

3D digitisation for Cultural Heritage

Insights from the CHANGES project - Spoke 4: Virtual technologies for Museums and Art Collections

Luisa Ammirati

Alice Bordignon

Francesca Fabbri

luisa.ammirati2@unibo.it

alice.bordignon2@unibo.it

francesca.fabbri80@unibo.it

VIDILAB – Department of Classical Philology and Italian Studies (FICLIT)-University of Bologna

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

CHANGES

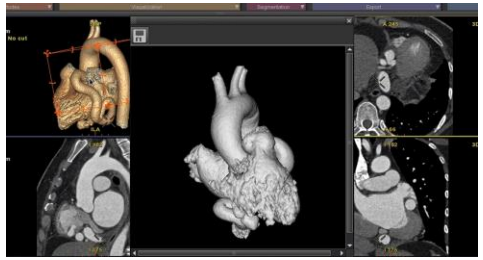
CULTURAL HERITAGE ACTIVE INNOVATION FOR NEX-GEN SUSTAINABLE SOCIETY
EXTENDED PARTNERSHIP

CONTENTS

1. INTRODUCTION

3D AND FIELDS OF APPLICATION

Medical Science



Animation

Cinema VFX

Architecture/civil engineering

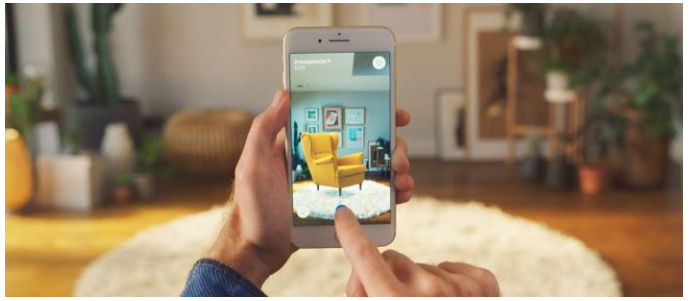
Design/Rapid prototyping

Videogames

Digital Art

Beeple, HUMAN ONE

E-commerce and retail

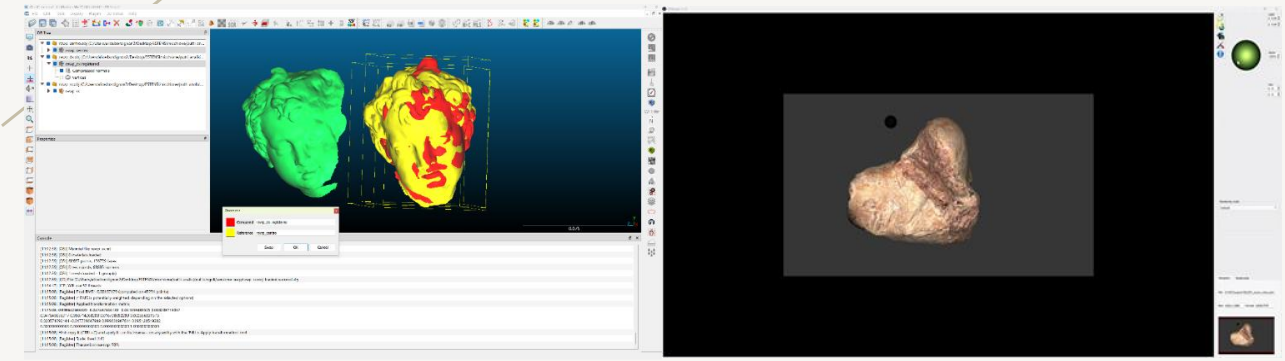


3D DIGITISATION IN CULTURAL HERITAGE

3D digitisation in cultural heritage refers to the process of creating **accurate digital representations of physical cultural artifacts**, **monuments, or sites** using 3D technologies

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DOCUMENTATION and RESEARCH



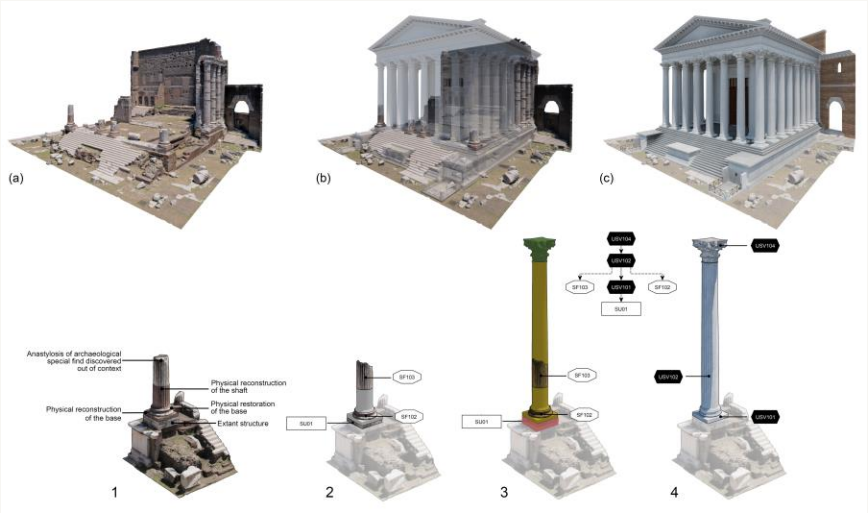
3D models as research tool for morphological analysis

DISSEMINATION

3D PRINTING

- Tactile museum tour for blind visitors
- Didactic activities
- Copies
- Merchandising
- Integrative restoration or support to physical restoration

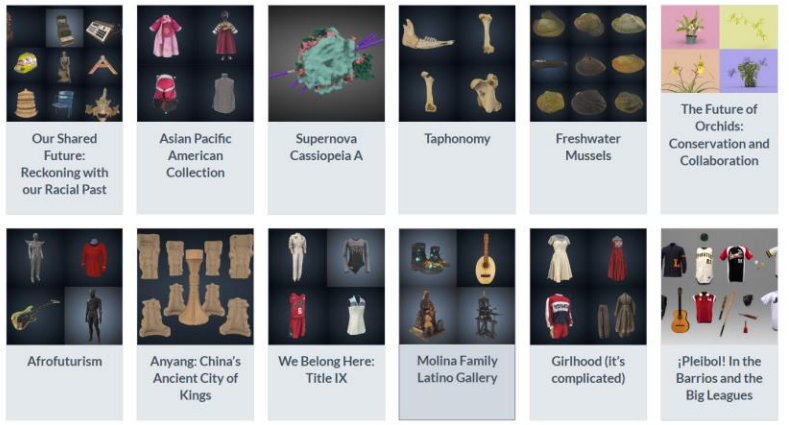
Education, valorisation, and public engagement



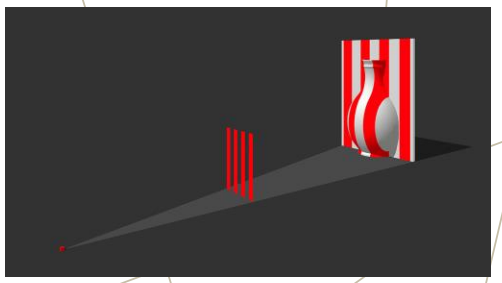
Virtual reconstruction of the Temple of Mars Ultor in the Forum of Augustus

VIRTUAL RECONSTRUCTION

- 3d simulation
- Visualisation and documentation
- Semantic analysis



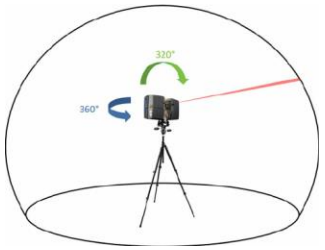
Digital collections



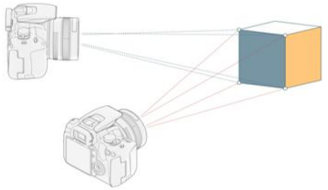
3D MODEL

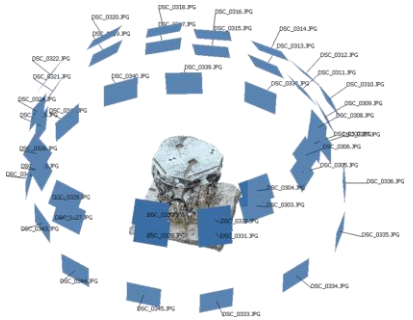
A 3D model is a **digital representation** of a **physical object** or scene **in three dimensions**, created using specialised software

Reality-based technologies



3D scanning technologies: structured light scanning (SLS) and terrestrial light scanning (TLS)

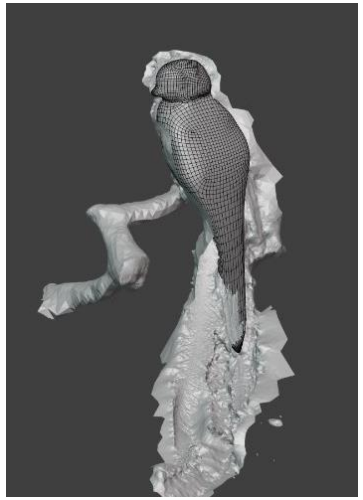




Photogrammetry: capturing photographic images from multiple angles.

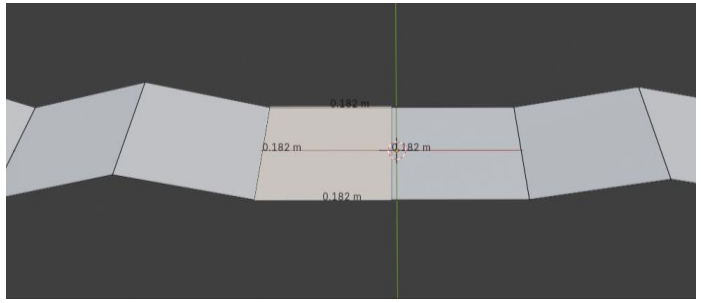
User generated modeling

- **Polygonal model** (Blender, Maya, 3ds Max)
- **Digital Sculpting** *(ZBrush, Mudbox)*
- **Parametric/Procedural Modeling** *(Grasshopper, Houdini)*



THE MUSEUM OBJECT IS ALWAYS THE PROTAGONIST

It directs and influences the choices of the equipment



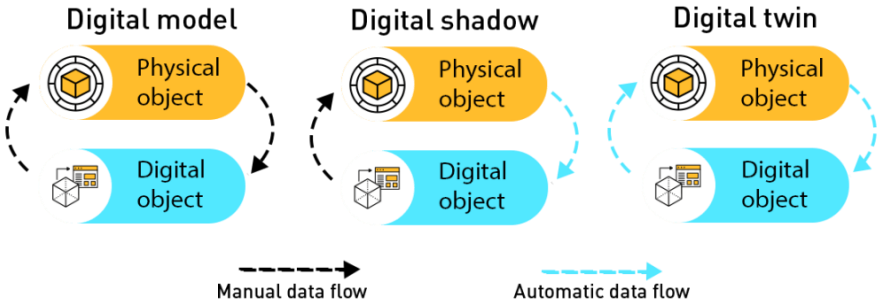
DIGITAL TWIN

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Definition and origins

- Concept introduced by Grieves and Vickers (2017), expanded in the Gemini Principles (Bolton et al., 2018).
- **Aim:** create digital counterparts of physical entities for analysis, simulation, and informed decision-making.

Interaction Levels of digital copies (Kritzinger et al., 2018)



Digital Model: no interaction.

Digital Shadow: one-way interaction (physical → digital).

Digital Twin: real-time, two-way interaction between physical and digital.

Conceptual Evolution

Traditional definitions seen as **too rigid**, especially for **cultural heritage**, where **objects can change or disappear**.

Gabellone (2022) and **Niccolucci et al. (2023)** propose **a more flexible interpretation,** viewing **digital twins as "knowledge models" that evolve over time rather than requiring continuous synchronization**.

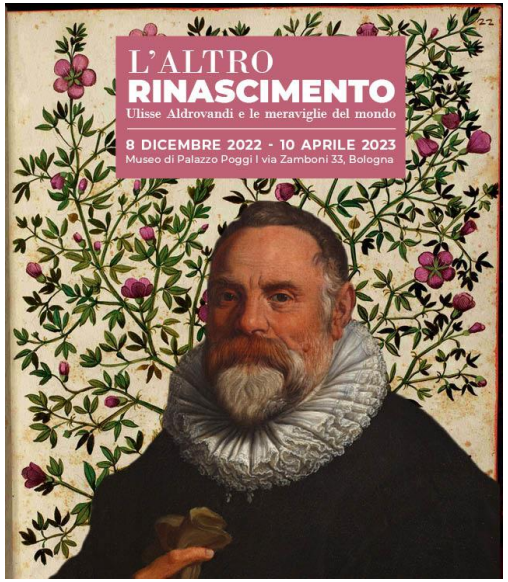
In the context of **Cultural Heritage Dissemination**, digital twin is not just a technical replica, but a **dynamic, evolving system of representation and knowledge, adaptable to context and purpose** (Niccolucci et al. 2023).

2. THE DIGITAL TWIN OF THE ULISSE ALDROVANDI EXHIBITION

ULISSE ALDROVANDI CASE STUDY

Why

- Preserve and make accessible **temporary exhibitions** and their **physical narratives**
- **Valorisation and dissemination** of cultural heritage
- Build a **FAIR methodology** and data flow suitable for other cultural heritage contexts and projects



What

Digitisation of the temporary exhibition "The Other Reinassance: Ulisse Aldrovandi and the Wonders of The World" composed by 258 items of different sizes, materials, and shapes

When

Exhibition duration: December 2022 – May 2023
On-site acquisitions: April 2023 – July 2023

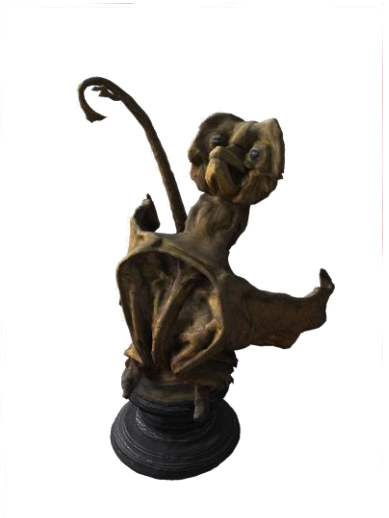
Where

Museum of Palazzo Poggi, Via Zamboni, 33, 40126 Bologna BO

Who

- researchers and students from five Departments of the University of Bologna
- researchers from the Digital Heritage Innovation Lab of CNR ISPC
- managers and staff of the University of Bologna Museum Network
- managers and staff of the Bologna University Library
- staff of the Archaeological Museum of Bologna
- staff of the Medieval Civic Museum of Bologna
- professionals for removing and reinstalling display cases

ULISSE ALDROVANDI



Profile

- Professor at the **University of Bologna**
- First chair of **Natural Philosophy** (1561)
- Founder of Bologna's **first Botanical Garden**

Contributions

- Collected thousands of natural specimens
- Created an extensive **museum** and **herbarium**
- Pioneer of **direct observation** in natural studies

Legacy

- Considered a **father of modern natural history**
- His collections are preserved at **Palazzo Poggi**
- Key figure of the **16th-century encyclopedic tradition**

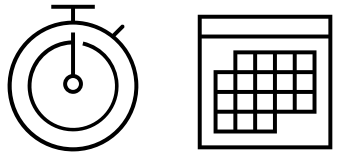
CHALLENGES IN DIGITISING A TEMPORARY EXHIBITION

Aldrovandi digital twin case study

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

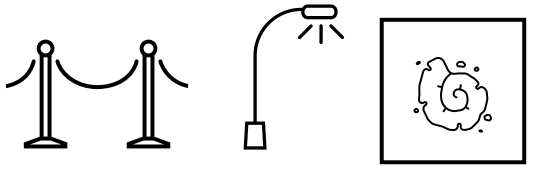
TIME CONSTRAINTS

- **Temporary nature** limited acquisition days.
- Loaned objects had strict return deadlines.
- Needed balance between quality and efficiency of data acquisition.



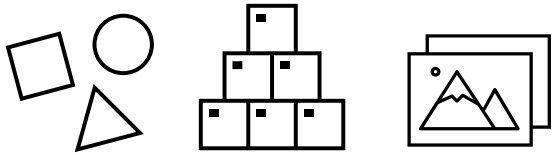
SPACE LIMITS

- **Museum spaces** not suited for **simultaneous data capture**.
- **Logistical issues:** few power outlets, limited workspace.
- Objects often **immovable** within **display cases**.
- **Low, fixed lighting** required detailed planning for scans/photos.



OBJECT FEATURES

- **Variability** in shape, size, and material.
- **Problematic materials:** black, glossy, or transparent surfaces.
- Resulted in **reduced precision and challenges** in dataset accuracy



Reference:
Balzani et al. (2024, https://doi.org/10.1016/j.daach.2023.e00309) – for further details on acquisition methods and object features.


192.168.1.73:8083 – To exit full screen, press Esc
Da qui inizia il tuo viaggio
del mondo di Ulisse Aldro
Ascolta il racconto del cu
collegandoti alla piattafo
code qui sotto.
Se non leggi il QR code v
unibo.it/aldrovandi500
e entra nella sezione L'a
Da qui inizia il tuo viagg
del mondo di Ulisse Ald
Ascolta il racconto del
collegandoti alla piatta
QR code qui sotto.
Se non leggi il QR code
unibo.it/aldrovandi500
e entra nella sezione L
BAMBINI
Quando vedrai quest
cosa Ulisse Aldrovan
KIDS
Quando vedrai ques
cosa Ulisse Aldrovan

METADATA AND FAIR PRINCIPLES

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

What are metadata (crucial for enabling FAIRness)

A definition: any **added data** that serves to **describe a certain digital object**, to **assist in its management and retrieval**

	Type of Metadata	Key Function	Components
1.	**Descriptive**	**Identification & Discovery** (The *What*)	**Bibliographic description** of the resource and its analog counterpart.
2.	**Administrative**	**Lifecycle Management** (The *How*)	**Technical** (digitisation params), **Preservation** (procedures), and **Rights** (licenses, access).
3.	**Structural**	**Internal Organization** (The *Of What*)	File lists, **component hierarchy**, and digital versions of the object.

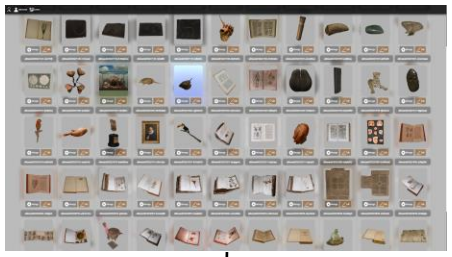
Research objects = data (in the FAIR ecosystem)

	Principle	Key Goal	Mechanism Required
F	Findable	Locate the Data	Metadata and data must **be easy to find** for both humans and computers.
A	Accessible	Retrieve the Data	The user must know **how they can be accessed** (e.g., protocols, authentication).
I	Interoperable	Integrate the Data	Data must be **compatible** with other datasets, applications, and analysis workflows.
R	Reusable	Maximize Value	Metadata and data must be well-described to facilitate replication and combination in new settings.

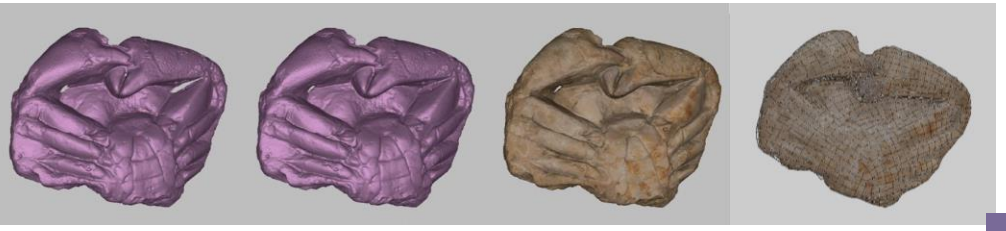
Peroni, S. (2024, luglio 19). Metadata. Zenodo. https://doi.org/10.5281/zenodo.12783378
Barzaghi, S., Bordignon, A., Gualandi, B., Heibi, I., Massari, A., Moretti, A., Peroni, S., & Renda, G. (2024). A Proposal for a FAIR Management of 3D Data in Cultural Heritage: The Aldrovandi Digital Twin Case (arXiv:2407.02018v1). arXiv. https://doi.org/10.48550/arXiv.2407.02018

ASSETS

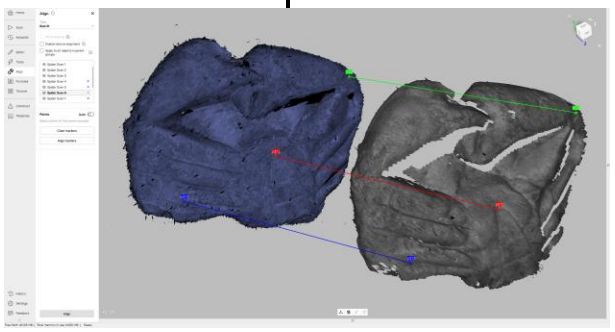
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



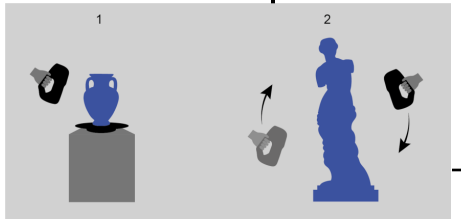
ATON framework



Reconstruction and retopology



3D scanning software



Structured Projection Scanner (SLS)

Presentation (step 7)

Provenance creation (step 6b)

Metadata creation (step 6a)

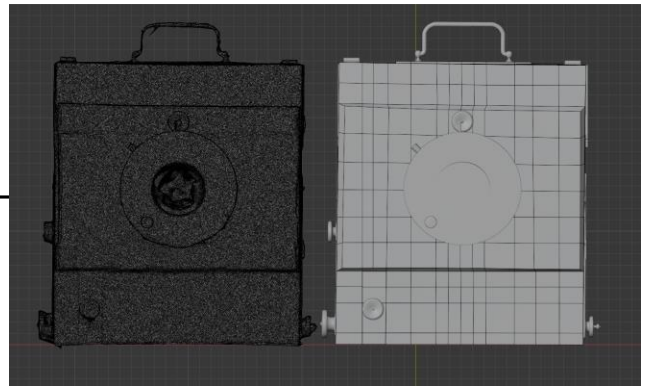
Export (step 5)

Optimisation (step 4)

Modelling (step 3)

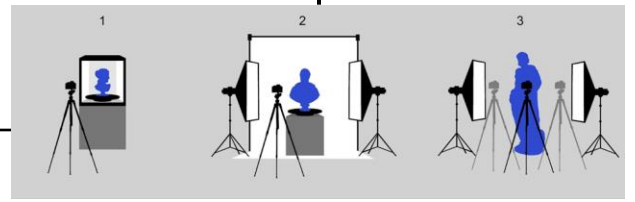
Processing (step 2)

Acquisition (step 1)



Reconstruction and retopology

Structure from Motion software (SfM)



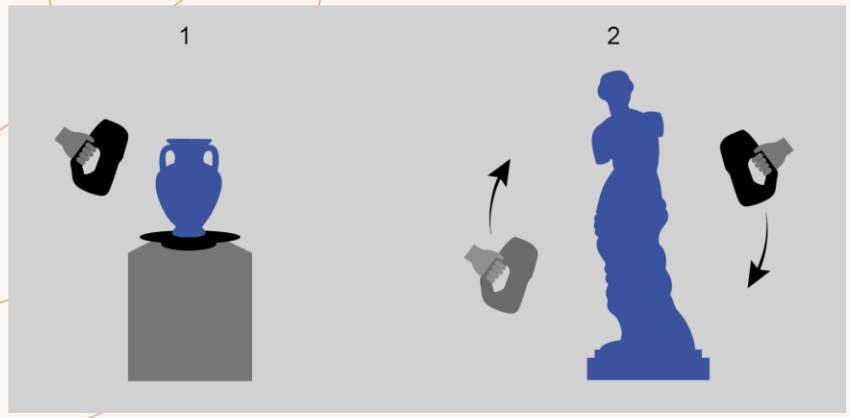
Photogrammetry

ACQUISITION

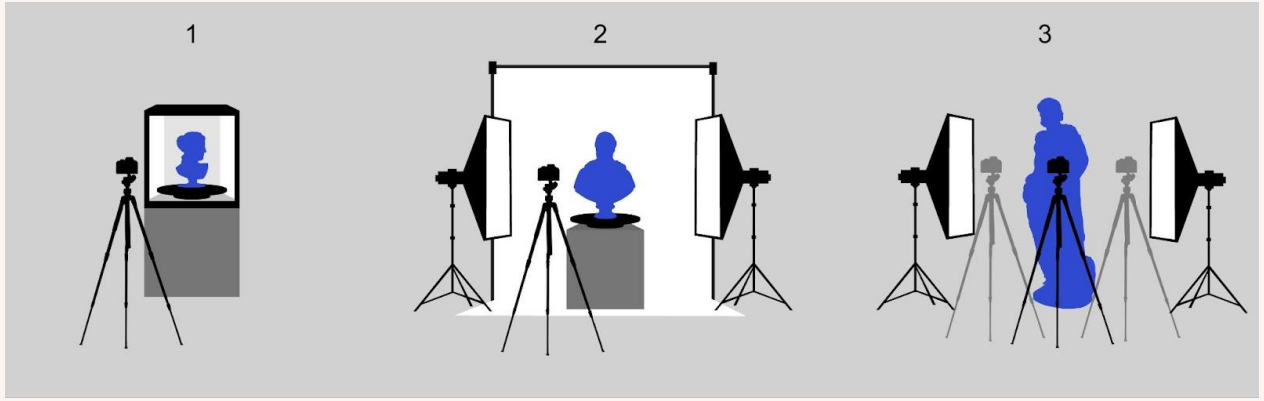
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Reality-based technologies

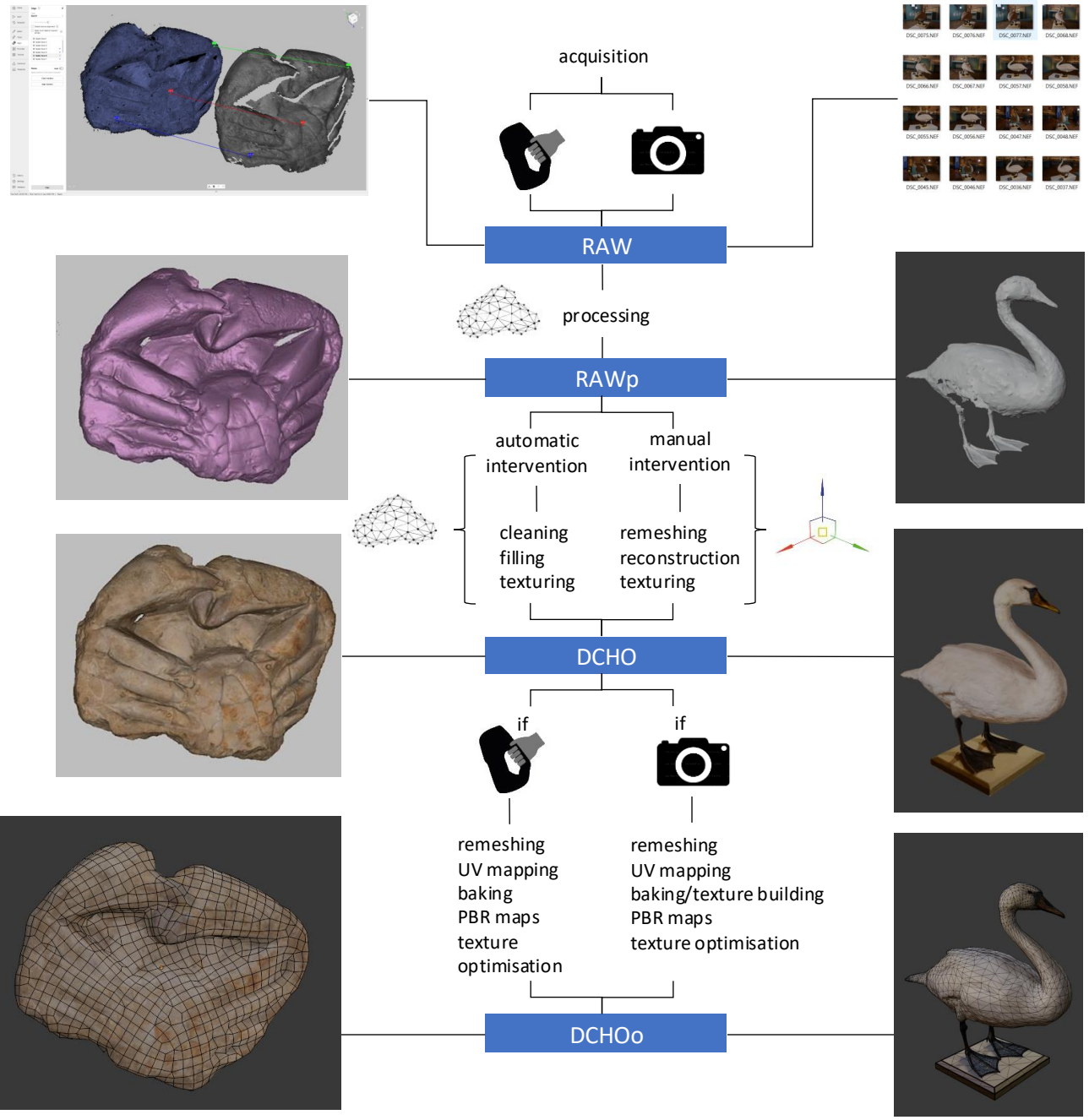
Structured Light Scanning



Photogrammetry



PROCESS AND DATA TAXONOMY



SL scanning

photogrammetry

processing software

computer graphic software

From PROCESSING to EXPORT

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Scanning

Photogrammetry

Sparse point cloud → Dense point cloud → Mesh → Textured mesh → Optimized textured mesh

Texture: In 3D modeling, a **texture** is a 2D image that is applied to a 3D model to give it color, detail, and realism.

Dactylopterus volitans (Linnaeus, 1758), pesce volante

The DCHO of the flying fish as displayed in the exhibition, representing the Cultural Heritage Object

The living, pre-taxidermied reinterpretation of the fish prior to becoming a Cultural Heritage Object

METADATA AND PROVENANCE CREATION
PARALLEL DATA MANAGEMENT

CHO → RAW → RAWp → DCHO → DCHOo

PID

PID

Official sources

Bibliographic data

- CIDOC-CRM
- LRMoo
- CRMdig
- AAT

CHAD-AP data model

Object Module (OM)

Process Module (PM)

RDF N-Triples conversion

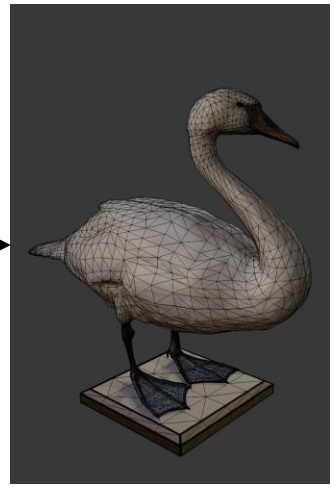
Digitisation process

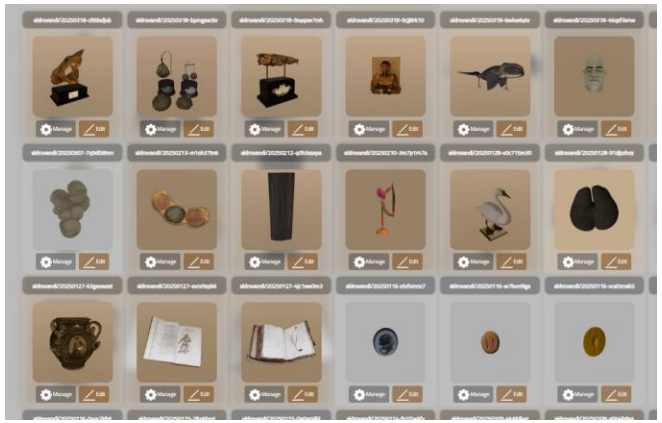
Process data

PRESENTATION

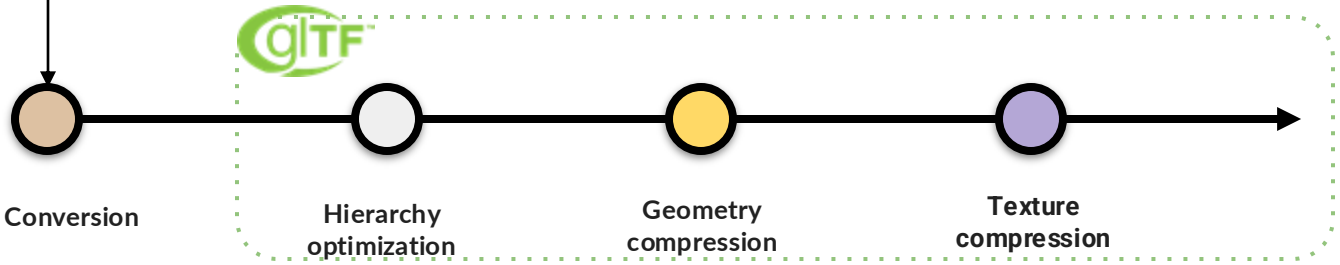
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Dissemination





DCHOo



https://aton.ispc.cnr.it/site/

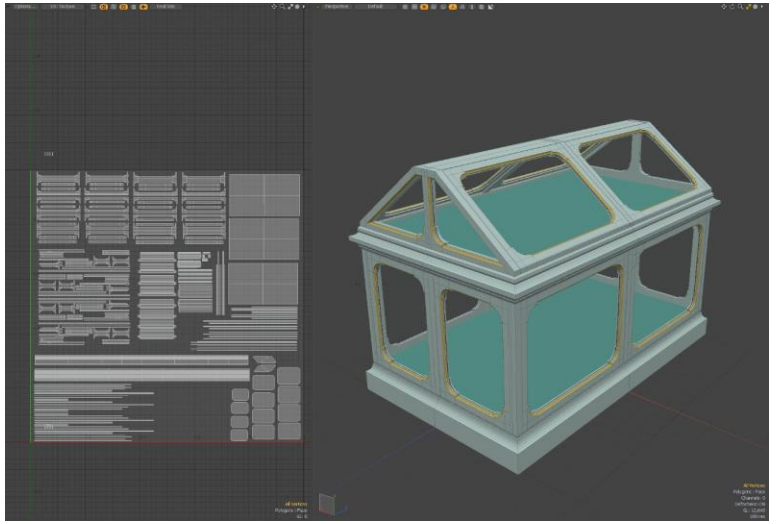
WebXR
three.js
DRACO
3DTiles
Express JS
Passport
socket.io

ENVIRONMENT

ENVIRONMENT RECONSTRUCTION

One of the final stages in creating a digital twin for the temporary exhibition involves the **meticulous reconstruction of the 6 display spaces.** This process includes recreating **not only the walls, floors, and ceilings** of the exhibition hall but also the **precise replication of display cases, panels, and captions** accompanying each item in the physical exhibition. The **re-creation of the rooms is a multi-faceted process** that requires various techniques and specialised software to achieve a realistic digital replica.

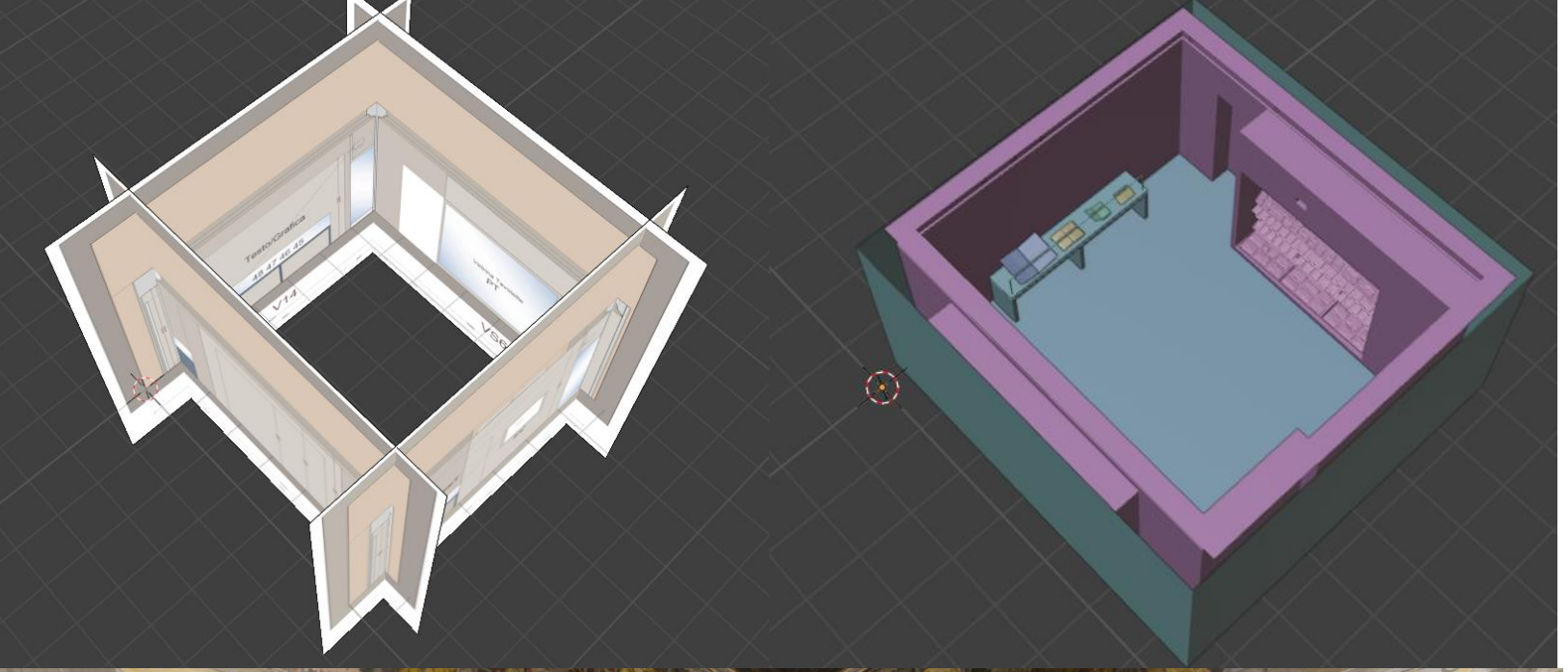
From **360** and **scanner documentation**

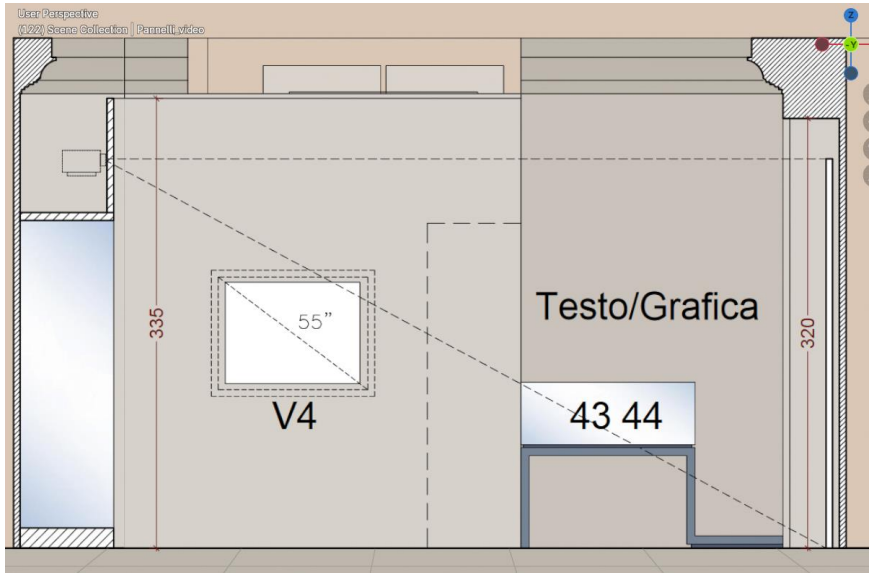


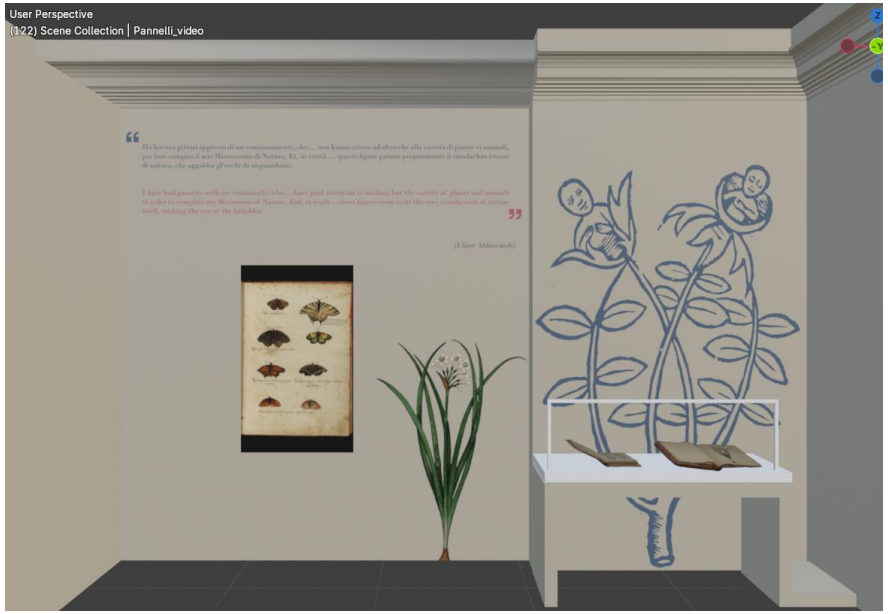
To **3D modeling reconstruction** and rendering

3D modelling based on
2D documentation data

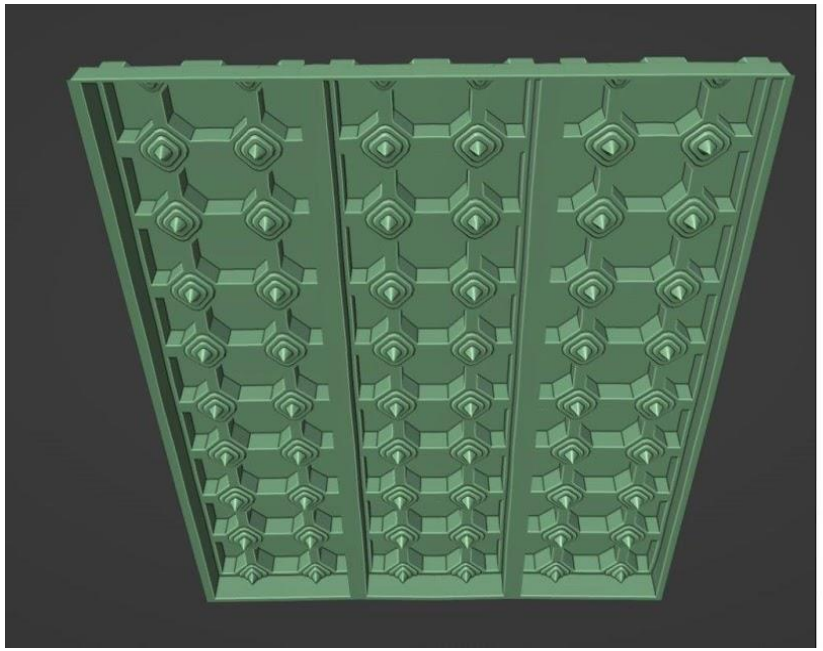
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



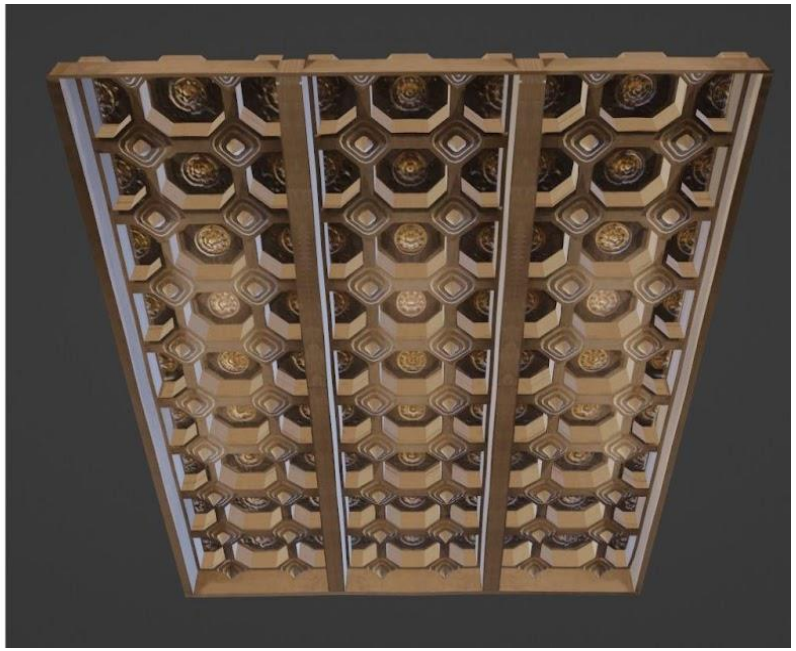




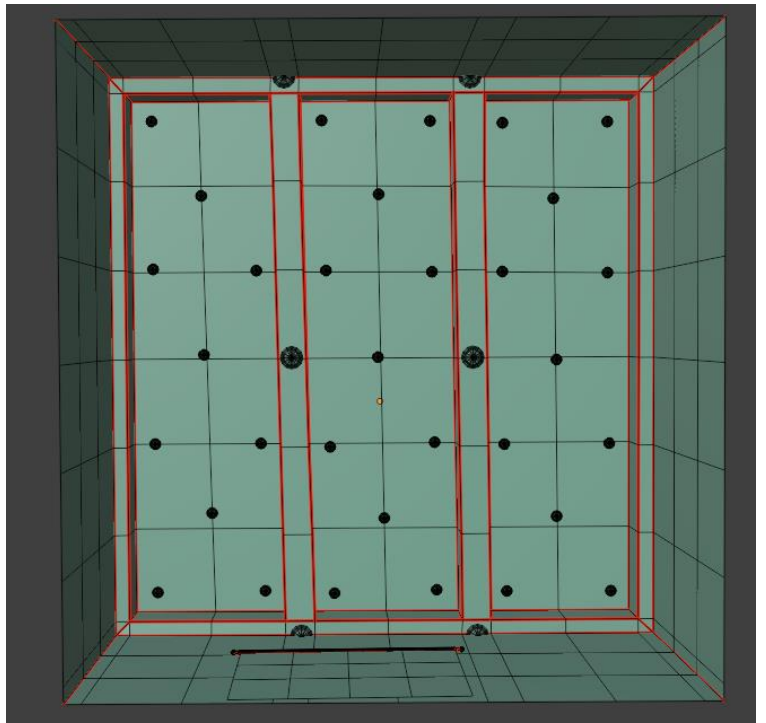
SfM output



3D modelling



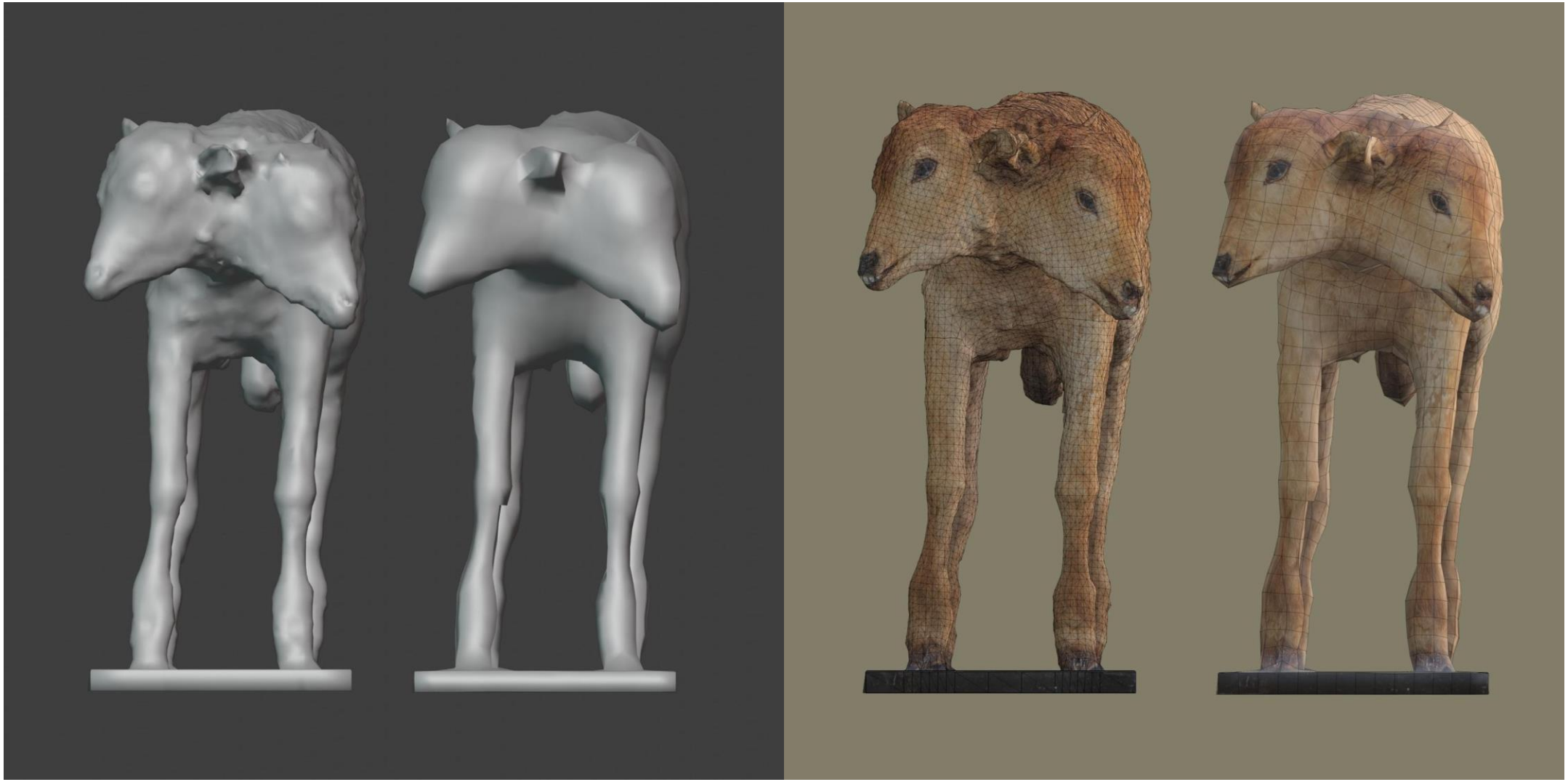
Texture building and mapping



3D rendering

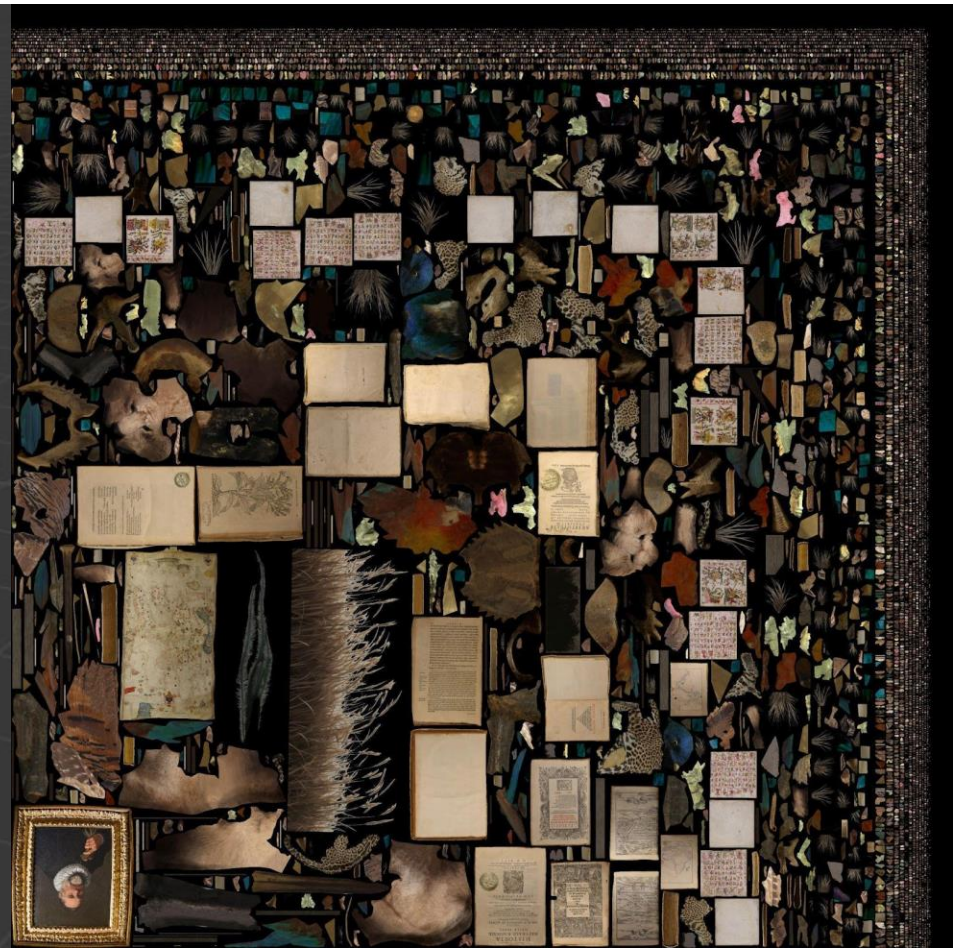
ASSETS MAXIMUM OPTIMISATION – PLACEHOLDER

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



From **DCHOo** to its **Placeholder** to guarantee efficient 3D real-time performance and interaction on ATON framework

ASSETS FINAL OPTIMISATION



Baking all textures in one to save storing space and enable faster real-time performances on ATON framework

3. THE 3D DIGITAL EDITION OF THE CODEX COSPI

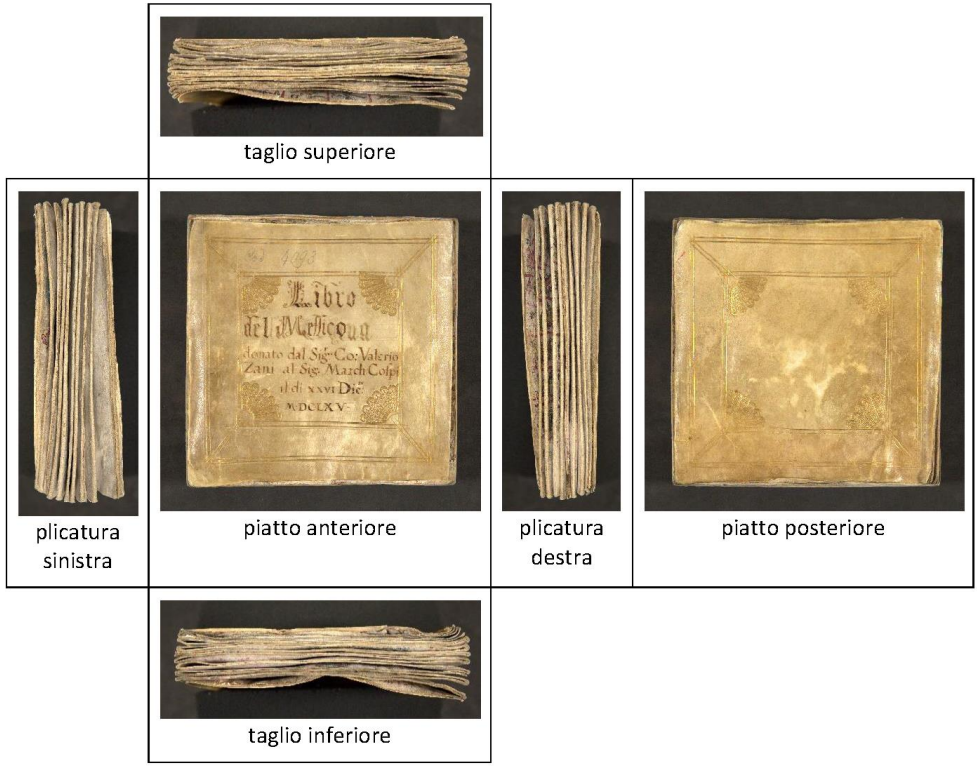
THE CODEX COSPI

1. HISTORICAL CONTEXT

- Pre-Hispanic Mesoamerican pictorial manuscript **(15th–early 16th c.)**
- **Origin:** Puebla-Tlaxcala region, Mexico.
- Brought to Bologna in 1533 by Dominican friar Domingo de Betanzos

2. PHYSICAL DESCRIPTION

- **364 cm-long** animal skin strip (likely deer), 5 sections, folded leporello-style into **20 plates**.
- Both sides painted with plaster coating and organic pigments
- **Recto** (L→R): 260-day calendar, Venus's heliacal rise, ritual year quarters
- **Verso** (R→L): divination tables, ritual offering instructions (rotated 180°)

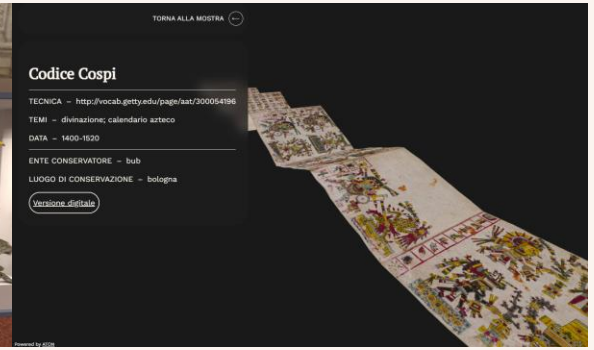


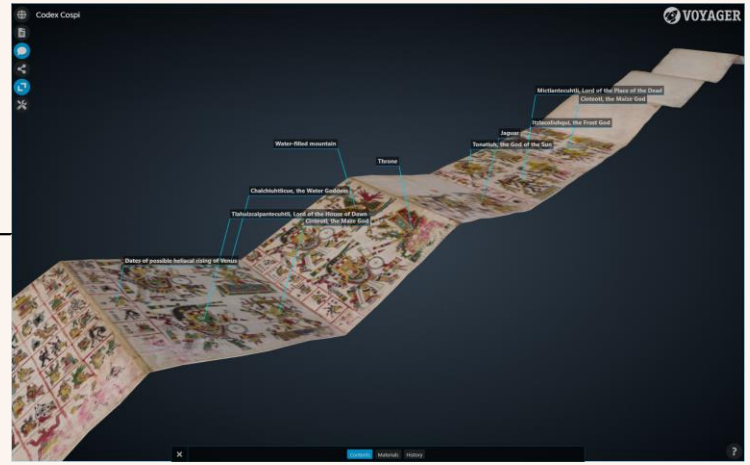
The Codex Cospi displayed during the temporary exhibition «The new Renaissance: Ulisse Aldrovandi and the Wonders of The World» (December 2022-May 2023)

STRUCTURAL AND INTERPRETIVE CHALLENGES

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

- Dual-sided and complex layout difficult to express in 2D
- Leporello format enabled dynamic ritual display
- 3D modelling aims to enhance understanding by:
  - Situating content in spatial context
  - Revealing functional complexity
  - Offering immersive and intuitive exploration

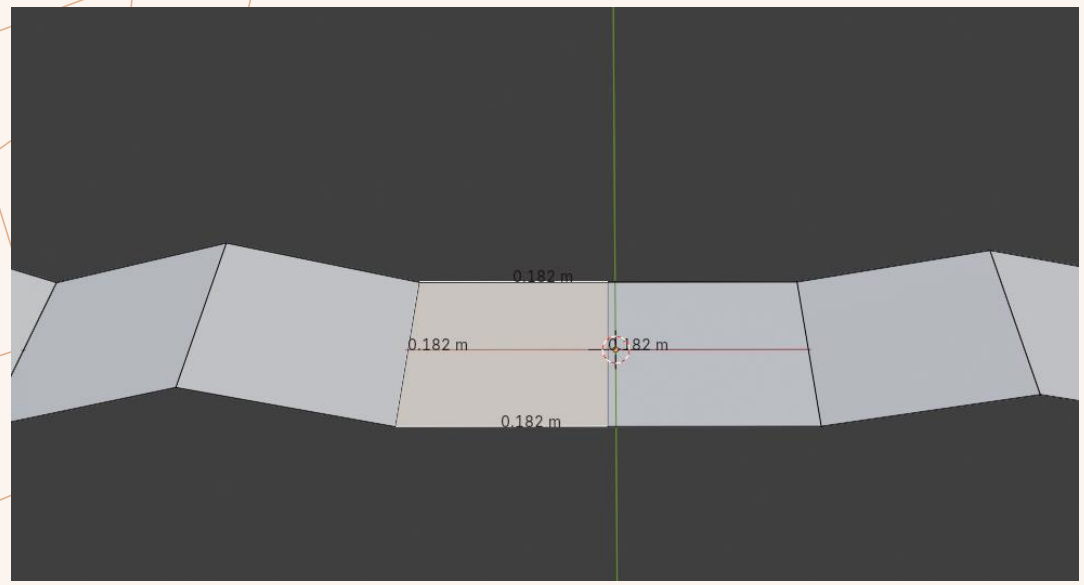


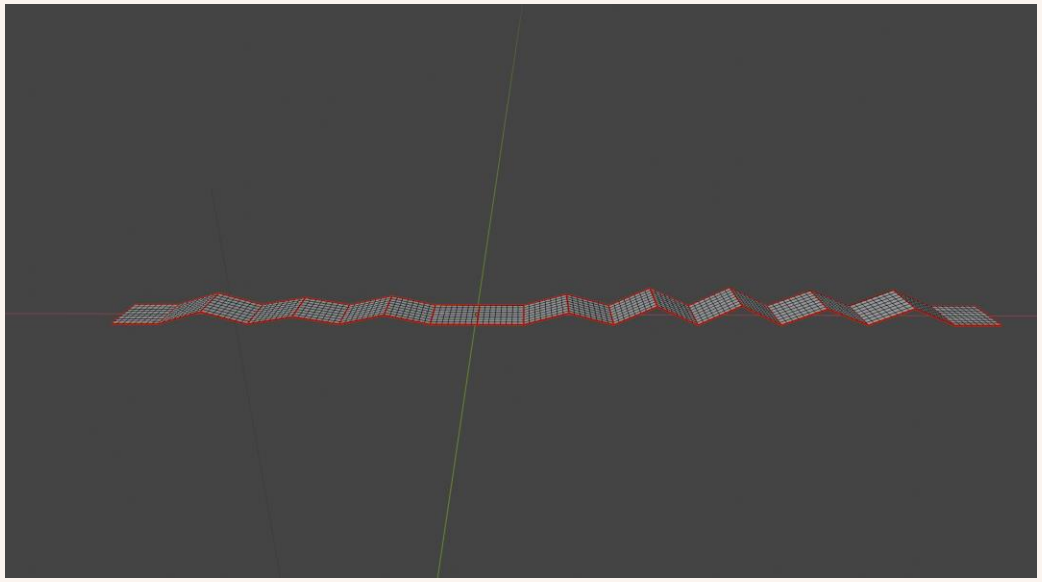


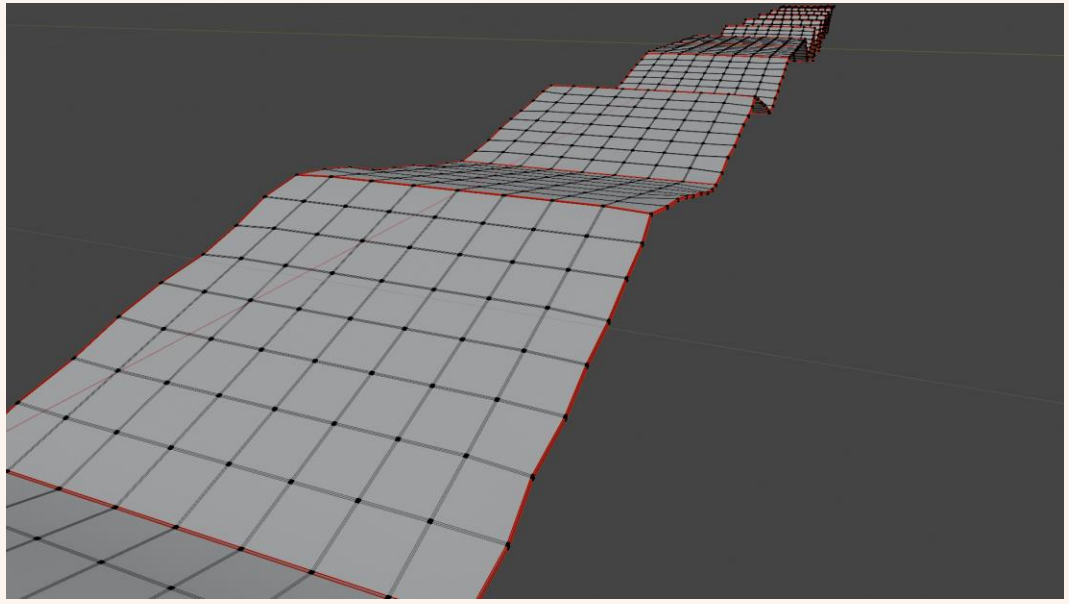
From the Aldrovandi digital twin to the 3D digital edition of the Codex Cospi

3D MODELLING

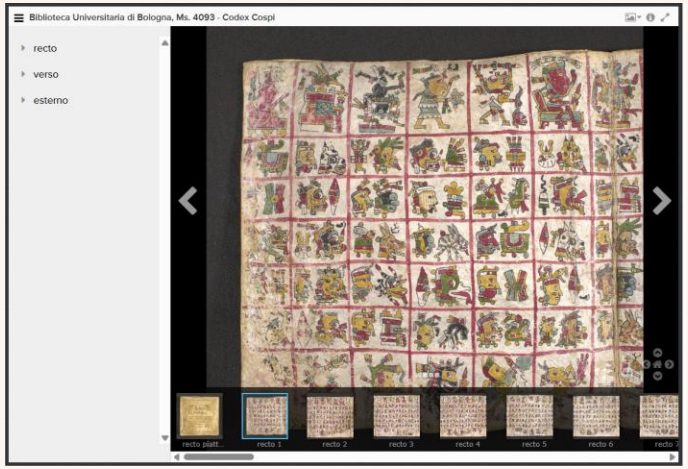
Procedural modelling

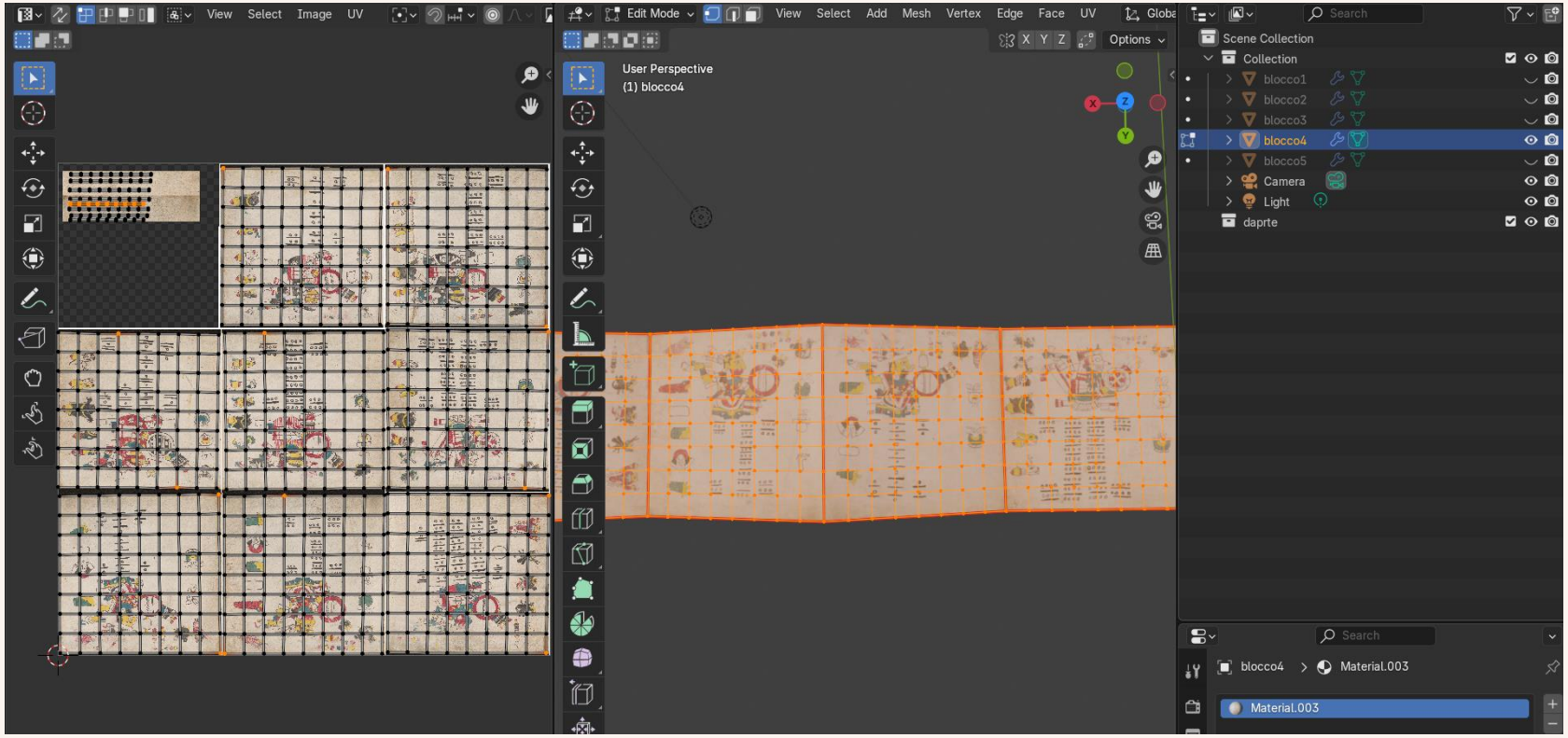






[2D digitisation of the Codex Cospi] – Biblioteca Universitaria di Bologna





Texture mapping

CHALLENGES

In **conveying the significance of ancient manuscripts** to museum visitors

PRESERVATION REQUIREMENTS — often necessitate **dim lighting**

INACCESSIBLE LANGUAGE — visitors tend to engage with manuscripts primarily for their **aesthetic value**, particularly when adorned with intricate decorations

DETERIORATION — the **fragile nature** of manuscripts prevents physical handling

INEFFECTIVE DISPLAY — **lack** engaging **storytelling** elements **or interactive features**

RQ1: How can **3D** enhance traditional 2D **representations** of ancient manuscripts?

RQ2: How can a reliable and engaging 3D knowledge space be created to **facilitate their understanding**?

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

3D MODELS AS TOOLS FOR KNOWLEDGE PRODUCTION

What we have with a 3D model:

- ✓ Make **complex two-dimensional** data more **comprehensible**
- ✓ **Simulate** spatial, temporal, or material **conditions**
- ✓ Digital **manipulation**
- ✓ **Photorealism**
- ✓ **Visualization and documentation**

But… it is **not enough**

How to create **engaging and transmedia resources** with 3D models?

- ✚ Adding **contextual information**
- ✚ **Storytelling** techniques
- ✚ Merging **different media**
- ✚ Planning **intuitive and consistent interaction** in a digital environment

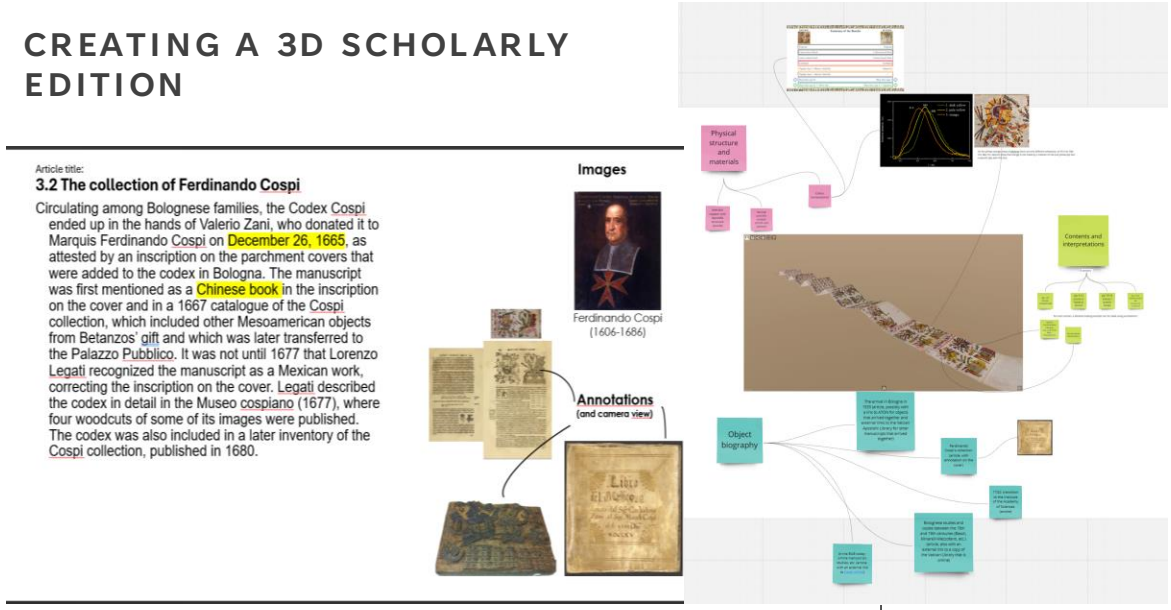
3D SCHOLARLY EDITION

A 3D Scholarly Edition is an innovative form of digital publication where **3D models serve as the primary "text",** accompanied by **rich contextual, interpretative, and process-oriented information**. Unlike traditional scholarly outputs that separate 3D models from their corresponding research narratives, 3DSEs integrate these elements into a unified, interactive environment designed to enhance scholarly communication and knowledge production.

PURE 3D
An Infrastructure for the Publication and Preservation of 3D Scholarship

https://editions.pure3d.eu/index.html

CREATING A 3D SCHOLARLY EDITION



1. USER RESEARCH

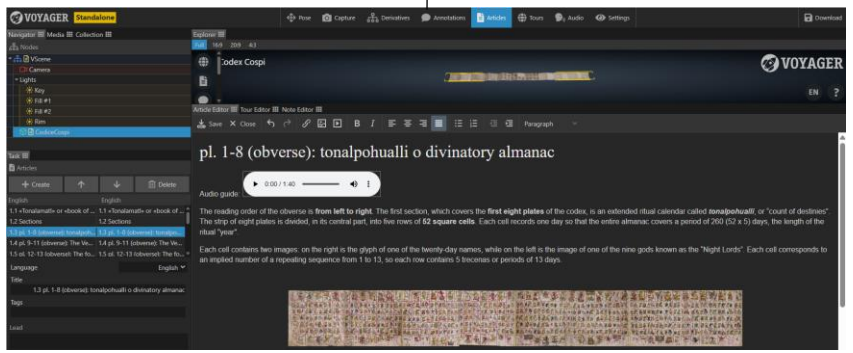
- Empathy maps
- Personas

2. DESIGN

- Data collection
- Conceptualisation

3. IMPLEMENTATION

VOYAGER



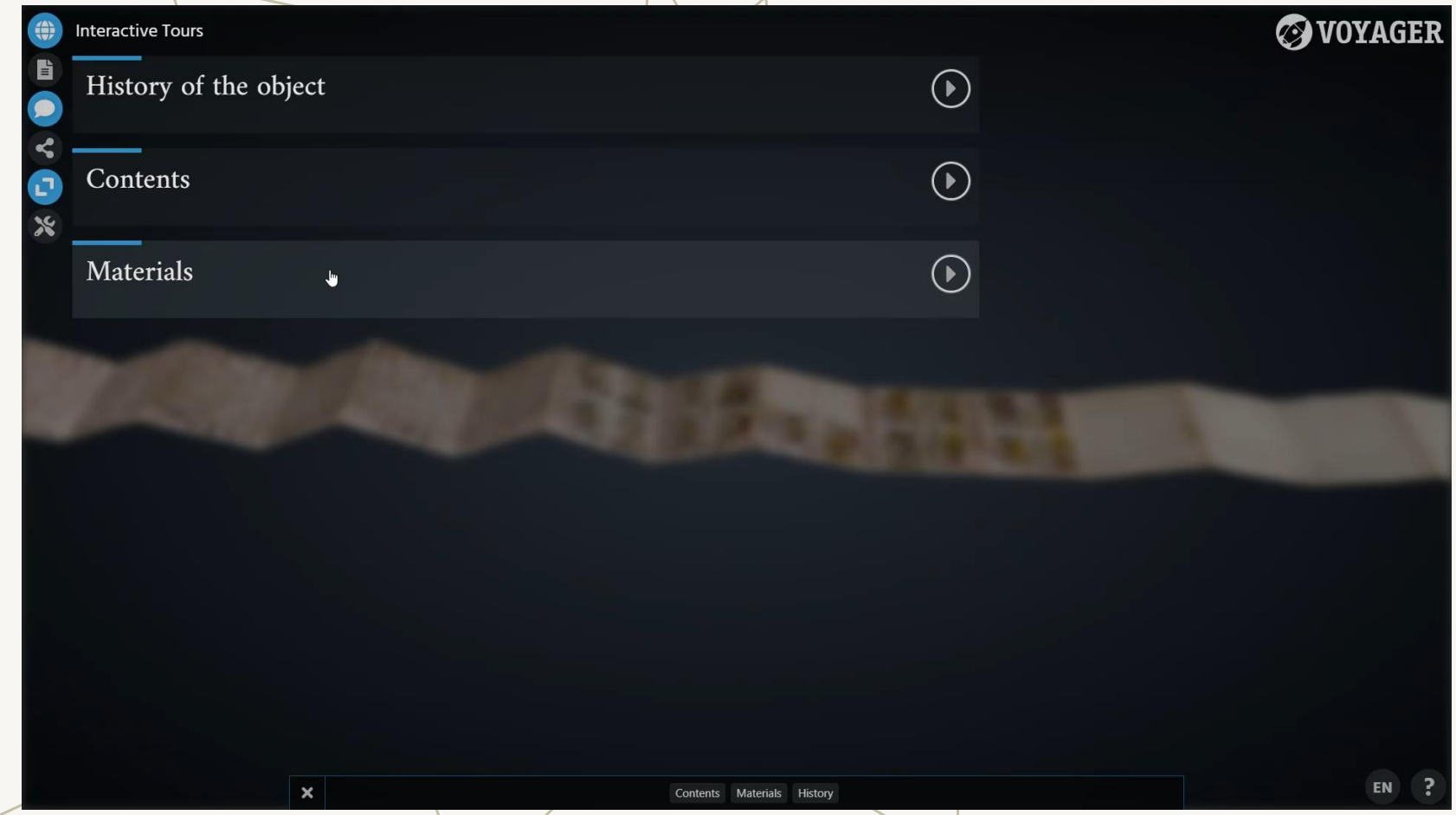
4. USER ASSESSMENT

Direct observation

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

CODEX COSPI 3D SCHOLARLY EDITION

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



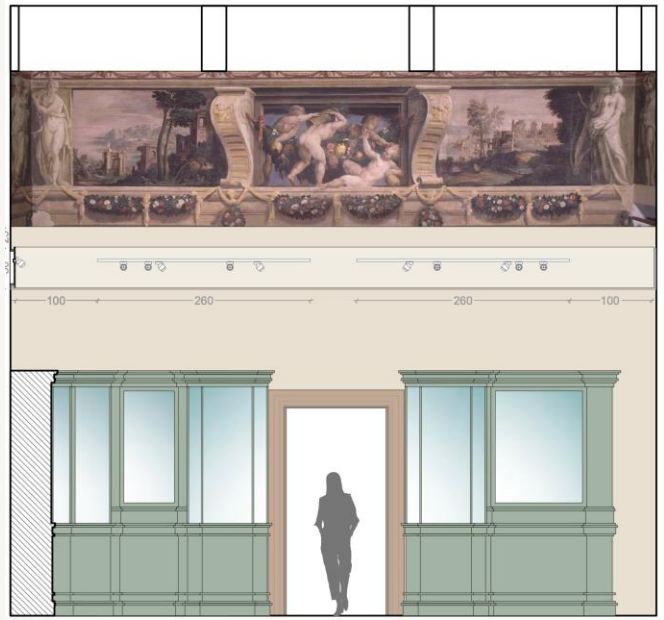
Alice Bordignon, Davide Domenici. 2025. Codex Cospi. PURE3D. https://editions.pure3d.eu/project/14/edition/1/index.html

FROM PALAZZO POGGI MUSEUM TO MUSEUM OF THE INSTITUTE OF SCIENCES:

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

THE NEW PERMANENT EXHIBITION FEATURING VIRTUAL, MULTIMEDIA, AND HISTORICAL ELEMENTS

A PNRR - CHANGES case study



TYPES OF INSTALLATIONS

3D PRINTING

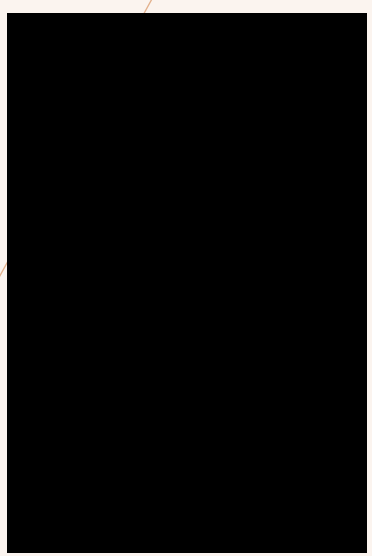
- Set of 3 objects from other SMA Museum
- objects printed to replicate the original tactile experience of those anatomical wax models

VIRTUAL ENVIRONMENTS

- Digital Twin of Ulisse Aldrovandi temporary exhibition
- Ispiring by Museo delle Cere Anatomiche Luigi Cattaneo

INTERACTIVE TOUCHSCREEN RESOURCES

- Codex Cospi
- Vol.II Erbario di Ulisse Aldrovandi (flipbook)



ANIMATIONS

- Video from 2D/3D animations

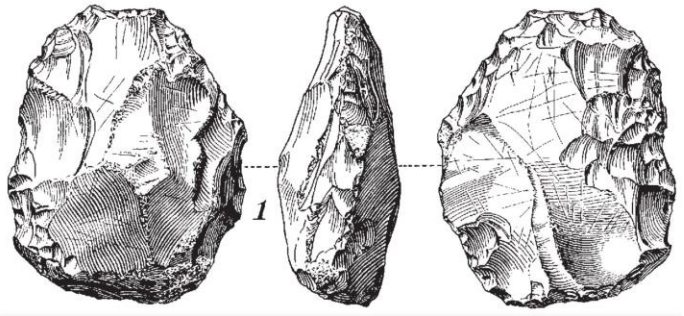
4. THE CAPELLINI CORE CASE STUDY

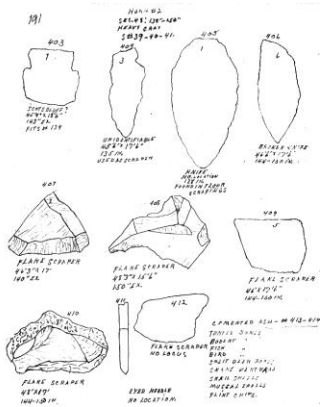
3D in paleonthological field
Geology Collection "Giovanni Capellini Museum

Dissemination porpouses

Aim of the project: Renovation of the museum's layout with interactive digital installations *Paleotwin*

Documentation porpouses





GEOLOGY COLLECTION "GIOVANNI CAPELLINI MUSEUM"

Digitisation of **90** objects

fossils

plastercasts

bones

Main acquisition Methodologies Employed

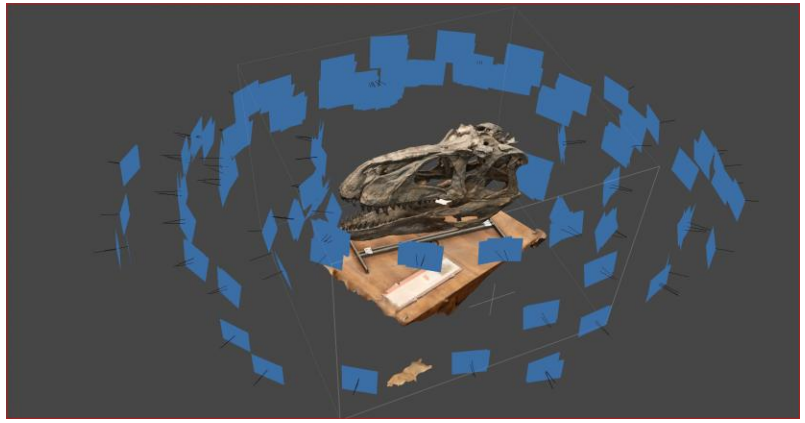
Depending on the characteristics and constraints of the cultural heritage objects (CHOs), different acquisition setups were adopted to ensure optimal data capture:

Lightbox Setup

Used primarily for small to medium-sized objects, the lightbox provided uniform and diffuse lighting conditions, reducing shadows and reflections. The object remained stationary while multiple images were taken from different angles around it.

Circular Walkaround

For larger or freestanding objects, a circular acquisition approach was employed. The operator moved around the object with the camera or scanner, capturing it from all necessary viewpoints to ensure full coverage, especially for undercuts and complex geometries.

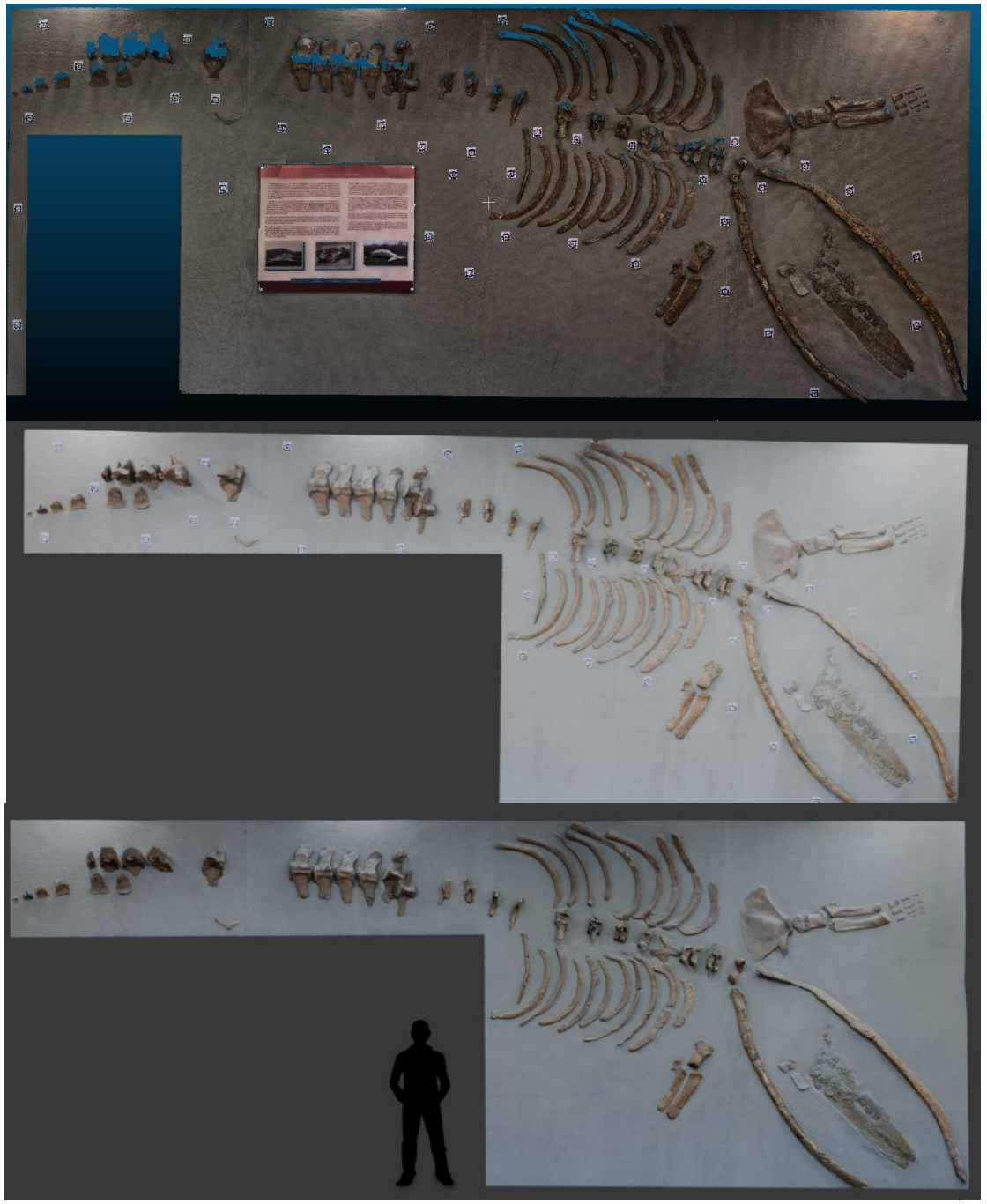


In-Case Capture

For delicate or immovable heritage objects displayed within vitrines or display cases, image acquisition was performed directly through the glass. This required careful calibration to mitigate glare, distortion, and refraction. Polarising filters and angled lighting were sometimes used to enhance image clarity and minimise artefacts.

Rhinoceros Etruscus

Whale skeleton

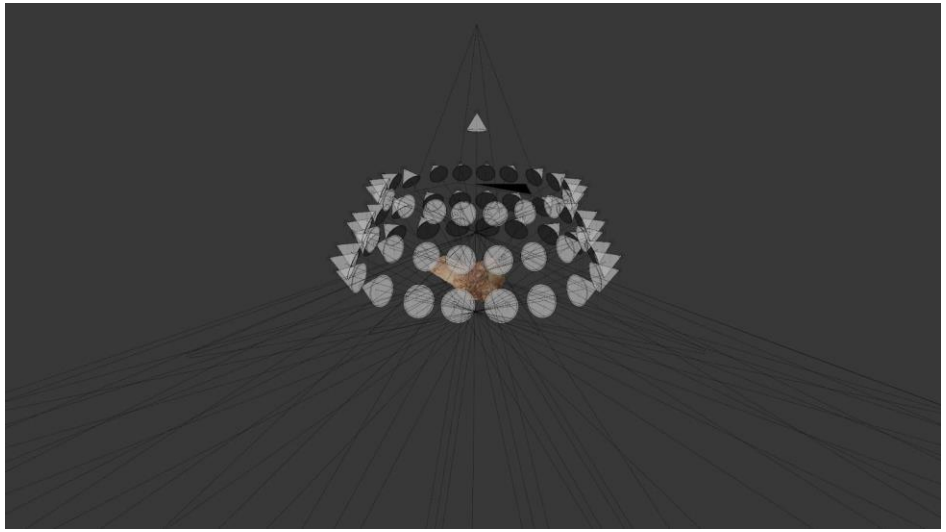


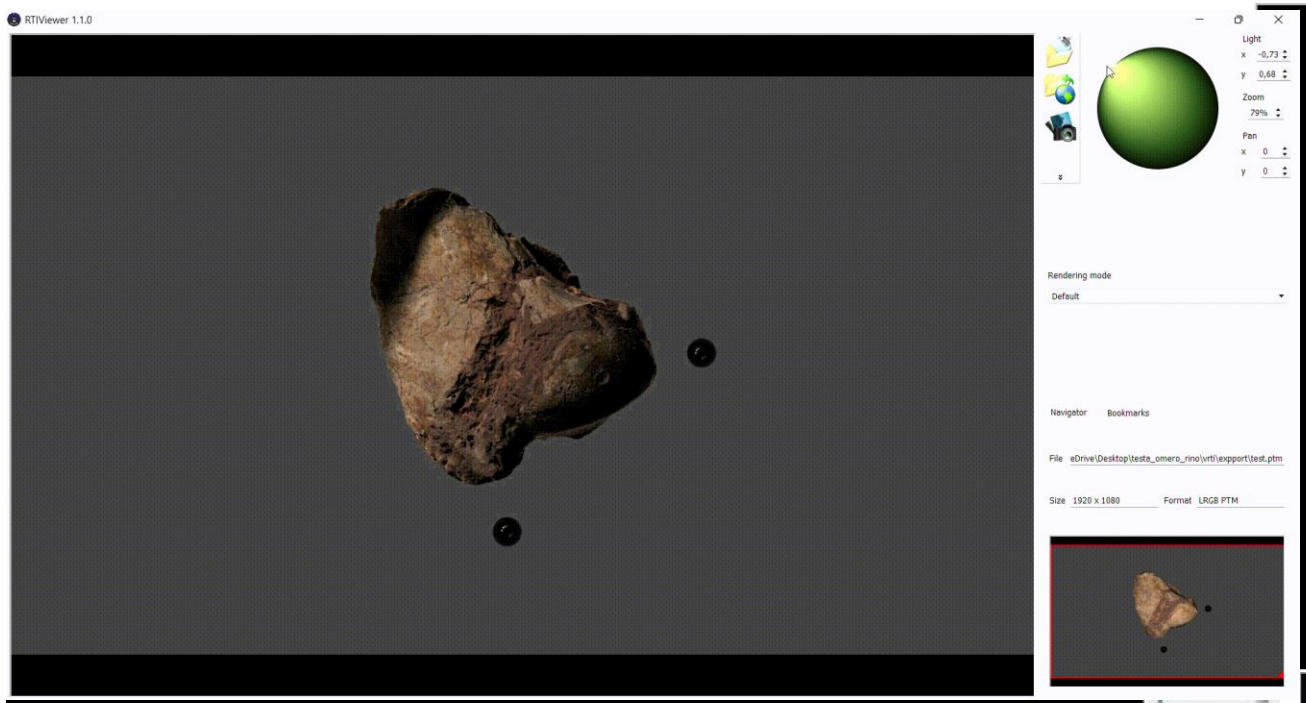
The humerus displays unnatural features and possible cut marks, which experts suggest may have been made by Neanderthals

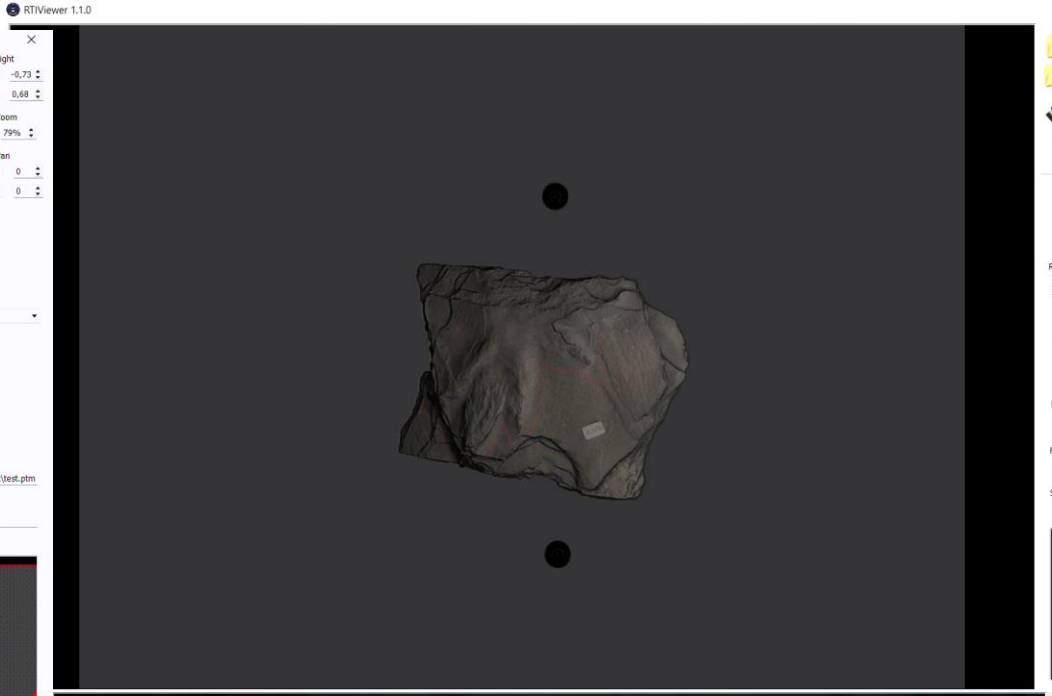
The footprints display features that are not easly visible at naked eye

RTI and VRTI

- SLS acquisition
- **RTI (Reflectance Transformation Imaging)** is a technique that reveals fine surface details by combining photos taken under different lighting angles.
- **VRTI (Virtual Reflective Imaging)** was performed on the model to further test the methodology




RTIViewer 1.1.0
Light
x -0,73
y 0,68
Zoom
79%
Pan
x 0
y 0
Rendering mode
Default
Navigator
Bookmarks
File eDrive\Desktop\testa_omero_rino\vrti\expport\test.ptm
Size 1920 x 1080
Format LRGB PTM


RTIViewer 1.1.0
Light
x 0,66
y 0,04
Zoom
16%
Pan
Rendering mode
Normal Unsharp Masking
Gain
25
Environment
21
Navigator
Bookmarks
File C:\Users\franc\Downloads\1943_vrti.ptm
Size 8192 x 6085
Format LRGB PTM


Light
x -0,12
y -0,32
Zoom
24%
Pan
x 463
y 108
Rendering mode
Default
Navigator
Bookmarks
File impronte\1944\RTI\ptm file\1944_rti.ptm
Size 8192 x 6144
Format LRGB PTM

5. GALLERIE ESTENSI CASE STUDY

BEGARELLI'S SCULPTURES AT THE ESTENSI GALLERIES AND MISLEADING RAPRESENTATION

- Begarelli created *Virgin and Child*, *Baptism of Christ*, and *Lamentation* for San Salvatore, Modena, likely produced after 1534.

- The current display alters Begarelli's original vision: **missing elements**, **incorrect positioning**, and exposed unfinished areas **distort the intended spatial and illusionistic effect.**

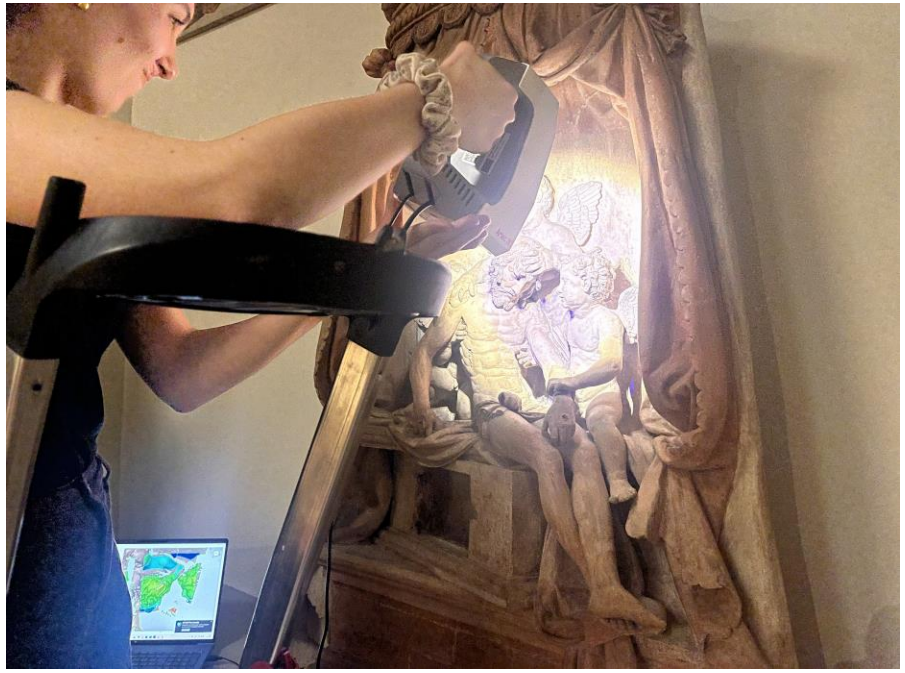
- 3D employed to acquire all the sculptures part of the complex and to carry out different analysis and rapresentation

ACQUISITION PROCESS

- hybrid acquisition Structured light Scanner - photogrammetry

PROBLEMATIC FACTORS

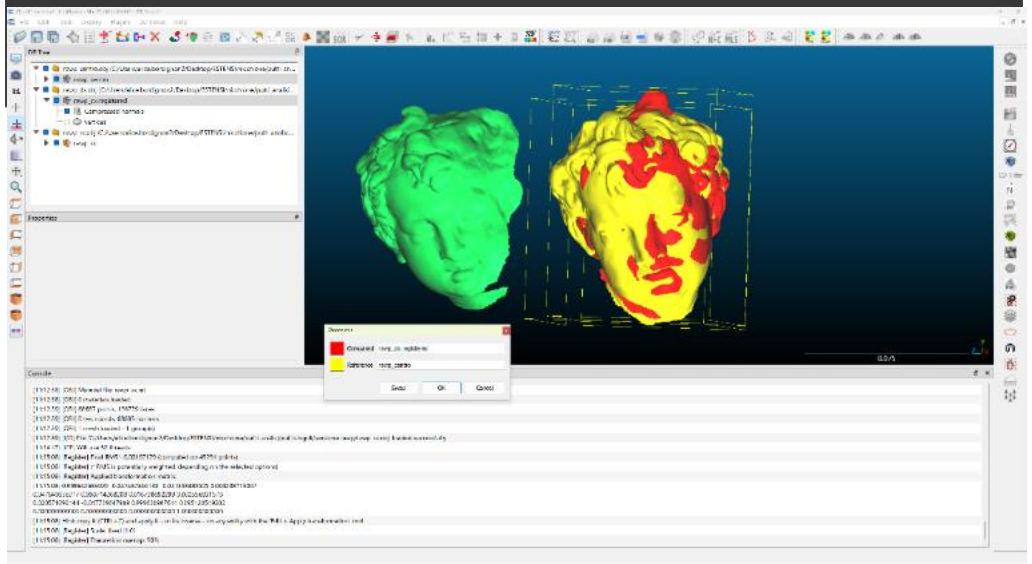
- Immovability of some objects due to weight
- non-adjustable lighting conditions
- conservation of the sculptural complexes in different museum spaces



Lamentation of Christ — Revealing Sculptural Variations through Distance Maps

Distance map creation

- comparison between the heads of the angels to understand if Begarelli had used the same mold

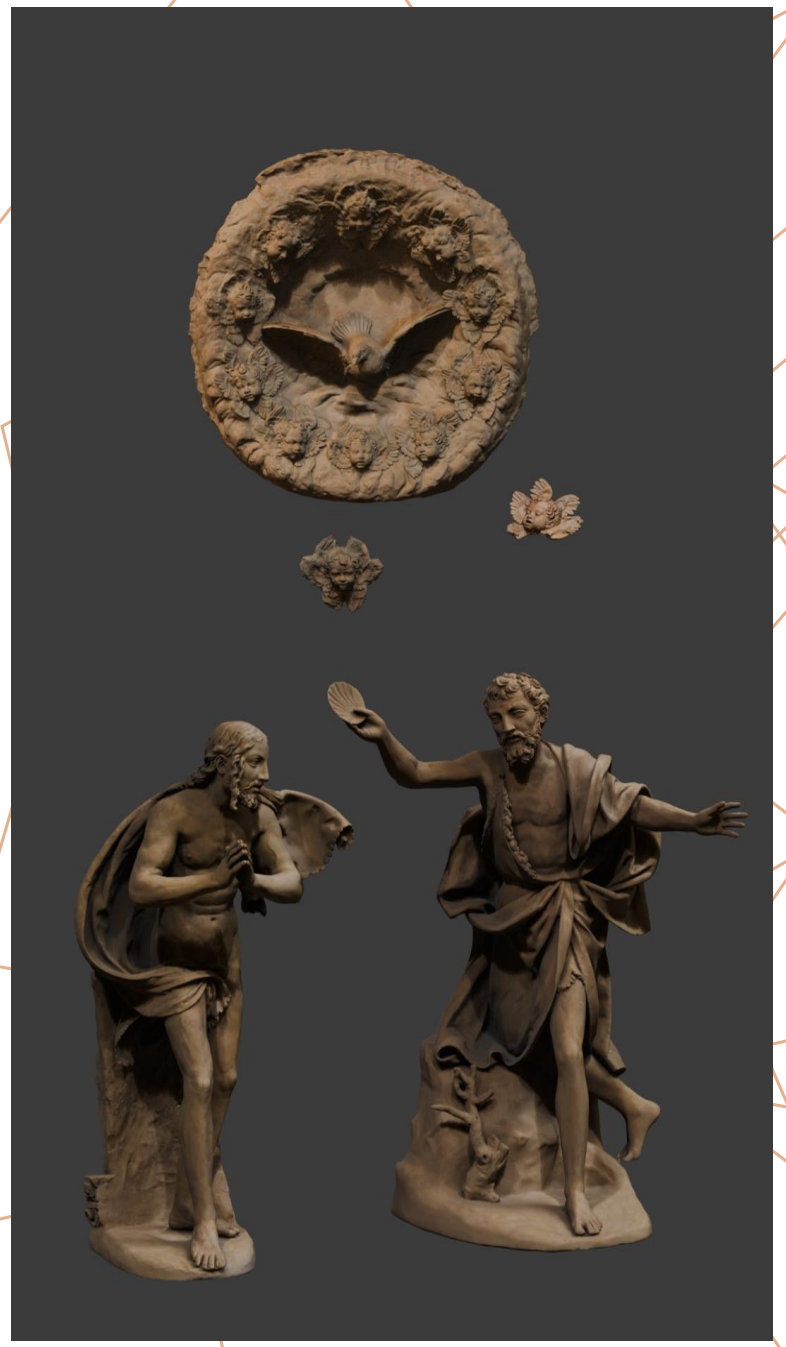


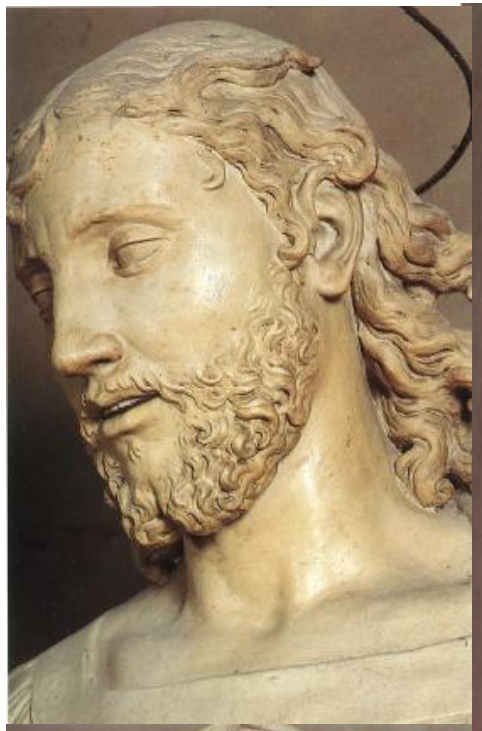
THE BAPTISM OF CHRIST: A NEW DIGITAL VISION

- Through the 3D acquisition of the individual components of the sculptural complex, their original configuration can be digitally reconstructed, despite it no longer being achievable in the physical context

Current display

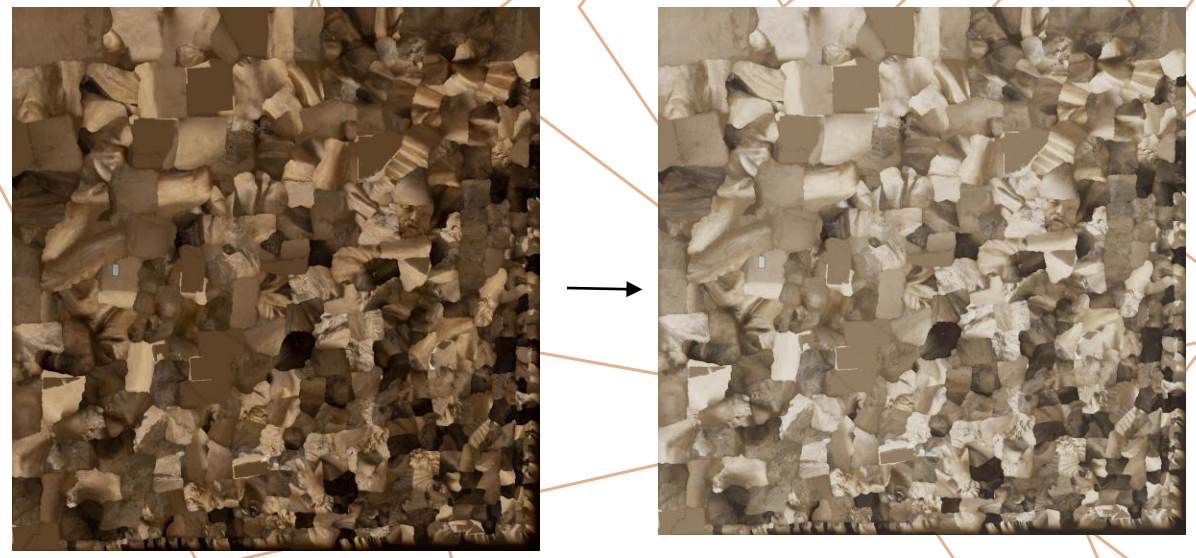
Original display





RESTORING THE ORIGINAL COLOUR THROUGH THE DIGITAL

Digital color processing whithin an image editing software (GIMP, Photoshop) applied to texture acquired in 3D



2025

THANK YOU!

Luisa Ammirati
Alice Bordignon
Francesca Fabbri
luisa.ammirati2@unibo.it
alice.bordignon2@unibo.it
francesca.fabbri80@unibo.it

VIDILAB
Department of Classical Philology and Italian Studies (FICLIT)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

CULTURAL HERITAGE ACTIVE INNOVATION FOR NEX-GEN SUSTAINABLE SOCIETY
EXTENDED PARTNERSHIP