Institute for Spatial Information
and Surveying Technology
Mainz University of Applied Sciences

COLOR & SPACE IN
CULTURAL HERITAGE

Recommendations and guidelines for the use or the implementation of processing chains of color/spectral and 3D data in cultural heritage

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Introduction

In Digital Cultural Heritage (DCH) one of the most challenging issues for end-users is to understand:

- Which software(s) to use?
- Which algorithm(s)/processing chain(s) to use?
- Which parameter(s) to set and why?
- What are the limitations and sources of error?
- How to adapt a processing chain depending of:
  - the object studied;
  - the digitization system used;
  - the application targeted?
- How to evaluate the quality of results obtained?

Introduction

In this presentation we will provide some **recommendations** and **guidelines** to end-users to use efficiency **commercial software** and **ad-hoc frameworks** proposed in the state of the art.

The main objective of this presentation is to increase end-users awareness of the effects of:

- input data;
- precondition and prerequisite;
- parametric factors, etc.

and to help them to be able to do the **best trade-off** between:

- the accuracy of results;
- the completeness of results;
- the processing time;
- the level of supervision requested; etc.

Introduction

We will also discuss why it is very important to apply processing tasks in a **logical order**.

Another objective is to increase software developers awareness of the **gap** that still exists between the standard procedures proposed in the state of the art and the needs of end-users (e.g. in terms of levels of details).

Introduction

There is **no universal automatic technique** that can be applied to each and every application scenario. Each processing chain has its own set of **advantages** and **disadvantages**.

When selecting a processing chain for a specific application, careful **tradeoffs** have to be made among the specific application requirements and to consider **key performance indexes** such as:

- Accuracy;
- Resolution;
- Speed;
- Cost;
- Reliability.

Sometimes, **multiple-modality methods** need to be used to address demands that cannot be met by a single modality.

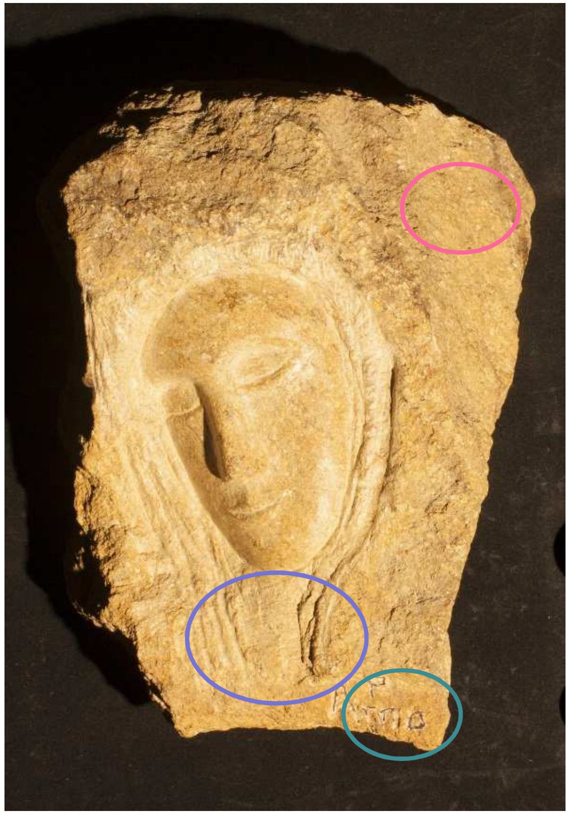
Recommendation 1: Don't use an inappropriate processing chain if data or object's properties are not compatible with such process.

As example, if you want to 3D reconstruct an object first analyze its intrinsic properties, next try to enhance the most useful features.

© Pierre Arnaud

This stone has some specific properties that should be taken into account:

- A curve surface (the human face) with specular reflectance;
- Some surface areas with strong variations of topography;
- Some unique patterns;
- Some featureless/textureless areas;



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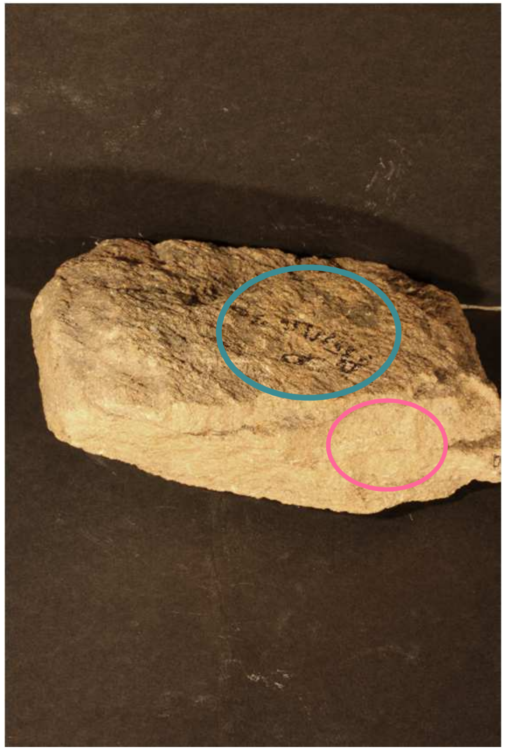
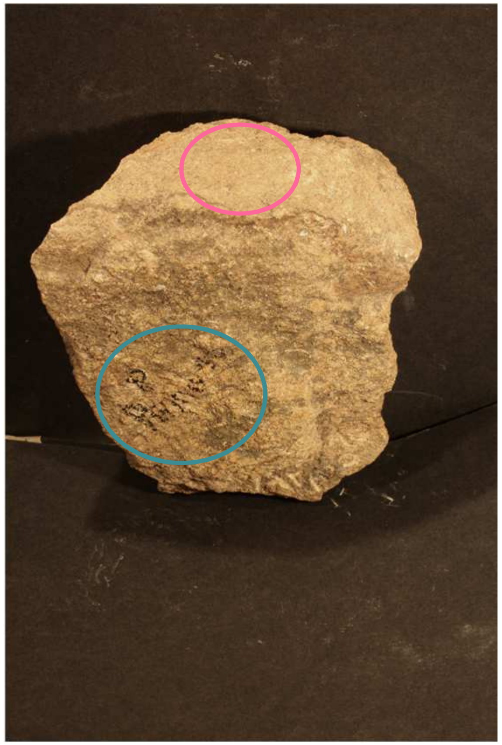
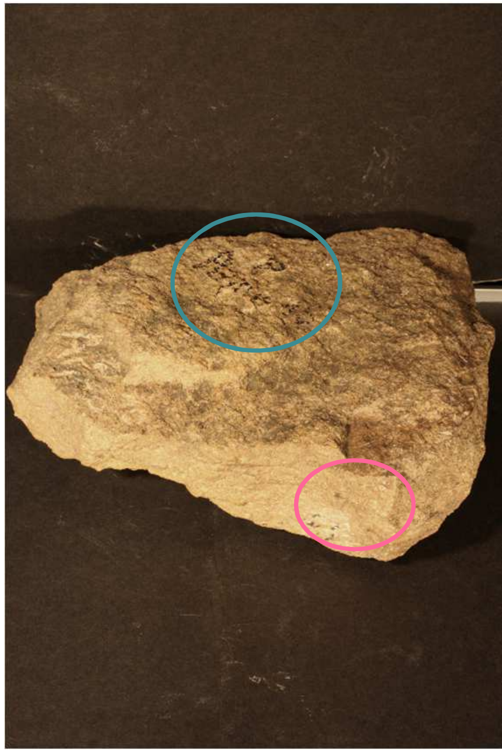
-Some featureless/textureless areas;



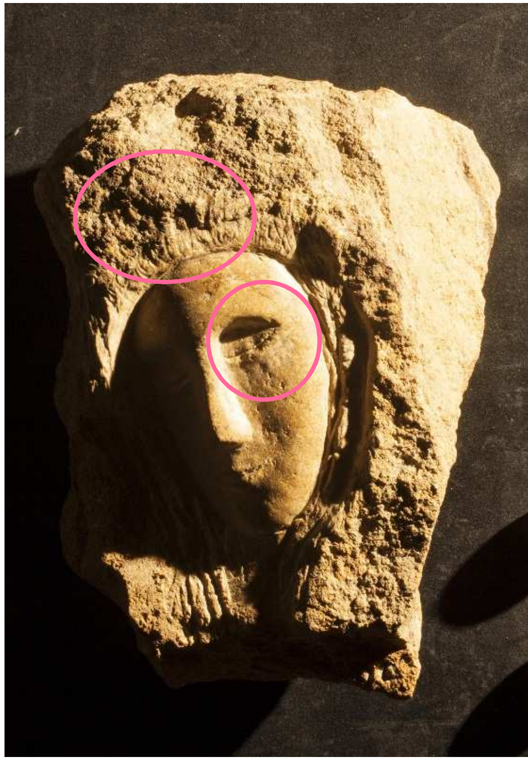




This stone has some **specific properties** that can be **enhanced** by different techniques, such as RTI:

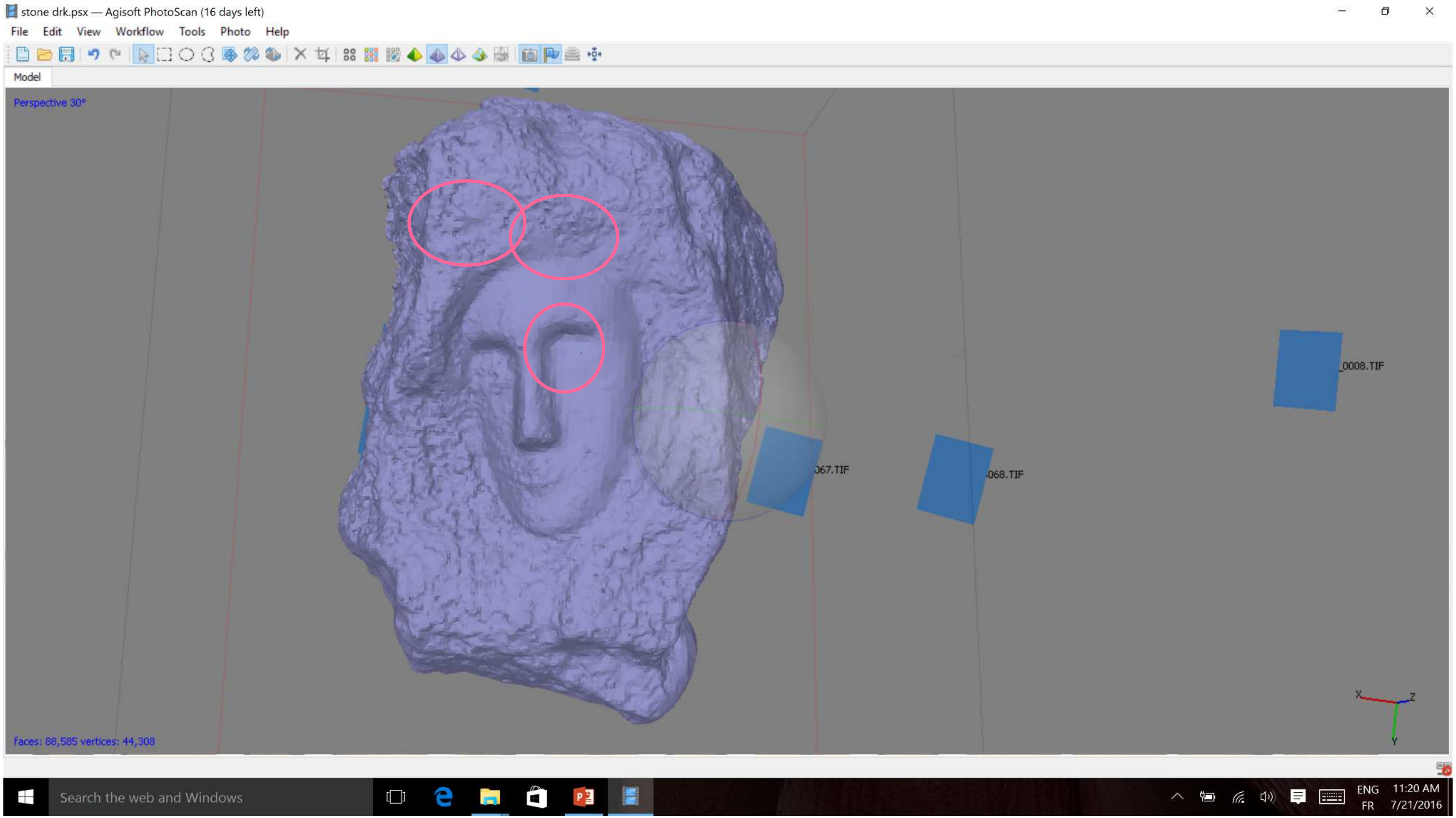
See surface areas with strong variations of **topography** and also “featureless” areas.

Remark: The more we improve the quality of the digitized data the less we have to pre-process these data.



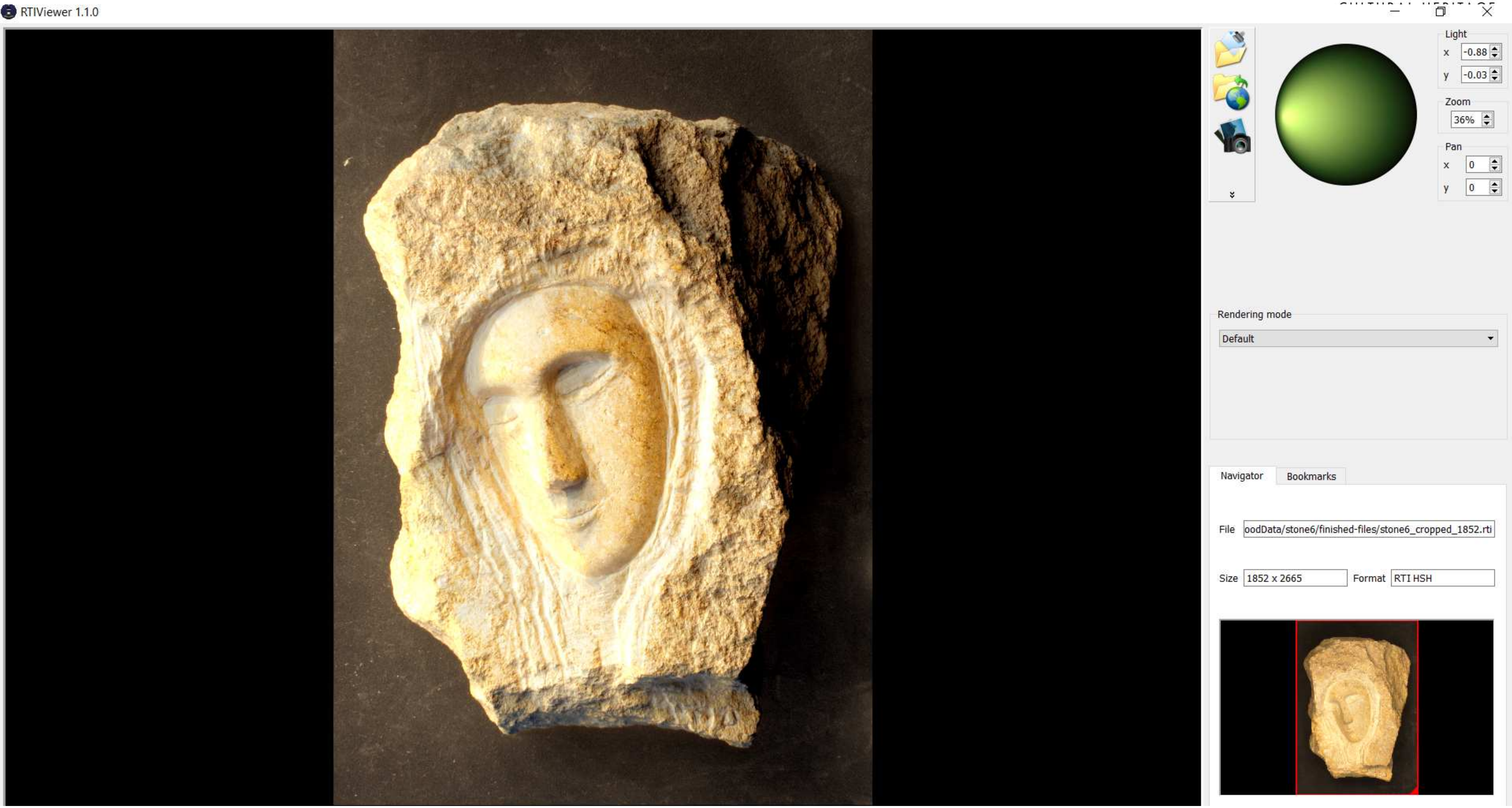
This stone has some specific properties that cannot be perceived using **photogrammetry** (such a the Agisoft software).

Remark: In some case 3D reconstruction can contribute to document some objects as it can help perceive details than experts cannot see directly.



For **Reflectance Transformation Imaging** (RTI) we used this RTI Software :

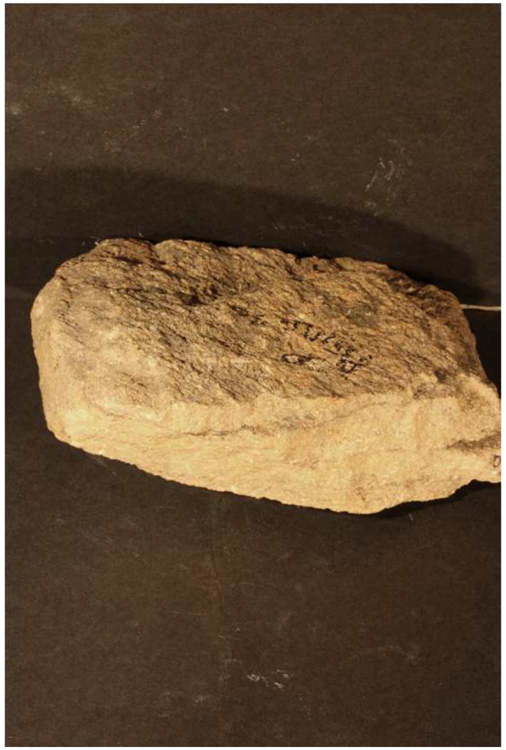
http://culturalheritageimaging.org/Technologies/RTI/index.html



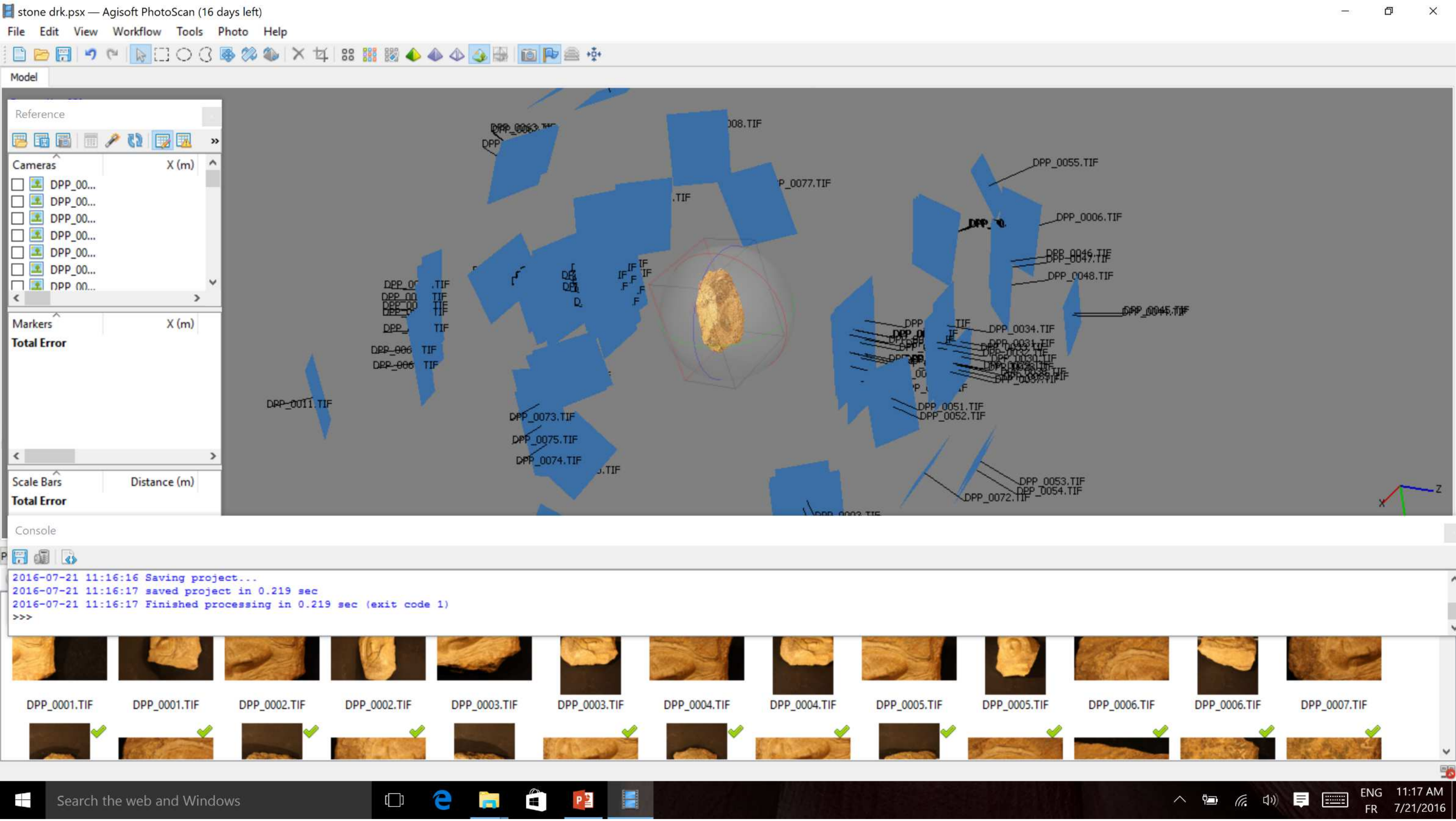
This stone has some specific properties that cannot be enhanced by any technique.

Recommendation 2: when we cannot exploit some features, such as texture, rather than processing inaccurate data it’s more efficient to use another digitization process, for example to use external markers.

Remark: when there is not enough common features between overlapping views it’s very challenging to align views.

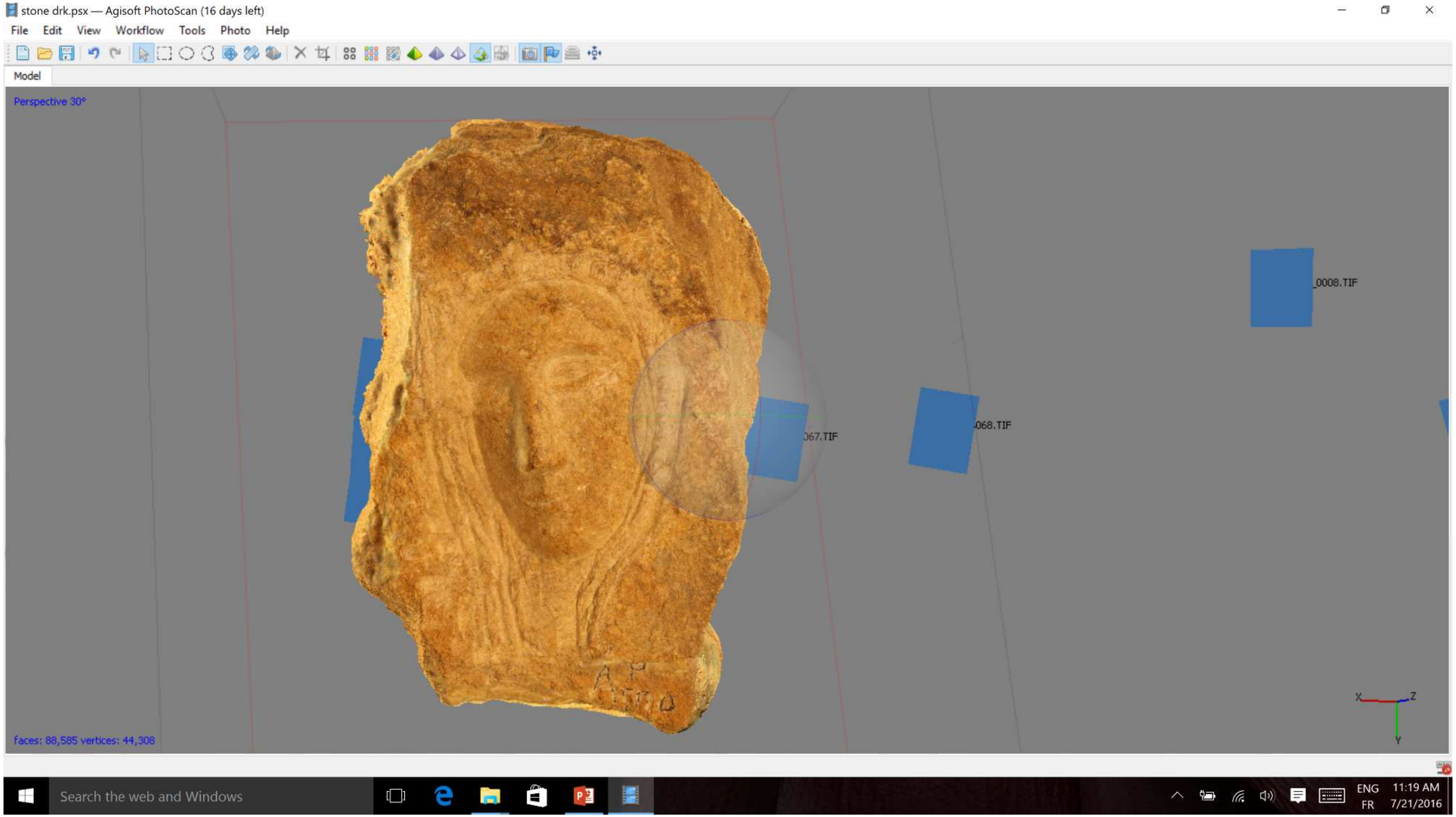


Example of 3D reconstruction using the Agisoft Photoscan software (based on photogrammetry)



Example of 3D reconstruction using the Agisoft Photoscan software (based on photogrammetry)

Remark: the **quality** of the result depends of the number of 2D images captured and also of the intrinsic quality of these pictures.



Example of 3D reconstruction using the Agisoft Photoscan software (based on photogrammetry)

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Remark: the **quality** of the result depends of the number of 2D images captured and also of the intrinsic quality of these pictures.

Remark: It is recommended to use **RAW format** to encode metadata in image (exif header).

Date taken:	6/28/2016 11:19 AM
Dimensions:	2592 x 3888
Size:	9.96 MB
Camera maker:	Canon
Camera model:	Canon EOS 1000D
Camera serial numb...	1430306133
ISO speed:	ISO-200
F-stop:	f/16
Exposure time:	2 sec.
Exposure bias:	0 step
Exposure program:	Aperture Priority
Metering mode:	Pattern
Flash mode:	No flash, compulsory

Date taken:	6/20/2016 3:44 PM
Dimensions:	2592 x 3888
Size:	9.00 MB
Camera maker:	Canon
Camera model:	Canon EOS 1000D
Camera serial numb...	1430306133
ISO speed:	ISO-100
F-stop:	f/5
Exposure time:	1/50 sec.
Exposure bias:	0 step
Exposure program:	Manual
Metering mode:	Pattern
Flash mode:	No flash, compulsory

Example of 3D reconstruction using the Agisoft Photoscan software (based on photogrammetry)

Remark: the **quality** of the result depends of color calibration process used to compensate color errors induced by lighting and viewing conditions.

Recommendation 3: the quality of features based techniques depends of the photometric/colorimetric invariance of feature descriptors computed, thus color errors due to lighting and viewing conditions must be compensated (using a geometry-independent color calibration process).

Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

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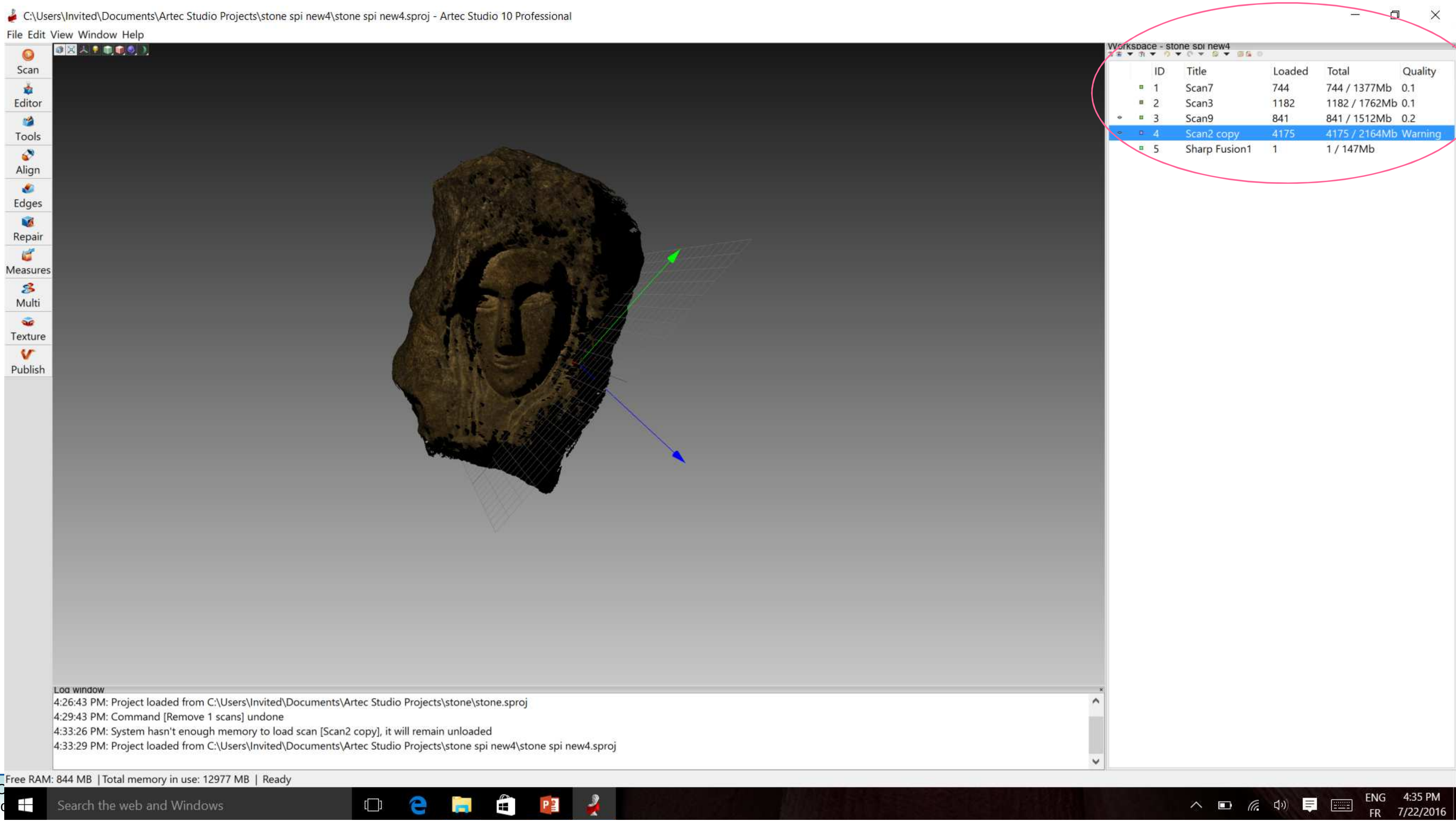

Remark: It's fundamental to get the best image quality before performing any computation, but how to evaluate the quality of images captured and how to improve it ?

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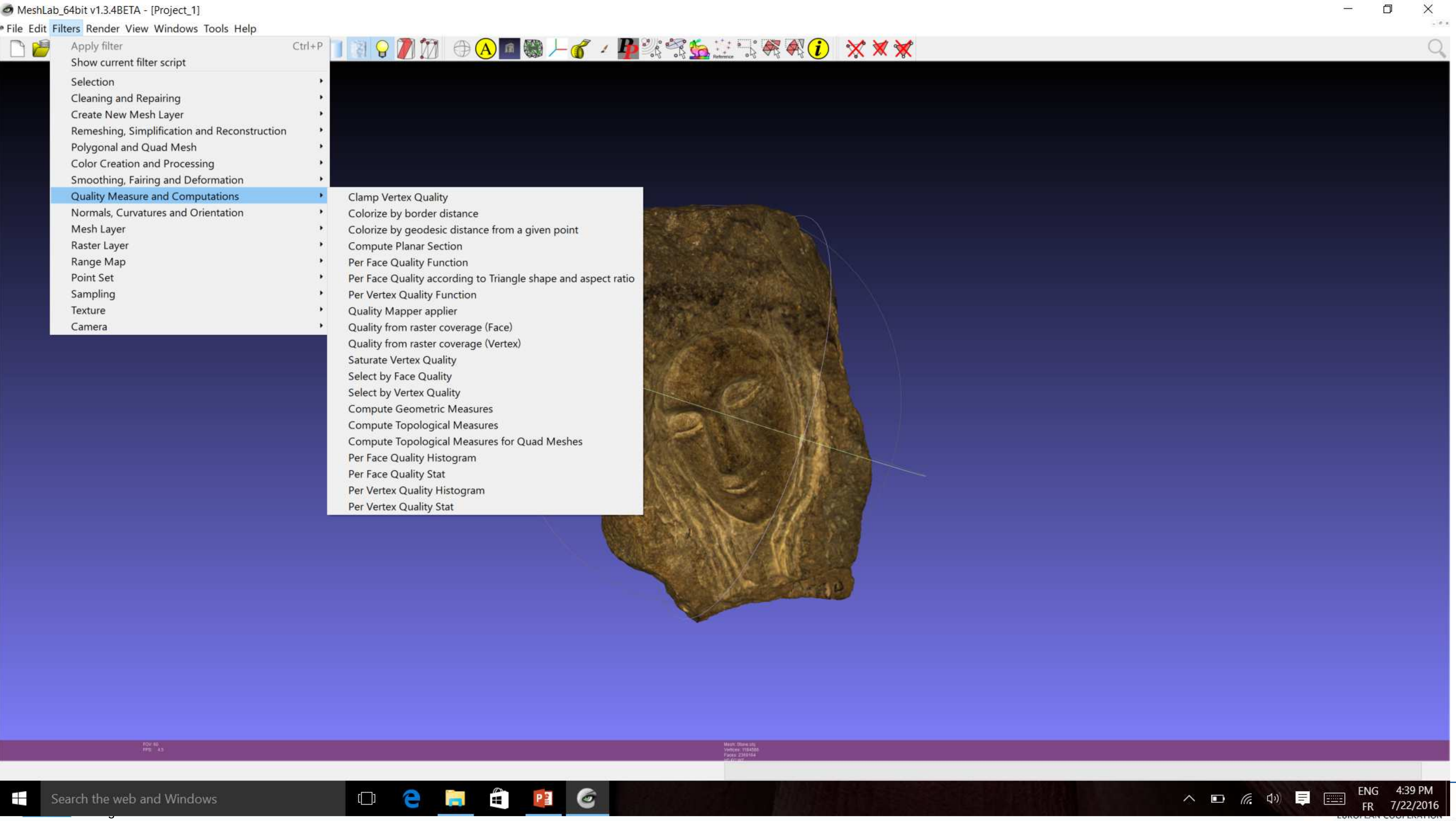
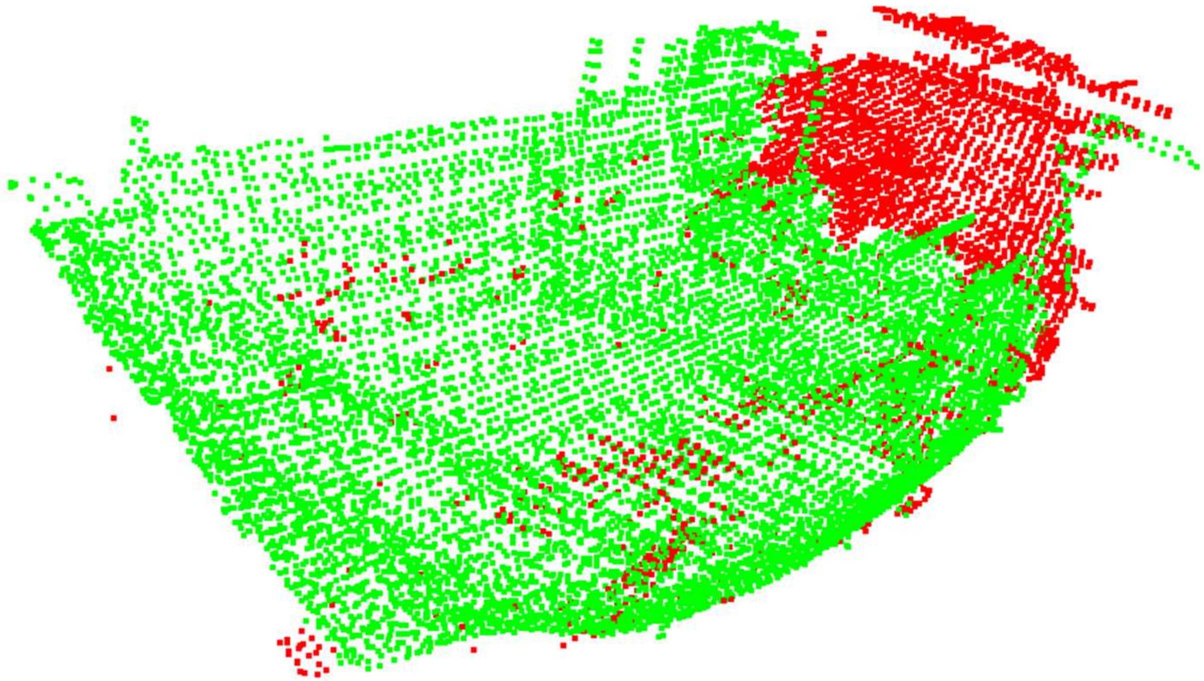
Many metrics exist (see for instance Meshlab software) but there are not obvious to use.



Remark: accurate analyze/comparison of 3D processed data (**at large scale and at small scale**) is fundamental to perform **accurate 3D documentation**.



Detecting changes related to the structure of the Bremen Cog
© Levente Tamás, German Maritime Museum/ i3Mainz

Scan comparison - Possible approaches:

- Euclidean metrics
- Quadratic/nonlinear methods
- Octree comparison
- Cross-section

Likewise, accurate analyze/comparison of results obtained by **3D documentation methods versus 3D processing methods** may contribute to improve the relevance of data analysis done..

Example of 3D reconstruction using both Structure from Motion (3D scans) and Photogrammetry (2D photos).

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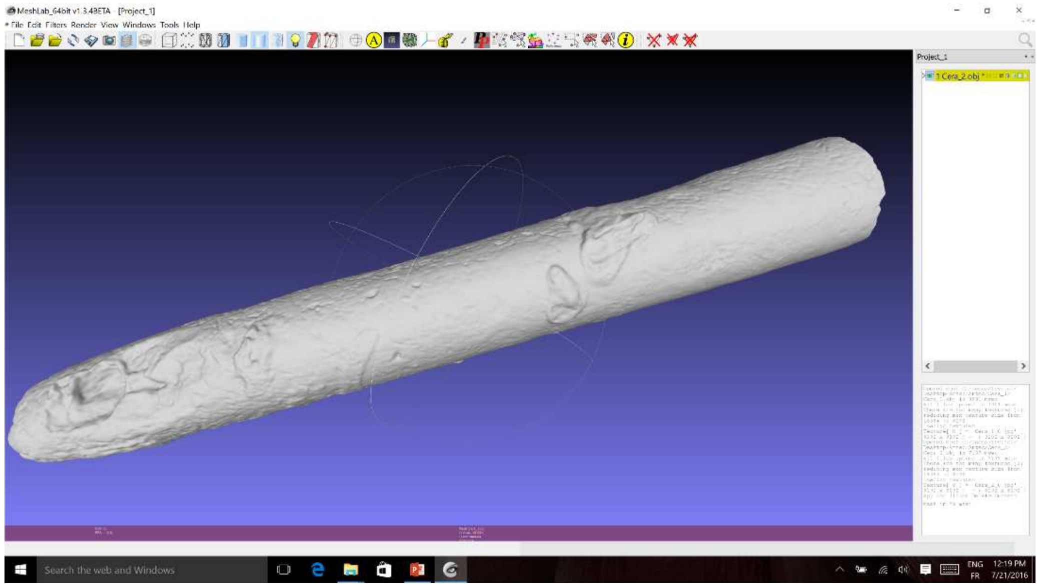
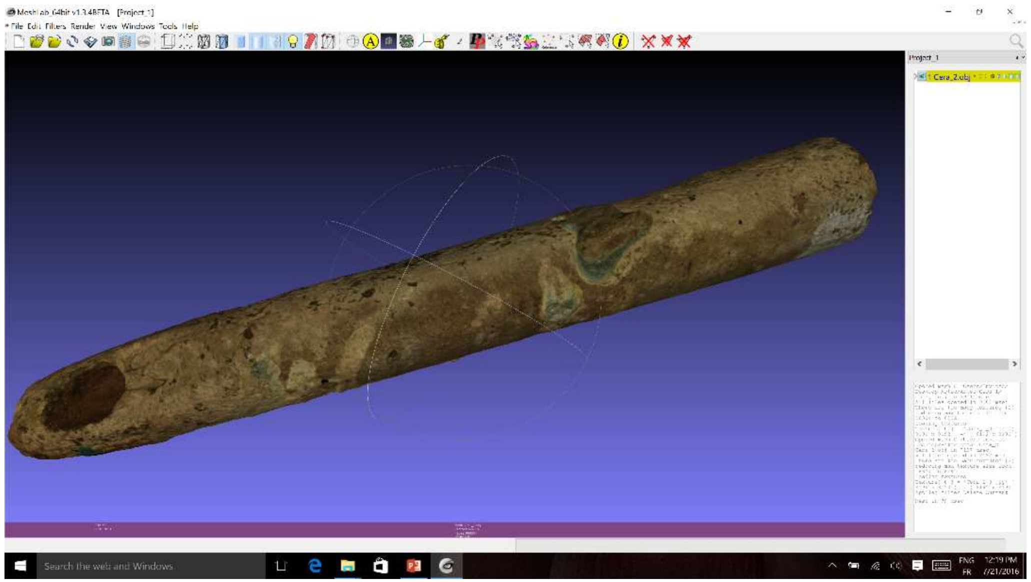
Remark: It is sometimes recommended to use various technologies to highlight different material properties (e.g. surface appearance and color appearance), in this case accurate geometrical calibration is requested.

As example

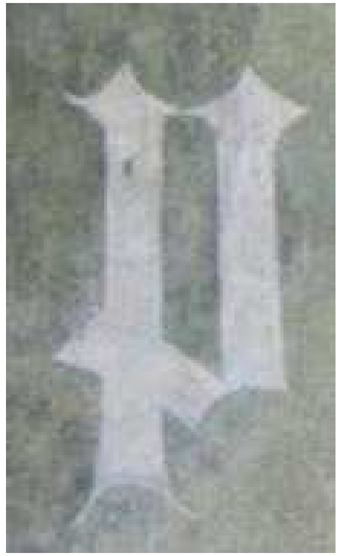


3D shape (image © Yona Waksman)



3D reconstruction after fusion of 2D pictures with 3D shape

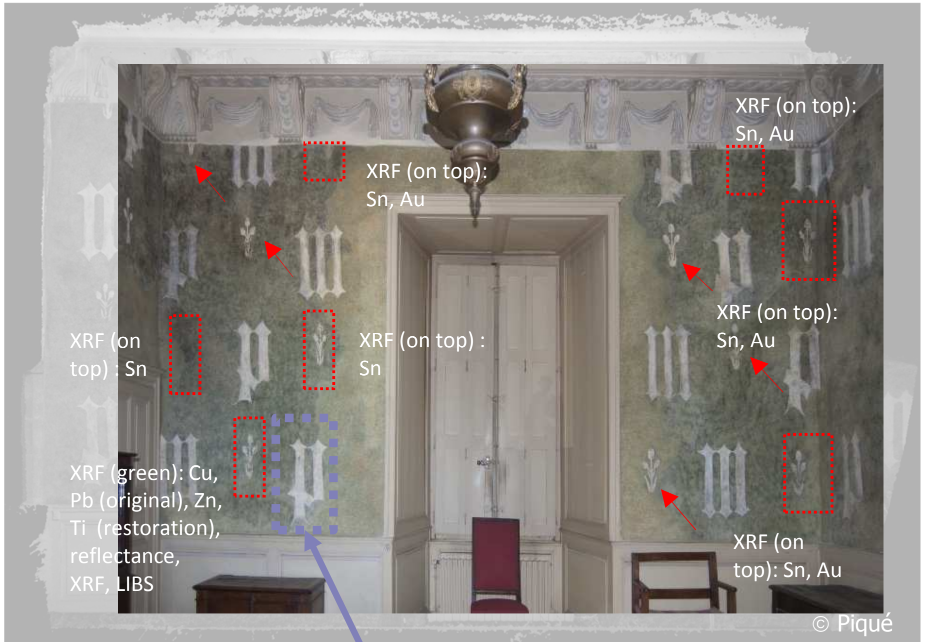
Remark: It is sometimes recommended to use various technologies to highlight different material properties, in this case accurate geometrical calibration is requested.



As example: **GERMOLLES case study.**

Can we detect this symbol on IR, UV, VIS and XRF images?

Otherwise what are the spatial features common to all image systems ?



Dressing Room of Countess of Nevers – South wall – dn_s

IR, UV, VIS, VIS raking light + micro, XRF (white): Pb (original), Zn, Ti (restoration) , reflectance, LIBS, IR thermography.

Recommendation 4: geometrical alignment (image registration) is possible only when common features can be detected among images.

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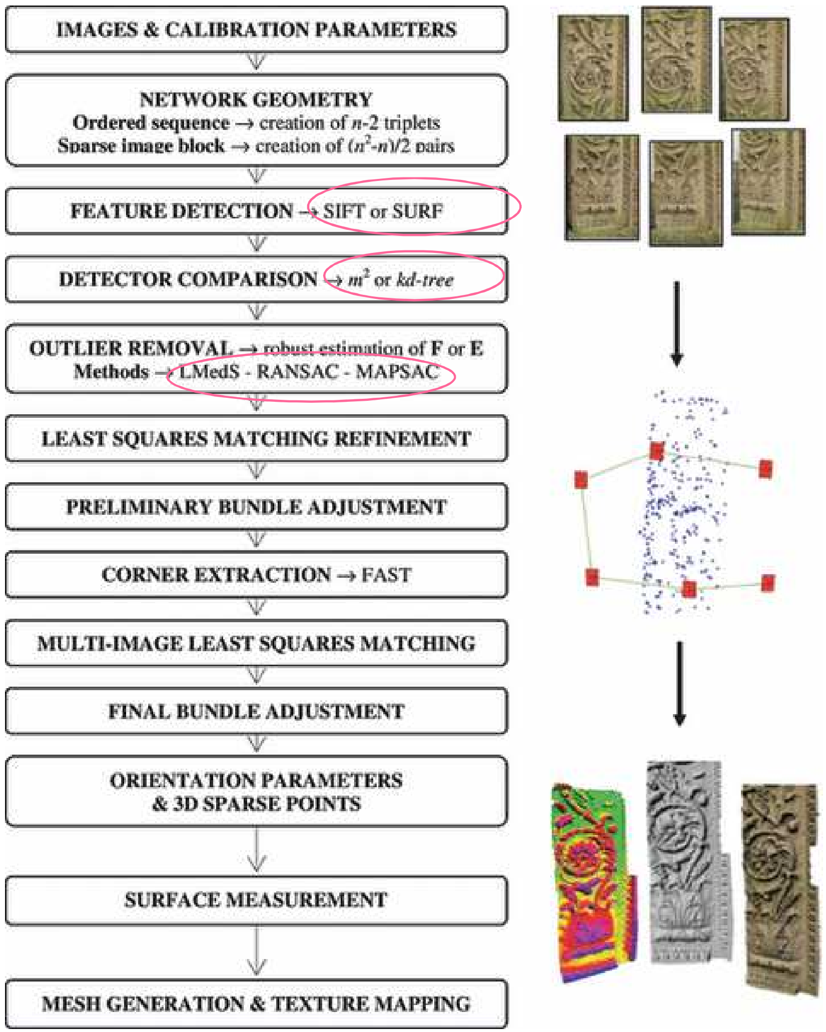
Remark: It is sometimes recommended to use various feature detectors (such as SIFT, SURF, FAST, ...) and optimization methods (IPC, RANSAC, ...) to obtain an accurate matching of images from images geometry.



Example of flowchart for automated image orientation and surface measurement procedures.

Example at right shows details from Pompeii Forum, Campania, Italy.

Luigi Barazzetti, Marco Scaioni, Fabio Remondino, Orientation and 3D modelling from markerless terrestrial images: combining accuracy with automation, The Photogrammetric Record 25(132): 356–381 (December 2010)

Remark: oppositely to general workflows used by commercial softwares here we know for each task which method is used but this **knowledge is difficult to understand** by non-experts in computer vision.

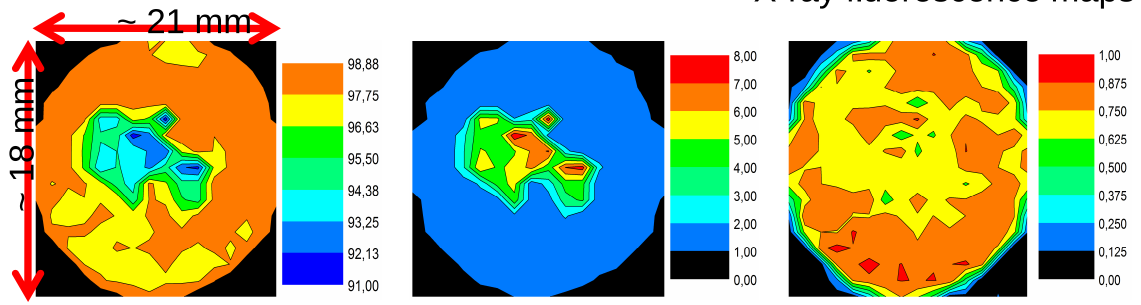
Other example: **Roman Silver Coins case study.**

Can we detect complementary data using different measurement systems ?

if yes, what are the spatial features common to all image systems ?

Here only manual alignment could be done but the accuracy of this alignment is low.

X-ray fluorescence maps



© Julio del Hoyo Melendez, National Museum in Kraków

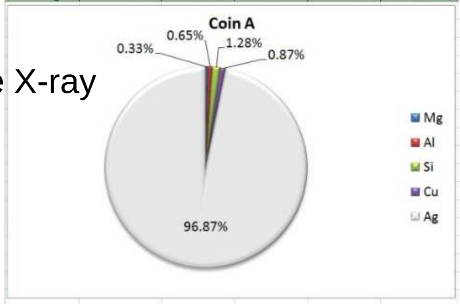
Structured light

© Aurore Mathys, Royal Belgian Institute of Natural Sciences

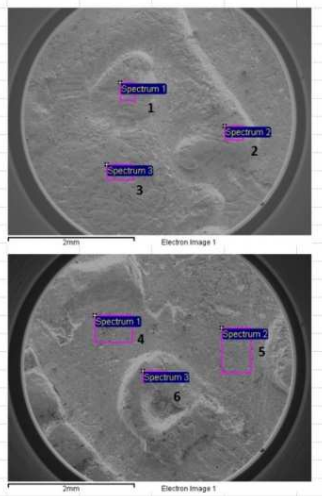
Energy dispersive X-ray spectro-scopy

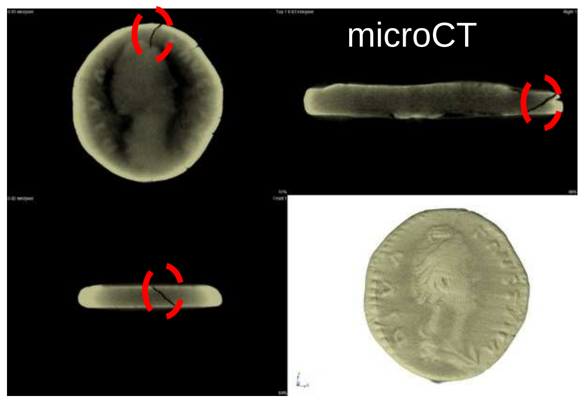
Coin A - elemental analysis (EDS)

Meas area No	Magnesium Mg	Aluminium Al	Silicon Si	Copper Cu	Silver Ag
1	0.37	0.84	0.89	0.39	97.52
2	0.27	0.88	0.77	1.25	96.83
3	0.31	0.52	1.1	1.13	96.94
4	0.37	0.78	2.38	0.71	95.75
5	0.37	0.52	1.37	0.51	97.23
6	0.31	0.37	1.15	1.23	96.94
Average	0.33	0.65	1.28	0.87	96.87



results in weight %





Coin diam. ≈ 17 mm

© Miroslav Hain, Institute of Measurement Science, Slovak Academy of Sciences, Bratislava

Other example:

According to Saval-Calvo et al.:

“*The most common algorithms for registering multiple views from a scene are based on **Iterative Closest Point** (**ICP**) and **RANSAC**.*

ICP iteratively registers in a fine way two point clouds using the closest point matching to evaluate the correspondences between them and it is still used in recent application.

Many variants have been proposed for enhancing the result adding normal information or knowledge about other kind of constraints (e.g., borders, color, etc.). However, this method needs an initial transformation to avoid convergence in a local minima.

*On the other hand, **RANSAC-based methods** evaluate matches (commonly estimated using 2D or 3D features) and remove the wrong correspondences between points of a view and the reference view. RANSAC is often used to extract the initial transformation for the ICP.*

***Those methods, despite the fact that are noise-resistant, only can deal with a certain level of noise.** Specifically, there exist various works dealing with RGB-D low-cost sensors*.”

Marcello Saval-Calvo, Jorge Azorin-Lopez, Andrès Fuster-Guillo, Higinio Mora-Mora, µ-MAR : Multiplane 3D Marker based registration for depth-sensing cameras, Expert Systems With Applications 42 (2015) 9353–9365

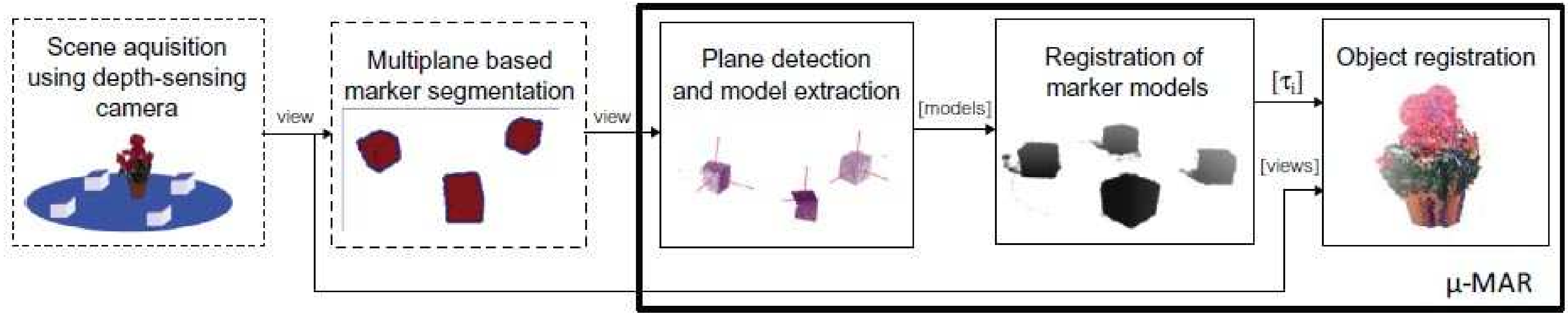
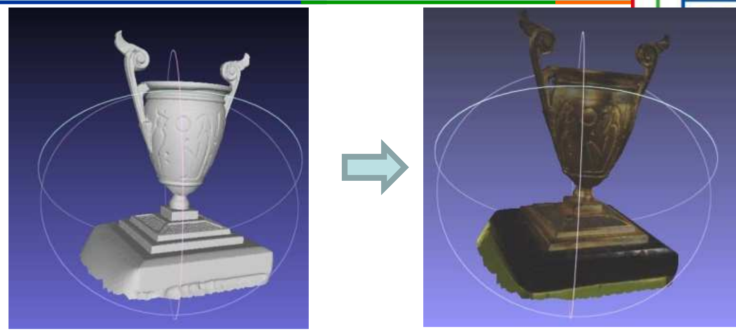
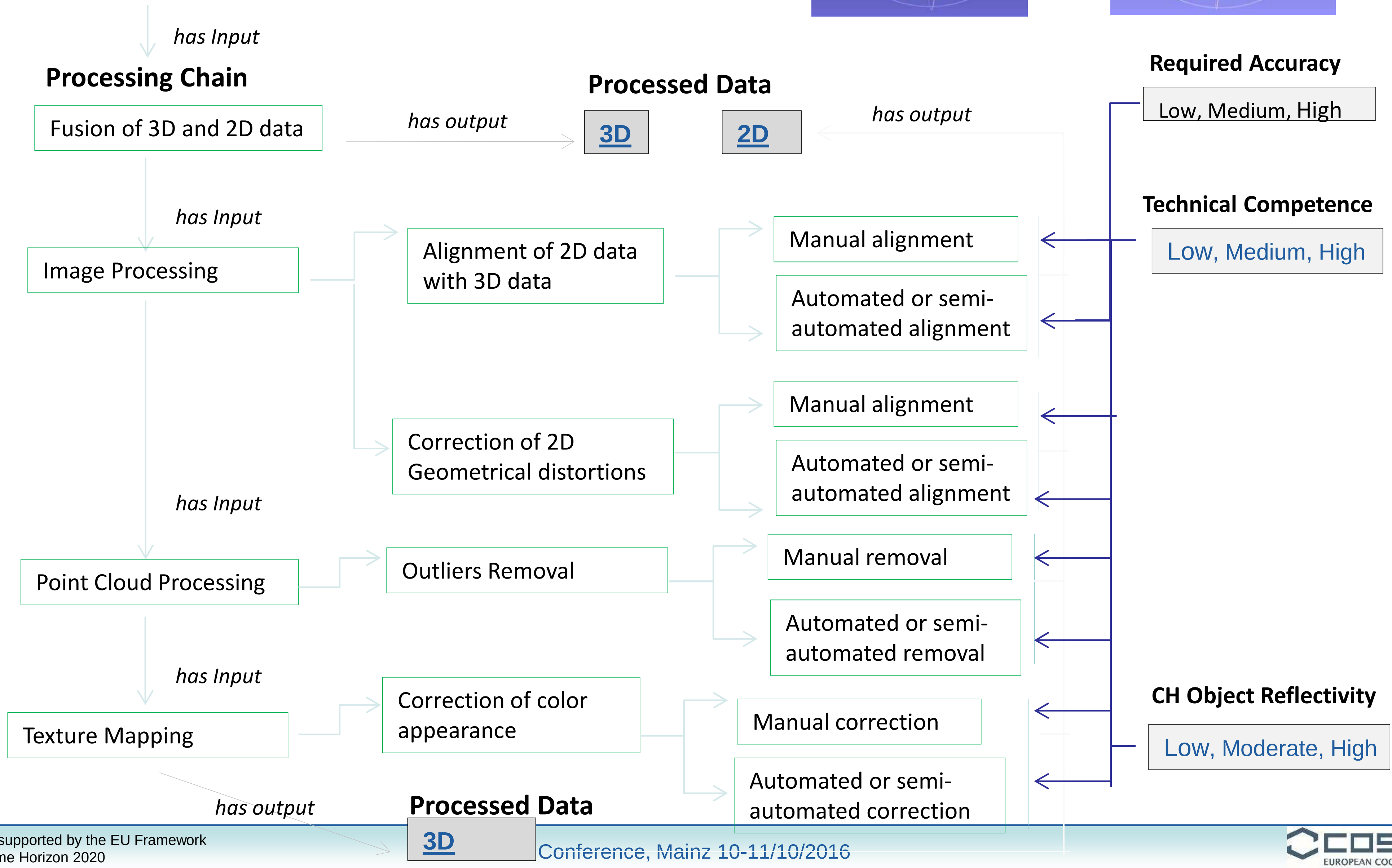


Fig. 1. Overview of the proposed object registration method. Hyphened rectangles represent previous steps.

Example of processing chain commonly used for fusion of 3D and 2D data



Example of information that end users should know.



Example of 3D reconstruction using both Structure from Motion (3D scans) and Photogrammetry (2D photos).

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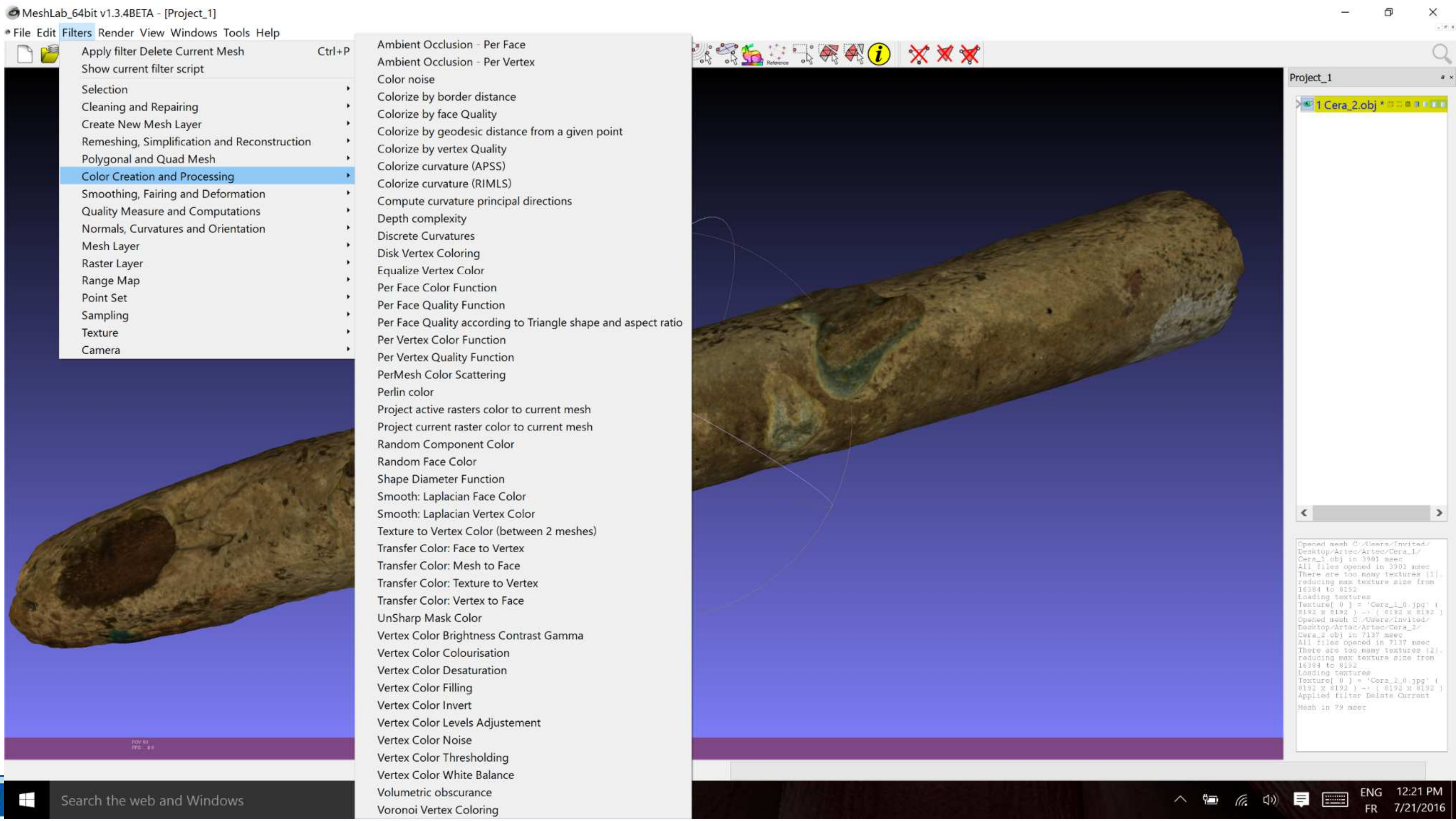
Remark: If the result is not “visually appealing”, several post-processing steps/stages can be performed (e.g. using Meshlab) but it usually causes decrease of accuracy of data



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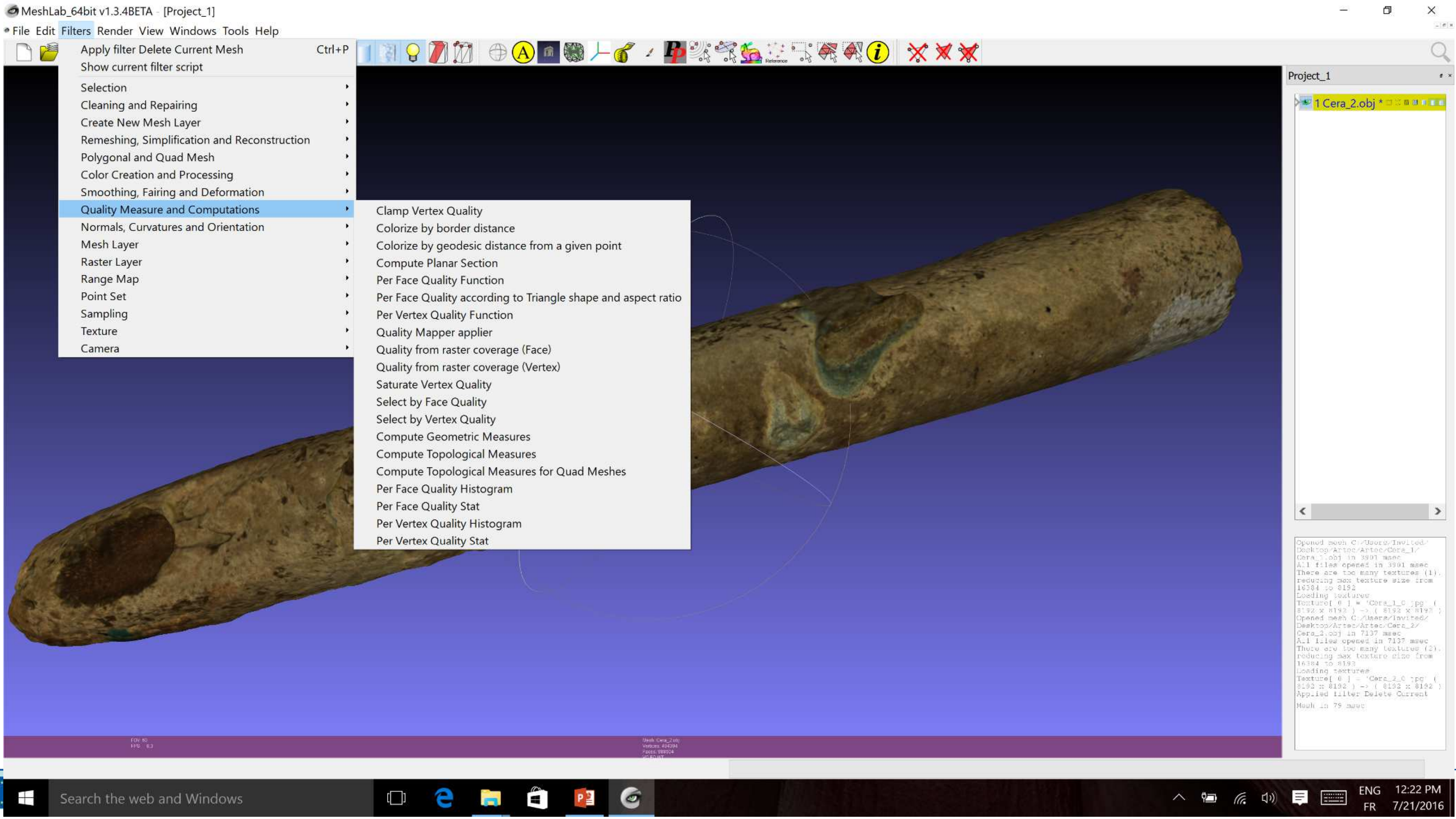
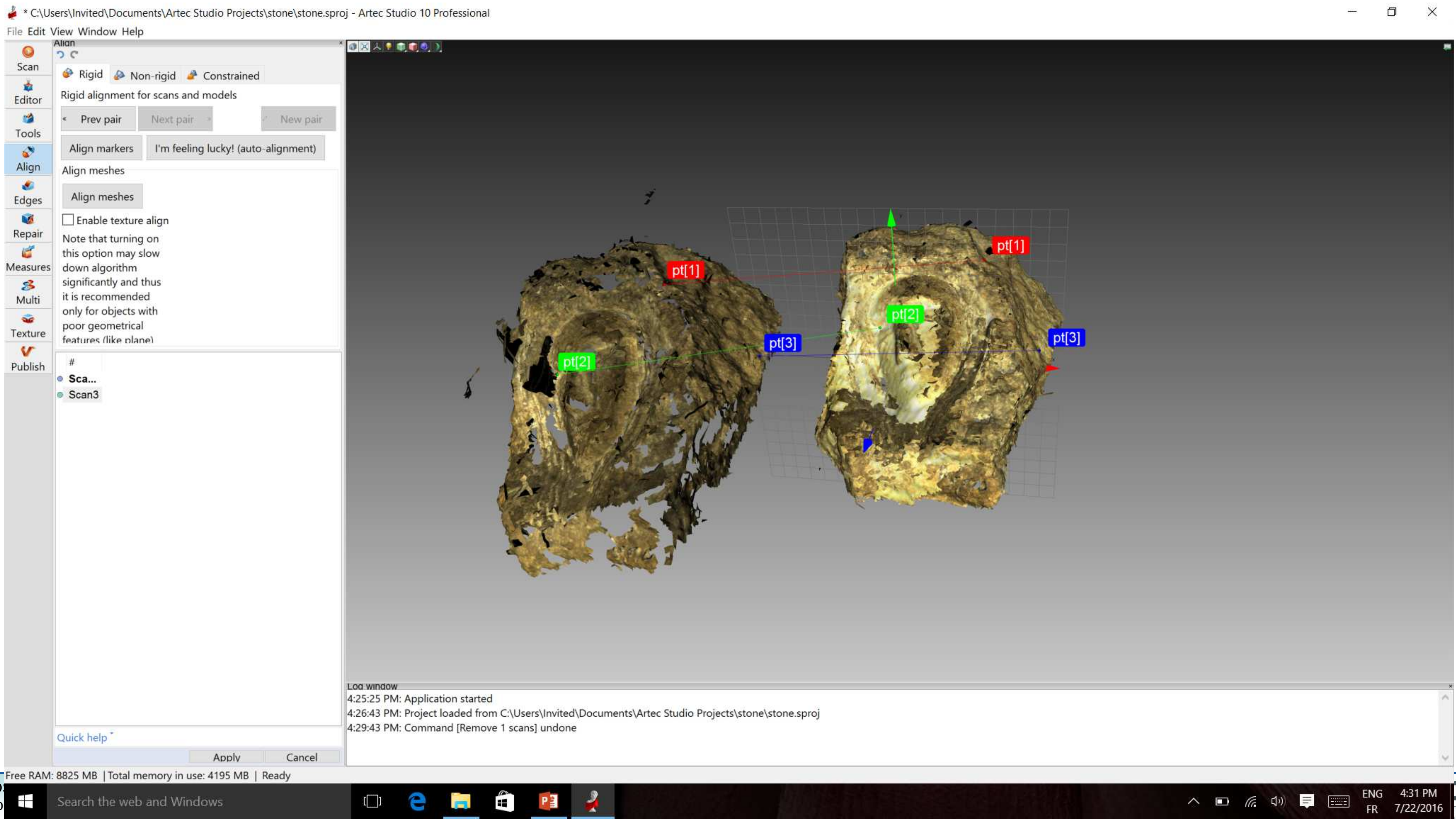


Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

Remark: the **quality** of the result also depends of: - the processing chain used; - the default parameters used; - the user interactions to be done; - …



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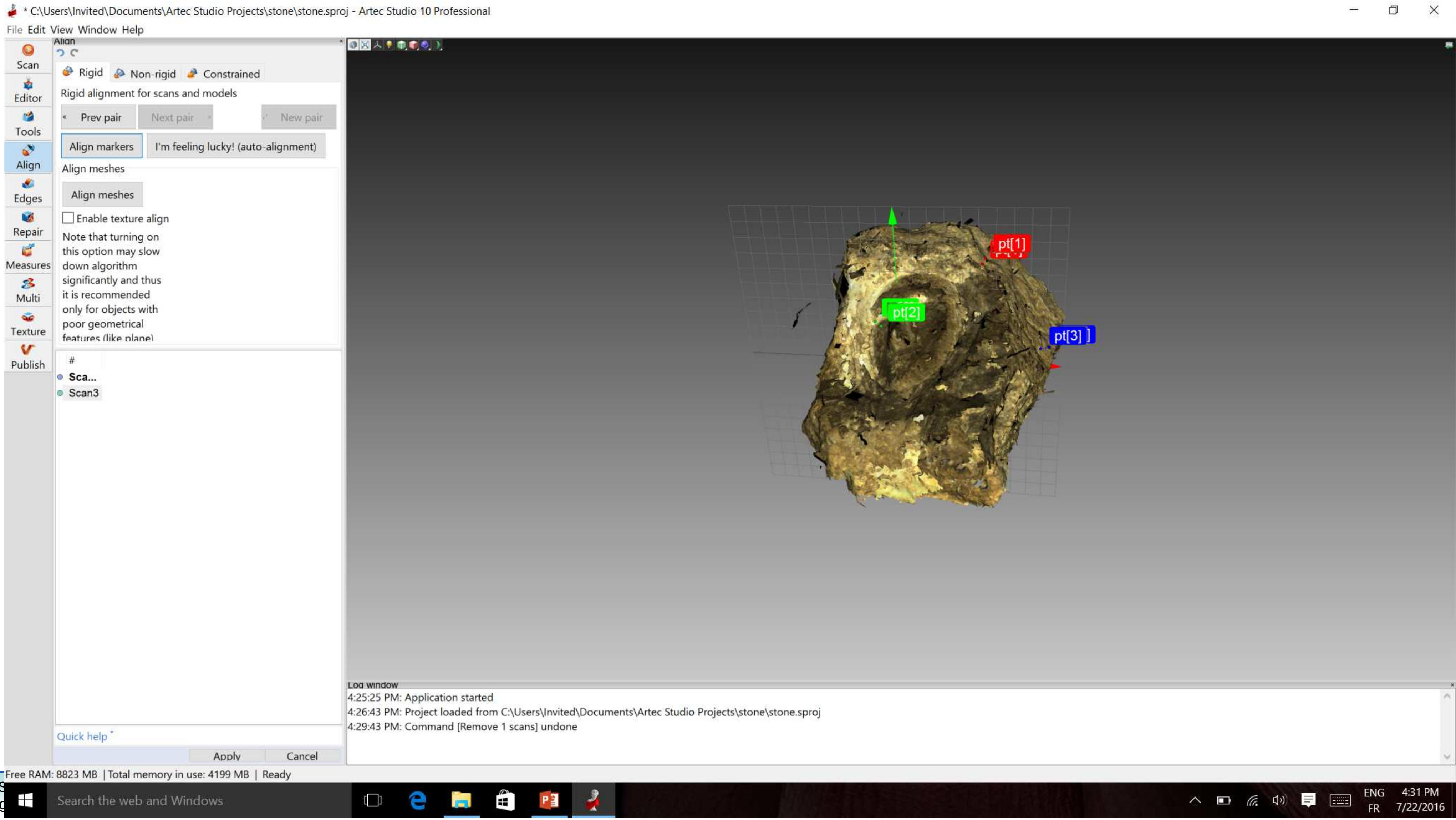
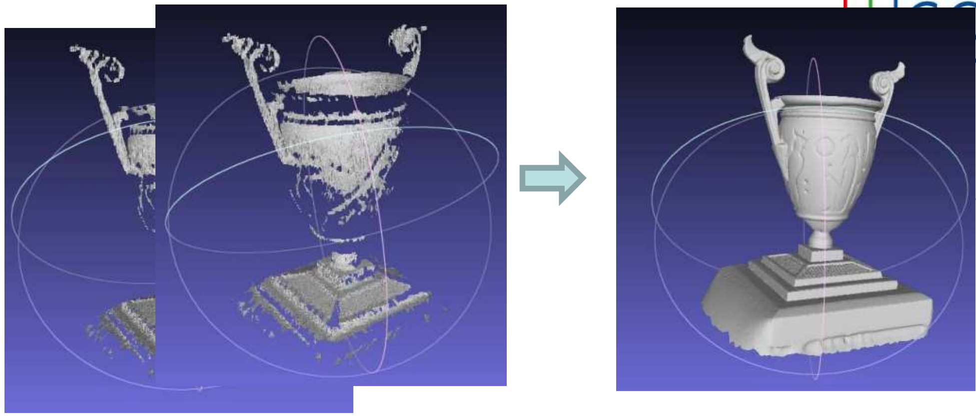


Processing chain commonly used for 3D reconstruction

Example of information that end users should know.



has Input

Processing Chain

- Scanning — *has output* → **Processed Data**: 3D
  - *has Input*
- Point Cloud Pre-processing
  - Filtering
    - Remove isolated points
    - Delete gross errors
  - *has Input*
- Point Cloud Processing
  - Alignment of scans
    - Manual alignment
    - Automated or semi-automated alignment
  - Remove redundancies in overlapping areas and outliers
    - Manual removal
    - Automated or semi-automated removal
  - *has Input*
- Meshing of the 3D Point Cloud
  - Decimation of the meshing
  - Remove meshing errors

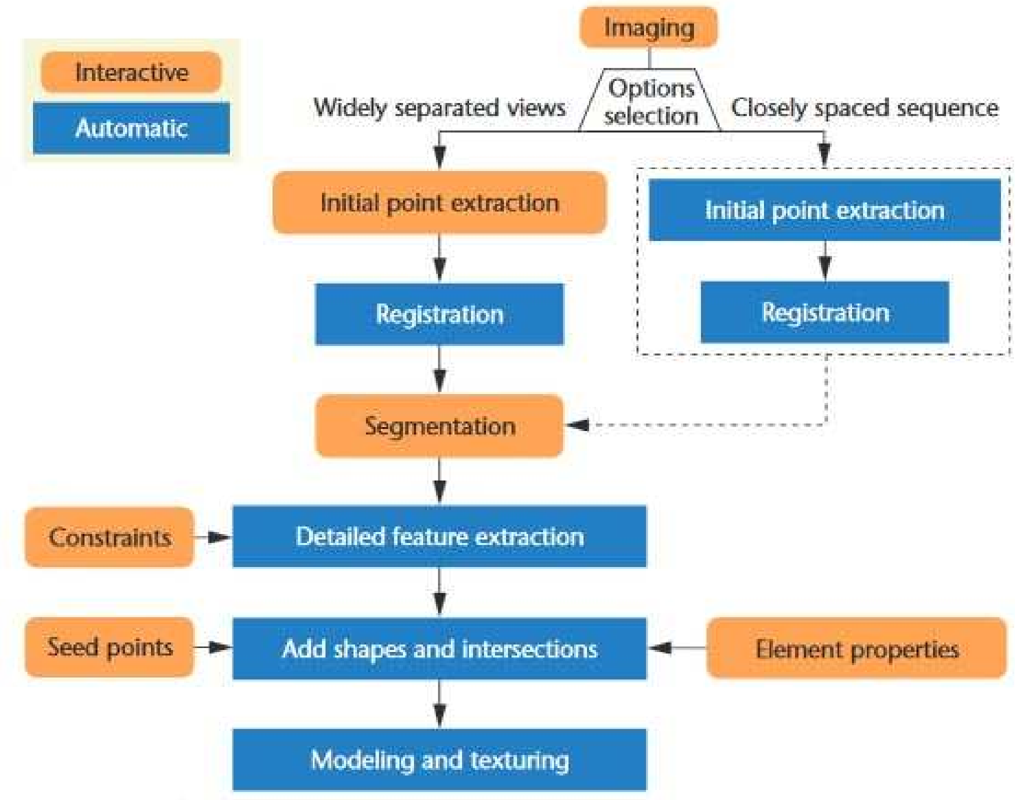
has output → **Processed Data**: 3D

Required Accuracy: Low, Medium, High

Technical Competence: Low, Medium, High

has output → **Processed Data**: Mesh 3D

Remark: despites the recent advances in computer vision **none universal automatic 3D reconstruction method,** that can satisfy all end users expectations (high geometric accuracy, capture of all details, photorealism, high automation level, low cost, portability, application flexibility, and model size efficiency), exists yet. That means that **significant human interactions are still required for some objects/scenes**.



General procedure for image-based modeling.

Remark: quality criteria can be defined to help end users to find the best choices when they interact with a software.

Sabry F. El-Hakim, J.-Angelo Beraldin, Michel Picard, and Guy Godin, Detailed 3D Reconstruction of Large-Scale Heritage Sites with Integrated Techniques, IEEE Computer Graphics and Applications, May 2204, pp 21-29.

Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

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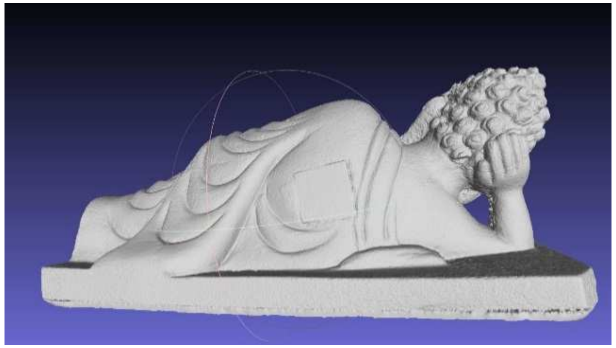
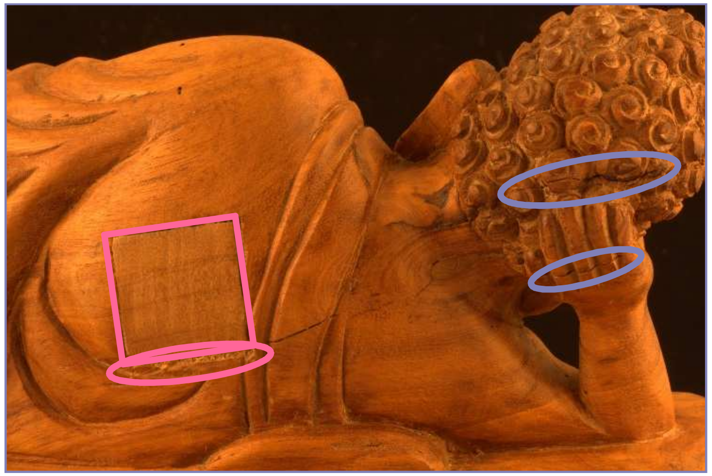
Remark: the **selection of a processing chain** depends of the research questions to address and of the relevant characteristics to reveal.



© Pierre Arnaud



Here, the quality of this 3D reconstruction (based on Structure from Motion) is enough good for interactive 3D visualization but the level of details is not enough high to survey macro and micro-structures.

Detection of cracks and of restorations from high resolution image (photogrammetry)

Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

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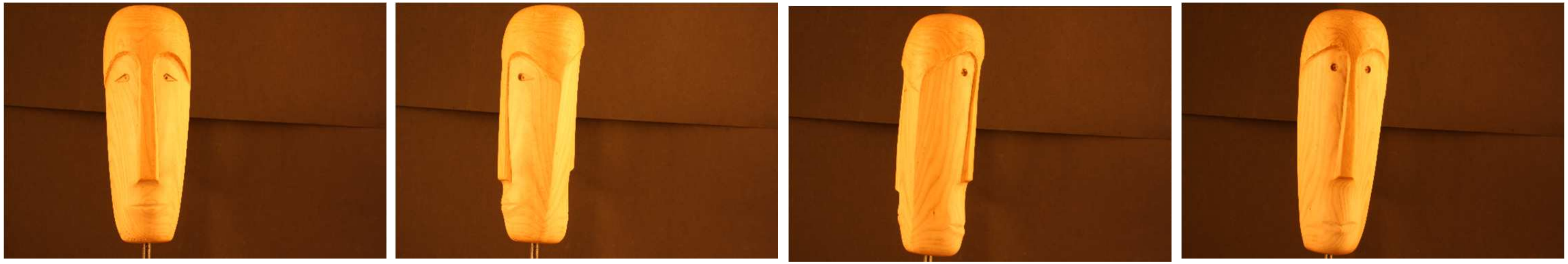
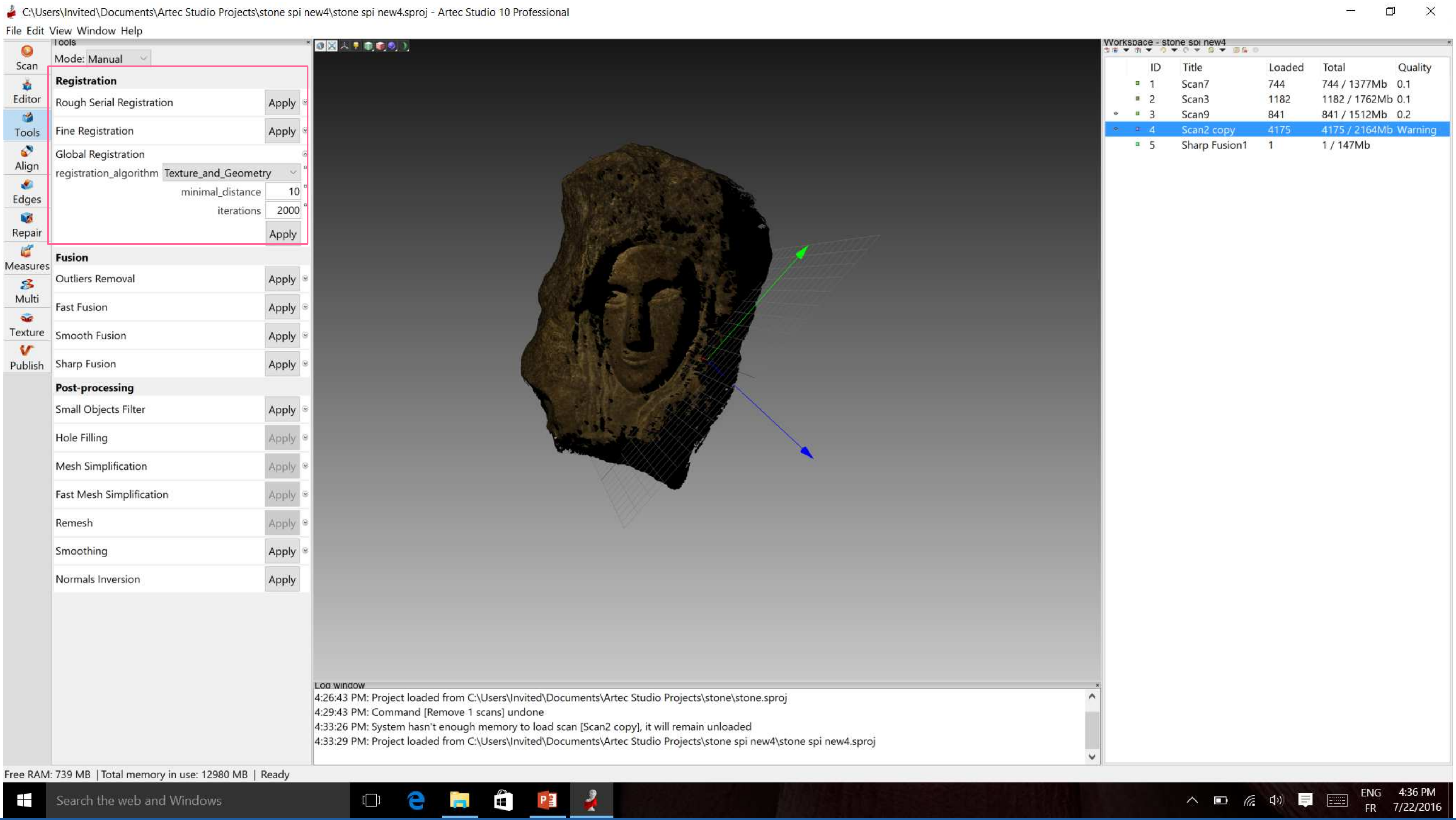


Here, due to a lack of uniqueness of corresponding points between images, very few 3D reconstruction methods will perform well: methods based on structure from motion (such as Artec Studio software) and methods based on photogrammetry (such as Agisoft software) fail to provide relevant results if some setting values are not adjusted in the right way.

In some case, end-users may face issues to adjust some setting values and consequently cannot use automatic methods in an appropriate way.

Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

Remark: the quality of the result also depends of: - the processing chain used; -of the **default parameters** used; - …



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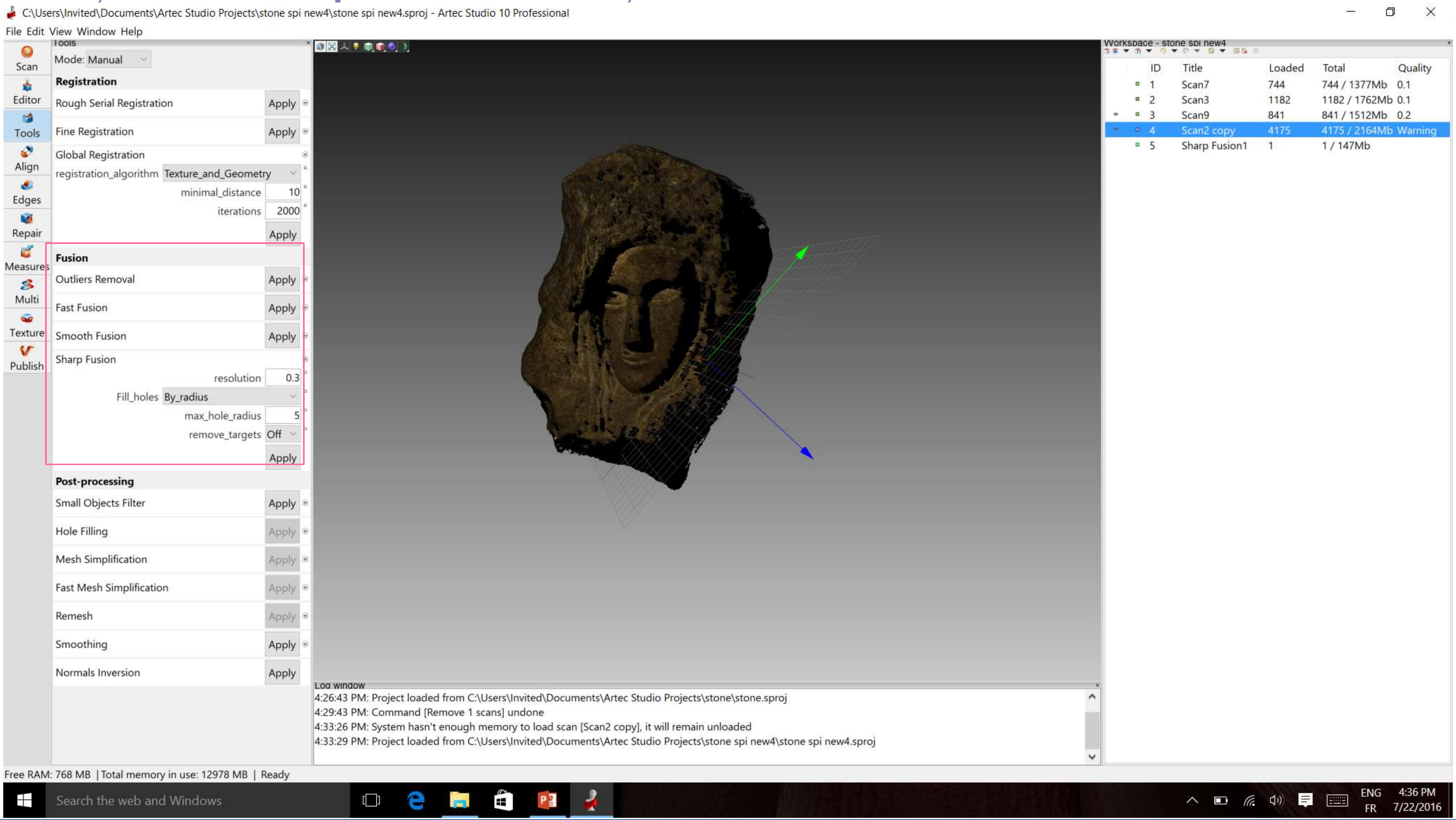

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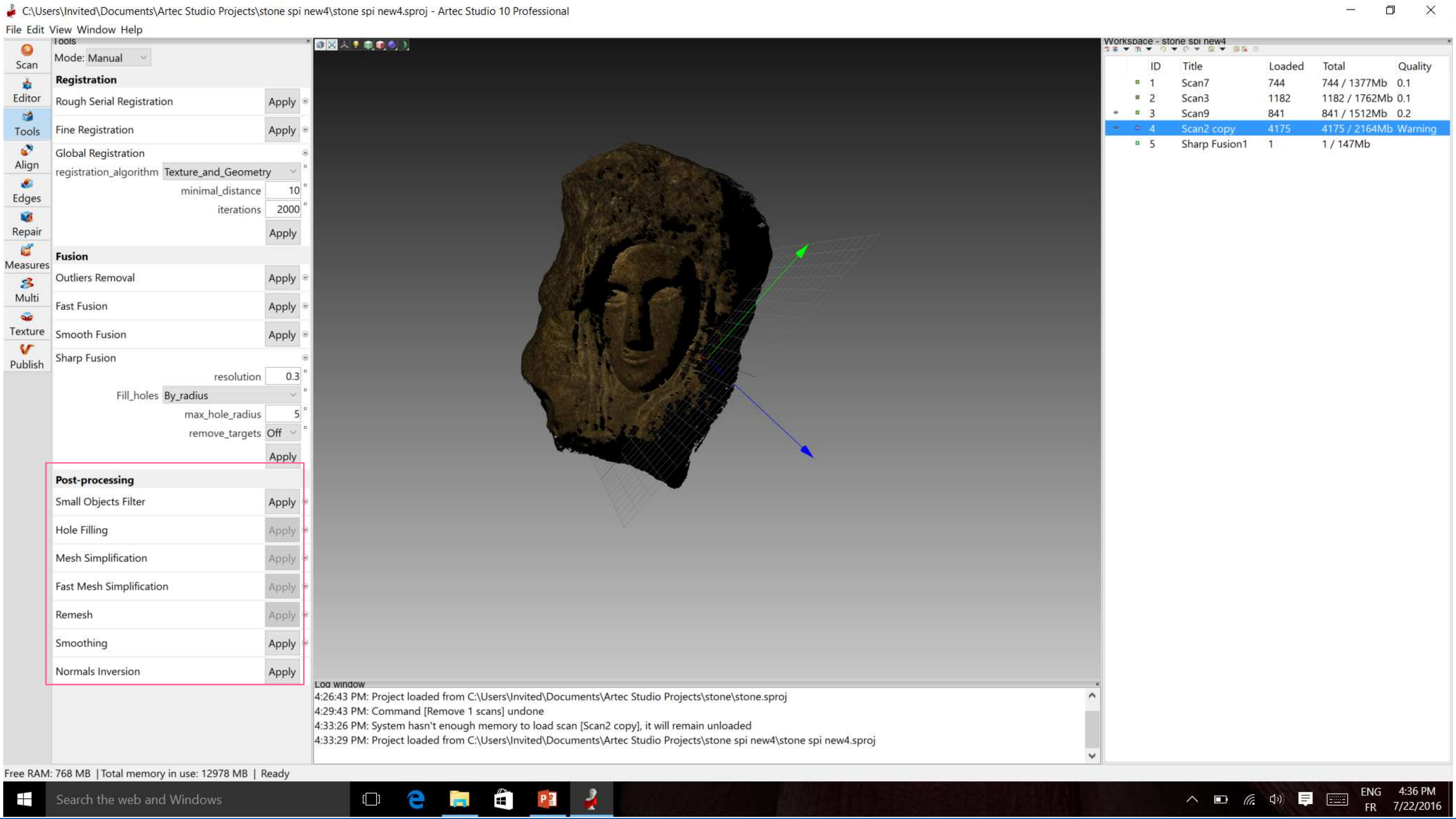
Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

Remark: the quality of the result also depends of: - the processing chain used; - the **default parameters** used; - …



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COLOR & SPACE IN CULTURAL HERITAGE

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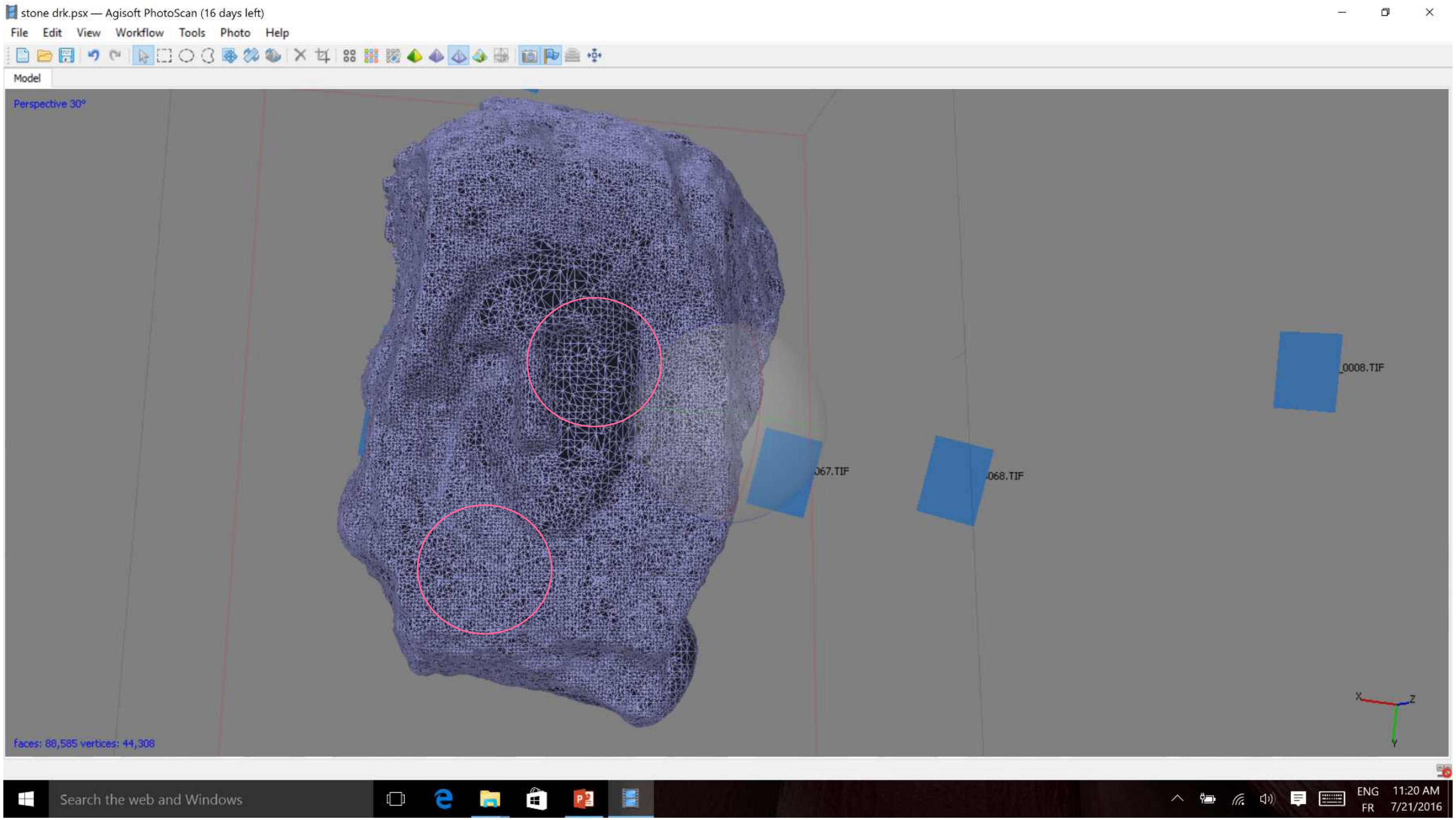


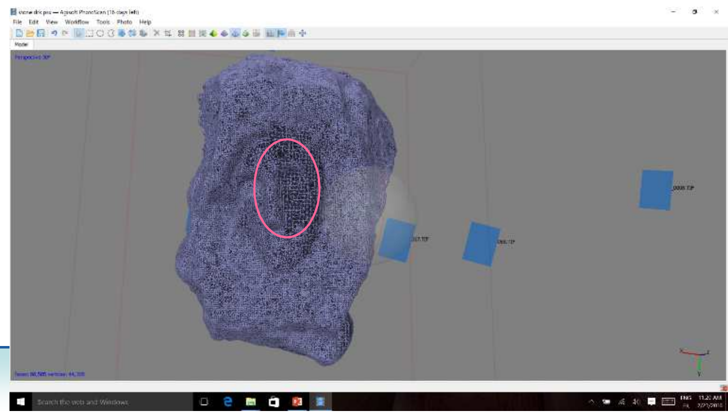
Remark: Usually if the **input data** does not satisfy **certain properties** required by the triangulation algorithm (good point distribution, high density, little noise, no occlusion and so on), surface reconstruction algorithms produce incorrect results.

According Remondino,et al. :

« The conversion of the measured 3D point cloud into a consistent polygonal surface is generally based on four steps:

1. ***Pre-processing**: in this phase erroneous data is eliminated and noise is smoothed out and points are added to fill gaps. The data may also be resampled to generate a model of efficient size (in case of dense depth maps from correspondence or range data).*
2. ***Determination of the global topology** of the object's surface, deriving the neighbourhood relations between adjacent parts of the surface. This operation typically needs some global sorting step and the consideration of possible constraints (such as breaklines), mainly to preserve special features such as edges.*
3. ***Generation of the polygonal surface**: triangular (or tetrahedral) networks are created satisfying certain quality requirements, for example, a limit on the network element size or no intersection of breaklines.*
4. ***Post-processing**: after surface generation, editing operations (edge corrections, triangle insertion, polygon editing, hole filling) are commonly applied to refine and correct the generated polygonal surface. »*

Remondino, F.; El-Hakim, Sabry, Image-Based 3D Modeling: A Review, The Photogrammetric Record Journal. Volume 21, Number 115.September 2006. pp. 269-291. NRC 48470.



Example of 3D reconstruction using the Artec Studio software (based on Structure from Motion)

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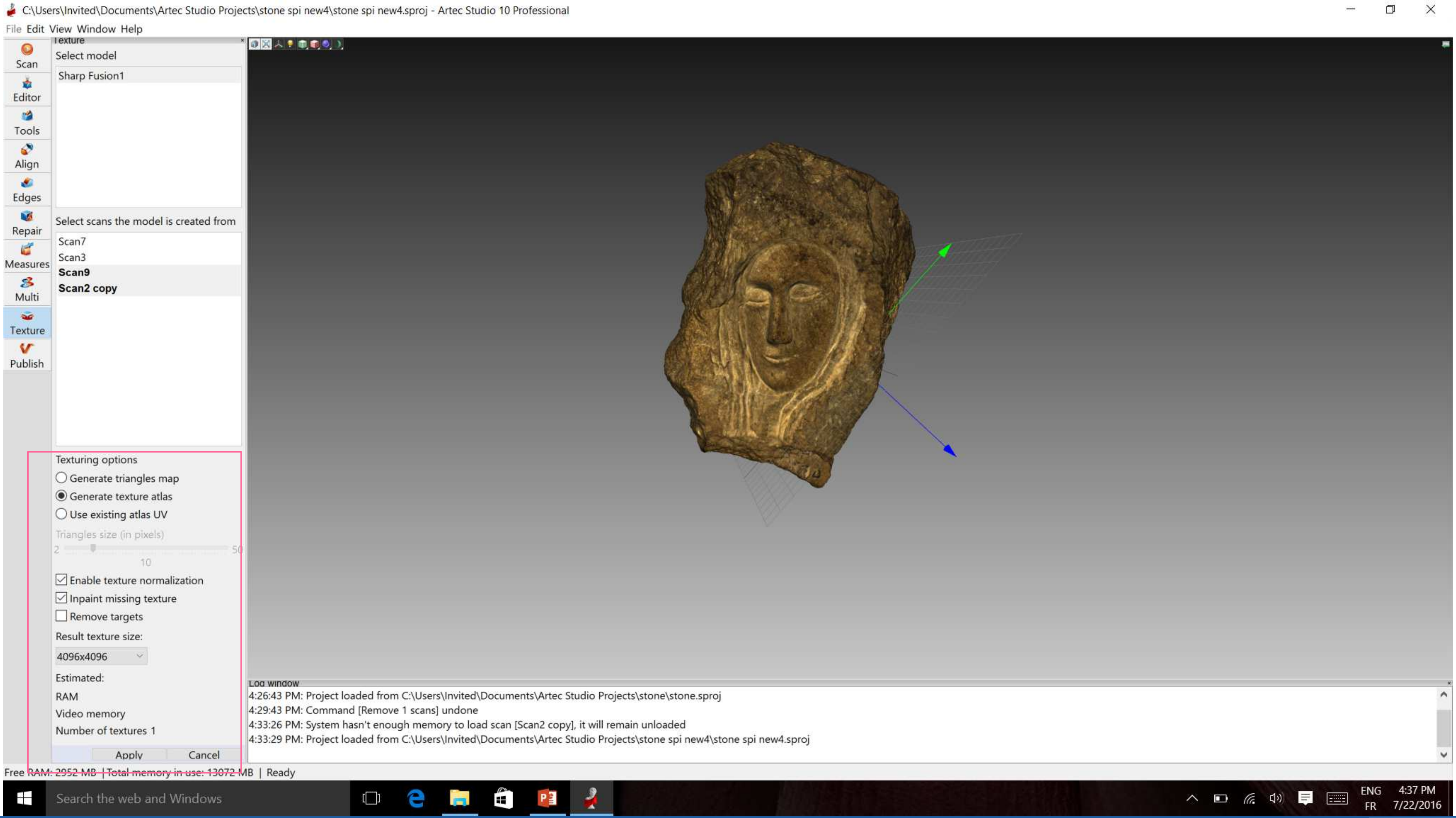

Conclusion

The quality of outputs depends of several factors:

- ✓ Input data, Input properties,
- ✓ Preconditions and Prerequisites,
- ✓ Parametric factors,
- ✓ Quality criteria

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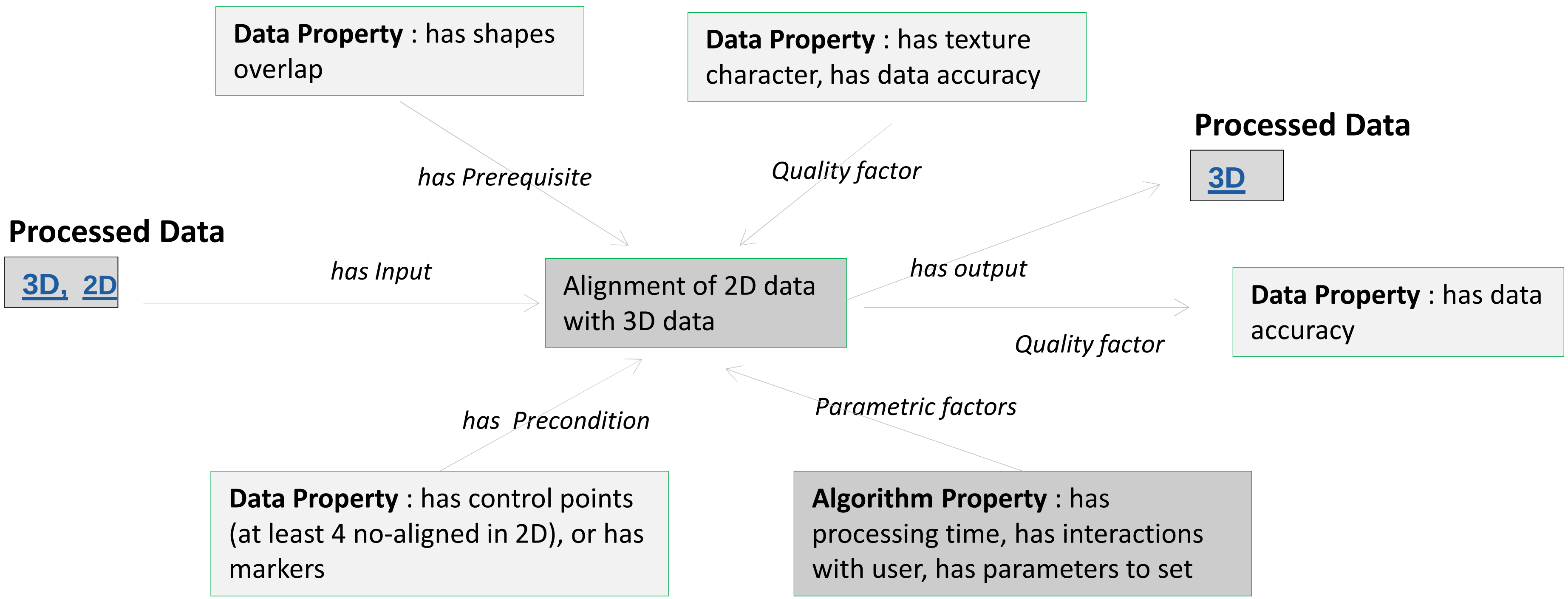
COLOR & SPACE IN CULTURAL HERITAGE

Example of information that end users should be aware



Conclusion

There is **no universal technique** that can be automatically applied to each research question and every application scenario. Selecting the most effective methodology and setting values for a given application is not obvious.

Each methodology has its own set of advantages and disadvantages, end-users should be informed about the most important ones.

Some solutions, developed by computer vision experts, exist in the state of the art to increase the level of automation and ease of use of processing methods but progresses still need to be done (for feature extraction, 3D modelling, texture mapping, manipulation of heterogeneous data, etc.).