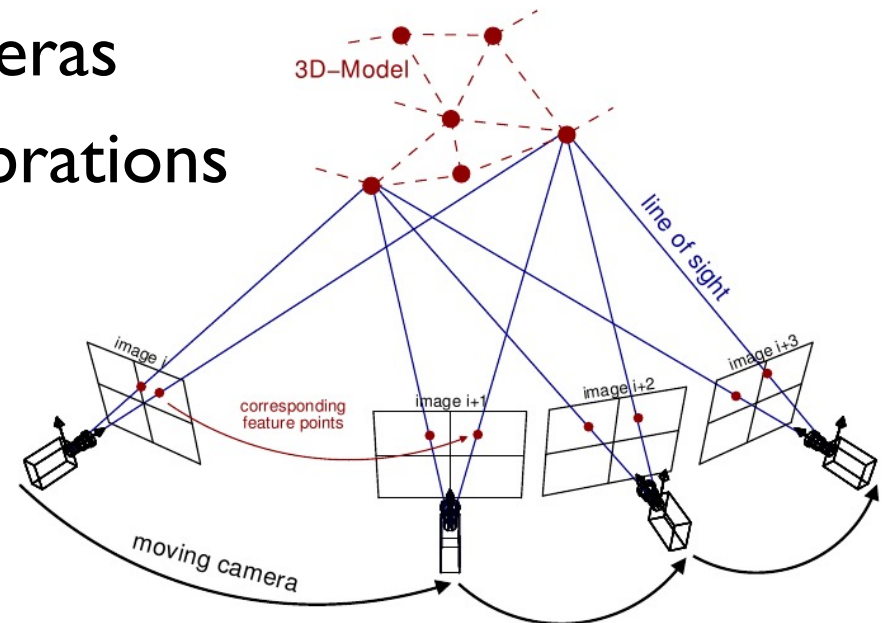


# How does it work?

- Multiple Steps
  - Finding Matches
    - Finding feature points
    - Actually matching them
  - Camera Calibration
    - Position and calibration of Cameras
    - 3D Position of matched feature points
  - Dense Matching
  - Merging, meshing and texturing

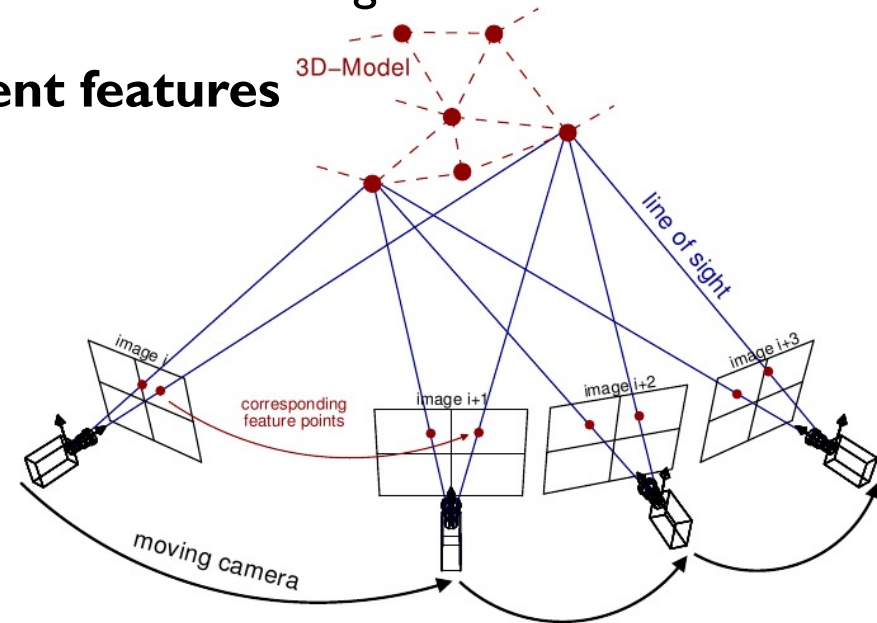
# How does it work?

- Multiple Steps
  - Finding Matches
    - Finding feature points
    - Actually matching them
  - Recovering Cameras
  - Position and calibrations



# Camera Calibration

- No prior knowledge about camera calibration is available, so all information must be recovered from the images
- It is important that **consistent features** are in the images!
  - *No white walls,*
  - *No changing appearance*
  - *No moving stuff*
  - *No blur*
- Important factors:
  - Position of the camera
  - Enough overlap  
(only points that are visible in at least 3 images are useful)

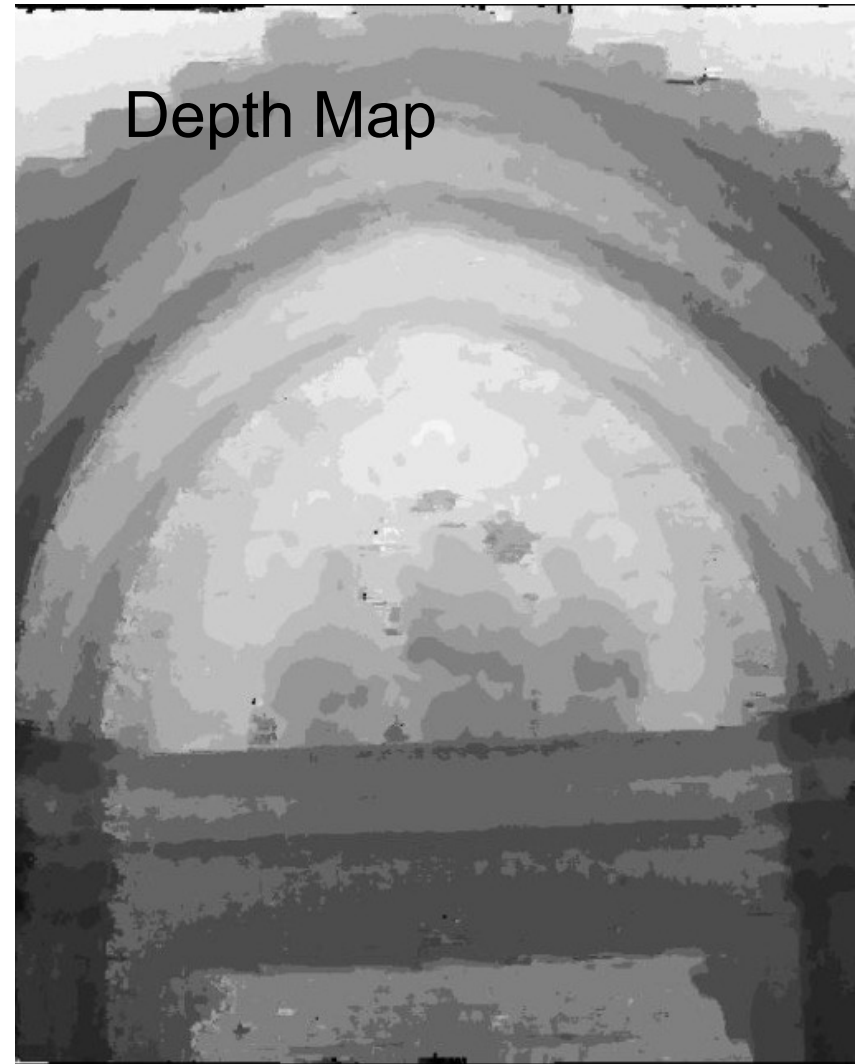


The scene to be reconstructed and how you shot photos have **HUGE** influence on the final reconstruction (!!)



# Dense Matching

- After recovery of the camera calibration, dense depth maps are computed
- These contain the depth of every pixel and a quality measure (how confident we are of each particular pixel)
- ***Output is a point cloud***



# Why this is important?

- Quality of reconstruction depend a lot on the quality of the photos
- Knowing the process means know how to improve the quality of the acquisition

# Image-based 3D Reconstruction

- **Advantages:**
  - Cheap (no scanning device needed), fast tech evolution
  - Good flexibility (both small and huge model can be acquired)
  - Cameras are more easy to use than a scanner (lighter, no tripod, no power, multiple lenses ...)
  - Non-expert users can create 3D models
  - KEEP THE PHOTOS
- **Disadvantages:**
  - Accuracy (not so accurate, problems with regions with insufficient detail)
  - Slower than active techniques (many images to process and merge)
  - Not all the objects can be acquired

# 3D/CH

- **Presentare**

- Telling Stories (interactively),  
display of reconstructions

- **Documentare**

- 3D scanning is the way of documenting shape in a  
measurable/repeatable/scientific way

- **Analizzare**

- 3D data can be the basis of further study and  
analysis

- **Supporto al restauro**

- Planning, comparing, documenting it.



# Visual presentation - Passive 3D

- **Computer animation** is a major media for telling the story of our heritage

## *Classic StoryTelling*

- Some examples:
  - “**Parthenon**” movie by USC, Paul Debevec (2004)
  - “**Teatro Greco di siracusa**” by IBAM-CNR, Francesco Gabellone (2016)



# Visual presentation - Active

- Representing a complete environment, supporting a navigation-based access metaphor?
  - Free navigation in a full-3D space is **complex to drive** (for a significant subset of the users)
  - Very valuable for ruined/lost architectures
- Active 3D visualization/inspection:
  - Great potential for the study of a **single object**
  - Support manipulation, access from any view
  - Extend to other geometric/visual processing (e.g. cut-through views, simulated X-ray, compute measures, ...)

***INTERACTIVE STORYTELLING***

# Visual presentation – Serious Games

The assets used for AAA games are often based on extensive historical research and can be **quite** accurate

The “*Discovery Tour*” for *Assassin’s Creed Origins* was one of the first serious exploitation for didactical purposes of gaming assets





# Cenobium: Monreale Cloister



Photos:

- all capitals
- 8 shots (16M pixel)

3D models:

- Scanned 20 capitals (Minolta VI910)
- 120-200 scan per capital
- 3D Models: 4-6 M triangles
- With color images mapped on the 3D model

**Demo 3D**







Most Visited

The CENOBIUM Project's Homepage

Kunsthistorisches Institut  
in Florenz  
Max-Planck-Institut



ISTITUTO DI SCIENZA E TECNOLOGIE  
DELL'INFORMAZIONE "A. FAEDO"  
Visual Computing Lab - CNR, Pisa



Soprintendenza  
per i Beni Ambientali Architettonici Artistici Storici  
per le province di  
Pisa Livorno Lucca Massa Carrara

Cultural  
Electronic  
Network  
Online  
Binding up  
Interoperably  
Usable  
Multimedia



CENOBIUM  
work in progress



Monreale cloister



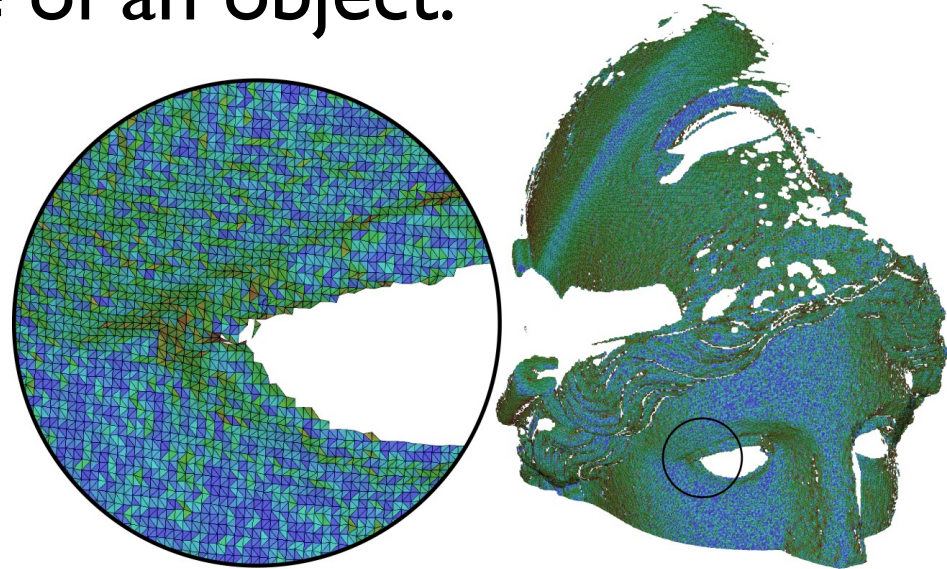
Aosta cloister



best viewed at 1280x1024 resolution - full screen

# Documentation

- Presentation is ***not*** the only use of 3D data.
- 3D Scanned data provides the best documentation form for capturing the geometric shape of an object.

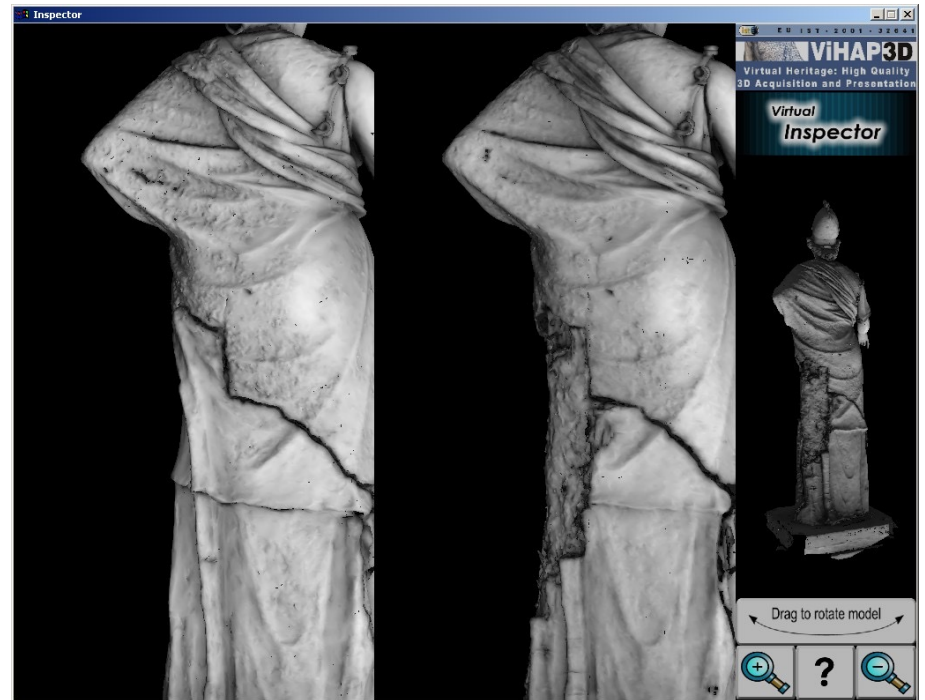


# Documenting: shape

## Minerva di Arezzo case study

Restoration with removal of:

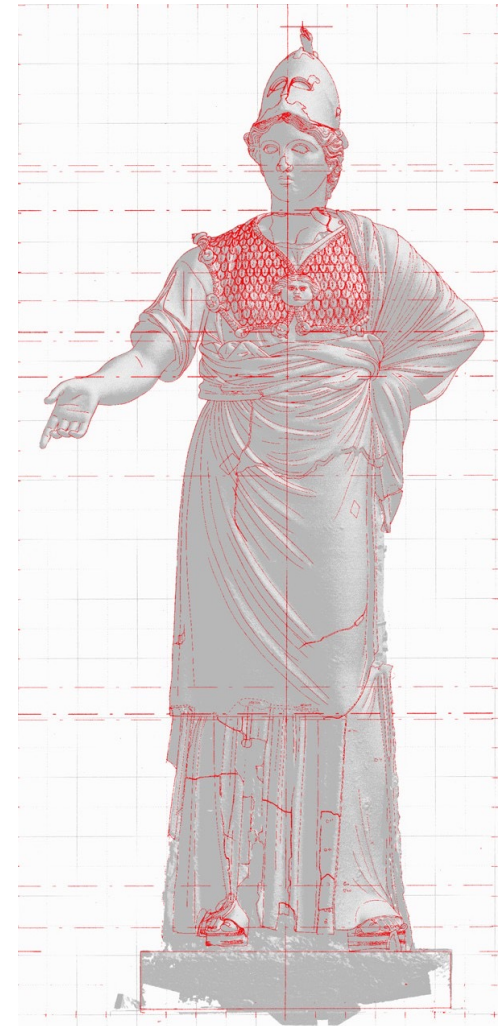
- Large parts added in ancient restoration (rx arm, plaster)
- Thick oxidation layers





# Documenting: shape

- Why a 3D scan instead of a standard photographic campaign?
  - 3D Model is measurable
  - Automatic production of pictorial material
  - Reproduction through rapid prototyping is a plus
- Does not cost much more than a standard photographic campaign.



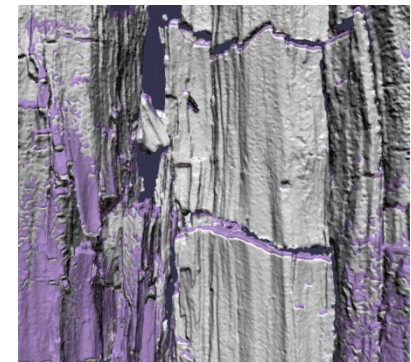


# Beni Culturali: Monitoraggio

- es: monitorare nel tempo la variazioni sui materiali deformabili



foresta di Dunarobba  
<http://www.forestafossile.it/public/new/>



# Documenting with 3D: appearance

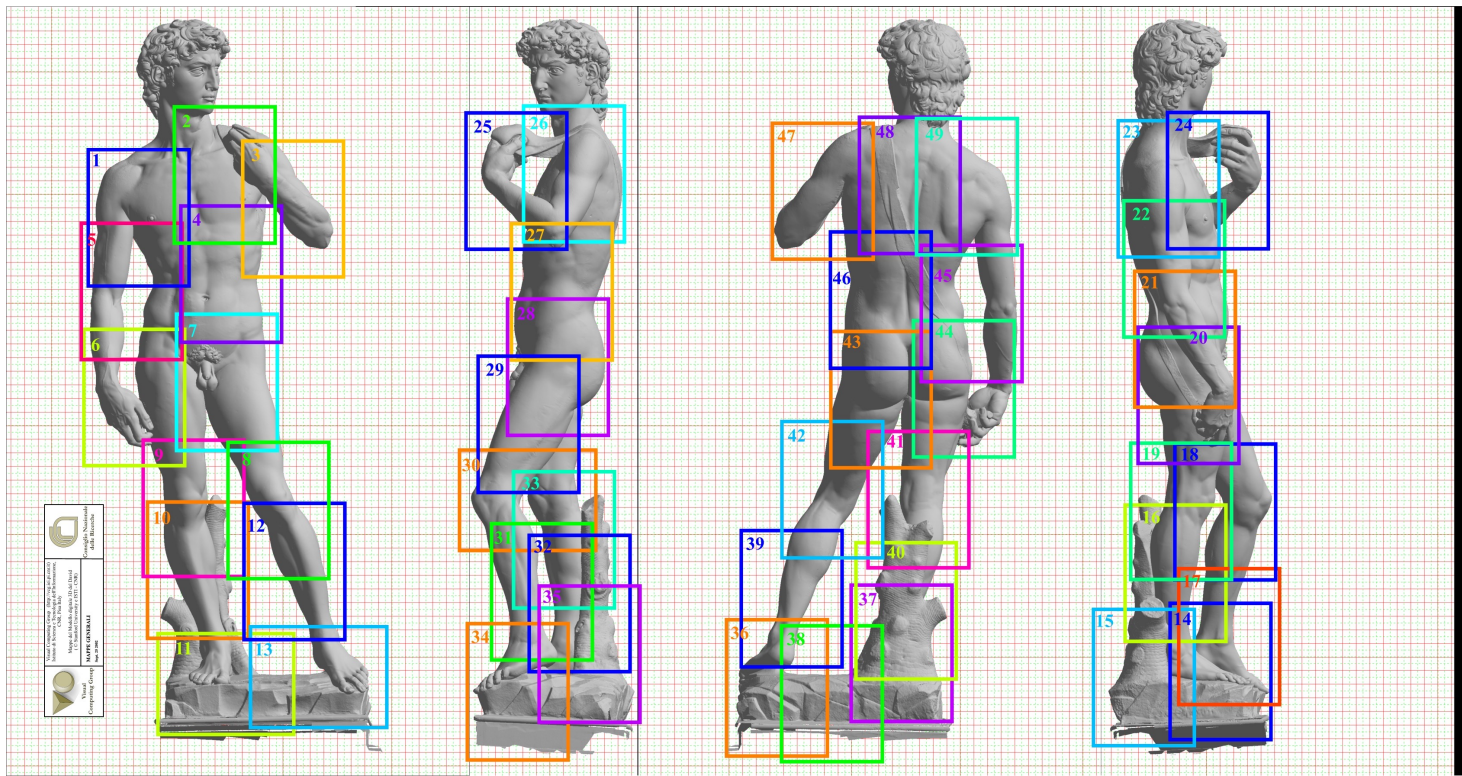
- Integrating 3D scanned model with a photographic survey:
- Documenting the status of the statue with respect to the color
  - Changes in color
  - Patinas
  - Very small scale details
- Case study: restoration of the Michelangelo **David**



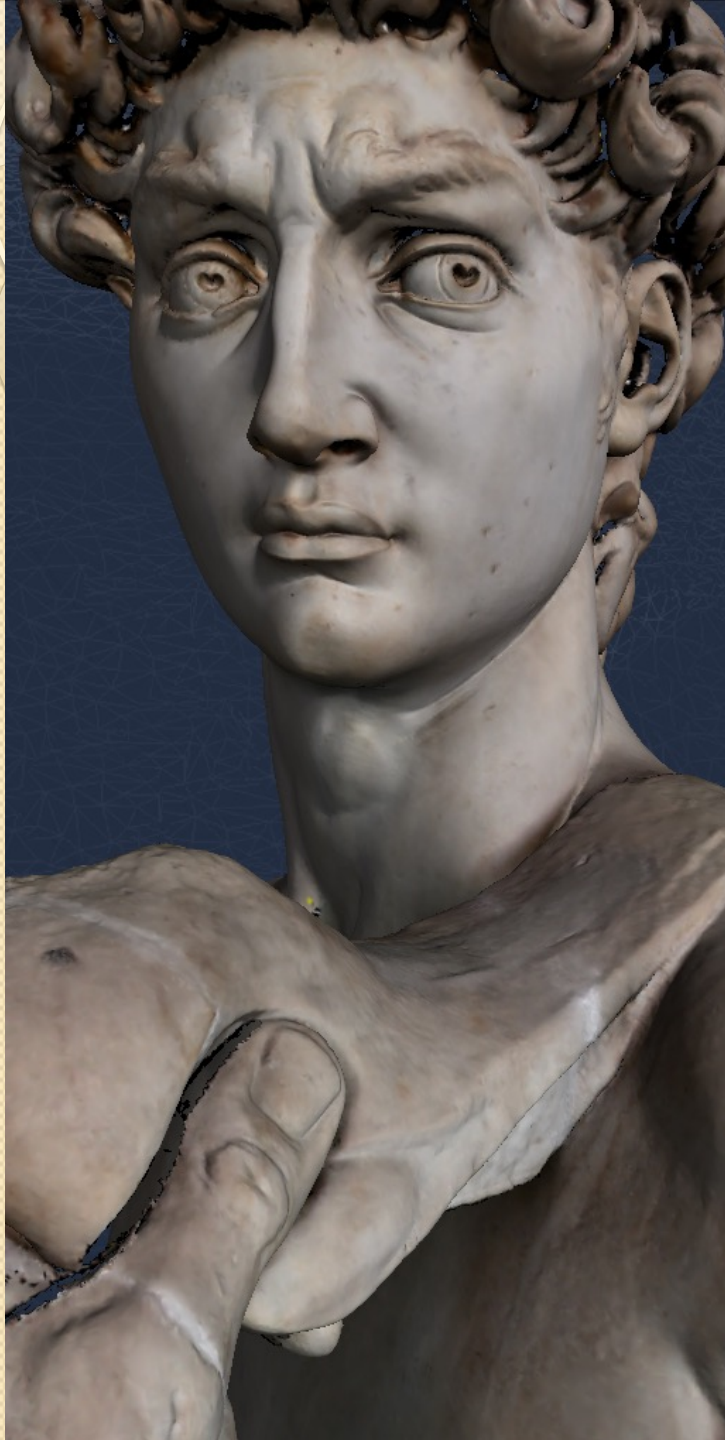


# Documenting Restoration - Color

- **High-quality photo** campaign by professional photographer (digital images)  
➔ 68 photos covering all the surface
- Photo shots planned with the photographer, Rabatti & Domingie (see below)
- Repeated at the **end of the restoration**







chiudi

X

  
*Virtual  
Inspector*



☒ **inquadratura**

illuminazione

zoom in

zoom out

attiva collegamenti

help





chiudi



Virtual  
Inspector



inquadratura



illuminazione

zoom in

zoom out

attiva collegamenti

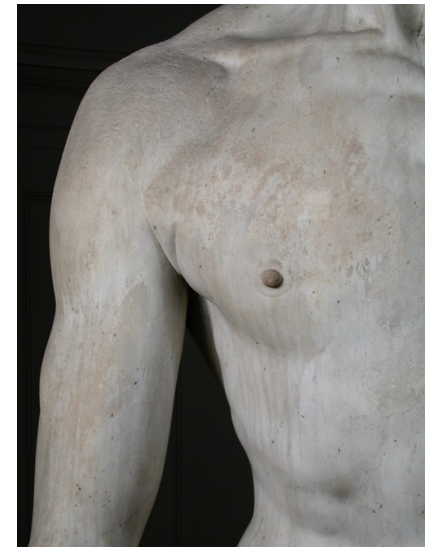
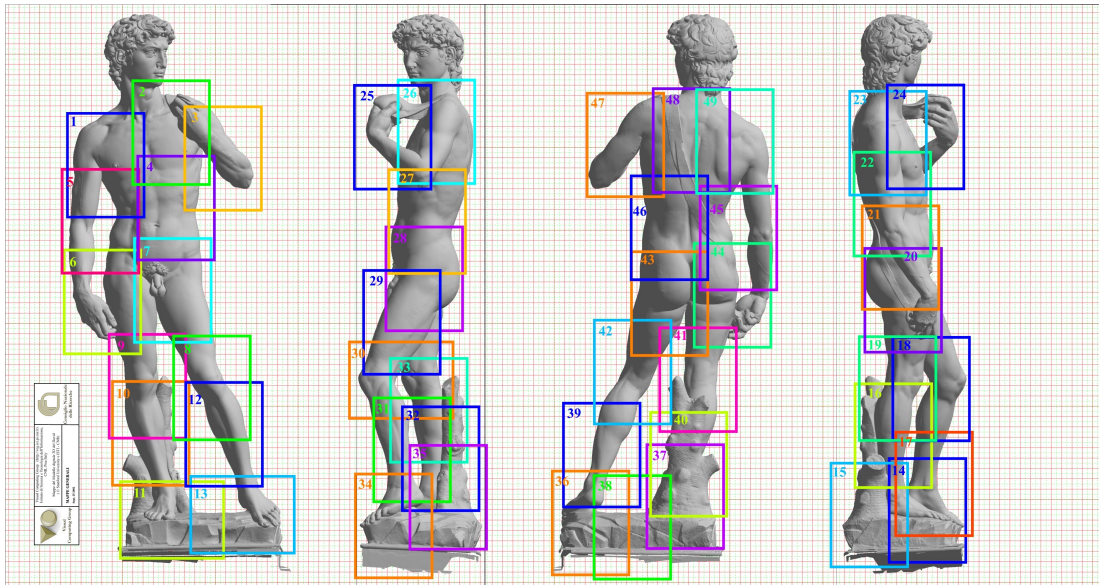
help

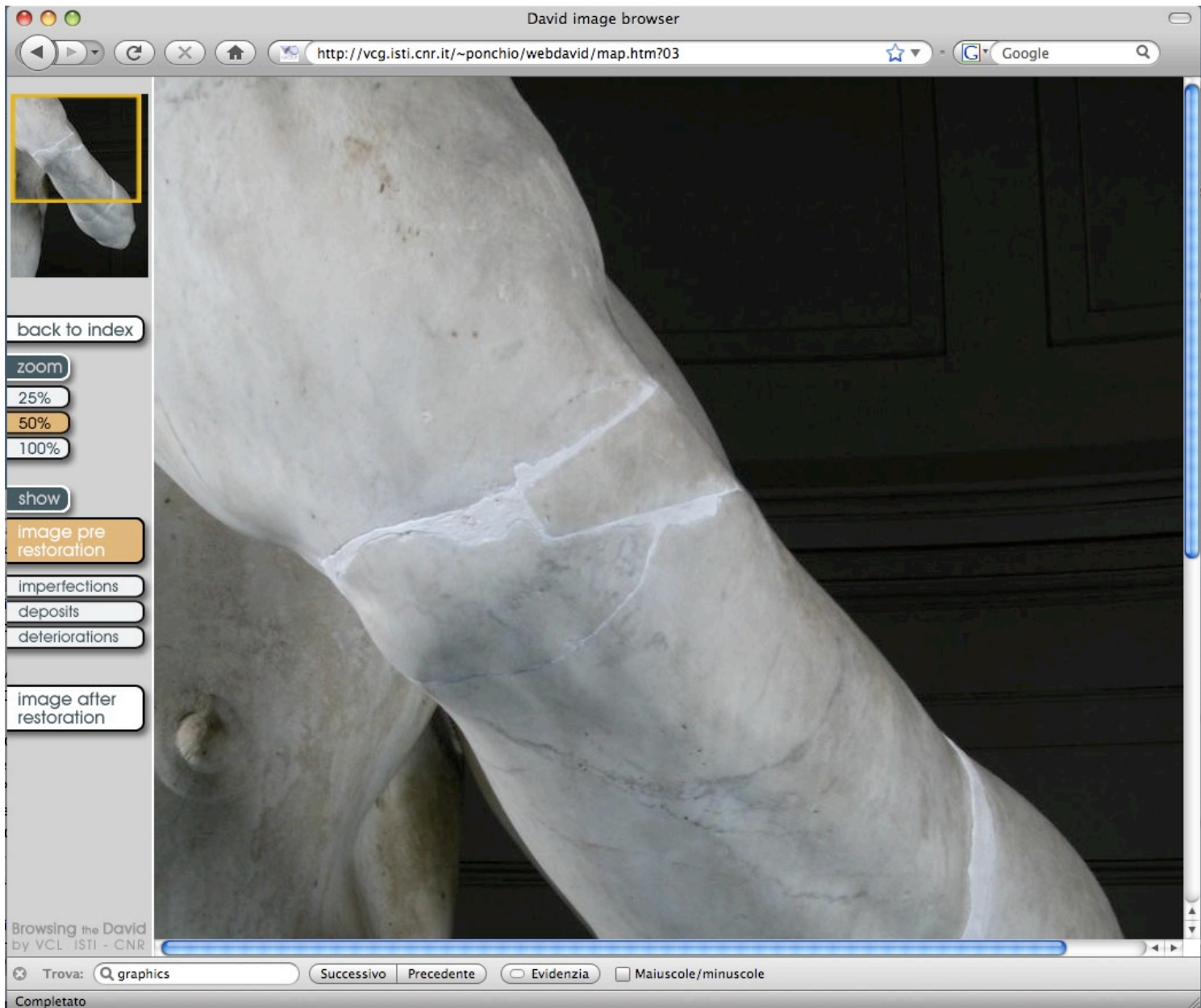
credits



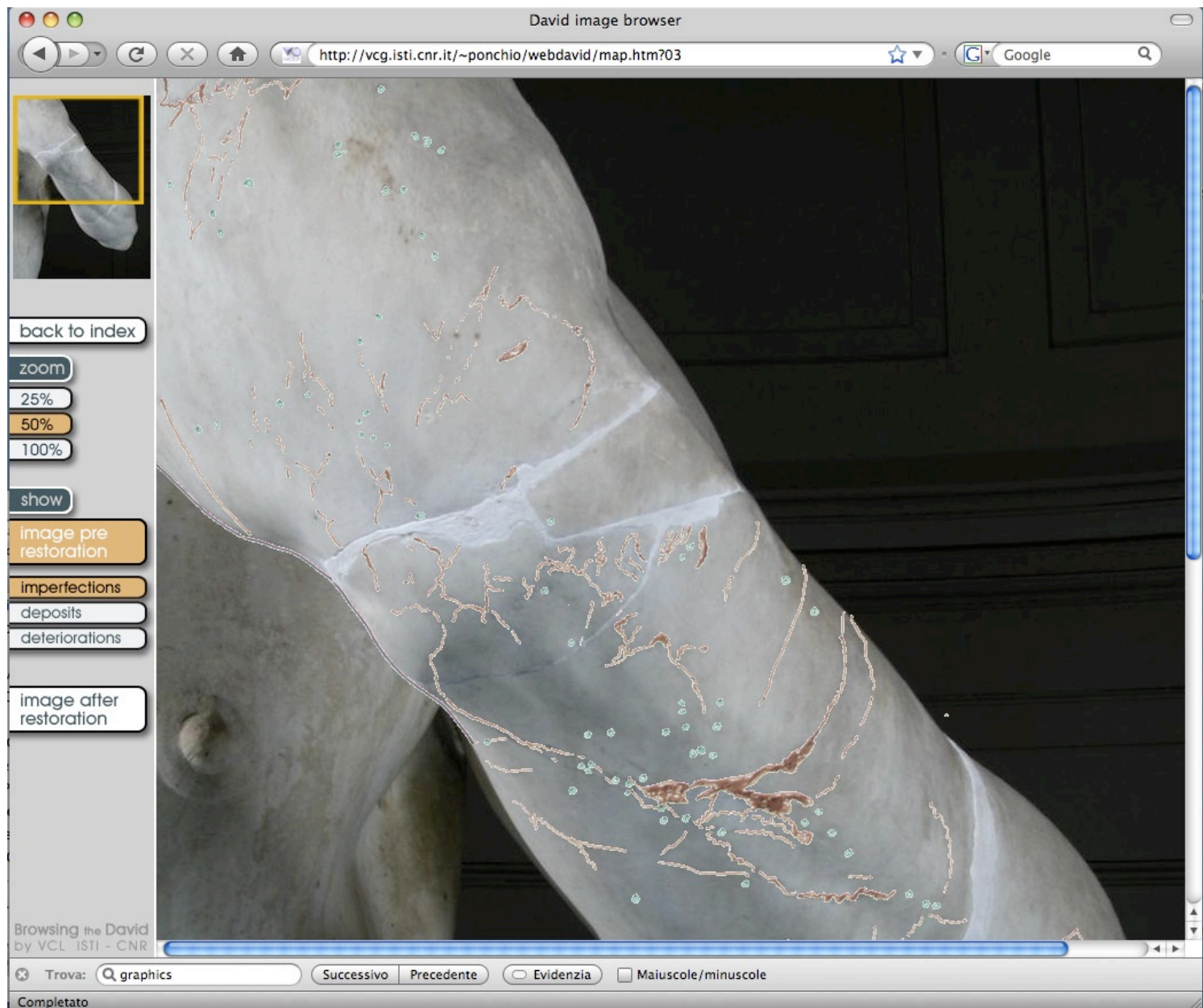
# Documenting Restoration - Restorer's analysis

- o **Visual analysis** of the status of the **marble surface** performed by restorers (Agnese Parronchi and Cinzia Parnigoni) before restoration
- o Usually documented with drawings
- o How can we manage those data with ICT tools?
- o Remember the photographic sampling available...

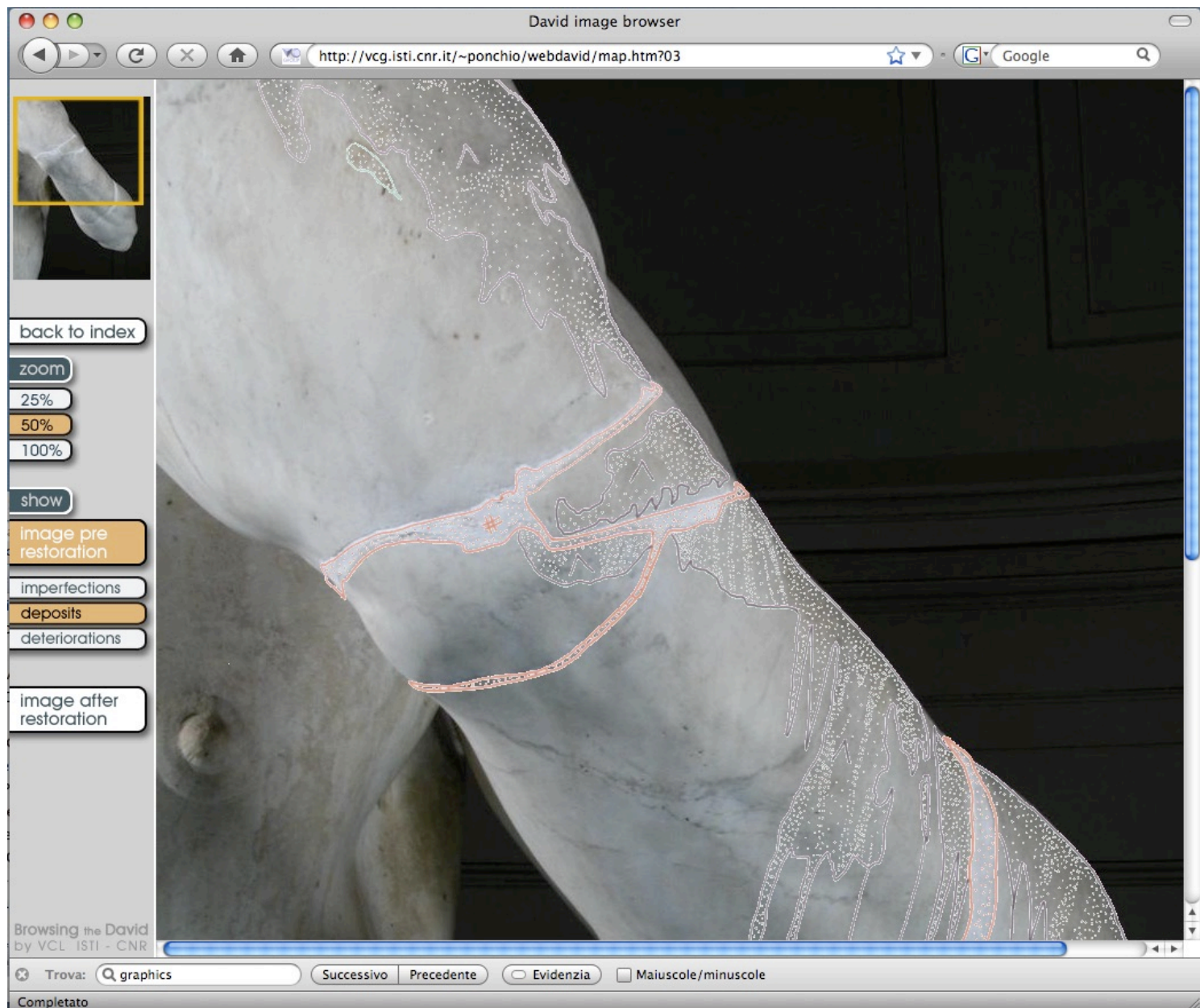






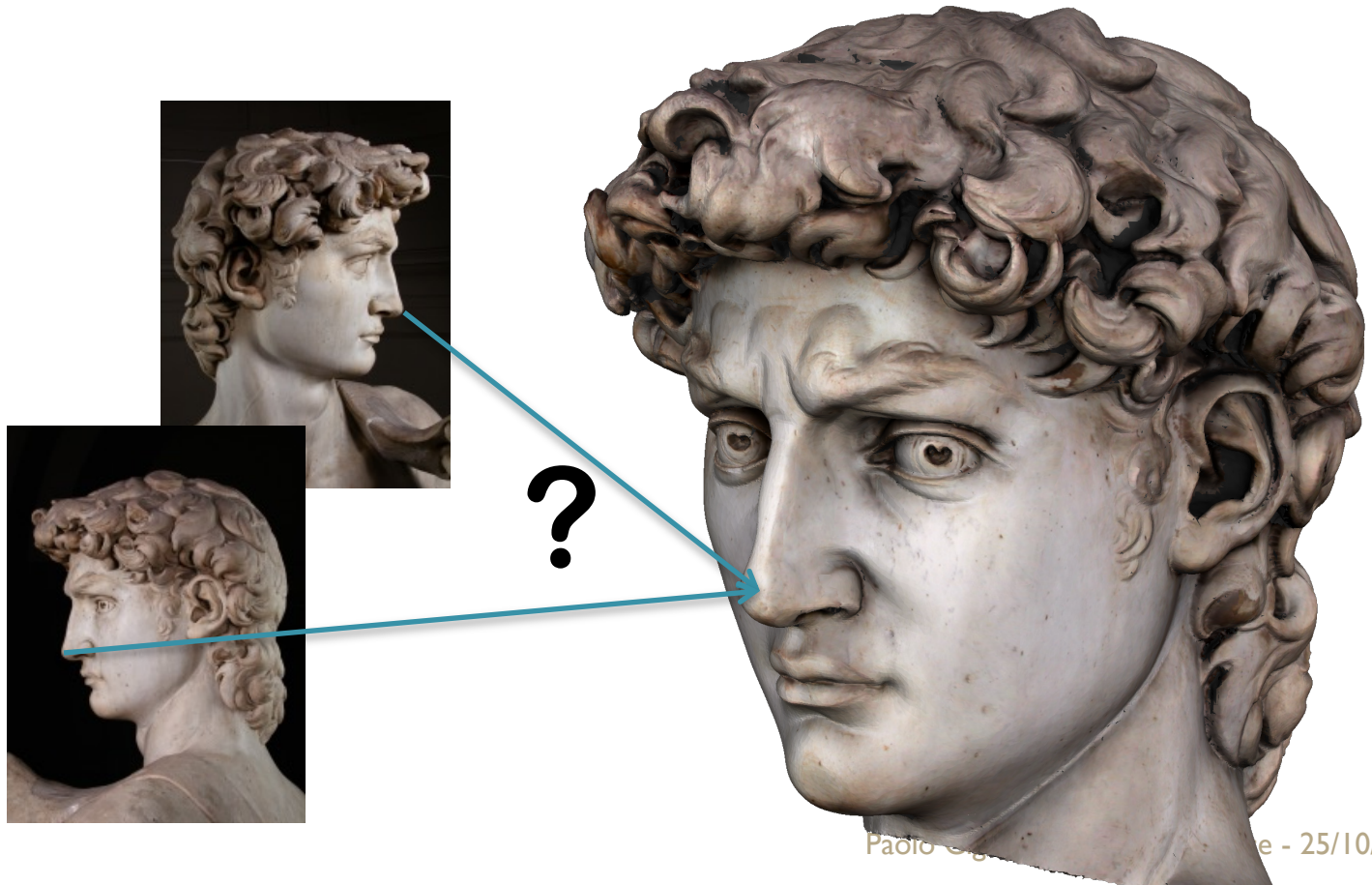






# Provenance issues

- What images contributed to build this model (or this texel?)



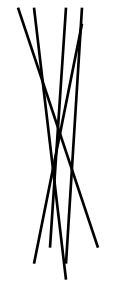
# Beyond Documentation - Analysis

- The 3D model can be the basis of further studies
- Exploit the accuracy of the acquired shape for simulations and computations.

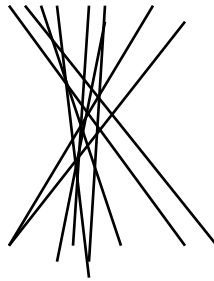


# Digital analysis: contaminant fall

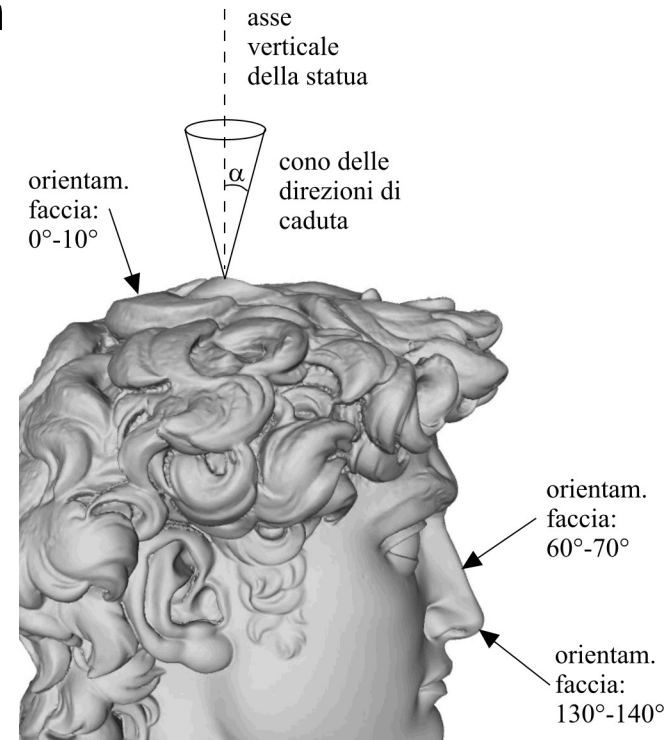
- Simulation of the fall of contaminant over the statue;
- What are the most exposed portion of the surfaces?
- Assume that particles fall vertically within a angle alpha



$\alpha < 10$



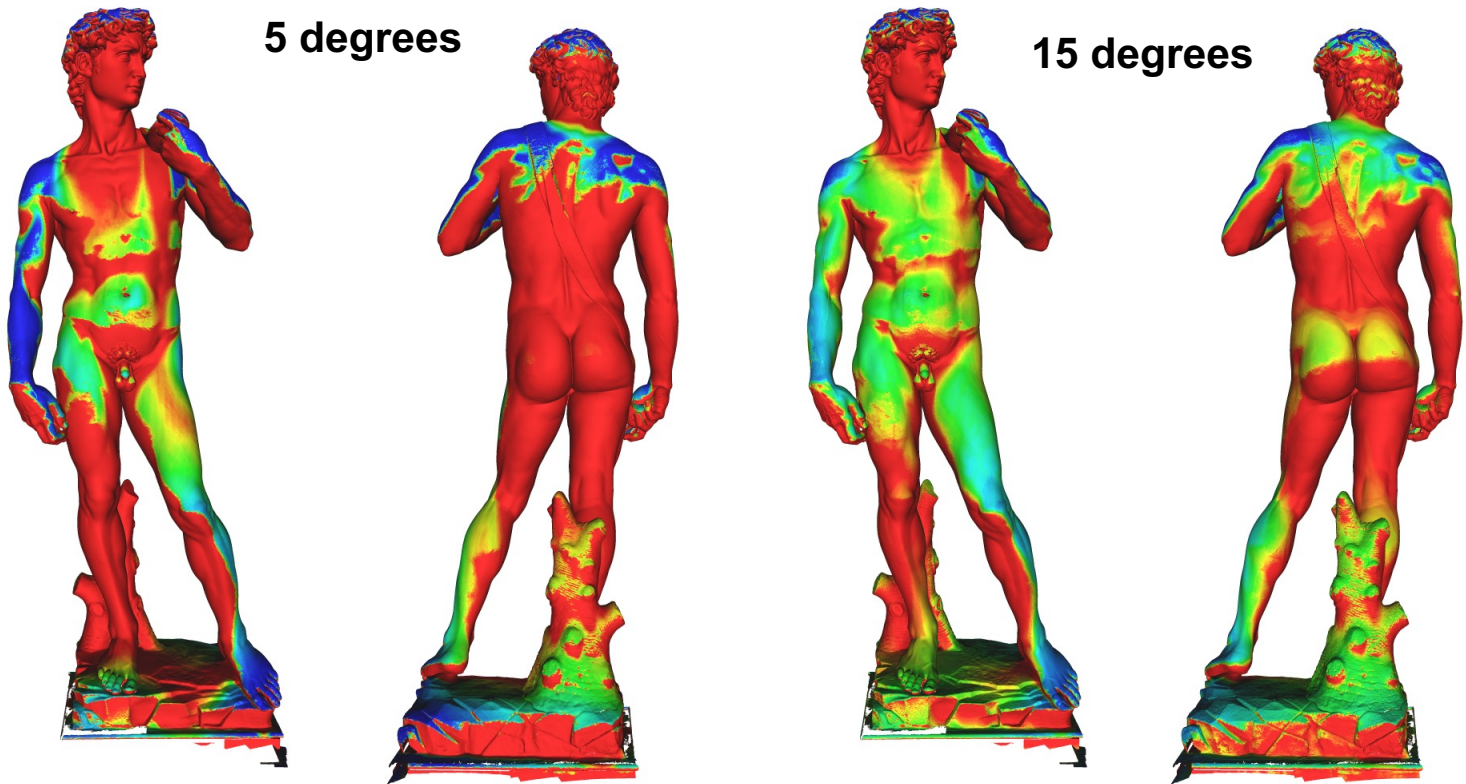
$\alpha < 45$





# Digital analysis: contaminant fall

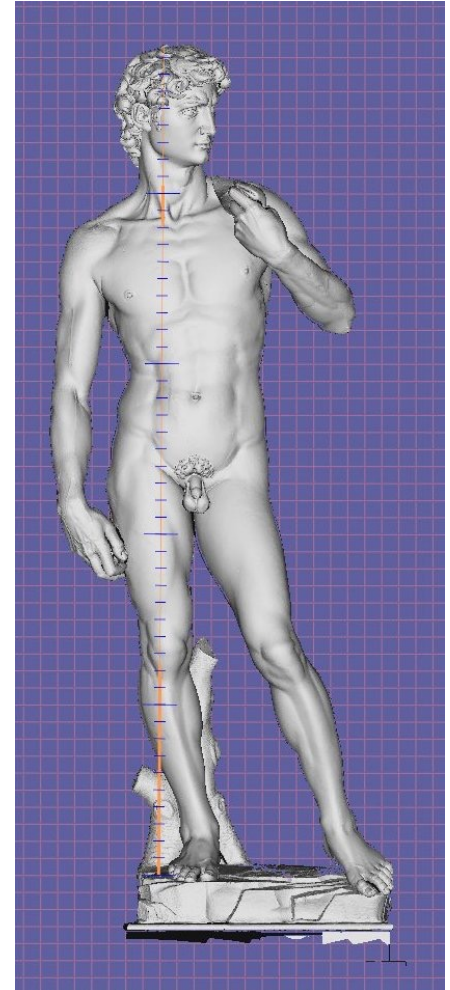
red -> no depos., blu -> max depos.



# Digital Analysis: Measure

Computing physical properties on the 3d model

- **Volume:** 2,098 m<sup>3</sup>
- **Surface:** 19.47 m<sup>2</sup>
- **height:** 486 / 516 cm
- **Static analysis**
  - **Barycenter and its vertical projection**



# Why interested in baricenter?

- There are severe cracks on the ankles (back side)
- Well known since XIX cent., the major reason for recovering the David in a museum
- Could these cracks be the alarm for a wrong placement of the statue? (historically or currently)





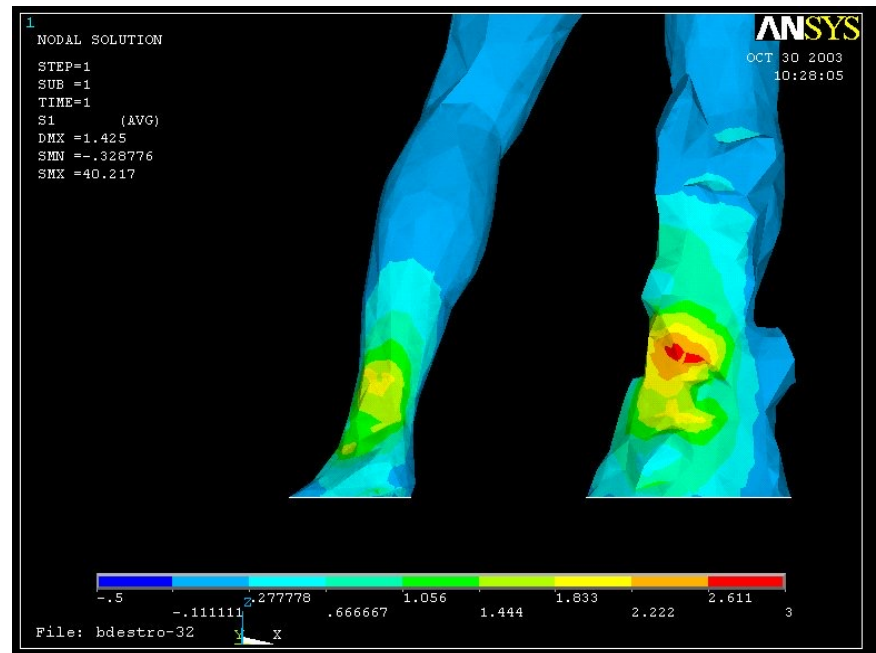
# Static analysis via FEM

- Could we simulate the stress induced by an inclination of the old basement? (Piazza della Signoria)
- Could this have produced the cracks in the ankles?
- Perform scientific **analysis** on the digital 3D models

Evaluate the static condition of the statue via **FEM** processing (by prof.A. Borri, Univ. Perugia)

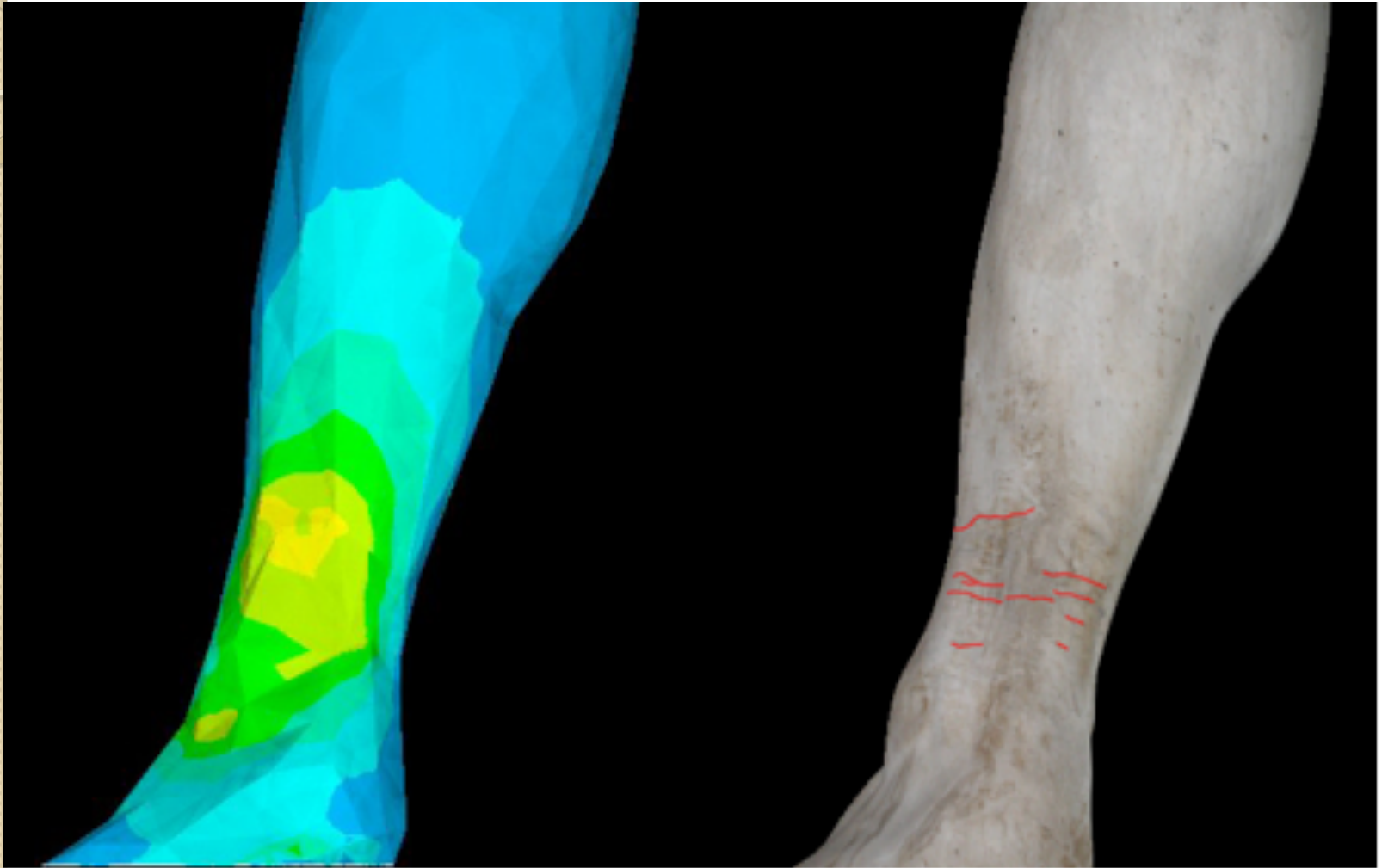
Evaluate just a 3 degrees rotation on the vertical axis

Stress regions correspond to real cracks locations!





# Static analysis via FEM



# Beyond Rendering

## Comp. Aided Restoration

- Reproduce **missing parts** (modeling + rapid prototyping)
- Simulate **deterioration** and **aging**
- Simulate **polishing/restoration** (color/reflection properties, micro/macro shape changes)
  - Simulate planned modifications to **appearance** and **shape** before acting on the real object → **Restoration planning**
- **Reassemble** fragmented [incomplete] artifacts
- Produce feature-oriented **non-photorealistic output** (mimicking classical pen&ink drawing style)
- or any other useful **tool**...

# Comp. Aided Restoration

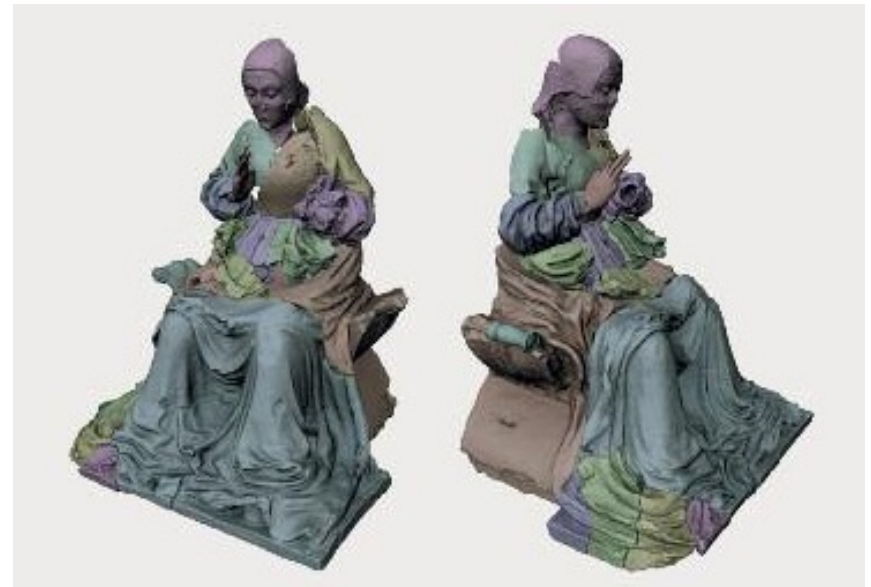
- The Madonna di Pietranico reassembling
  - Destroyed during the 2009 earthquake





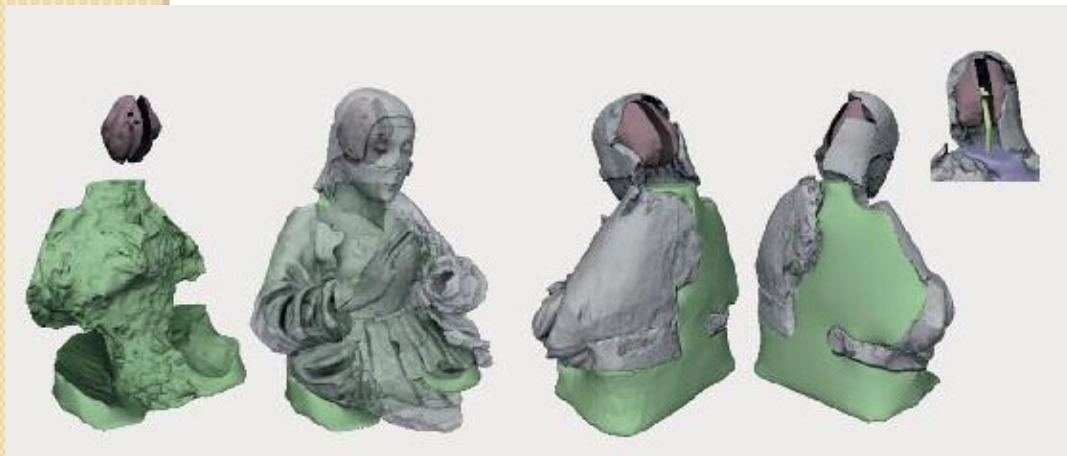
# The Madonna di Pietranico

All the pieces were scanned and virtually re-assembled



# The Madonna di Pietranico

The 3D model was used to design a complex support structure to allow a reversible, non invasive reassembling of the pieces



# Using 3D- Beyond Rendering

- Support **physical reproduction** from digital 3D models (avoiding to cast endangered artifacts)
- **Digital Fabrication:**  
The process of digitally driving hardware devices to produce actual 3D objects
- Also known as **3D Printing**





# Why we need Digital fabrication

- Reproducing 3D artworks is an ancient skill
- Rubber/Gypsum Molding have been done for centuries
- Gypsotheques have been an excellent way to distribute knowledge of 3D shapes



# Why we need Digital fabrication

- Making gypsum copies has many issues:
  - Manual/Difficult
  - Invasive
  - Imprecise
    - High quality at high frequencies
    - Varying quality at low frequencies

# Digital fabrication

- Support **physical reproduction** from digital 3D models (avoiding to cast endangered artifacts)
  - With **no harm** for the original (much safer than a “calco”)
  - In **any reproduction scale** (1:1, reduced, magnified)
  - Using many **different materials** (plastic, gypsum, stone, marble ...)
  - **Cost** are becoming affordable



# Digital 3D for reproduction

- **Calco (mold)**

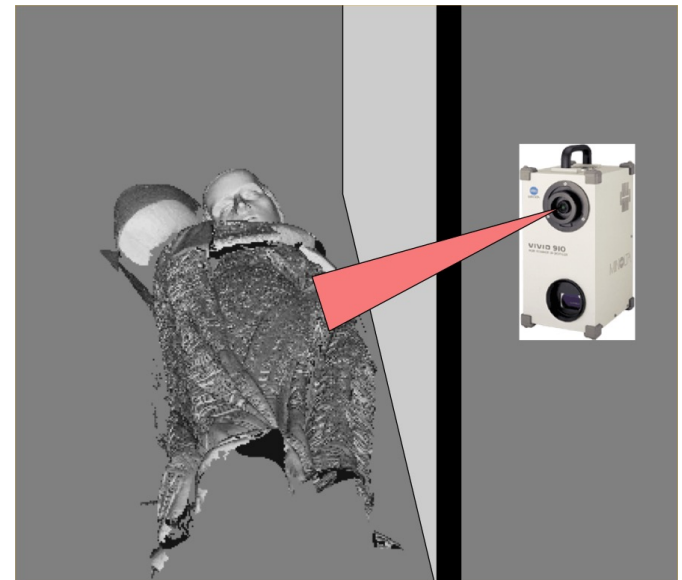
- Can reproduce only in **1:1 scale**
- Can be used only for a small number of copies
- Copies are only in gypsum or resina
- It may **degrade** the original (removal of patinas or small detachable parts)
- *It is very precise* (false belief!)

- **Digital 3D model**

- Can reproduce in **any scale**
- Can be used forever
- Copies are in many materials (e.g. marble, stone)
- It is a not-contact, safe technology
- *It is less precise* (false belief!)

# Are molds of better quality?

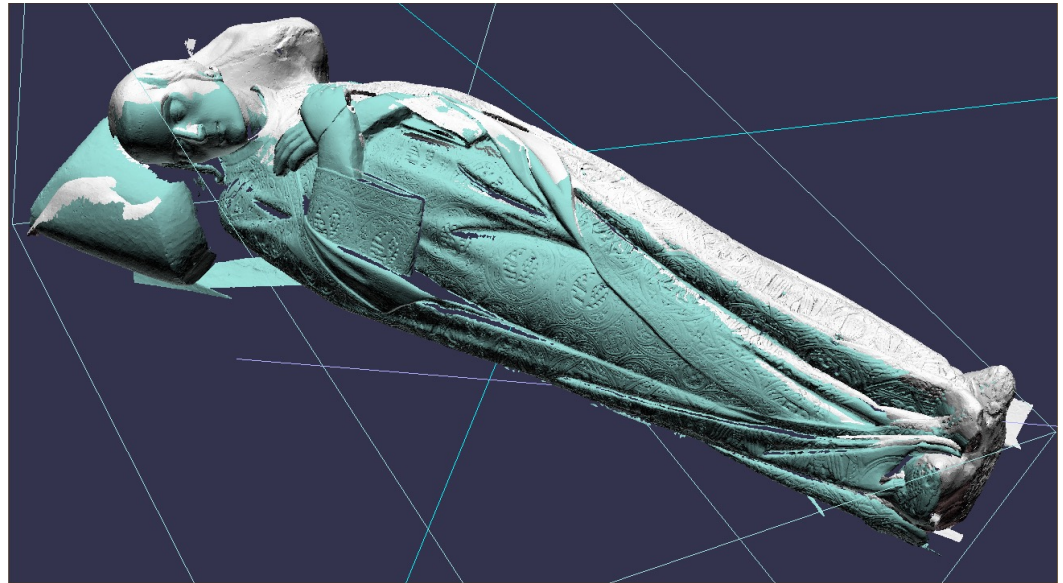
- Most of curators and art experts consider molds/calchi as **very accurate**
- *Are we sure?*
- Our experience:
  - **Arrigo VII "Giacente"**, lying in a niche
  - it was not possible to scan it in a complete way
  - Scanning the right-side is impossible, scanner should be on the other side of the wall



# Are molds of better quality?

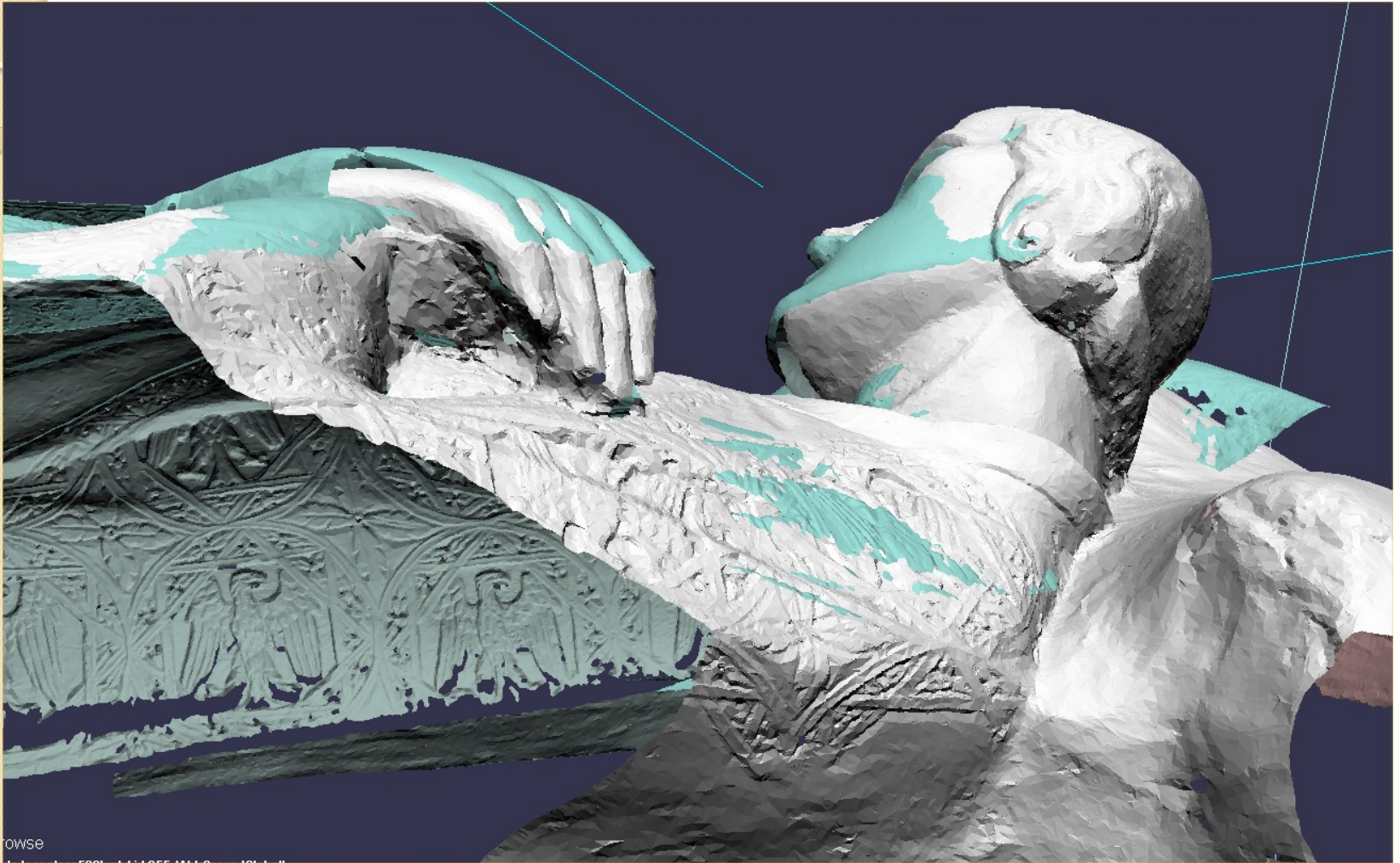
*Since there is a good quality gypsum "**calco**" (mold), why not sampling the missing part from the mold?*

- 3D scanned the "calco"
- Join the section scanned from the **original** (light blue) with the one scanned from the "**calco**" (white)
  - ➔ found a deformation of the "calco" of several centimeters!
- Digital vs. consolidated techniques...





# Are molds of better quality?





# **Technologies**

# Digital Fabrication - Technologies

Two main categories:

- **Subtractive Technologies**
  - Start from a block of raw material and **carve out** the target shape
- **Additive Technologies**
  - Build the target shape one bit at a time. Usually by **slices**



# Subtractive Technologies

- Quite old technique
- Computer Controlled Lathe machining was one of the first application of digital tech to the industry

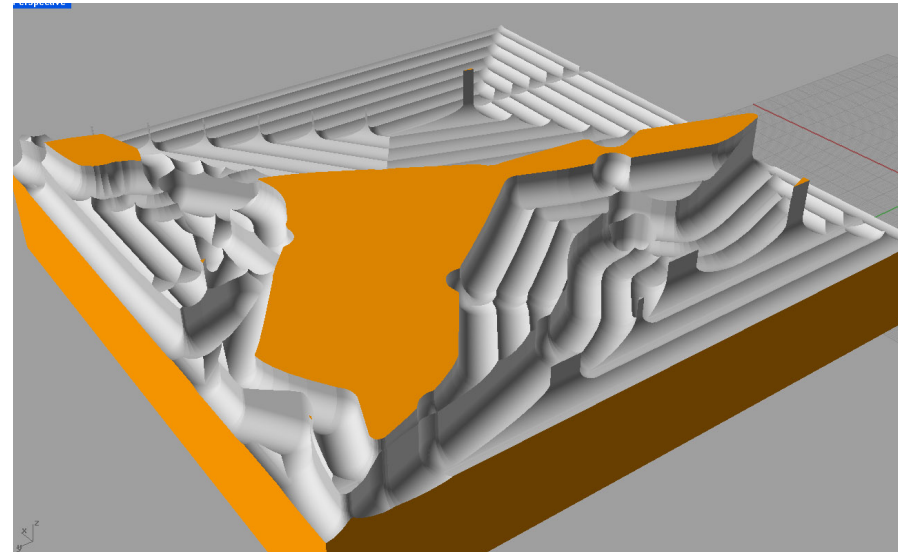


- Lathe are ID axis machine
- The main idea is to drive a drilling machine over some material



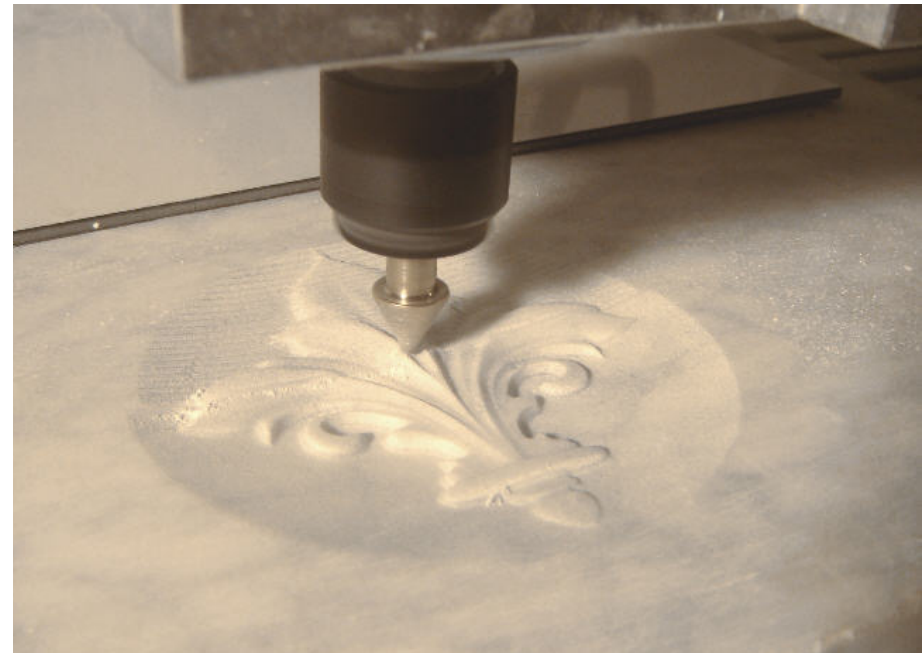
# Subtractive Technology

- Many different milling / carving techs.
- Multiple carving tools
  - Rougher means faster
  - Smaller and more precise means slower
- Milling paths
  - How to move the carving head over the surface of the object is **THE** problem.



# Technologies: Subtractive 2.5D

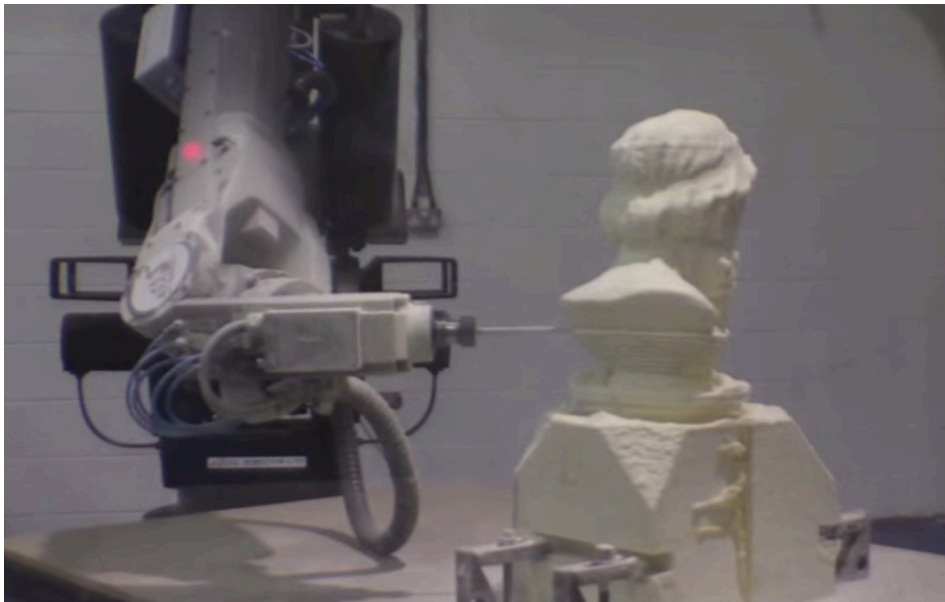
- The simplest subtractive technique
- The carving tools moves over a plane and only the height of the carving tool can be controlled.
- Only height fields can be fabricated
- Size and shape of the carving tool affect the quality





# Technologies: Subtractive 6-Axis

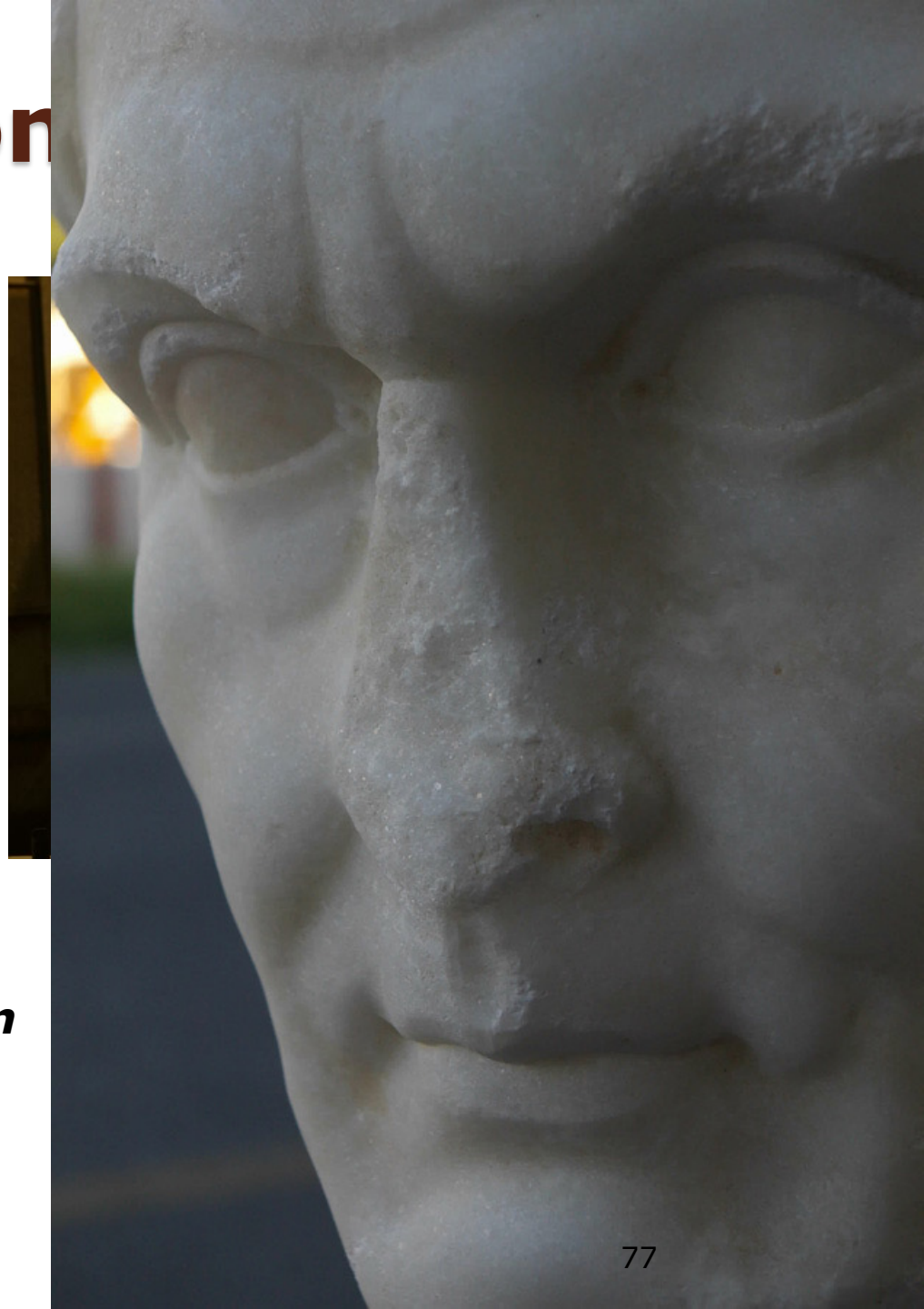
- The most complex of the milling technologies
- Fully controllable robot arm with milling device
- Quite complex to **design the milling path** → affect reproduction cost!!



# A reproduction

- German government commissioned to us the reproduction of a Roman head of Mecenate
- Work was supervised by Prof. Bernard Andreae,
- Goal: highly accurate reproduction in marble
- Original plan: mold + reproduction in resin with marble powder

***3D scan + semi-automatic reproduction***





# **Additive Technologies**



# Technologies: Additive

- Main idea build an object **a slice at a time**
- Many different ways of depositing different kind of materials
- Basic concept: Slicing



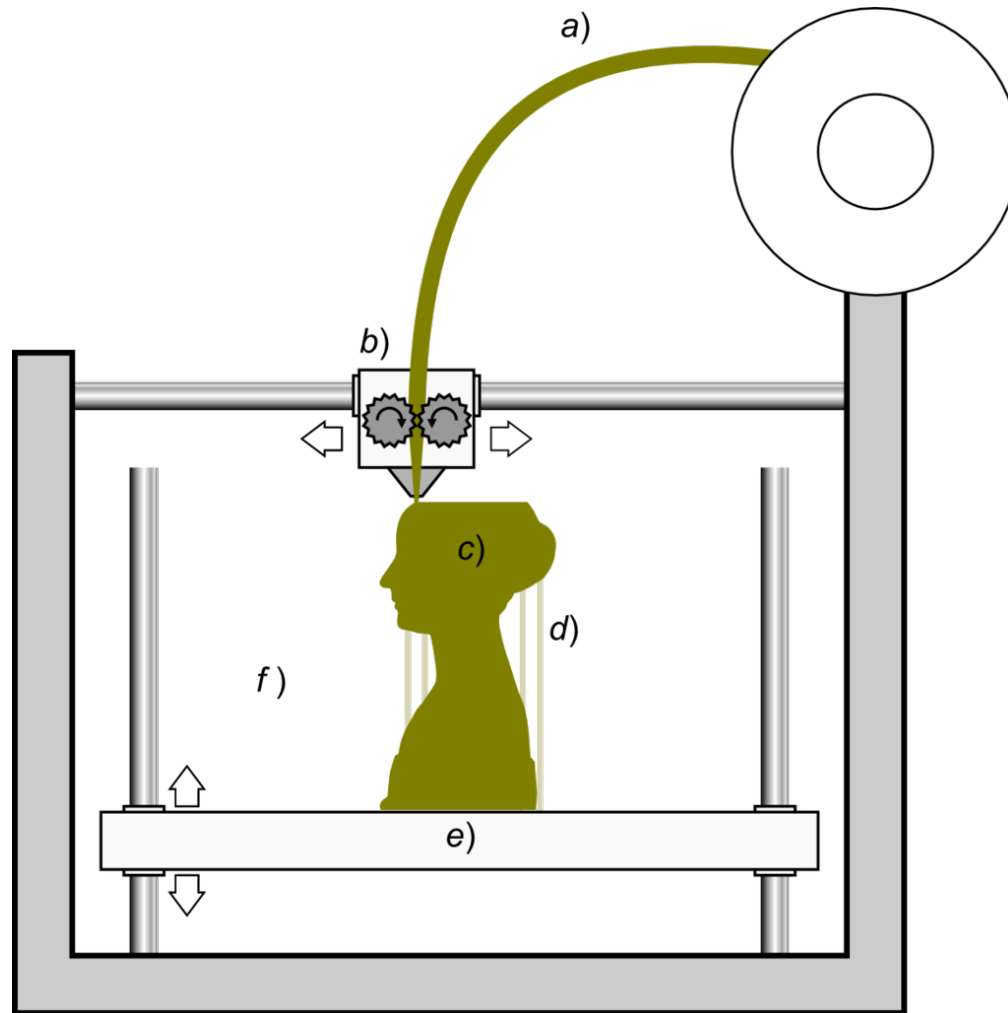
# Technologies: Additive FDM

## Fused Deposit Modeling (FDM)

- By far the most diffuse
- Hundreds of 3D printers on the market
- From 300 € up
- Suitable for home and office use



# Technologies: Additive FDM





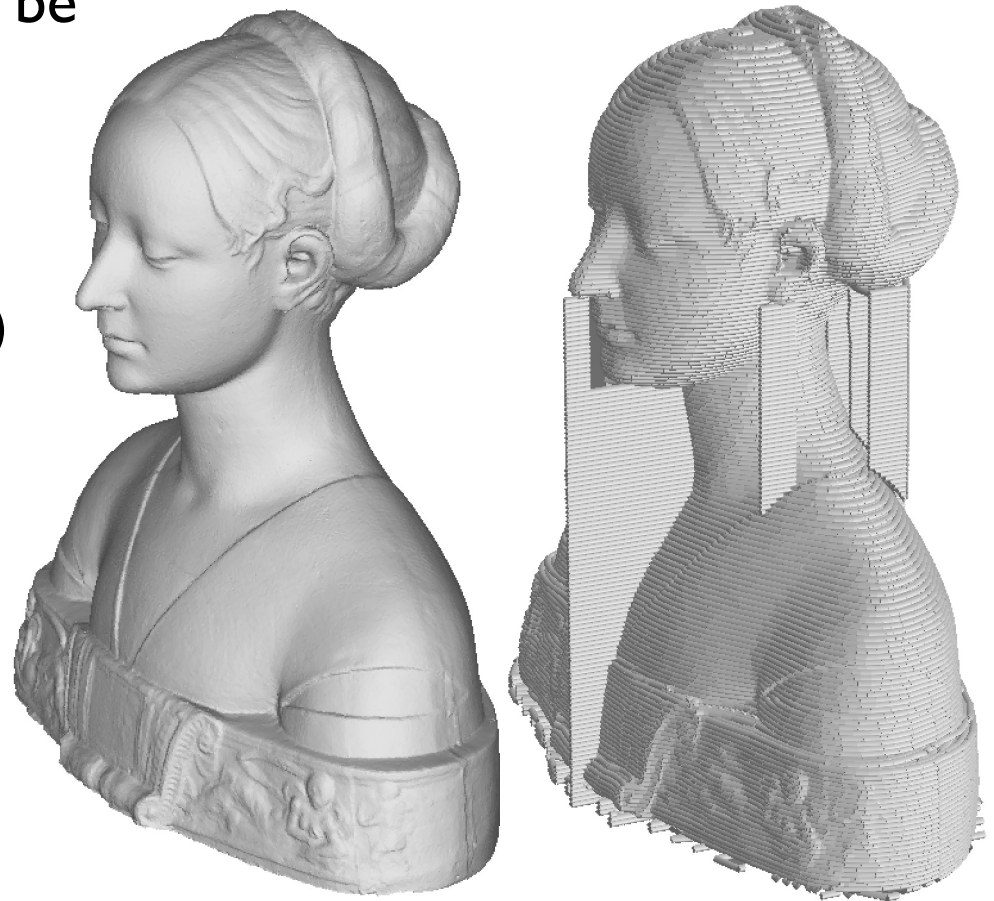
# Technologies: Additive FDM

- The slicing of the process is evident
- Different materials can have quite different appearance



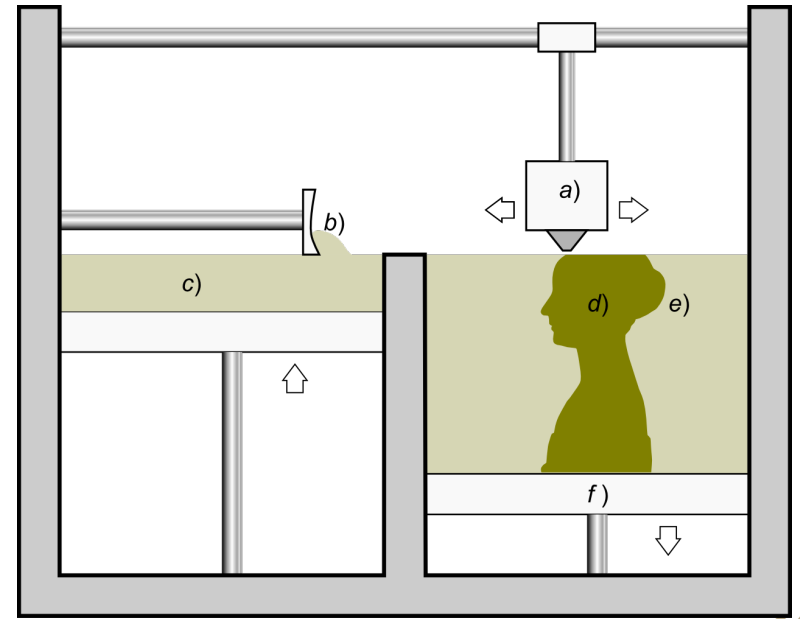
# Technologies: Additive FDM

- Deposited material is not self supporting!
- Explicit support construction done by most sw tools
- Supports have to be removed later
- Some FDM's use different support material (soluble)



# Technologies: Additive Gypsum Binding

- Work by layers
- The object is build by dripping glue (binding) on gypsum
- Color can also be dropped on the gypsum
- Object is created immersed in the powder
- No support needed





# Technologies: Addictive Gypsum Binding

- Not a very clean technology
  - Not suitable for a usual office
- Full Color (but with a limited gamut)
- Costly
- Post processing required:  
Infusing with glue for robustness



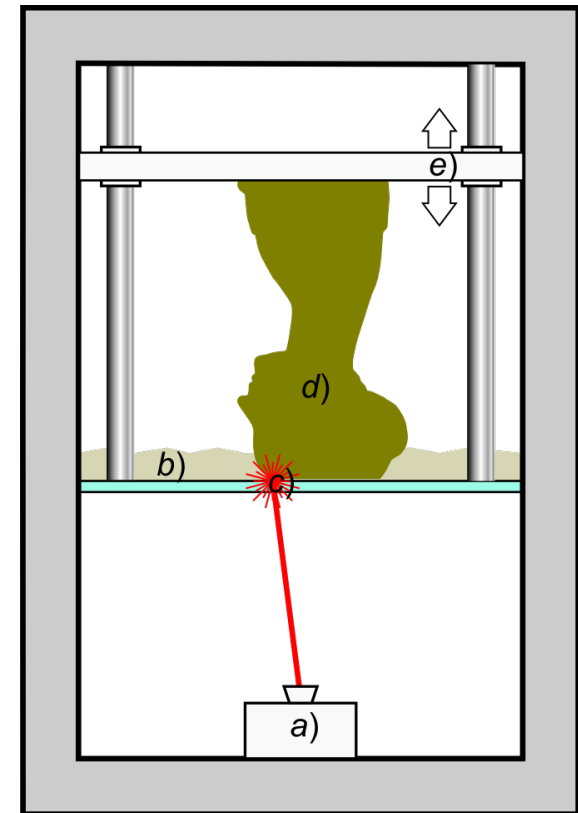
## Technologies: Additive Gypsum Binding

- Sandstone like finishing (very nice for CH replicas)



## Technologies: Additive Photopolymerization

- Again, it works layer by layer
- Liquid resin is cured (solidified) by a UV laser or projector
- Almost no need of support





# Fabricating Replicas

Original / first domain of application:

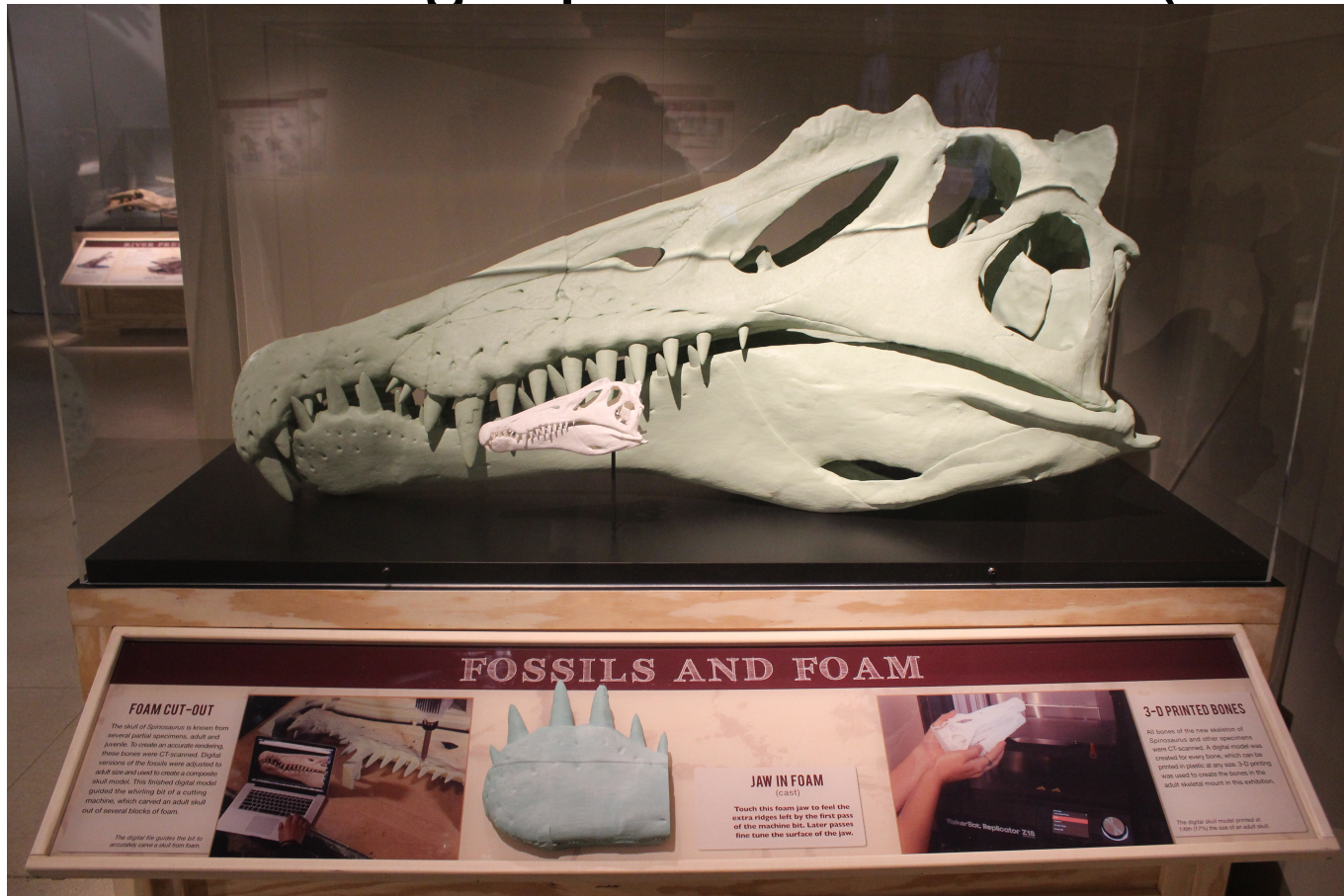
- **Rapid prototyping in**
  - Mechanical
  - Automotive
  - Creative industries



Rapid Prototyping | © 2012 Solid Concepts Inc.

# Museums

- Producing replicas of artifacts (3D scan +





# Fabricating Marble Replicas

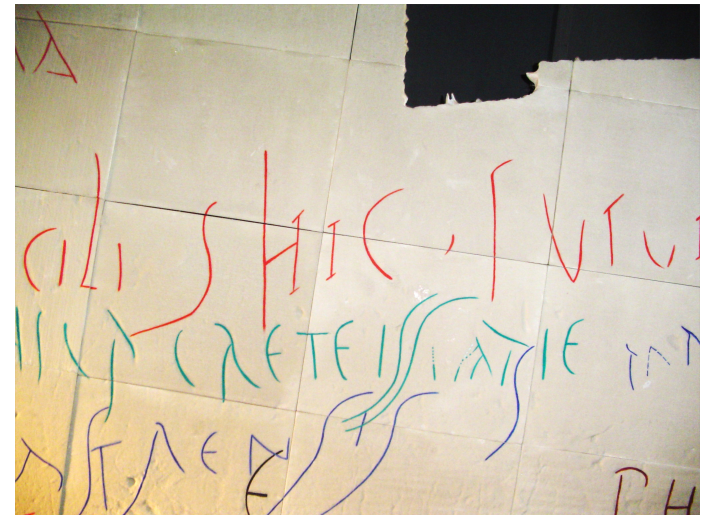
- Mecenate head
- Classic real-digital-real pipeline
- 6 axis cnc for marble reproduction
- Final finishing by a sculptor





# Fabricating Inscriptions

- Reproduction of a portion of a wall in Pompei covered by inscriptions
- High-quality replica
- Color enhancement of the many Latin inscriptions to increase their readability.



BALZANI M., CALLIERI M., FABBRI M., FASANO A., MONTANI C.,  
PINGI P., SANTOPUOLI N., SCOPIGNO R., UCCELLI F., VARONE A.:  
Digital representation and multimodal presentation of archeological  
graffiti at pompeii. In VAST 2004 (2004), Fellner D. W., Spencer S. N.,  
(Eds.), Eurographics Association, pp. 93–103. 6, 12

# Illustrative relief

- Unrolling 3D objects
- High-quality replica



PITZALIS D., CIGNONI P., MENU M., AITKEN G.: 3D enhanced model from multiple data sources for the analysis of the cylinder seal of ibni-sharrum. In The 9th International Symposium on VAST International Symposium on Virtual Reality, Archaeology and Cultural Heritage (2008), Eurographics, pp. 79– 84. 6



# Fabricating Supports

- High quality support structures for safe transportation of valuable CH
- Customizable in shape
- Light and soft



MEDEIROS E SA' A., RODRIGUEZ ECHAVARRIA K., ARNOLD D.: Dual joints for 3D-structures. The Visual Com- puter Published on line on Oct. 2013 (2013), 1–11. 14



# Creating Missing Parts

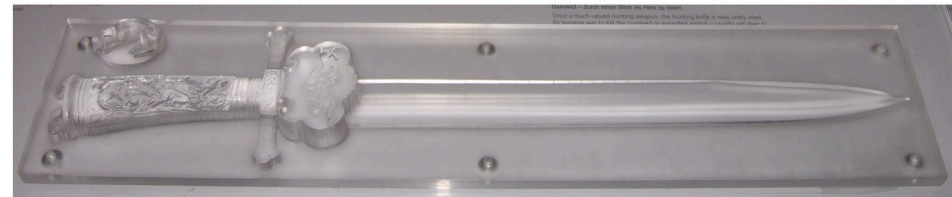
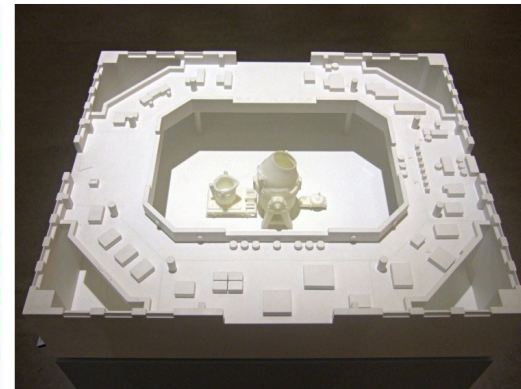
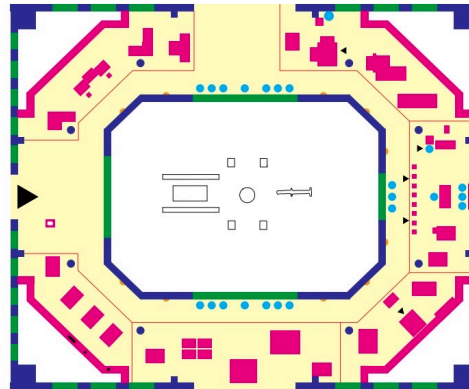
- reproduction and reversible installation of missing parts in a Canova gypsum
- Damaged in WW I missing parts were recreated using the marble final model at hermitage



Reversible integration on the dancer with cembali by A. Canova.  
More info on: <http://www.unocad.it/cms/index.php/storie-di-successo/integrazione-danzatrice-con-i-cembali>, 2013. 9

# Visually-impaired people

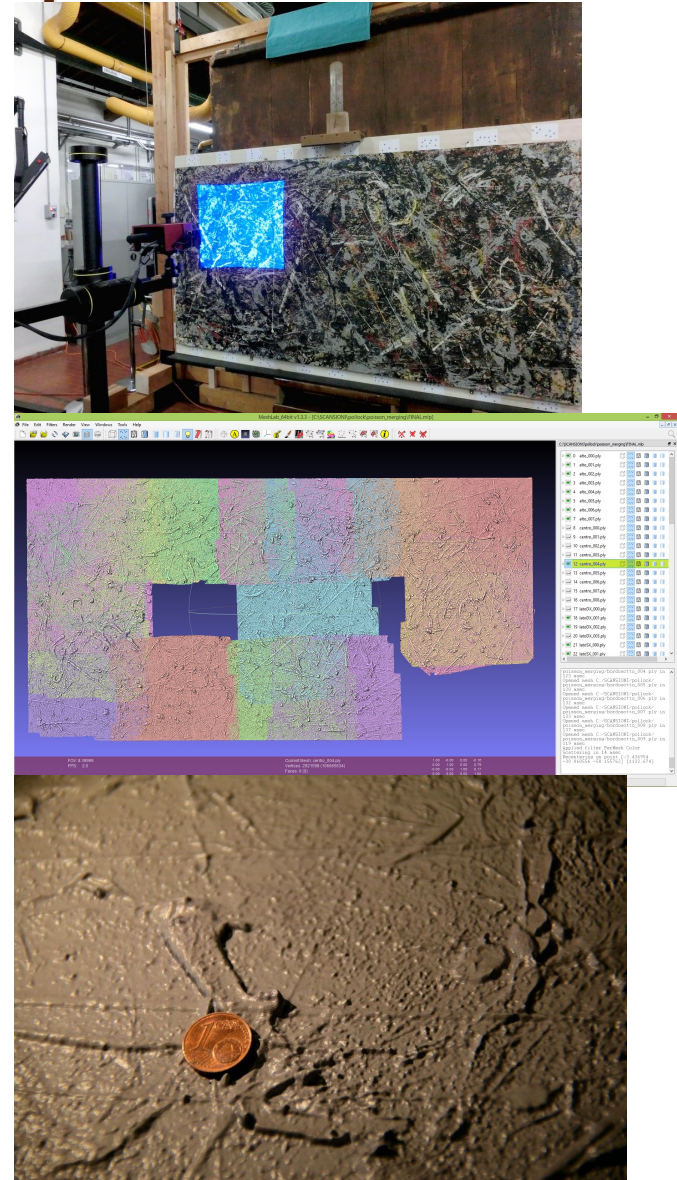
- 3D replicas are an ideal support to allow visually impaired people to explore sculptures, artworks or even paintings
- Abstraction or bas-relief representations





# Visually-impaired people

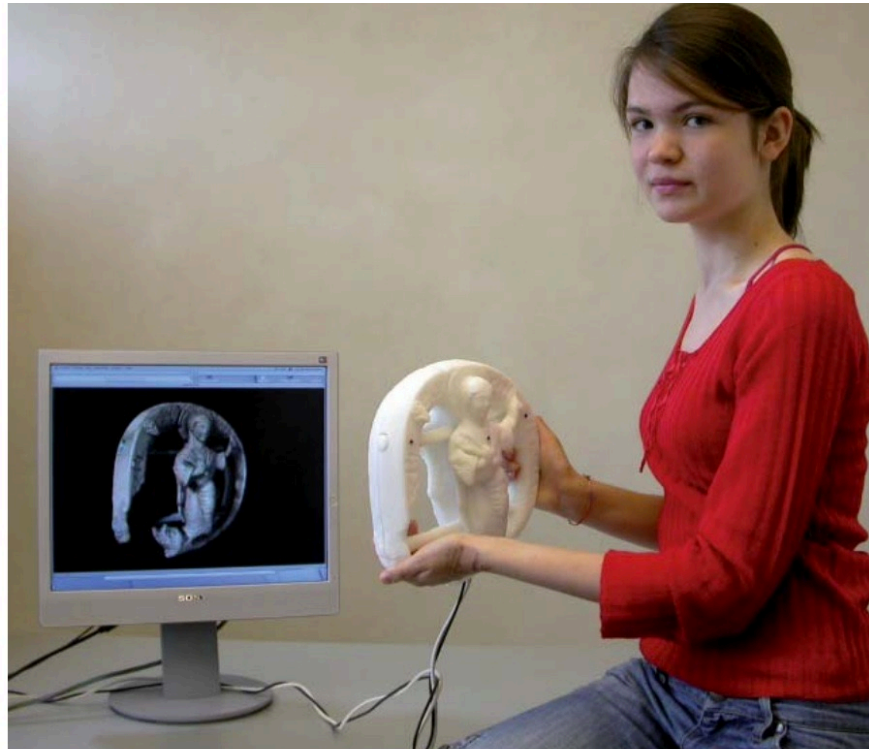
- 3D scanning of the painting
- 80 millions triangles!!
- Printed as an height map





# Sensorizing Replicas

- 3D replicas can be enhanced sensors to transform them into *active* replica
- Enable more rich interaction with physical replicas



# Improving the quality:Finishing

- 3D printed objects can always be hand finished
- Skilled painting can make a huge difference



# Conclusions

- **Presentare**
  - Very common application, display of reconstructions
- **Documentare**
  - 3D scanning is the way of documenting shape in a measurable/repeatable/scientific way
- **Analizzare**
  - 3D data can be the basis of further study and analysis
- **Supporto al restauro**
  - Planning, comparing, documenting it.
- **Riprodurre**
  - 3D printing for many purposes



# References

- **Digital fabrication techniques for cultural heritage: A survey**  
*R Scopigno, P Cignoni, N Pietroni, M Callieri, M Dellepiane*  
Computer Graphics Forum 36 (1), 6-21, 2017  
<http://vcg.isti.cnr.it/Publications/2017/SCPCD17/>
- **3D models for cultural heritage: Beyond plain visualization.**  
*R Scopigno, M Callieri, P Cignoni, M Corsini, M Dellepiane, F Ponchio, ...*  
Computer 44 (7), 48-55, 2011  
<http://vcg.isti.cnr.it/Publications/2011/SCCCDPR11/>
- **Sampled 3D models for CH applications: A viable and enabling new medium or just a technological exercise?**  
*P Cignoni, R Scopigno*  
Journal on Computing and Cultural Heritage (JOCCH) 1 (1), 1-23, 2008  
<http://vcg.isti.cnr.it/Publications/2008/CS08/>