High Resolution 3D for Scientific and Cultural Heritage collections (AGORA 3D)

Research project AG/LL/164 (Research action AG)

Duration: 1/9/2012-30/6/2014

Final Report

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WP-1 Networking & dissemination
(4 PM AGORA3D+ 2,2 PM Consortium; T0 – T18)

WP-1 ***a: Project CMS***

Reminder:

The AGORA3D CMS is available at the following address: http://mars.naturalsciences.be/agora-3d/

The members of the following-up committee and the board of international experts can access using

User Name: Agora3D
Password: Agora3DAgora3D

The list of the board of experts is available here and the list of the members of the following-up committee is there.

The CV of the staff members can be found there.

WP-1 e: ***International Cooperation, Participation to Conferences and Workshops***

Open-up Meeting Bratislava

The conference was organized by the Botanic institute of Bratislava and most of the conference was hosted in the nearby building of the Virology Institute.

Several researchers presented their digitization results and/or the implementation of it into GBIF and/or Europeana. As it was the final meeting on Open Up! The main focus of many talks was about the quantity they achieved in the past months and what can be expected for the future. Aside from the digitization processes, there were talks about metadata and how to add them to the database in an inexpensive way (ex crowd sourcing) and an interesting talk about copyright on the digitized matter once it is online.

PAH Colloquium Ghent

Some interesting talks, most of them were about 2D digitisation and the different database systems the universities use to digitize their collections. It was striking though that for these problems which are also apparent in federal museums and alike, the universities try to find their own solutions, while museums already did this exercise in the past and are still doing it in the present. If the two would work together on the digitization issues, a lot of solutions would be there sooner.

Meeting in Leiden Naturalis

The meeting on digitization in Leiden was organized during the 27th and 28th of February. During this meeting a short presentation was given about the different digitization streets within the main digitization project. Afterward we visited the different digitization strezets and could see how the process worked.

Naturalis is funded by the Dutch government for 13M euro to physically digitize the collection which consists of 37M specimens. The 13M euro is part of a total sum of 30M euro made available for digitization of the Naturalis collection. In the project the major goal is to digitize all the 37M specimens, of which 7M need to have an object (picture, film, etc) in the database, while the rest only need to have limited Metadata digitized in some kind of form. Most of the time this metadata consists of answering the questions: What?, Where?, When? and Who?. The pictures are only taken in case of necessity. So in fact after the digitization is done, they will have a catalog of what they have and most of the times where it is stored in the collection. Unfortunately none of the pictures taken, aside from those of the Herbarium are useful for detailed research. This is due to the detail of the specimens pictures is too low to determine a species and are only taken in one orientation. The main goal of taking the pictures is to read some of the labels for metadata use later on, but more importantly to have a clear view of the QR code they provide the specimens with.

The set-up for the Herbarium specimens is done by a third party (Picturae) and is able to digitize 33k of specimens in a day, when operating on full speed. Although on average they have digitize around 25k of specimens a day. They work in several shifts and with multiple conveyor belts at the same time. Whenever a picture taken from an herbarium sheets doesn't meet the criteria, the belt stops immediately and it goes back to retake the position. The digitized files are send to Suriname, where a team of up to 50 employees encode the meatadata. In The Netherlands an additional team checks the encoded metadata before it is send the Naturalis again.

Regarding the digitization of the entomology collection. Pictures are taken of an entire box of insect specimen by a SatScan system. This is able to taken multiple high resolution pictures and combines them into a panoramic (Gigapixel) image. In this way you have an entire box of which each insect can be viewed with high resolution. However the resolution still is too low to determine specific characters of the specimens pictured. Together with the high cost of the equipment it is a rather expensive solution. An extra downside is that every box has to be opened to take pictures, which can be devastating in case a parasite might enter the insect drawer. Therefore each box has to be frozen for a certain period to exterminate possible parasites. A solution where the box can remain closed, would ease the workflow a lot.

The wet collection is pictures as well. However the goal is to have a picture of the label inside the jar. The specimen inside is not a priority. The same goes for the most part of the dry collection where only a picture of the label on the box is made, without checking the contents of the box.

For the entire collection no enhancement of the metadata is done.

The following costs per specimen (Table 1) were mentioned by Naturalis on the digitization of the collection:

Table 1: The digitization costs per specimen group at Naturalis, Leiden, The Netherlands.

Digistreet	**In house**	**Out house**	**Progress**
Herbarium	€ 1,47	€ 1,29	In progress
Molluscs	€ 1,37		Done
Wet collections	€ 4,65		In progress
Entomology	€ 1,51		In progress
Wood	€ 1,27		Done
(In)vertebrates Dry	€ 2,37		In progress
Microscopic slides	€ 1,57		In progress
Paper 2D	€ 1,87		In progress
Geology\Paleontology	€ 1,90		In progress

Rapidpro 2014 Veldhoven

More information about the fair can be found below in the 3D print section. The fair is hosted each year around February. Most of the companies from the BENELUX which are dealing with 3D printing or scanning are present on this fair. The fair itself is free to attend.

TDWG 2013 (Florence, 28 oct – 1 nov 2013)

Presentation of a poster: *Agora 3D: Evaluating the digitisation of scientific collections.*

Digital Heritage Marseille (28 oct – 1 nov 2013)

Our paper "Comparing 3D digitising technologies: what are the differences» was accepted for a presentation in the Session T1 SP2: Technology and published in the proceedings.

Mathys, A., Brecko, J. & Semal, P. 2013. 'Comparing 3D digitizing technologies: what are the differences?'. In: Alonzo C. Addison, Livio De Luca, Gabriele Guidi, Sofia Pescarin (eds), Proceedings of the Digital Heritage International Congress. Vol. 1. Marseille: CNRS. (PR) ISBN: 978-1-4799-3169-9.

Notae Prehistoricae (dec 2013)

We published a paper in the Notae Prehistoricae 2013:

Mathys, A., J. Brecko, K. Di Modica, G. Abrams, D. Bonjean & P. Semal, 2013. Agora 3D. Low cost 3D imaging: a first look for field archaeology. Notae Praehistoricae, 33/2013: 33-42.

V-MUST training Falmouth (december)

Aurore had the opportunity to attend the V-MUST training in Falmouth organised by King College. King College has a Digital Humanity field of study.

Formation GOM inspect Paris (29/04/2014)

In order to understand better GOM Inspect software we followed a short training in Paris.

Séminaire Avizo/Amira Brussels (21/05/2014)

Avizo/Amira came to RBINS to demonstrate the novelty of there new version of the software.

CAA Meeting Belgium (04/12/2013)

Mainly presentations of what is done in the field in Flanders and The Netherlands.

COSCH: Colour and Space in Cultural Heritage (Cost TD-1201)

We kept working with COSCH as mentioned in the previous report.*COSCH Training Warsaw (**21-23 October 2013)***

Aurore was able to participate to this training provided by the University of technology of Warsaw in the Mechatronic faculty, which works in conjunction with the museum palace Wilanow. The faculty build their own structured light scanners which we were able to test with 2 of our specimens (a beetle and a sea urchin). The 3D structured light scanner they build are mounted on a robotic arm. The scanner is commanded from a computer by a software designed by the faculty. Each measurement needs an action from the operator. The object is placed on a turntable which is also commanded at each measurement by the user of the computer. So even though the system is mounted on a robot, the system is not automated to act alone for the moment, although they aim in the future to a complete automation of the system.

The 2 systems at the palace of Wilanow are very precise. They are mounted on a Kawasaki arm and use a large projector created by the faculty and Canon DSLR cameras. The scanner with the large resolution takes up to 2 million points per measurements, each measurement consists of a surface of more or less 10*5cm. And both systems are operated manually as well. A statue of 80-100cm high takes a month to scan. And the resulting data takes about 1 Tb of storage space.

We were able to scan the sea urchin with one of the 2 systems from Wilanow palace. To capture half the surface it took more than 1 hour and a half. The scans take 4 Gb storage. The scans needed to be realigned in the processing software, which was not possible to do on the computer of the labs nor from our computers in Brussels, due to the large amount of data.

So regarding their scanners and methods: they have a good precision but are definitely too slow for a common and cost-effective usage. They still have work to do to finish automating the system (since for the moment they don’t want the robots to act by them self because the objects are too fragile). Their goal is to have something fully automated to gain objectivity since they notice that between 3 operators scanning the same object with the same system the final results are different.

Professor Sitnik gave us some interesting input on scanning condition and on kinect. He explained that the change of light in the scanning environment can create extra noise, this is why ideally, scanning must take place in a controlled light and temperature environment.

For kinect he explained that the sensors inside the kinect are not fixed and that they can move during the acquisition creating artefacts and misalignment.

<u>*COSCH Jeonsuu meeting (Helsinki, 31/03-02/04/2014)*</u>

Visit of the Digitarium and COSCH discussion. COSCH participant are reflecting on the possibility of submitting several projects together.

The Digitarium from Joensuu is a service centre were museums can send specimens in order to be digitised in 2D. They digitise books, maps, herbariums, beetles... and are specialised in high performance digitisation of natural history collections.

Fig. 1: The digitization belt for the Herbarium species at Joensuu Digitarium facility.

They can digitise 400 000 specimens per year. They can digitise 200 samples in an hour for herbarium and 16-17 beetle per hour (they estimate that for an insect collection of 10 000 specimens they need approximately 3 months).

For the herbarium (fig. 1) they have a semi-automatic chain that can be operated by one or two persons. One places an herbarium sheet in a tray and puts the tray at the beginning of the conveyor belt. When 4 trays are placed one has to push them to the automated conveyor belt that brings the tray to the camera, the picture is automatically taken and the other tray follows. In the meantime the person prepares the next four trays and then replaces the sheets from the herbarium from the four previous trays.

Fig. 2: Joensuu Digitarium, insect digitisation.

For the beetles (fig. 2) they remove the specimens one by one from there boxes and place them all at the same height on a home made support (3D printed, with a scale and a mirror). Consequently they place them on a conveyor belt. The specimens are brought under the camera where 2 DSLR cameras take automatically picture from 2 angles: one from the top of the beetle, and one from the side. In order to take the picture of the labels, they use a mirror to capture the writings from the backside of the labels. If the beetles are bigger or smaller they raise or lower the camera when needed. They don't use focus stacking, so for small beetle you don't have any detail.

COSCH STSM

After Mona Hess' Short Term Scientific Mission (STSM) in RBINS last year in August, it is the turn of Ann-Kathrin Wiemann to come to examine the data from AGORA 3D.

In August, Aurore will also go for an STSM to i3Mainz in order to share the result from AGORA 3D with the COSCH community for the COSCH KR App, and test to more extend the TSL scanning for large structure/object.

WP-3 Digitization & Standardization

b. Formats

Regarding formats for storage, it is difficult to know what the future will hold and which format will be more sustainable. It is difficult to know which format between ply, obj or collada would be the best continued. Stl is less interesting for us (except for CT/µCT data), because most stl format don't keep texture information. Ply on the other hand has the advantage of being able to keep both vertex colour and texture file, while for collada and obj you have only a texture file, no colour vertices, and the obj need an extra mtl file to do the link with the texture. "*Many formats already exist and provide a good degree of standardization: the COLLADA, for instance, was created to represent 3D models with a standard syntax and many important applications natively support it.*"*

Regarding photogrammetry it seems pretty obvious that the best solution is to keep the pictures since photogrammetry software will keep improving in the following years. But it is still useful to keep the finalised models as well.

For visualisation or sharing of the model, 3D PDF is in our opinion a good option, especially since *"3D PDF is now an ISO standard (ISO 32000-1:2008) enabling users to create their own* *3D PDF library and related software."* *****

**** A. Felicetti, M. Lorenzini: "Metadata And Tools For Integration And Preservation Of Cultural Heritage 3d Information". 23rd International CIPA Symposium, September 12-16, 2011. Prague, Czech Republic.***

c. Meta data (Franck & Aurore)

Patricia did an evaluation of the existing system for Natural Sciences in the previous report. We continued this evaluation for Cultural Heritage already existing system and did the exercise with Franck Theeten to create our own metadata field centred on the metadata related to digitisation.

Several metadata standards for cultural institution are already in place:

- Dublin Core
- POLIS
- LIDO (europeana project)
- CARARE (europeana project) =>"So far only the CARARE metadata schema has paid particular attention to the type of digital media files, such as 3D objects" (2)
- CIDOC-CRM => guidelines, the CIDOC-CRM DIG extension give descriptive guidelines for metadata systems regarding digitisation.

The problem we encounter here is that basic information relative to the specimens are really different from natural history specimens than cultural heritage. But 3D data, paradata, etc. should be the same.

Paradata: "*The London Charter defines "paradata" as information about human processes of understanding and interpretation of data objects. Paradata include, for example, a note recording the methodology used in a laboratory, descriptions stored within a structured dataset of how evidence was used to interpret an artefact, or a comment on methodological premises within a research publication. It is also important to record weather and light condition during the data acquisition process, because these factors can influence the final result quality (e.g. processing data acquired with image matching software).*" (2)

(1) D'Andrea, A. & K. Fernie, 2013, *CARARE 2.0: a metadata schema for 3D cultural objects.*

This paper describes provenance in the CRMdig schema, the *paradata principles* of the London Charter and how provenance and paradata could be relevant for the new strategy of Europeana.

The scope of the CRMdig is to describe all the processes starting at the level of human activities or actions, which in turn initiate "machine events" on devices and computers, and form a connected graph through the data, people and things involved in multiple events in various roles. The relevant context of these actions comprise descriptions of objects, people, places and times, which in turn may be related to other things.

The CRMdig, model is particularly appropriate in describing a typical workflow, from acquisition to processing, synthesis, presentation and, finally, reuse. Creating in this way a complex semantic network of relationships. The model is designed to provide reliable registration of the capture devise instruments, the parameters used in data-acquisition (geometry, light sources, obstacles, sources of noise/reflections, etc.) and in the subsequent processing phase (registration, meshing, texturing, decimation, simplification, etc.). CRMdig also allows for a clear description of the organization of data-acquisition and the system adopted for the alignment of the shots (targets, TLS, GPS). After considering the objectives of 3D-ICONS, the CRMdig model was chosen because it allows a simple and clear description of he processes carried out to digitize and render a 3D model.

Among the possible models for descriptive metadata, EDM distinguishes *"object-centric"* and *"event-centric"* approaches. EDM allows either approach.

The *ObjectCentric* model focuses on the provided object: information are expressed in the form of statements that link the described object and its features; they can be simple strings or more complex resources denoting entities from the real world. Most metadata practices making use of the Dublin Core metadata set [DC] can be seen as an application of such an approach. To support enrichment, EDM includes a number of classes devoted to the representation of "contextual" entities:

- edm:Agent: for representing persons or organizations;
- edm:Event: for events;
- edm:Place: for spatial locations;
- edm:TimeSpan: for time periods or dates;

• skos:Concept: for knowledge organization systems

such as thesauri or classification schemes.

In the *Event-centric* approach the focus is on characterizing the various events in which objects have been involved. This approach underlies models such CIDOC-CRM and may suit the data of some Europeana providers.

An object in the CARARE schema consists of the Heritage Asset Identification (HA) wrapped together with the related Digital Resources (DR), Activities (A) and Collection information (C).

“Born-digital resources related to these objects, such as 3D models.”

According to the principles of the London Charter information should be provided to define aims and objectives of 3D data-capture. Two new elements were proposed for the Activity theme to capture this information:

• **Had General Purpose** (source = CIDOC CRM) – this is a free text description of the general goal or purpose of an Activity. For example this could include practising, preparing, monitoring, researching, designing, testing etc.

• **Had Specific Purpose** (source = CIDOC CRM) – a free text note describing the specific goal or purpose of this activity. For example, carrying out 3D data acquisition, restoration of a part of a building, completing a survey, constructing a building, etc.

(2) Ronzino, P., S. Hermon & F. Niccolucci, 2012, A Metadata schema for cultural heritage documentation.

STARC schema. STARC has started to develop its own schema when it was involved in two different e-content projects (EuropeanaLocal and Athena), and eventually in a third one (CARARE). Its structure allows retrieving models, activities, decision and answers the research question on how data can be used for data interpretation and re-used to perform further analysis and post-processing of raw data. refer to 2D and 3D archaeological data including archaeological sites, museum objects and architectonic elements. Mostly based on LIDO and CARARE ones and is CIDOC-CRM compliant. The novelty of this metadata schema is the subset of metadata that has been designed to allow recording the information about the provenance of the digital objects, a particularly important aspect when the objects are 3D digital replicas of cultural objects as is the case for the majority of STARC assets.

The schema has a global wrapper named *PROJECT* and is divided into four main wrappers:

1. **Project Information (administrative and descriptive data, references)**

2. Cultural Heritage Asset (general and descriptive information on the asset)

3. Digital Resource Provenance (novelty in the metadata schemas for the documentation of CH assets, principle of recording every important detail of the

digital provenance like acquisition operative and technical information and processing)

4. Activities (activities related to the digital objects (e.g. scanning acquisition, photographic campaign, aero-photogrammetric survey, virtual reconstruction, imaginary digital object creation).

http://public.cyi.ac.cy/repoBrowser/StarcRepoBrowser.html

If in theory the STARC metadata schema look very interesting for us. But after testing it, it wasn't so practical of use, many fields seems to be repeating themselves.

WP-4 Evaluation of the technologies

(20 PM AGORA3D+ 5,9 PM Consortium; T3 – T16)

X-Ray Computed Tomography (CT)

Software's tested:

- Amira/Avizo: both products are very similar since owned by the same company. When you first open this software, you are a bit lost, but ones you're used to it, it is quite easy to use and has good tools. The exported model when segmented shows very strong steps, while if you just produce the model directly from the images you have a relatively smoothed model.

- Mimics: more user-friendly than Avizo/Amira, good segmentation tools, especially for flesh and bone models.

- ITK-SNAP =>free as well. Good "snake" tool for segmentation. User-friendly. Ref: Paul A. Yushkevich, Joseph Piven, Heather Cody Hazlett, Rachel Gimpel Smith, Sean Ho, James C. Gee, and Guido Gerig. User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability. *Neuroimage*. 2006 Jul 1; 31(3):1116-28.

- Seg3D => open-source software, user-friendly tools, good visualisation but we were not able to export the models.

- TIVMI => produces a decent visualisation of the model in the software, but when you export it the model is of bad quality. Relatively user-friendly. TIVMI inverted the image orientation in regard to the real fossil.

- SCIrun & Biomesh: open-source but not user-friendly.

- ORS Visual SI: Nice interface. Easy to segment data in consecutive layers, which really speeds up the segmentation process. There is also a nice tool that allows you to add and subtract regions really easily.

Amira, TIVMI, ITK-SNAP and Seg3D were able to automatically segment the model in order to extract the fish from the stone. The result was found very useful by Louis Tavernier who is using the images to write a paper about this fossilised fish. We didn't try it with Mimics because the trial licence had expired.

Micro-CT

We evaluated several different µCT scanners. This technique is mostly used when the internal structure of a small specimen is of interest and/or the specimen is too complex to produce a 3D model out of it by surface scanning techniques. One of the scanners we tested is based at the Muséum National d'Histoire Naturelle in Paris and it is a µCT of Phoenix instruments (General Electrics), the AST-RX. The other two, the SkyScan 1173 and the SkyScan 1172 were tested at the Bruker office in Kontich (Antwerp). The samples we tested were a skull of *Chlamydophorus truncatus* and a human skull for the AST-RX and three geological samples, a fossil mammal skull with lower jaw, an ant and a pinned beetle with the Bruker scanners (Table X)

For the human skull we received a scan of the complete skull and one with a detailed part of two teeth which are still embedded in the skull. The strength of the AST-RX is that large object can be scanned with high precision. Or as shown with the teeth, which are still inside the skull, one can chose to scan a part of a larger object with the same level of detail as only would be possible when the teeth are on their own. The maximum size able to scan by the detector is 400 x 400 mm. However, it is possible to do multiple scans of larger objects up to 800 x 600 mm. The only downside is that the amount of data will be 4x to 12x larger. The final resolution of a scan is determined by the size of the specimen. When a specimen is approximately 10 cm, the final result will be 50 microns. As a rule of thumb one can say, 5 microns for a region of 1 cm. Of course it is possible to get better results with multiple scans of an object (formulaires.mnhn.fr/en/ast-rx/numerisation). The costs for scanning are as follows:

Internal use with MNHN specimens costs 125 euro for each half day. If the object is from another collection, it's 300 euro per specimen, which is the same for an external user who wants to scan something from the MNHN collection. When the user is external and the specimen as well, it is 600 euro per specimen.

The SkyScan 1172 is at the moment succeeded by the SkyScan 1272. However it was not possible to have a test scan with the new machine as the waiting list was quite extensively. But the difference between two µCT scanners is not very large. But there are a few nice features on the 1272. The detector are new ones capable of delivering 16Mp and 11mp in up to three offset positions. There is the option to enhance the phase-contrast allowing to view details up to 0.35 µm. However, staining the samples is often needed. The best one is an automatic sample changer that can handle up to 16 samples. This will of course downsize the operator costs. Aside from these features the 1172 is capable of delivering stunning results. The maximum size of a specimen scanned with this scanner is 27 mm in diameter for a single scan or 50 mm with offset scanning, with a detectable resolution of 0.5 microns. The ant specimen was scanned with this µCT scanner and can be seen on figure X. The only problem with µCT data is that the files itself are extremely large. For the ant scanned at 1.3 micron the size is 112 GB. Segmenting the ant was not possible unfortunately as the size of the file was too large for the computing power of our workstations. At least 64GB RAM memory is needed to deal with such a file, preferably 128GB.

The SkyScan 1173, distinguishes itself from the 1172 by the size of the object that can be scanned with it. An object of 140 mm diameter by 200 mm in length can be scanned without a problem. The resolution possible to detect is lower with a spacial resolution of 4-5 microns at highest resolution. The machine itself is capable of delivering up to 130 kV, which is ideal for geological samples or fossils (figure 3 and 4).

The cost of the scanners is as follows: The SkyScan 1173 has a purchase cost of 242 000, while the SkyScan 1172 and 1272 have a cost of approximately 200 000 and 300 000 respectively. In case only a limited amount of samples need to be scanned the company can provide two other options: renting day (500 euro per day) or contract scanning. The renting day only includes the use of the machine. There is a small intro when getting started, but a technician which assists you from beginning to the end is not included. This would be the case for contract scanning of which the price has to be determined according to the amount of specimens and work that has to be done by the company.

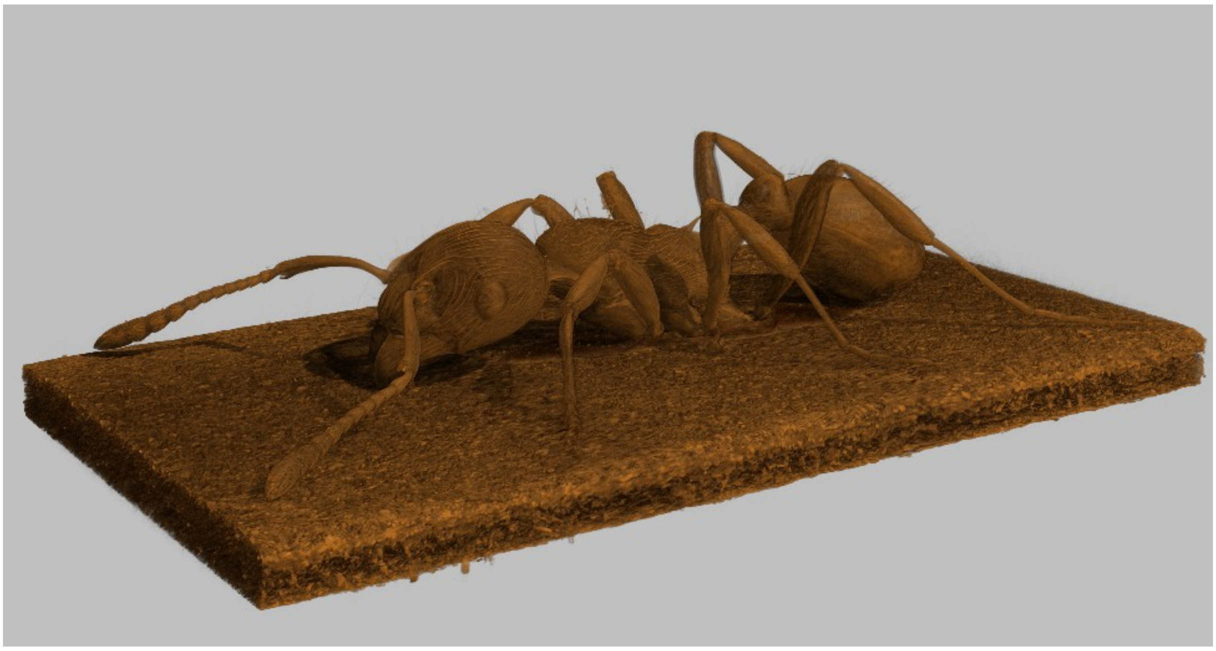


Figure 3: an Ant scanned with the SkyScan 1172 at 1.3 µm.

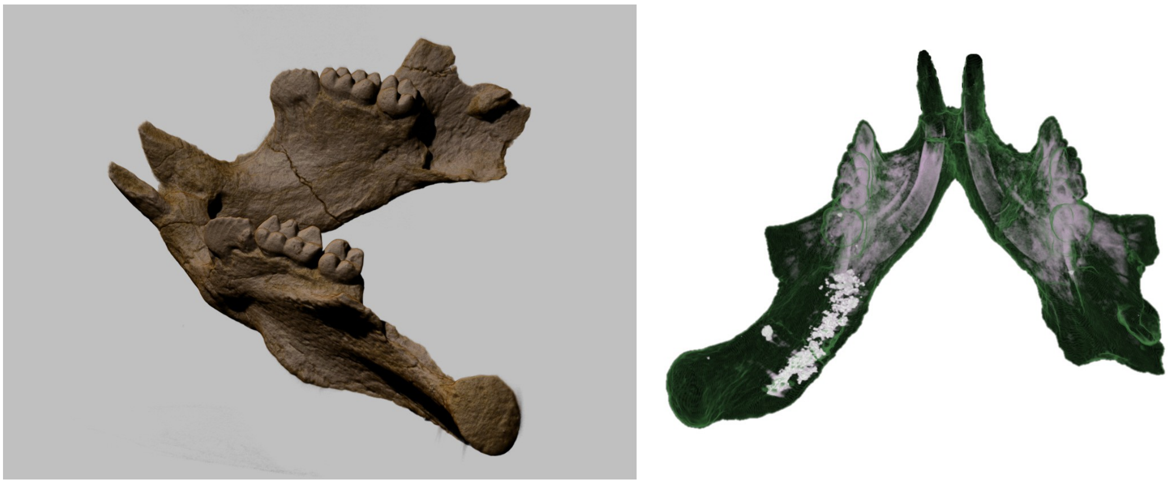


Figure 4: jaw of a fossil Mammal scanned with the SkyScan 1173.

Table: Representation of the different µCT scanners used, with the specimens tested, the scanning resolution, scan duration and reconstruction time.

Specimen	**Scanner**	**Slice Distance**	**Scan Duration**	**Total Reconstruction time**
Stone 762	SkyScan 1173	9 µm	1h56	0h09
Stone no label	SkyScan 1173	10 µm	1h56	0h13
Stone B538	SkyScan 1173	10 µm	1h56	0h07
Jaw (Fossil Mammal)	SkyScan 1173	15µm	1h10	0h22
Skull (Fossil Mammal)	SkyScan 1173	21 µm	1h09	0h23
Ant	SkyScan 1172	1.3 µm	1h57	3h39
Teeth in Skull	AST-RX	19 µm	+/- 0h30	
Human Skull	AST-RX	115 µm	+/- 1h	

Surface scanner tested

List of all the surface scanners tested during Agora 3D project:

		Theoric accuracy (mm)	Resolution (mm)	Color	Price (€)	Software
Artec	**Eva**	0.1 (1.5)	0.5	RGB	15200	artec studio
	Spider	0.05 (0.3)	0.1	RGB	17200	artec studio
Mephisto	**Gotcha**			RGB	1000	mephisto
	Eos	0.01-0.2		RGB	20 000	mephisto
	EX-pro	0.05		RGB	39 000	mephisto
FARO	**focus 3D**	±2		RGB	35 000	
	scanarm	0.035		none	60 000	
LMI	**HDI Advance R3 x**	0.045-0.105		RGB	22000	flexscan
MechScan	**MechScan**	0.001-0.01		RGB	45000	flexscan
Creaform	**Handyscan**	0.03-0.04	0.1-0.05	none		
NextEngine	**NextEngine**	0.127		RGB	3000	scanstudio HD
Mantis	**F5**	0.05-0.5	1 mm	Grayscale	29 000	
	F5 Short Range	0.05	0.5 mm	Grayscale	23 000	
Breuckmann	**SmartScan C5**	0.01-0.128	XY: 0.045-0.480 Z: 0.002-0.028	RGB	55 000-95 000	OPTOCAT
GOM	**Atos Core**	0.02-0.19		Grayscale	30 000 – 80 000	GOM Scan

All the prices are approximated and are there to give an order of magnitude only and might not be exact. This list must not be shared or rendered public.

Most of the equipment here has already been reviewed in the previous report. Therefore they will only be mentioned here with a final review. All equipments are transportable, but have different levels of portability

		Automated turntable	**Technology**	**Cameras**	**Result**	**Opinion on recommended size usage**	**Level of portability**
Artec	**Eva**	no	White light	1	Mesh	large	Backpack
	Spider	no	Blue light	3	Mesh	medium	Backpack
Mephisto	**Gotcha**	no	Infra-red	2	Mesh	large	Backpack
	EosScan	yes	White-light	1	Mesh	medium	Suitcase
	EX-pro	yes	White-light	1	Mesh	medium	Suitcase
FARO	**Focus 3D**	no	Laser		Point cloud	large, scene	Backpack
	ScanArm	no	Laser		Mesh	middle	Suitcase
LMI	**HDI Advance R3 x**	yes	White-light	2	Mesh	middle	Suitcase
MechScan	**MechScan**	yes	White-light	2	Mesh	small	Suitcase
Creaform	**Handyscan**	no	Laser	2	Mesh	medium	
NextEngine	**NextEngine**	yes	Laser	1	Mesh	medium	Backpack
Mantis	**F5**	no	Laser		Point cloud	large	Backpack

	F5 Short Range	no	Laser		Point cloud	medium	Backpack
Breuckmann	**SmartScan C5**	yes	LED White (or green/blue/red)	2	Mesh	variable	Suitcase
GOM	**Atos Core**	no	Blue light	2	Mesh	variable	Suitcase

Laser scanners

1. NextEngine

Cost (€)	3000
Theoretic accuracy	0.127 mm
Time constrains	Setting up equipment & preparation: 15 min Acquisition: Consider approx 40 min for 1 rotation to have descent quality. And minimum 2 rotations for a full simple object. (50,000 processed points/sec throughput. Typically 2 minutes per scan of each facet.) Post-processing: depends on your aims and computer but can be quite time consuming
Preparation process	Auto-calibrated
Texture	Colour texture. Needs a lot of post-processing, especially when using wide setting.
Limitation	In wide range use, the texture produced is tending to be blue-ish. The software is very slow while saving and save between every steps (recommended because it might crash). Doesn't work with shiny reflective objects. Slow capture, but nicely automated.

Reliability	
Recommendations	Objects between 6 cm and 25 cm with the turntable, it can be used for larger structures without turntable but more post-processing time. Practical for occasional digitisation of objects were photogrammetry doesn't work like plaster.

2. FARO ScanArm ES

Cost (€)	60 000
Theoretic accuracy	35 µm
Time constrains	Can rate up to 45,120 points/sec. Consider 1 minute of process for 1 min acquisition.
Texture	Doesn't capture texture
Preparation process	Integrated calibration + calibrate before use with tactile sphere.
Limitation	Doesn't capture texture. The arm is not always easy to handle. Although transportable, you cannot take it every were because the scanner need to be fixed on a stable table, preferably a heavy marble table
Reliability	Reliable data
Recommendations	Although the new version coops well with shiny objects, it has its main use in industrial applications were materials are spayed to create a matte effect. When object are allowed to be sprayed and texture doesn't matter. This might be a solution.

3. FARO focus

Cost (€)	35 000
Theoretic accuracy	±2 mm
Time constrains	1 minutes for 330° acquisitions (up to 976,000

	points/second)
Texture	Captures colour
Preparation process	Integrated calibration and GPS
Limitation	Needs 0.6m of distance from the topic captured.
Reliability	4 mm reliability
Recommendations	Useful to digitise architecture, excavations, large scenery in general.

4. Mantis F5 & F5 short range

Fig. 5: Mantis F5.

Mantis F5 and Mantis F5 short range are 2 hand-held laser scanners with a "micro" portable computer (hand-held as well) working fully on battery. It has an autonomy of 4h of memory (128 Gb). No power station or plug needed.

These two scanners are infra-red laser scanner, which allow them to work outside in the sun. It capture ½ million pts/sec and 10 frames/sec. With the standard F5 you can capture object from 0.5 to 4 meters. With its little brother the F5 short range you can capture object from 30 to 80 cm diameter.

They produce only a point cloud and only capture grayscale vertices colour for the moment. We scanned a skull with the short range, the point cloud seems relatively precise. They show us models of trucks and helicopters they scanned, the models looked good but the scanner didn't capture the glasses.

It has been developed for the Israeli army. Doesn't need markers to realign scans and the acquisition is quite fast. The process has to be done on the computer. The minimum requirement for the computer are:

- windows
- 8 Gb ram
- good graphic card (2Gb)

At the era of the smartphones and tablet, there µ-PC is a bit too big and too heavy to work with. Although they are the ones working for the Google Tango project, so it might be interesting to keep an eye on it.

Cost (€)	29 000 & 23 000 (short range)
Theoretic accuracy	1 & 0.5 mm (short range)
Time constrains	Fast acquisition.
Texture	Greyscale colour vertices
Preparation process	Integrated calibration
Limitation	Even the short range is not adapted to small objects. Heavy, not possible to do acquisitions during an entire day. Only produce point cloud. Doesn't work for glass (like every scanner) and dark shiny object.
Reliability	
Recommendations	F5 is useful for very large structures (a car for example). Even with the short range, not adapted to objects smaller than 30 cm diameter. Very portable, ideal to work outside on the field. Good autonomy.

Structured light scanner

a. With 1 camera

i. Mephisto EX-Pro

Cost (€)	32 000 + 5 000 for automated turntable + 2 000 for micro add-on
Theoretic accuracy	50 µm
Time constrains	Acquisition: 20 min for middle sized object (like a skull) Process: 65 min for same object Post-processing: 25 min for same
Texture	Produces an albedo texture (texture without shade) which without recreating illumination looks a bit flat and inaccurate colour wise.
Preparation process	Check board calibration.
Limitation	Even with the micro lens the system cannot do detailed models of object smaller than 6 cm. Probably because of the meshing algorithm because the point cloud when acquired looks fine. Doesn't work with transparent surfaces. Processing settings unclear. Needs relative darkness to do the acquisition but all the pieces are easy to replace.
Reliability	Not reliable, creates artefacts.
Recommendations	Needs smooth lighting (cannot scan outside). No need of photographic skills of the user, everything is controlled by the software.

ii. Mephisto EOScan

Cost (€)	15 000 + 5 000 for automated turntable + 2 000 for micro add-on
Theoretic accuracy	0.01-0.2

Time constrains	(slightly slower than the EX-Pro but suppose to be more precise)
Texture	Produces an albedo texture (texture without shade) which without recreating illumination looks a bit flat and inaccurate colour wise.
Preparation process	Check board calibration.
Limitation	As for the EX-Pro: Needs relative darkness. For size the only real limitation is the calibration board.
Reliability	Software not reliable, creates artefact during the meshing process (since the same artefact was created for both acquisition by EX-Pro and EOS it is probably due to the software).
Recommendations	Needs smooth lighting (cannot scan outside). Needs photographic skills of the user.

iii. Artec EVA

The Artec EVA white light scanner is also equipped with one camera. It is a hand held scanner that can capture objects from 30 cm diameter to bigger (the maximum size depending on the power of your work station). For example, to capture a full skull you will need 10 minutes of acquisition. The scanner captures 15 frames/seconds. It can work with a manual turntable. It is possible to have batch processes or to take measurements directly with the scanner.

You have the possibility to adjust brightness and contrast of the texture. You can use colour information for registration (it is the only one on the market doing that), which allows to move the object in real time and continue aligning without photogrammetry markers.

Our analysis shows that EVA has approximately the same accuracy as the NextEngine in wide mode, but the NextEngine data is more, smoothed, while EVA's has some extra noise.

The scanner work through USB 2.

The minimum configuration recommended is:

- Windows 7
- 64 bits
- i7 quadcore

- 16 gb RAM
- Good graphic card (NVIDIA GeForce)

The price of the scanner includes training and a software licence. 1 extra licence is 500 €, 3 extra licence 1200€.

Cost (€)	15 200
Theoretic accuracy	1.5 mm according to the reseller, 0.1 mm according to the scanner sheet
Time constrains	15 frames/second. 10 minutes for an object of 25 cm of diameter.
Texture	RGB
Preparation process	Integrated calibration
Limitation	
Recommendations	

b. With 2 cameras

i. Breuckmann SmartScan

Breuckmann SmartScan is a structured light scanner. It has a LED projector and has the option to work with white light for C5 or blue, green or red light for R5 (separate module, not inclusive).

The Breuckmann software allow to reprocess data from previous acquisition with the new software.

The time needed to scan a specimen is very depending on the user. The reseller mentioned the example in an institute were they scan cuneiform tablet: 1 user does 30 tablet a day while the other does only 10.

The standard working distance is 1 meter. The minimal working distance is 37 cm and the maximum working distance is 1.5 meters.

The scanner allows to do several exposures like the HDR mode of the HDI Advance R3 x.

You can interchange lenses in relation to your need of scanning and you can combine scans made with different lenses.

The scanner is available with blue, green or red led light projector, but it is a complete different module and don't allow to capture colour. Blue is advised for reflective surface like enamel or metal.

Cost (€)	50 000 – 100 000
Theoretic accuracy	10-128 µm (depending on the configuration chosen)
Time constrains	
Texture	RGB
Preparation process	Factory calibration + check board calibration.
Limitation	
Recommendations	Depending on the configuration, can be use for object from 3 cm to 1m50 of diameter

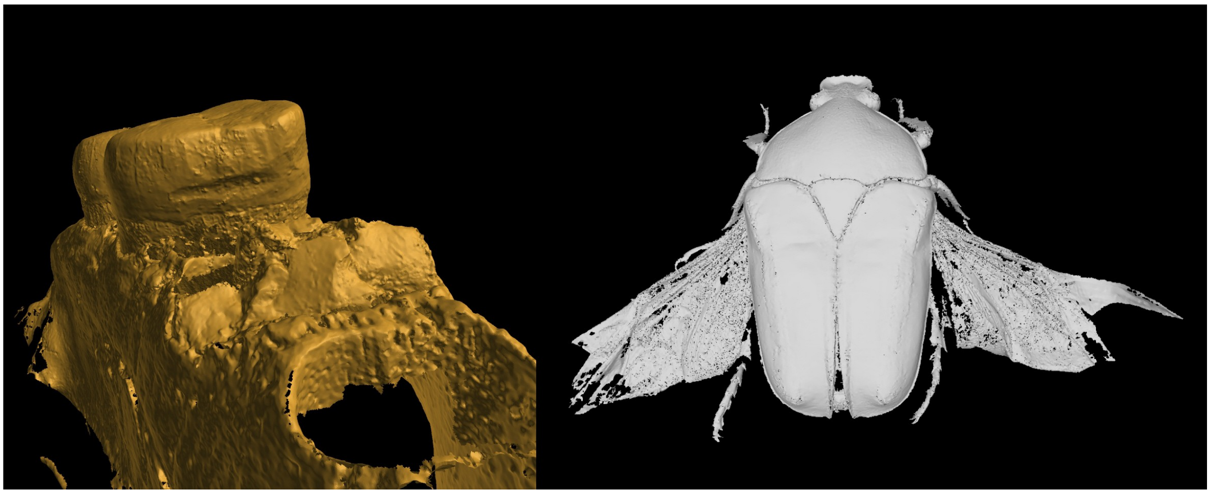


Fig. 6: Examples made with the Breuckmann SmartScan.

ii. GOM Atos Core

The GOM Atos core is a blue light scanner consisting of several modules with different field of view. Each module is self calibrated.

The GOM Atos Core has 2 versions of it's software: one standard package, the other is the professional package. The professional package allows the user to process a more detailed mesh than the standard version.

After analysis we have the impression that the relief is enhanced by the GOM software and the volume is more adapted to engineer objects than to organic specimens. The model has a very smooth industrial look.

Cost (€)	30 000 for one essential line module + 15 000 for extra module + 20 000 for professional upgrade
Theoretic accuracy	0.02-0.19 (depending on the module)
Time constrains	
Texture	Can produce greyscale texture if required.
Preparation process	None, factory calibration.
Limitation	
Recommendations	

iii. HDI Advance R3 x (LMI, former 3D3 solutions)

This structured light scanner had already been mentioned in our previous report. Since then and after evaluation of many scanners, this scanner was acquired (in the framework of DIGIT).

The HDI Advance R3x was chosen for the following reason:

- it seems to be the best quality value for money since it has a resolution similar to the Breuckmann SmartScan and the GOM Atos Core of the corresponding field of view, but it's cheaper.

- it is possible to work together with a DSLR camera controlled by the software for better texture acquisition.

- acquisition and processing are fast tanks to a pro-efficient software and relatively user-friendly.

- it has an adjustable field-of-view between 200 to 600 allowing to capture different sized objects.

Acquiring this scanner allowed us to test it further. So far we encountered some issue' working with the DSLR in the alignment of the texture from several rotations creating a blurt effect. Otherwise the scanner is quite efficient (when no issue are encountered). The calibration process is relatively easy to handle and only necessary when the field of view is changed.

Different settings are available to deal with different materials. The HDR setting is very interesting to capture reflective objects but takes more time.

High sensitivity setting can be more useful to capture fur, feathers or textile.

The test of different material we did shows that the scanner has trouble with quartz (translucent material). It is also interesting to mention that the scanner can scan through glass like kinect does.

Cost (€)	**22000**
Theoretic accuracy	45-105 µm
Time constrains	20-30 min
Texture	Can either be capture by the DSLR or by the scanner it self and can be applied as a file texture or as a vertex colour texture.
Preparation process	Check board calibration each time you change the field of view or include the DSLR.
Limitation	
Recommendations	Adapted to specimens bigger than 10 cm diameter.

iv. MechScan

The MechScan can be considered as the little brother of the HDI although it is not an LMI scanner but an independent scanner developed by Simon Stone in the UK. It uses the same software as the HDI: FlexScan. But is dedicated to smaller objects.

It can also work with a DSLR camera commanded by the software and must work with the automated turntable.

Cost (€)	45 000
Theoretic accuracy	0.001-0.01 mm
Time constrains	- 5 min for calibration - 2 min 45 sec for a rotation of 8 scan in normal mode (usually advise to do 3 rotations) - 40-60 second to combine scans - 16-20 second to align 2 combined scans - Consider approximately 20 minutes in total (in normal mode)
Texture	Can either be capture by the DSLR or by the scanner it self and can be applied as a file texture

	or as a vertex colour texture.
Preparation process	Check-board calibration.
Limitation	
Recommendations	Dedicated to object less than 10 cm diameter.

c. With 3 cameras

i. Artec Spider

Fig. 7: Artec Spider scanning.

The Artec Spider is a blue light scanner equipped with 3 cameras. It works on the same principle as the EVA mentioned previously, but is more precise. It is a hand held scanner as well that can capture object from 4 cm diameter to 30-50 cm diameter (the maximum size depends on the power of your work station and by experience it is not advised to go above 50 cm). For an object of 30-50 cm you will have 3-4 Gb of raw data. But you can combine the acquisition from EVA for large structure with few detail and record the detail with the Spider.

For example to capture a full skull you will need 45 minutes of acquisition. The scanner captures 6-7 frames/seconds, the amount of frames per second is limited by the USB 2.

As for EVA, it can work with a manual turntable. It is possible to have batch processes or to take measurements directly with the scanner.

The software allows you have the possibility to adjust brightness and contrast of the texture. You can use colour information for registration (it is the only one we encountered on the market doing that), which allows to move the object in real time and continue aligning without photogrammetry markers.

The stromboscopic effect is unpleasant and would probably be quite tiring for the eyes in the case of long-term use.

The minimum configuration recommended is:

- Windows 7
- 64 bits
- i7 quadcore
- 16 GB RAM
- good graphic card (NVIDIA GeForce)

The price of the scanner include training and software licence. 1 extra licence is 500 €, 3 extra licence 1200€.

Our analysis show that is more precise than the Mephisto EX-Pro.

Cost (€)	17 200
Theoretic accuracy	0.3 according to the reseller, 0.05 according to the scanner sheet
Time constrains	45 min for a 25 cm diameter object
Texture	RGB
Preparation process	None, integrated calibration
Limitation	Is limited in size of object of 50 cm diameter top, due to hardware limitation.
Recommendations	

Depth sensor (Kinect)

Scanner based on depth sensor type continues to develop fast. Several similar device to kinect, primesense or Xtion appeared recently on the market: the sense 3D scanner from cubify, the structure sensor, the iSense for iPad... And besides the hardware, other software is developed as well.

The problem is still the accuracy of those devices, since the sensor is not calibrated, only one out of ten could be precise, the sensor can move inside size causing differences and this added up to change of temperature or light make it really difficult to realign a great number of scan for large object like needed with the Gotcha.

Regarding the Gotcha software, after numerous test and numerous contact with the Mephisto firm, we realised that although it seems to work nicely to begin with, the software was actually quite limited and bugged. We have faced repeated crashes. The firm couldn't explain us the different setting of processing.

	Gotcha
Cost (€)	1000 € (sensor included)
Theoretic accuracy	
Time constrains	1 min by acquisition, the number of acquisition depend on the size and complexity of the specimen.
Texture	RGB
Preparation process	Check board calibration
Limitation	Doesn't work in the sun, doesn't like change of light.
Reliability	Not reliable
Recommendations	

Nevertheless since this category of sensor was practical for some cases, we still took the time to test another software: the Artec Studio software. The Artec Studio software for kinect is the same as the one for the structured light scanning. It works with the same principles of capturing frame by frame in a continuous way but with the possibility of removing or realigning frames. The Artec Studio software cost 500 € for one, 1200 for 3 copies. The sensor has to be purchased separately (and Primesense doesn't exist anymore, it has been acquired by Apple). The results looked very good.

	Artec Studio
Cost (€)	500 € for one licence of the software, 1200 € for 3 licences of the software + price of the sensor
Theoretic accuracy	
Time constrains	1-2 minutes by acquisition
Texture	RGB
Preparation process	
Limitation	
Reliability	Not reliable
Recommendations	

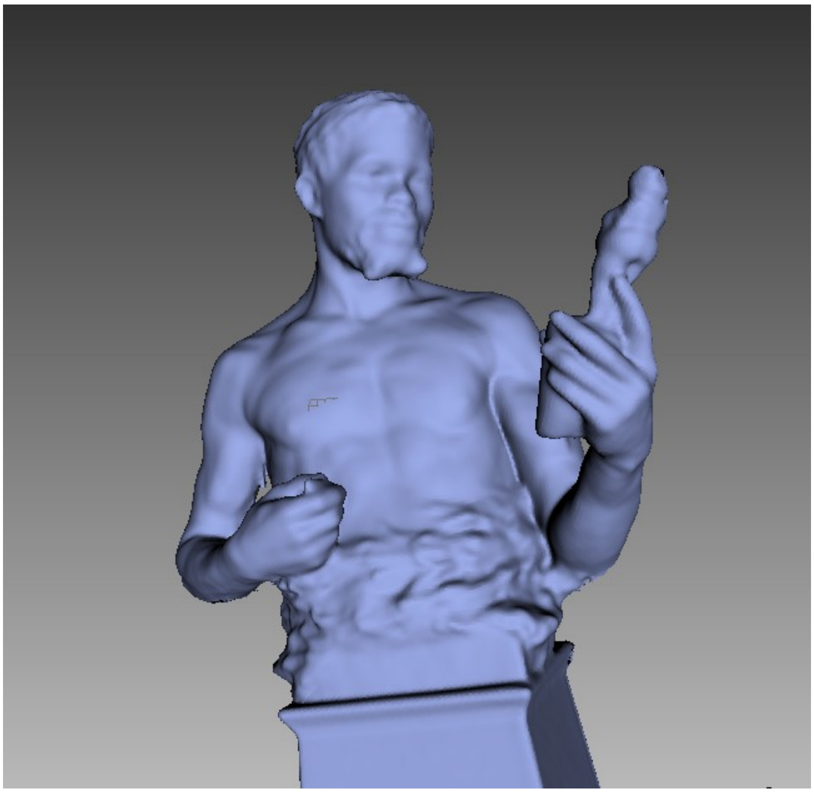


Fig. 8: Screen shot of one of the test with Artec Studio. The statue is approximately 80 cm high.

3. Microscopic techniques

We tested two different types of microscopes besides the Leica MZ16A and Leica Z5 APO, which are discussed in the Image stacking section. One was the Keyence VHX-5000 and another was a solution of 'Information in Images'.

The latter consists of an Olympus BX51 Bright---field and reflected light Trinocular Optical Microscope with a motorized stage, motorized focus adapter and a QiCam colour camera of 1392 x 1040 pixels, 1/2" Sensor with 4.65 x 4.65 micron pixels, 12--Bit colour output.

The microscope is able to make both focus stacks and Gigapan images, as with a SatScan system, but with the precision and magnification of a microscope. In this way it is possible to zoom substantially on a microscopic image.

Figure 9: Image of a Copepod on a microscopic plate, made by the 'Information in Images' solution with detail of the highlighted region at the highest resolution.

The Keyence VHX-5000 is a fairly new digital microscope. This microscope has several nice features. One is an attached screen, so you have instant live view. By moving the cursor one can control the zoom and the motorized microscopic stage. The microscope tube with the camera and the lenses can be unplugged from the holder so it can be applied on large surfaces, which physically won't fit the motorized stage. This system is also able to make instantaneous focus stacks and thanks to the special lenses and software the view of an object is overall sharp even when parts are at different focus ranges. Another feature which can be interesting is the ability to measure directly and export the measurements. It is possible to export 3D models as well, however these only work well for more or less regular surfaces and can't be applied on insects or similar though fine, detailed objects.

Figure 10: Image of a Copepod on a microscopic plate with detail of the highlighted region at the highest resolution.

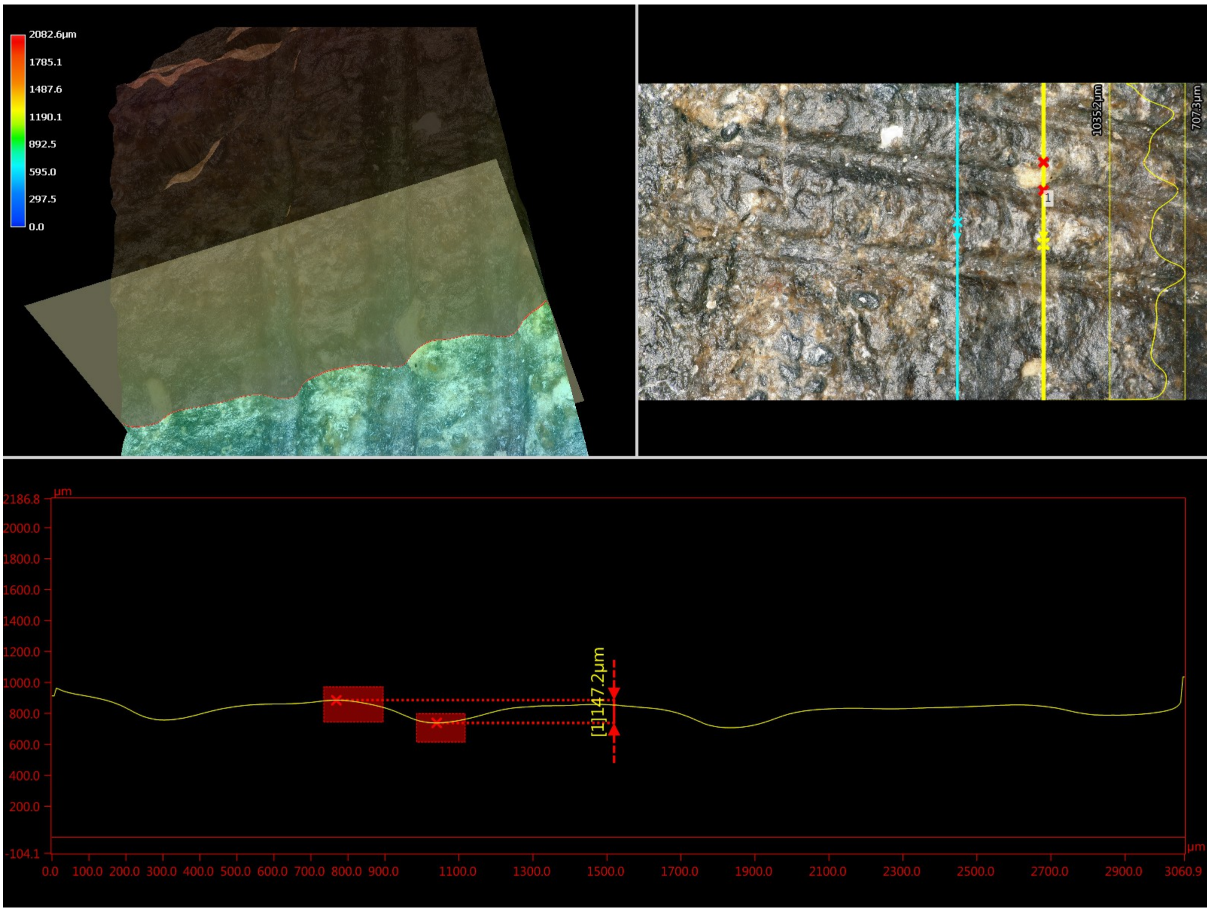


Figure 11: High detail pictures of the Ishango Rod with measurements taken on the 3D model extracted by the Keyence VHX-5000.

4. Photographic technique

a. Focus stacking

Taking pictures of specimens which are small and have lots of detail is not as straightforward as it seems. The low depth of field makes it almost impossible to get the complete object in focus (Figure 9), unless the aperture is stepped down. However this results in other aberrations as the optical resolution reduces due to the diffraction effect.

Fig. 12: Three views of an Asilidae at different focus depths, shot with the following parameters: 100 mm, f/5.6, 1/200 s, ISO-100 and 1/32 power of double flashlight.

We did several tests during the course of the project. At first we started with a manual approach. In essence we had a Canon 600D equipped with a 100 mm Macro Lens attached to an XY-stage of Manfrotto. The lighting we used was a continuous lighting delivered by up to four LED lights and/or a continuous LED ring. The software we tested at the beginning was Helicon Focus and Zerene Stacker. The set-up worked fine for larger specimens, and the Zerene Stacker software gave us the best results. The downside was that everything was done manually and this created errors sometimes. The set-up itself wasn't very stable because of the rather long shutter speed.

Because smaller specimens didn't work with the 100 mm Macro we ordered the Canon 65 mm MP-E lens which has the capability of magnifying up to 5x. When working with this lens it was clear that the manual set-up was not sufficient as each time the micro-screw was turned the camera and the lens moved substantially. Moreover if you want to take up to 70 pictures of one specimen it was quite a tedious job to do. Together with the continuous light setting the results were fine at 50%, but not sharp at all when viewed at maximal resolution (Figure 12). Therefore we decided to buy a StackShot made by Cognisys. This made life easy again as the process became semi-automated at this point. The StackShot controls the camera after setting the begin and end position of the specimen. There are several possibilities to control this process. The one we usually use is the setting of the stepsize as this is dependent on the specimen and is the more accurate way to shoot a stack. In the mean time we altered the set-up around the specimen as well. We included a flash light to the ambient continuous light and placed all together with the specimen inside a styrofoam box, which serves as a light box, as previously tested by (Alexander and Droege, s.d.). At this point we have fast shutter speeds, stable light conditions, a solid camera control with fixed step sizes and in the end superb results which need minor or no post processing at all.

After the fine tuning of the system we started to look for challenging specimens. In general we tested specimens with different difficulties to picture regarding: colors: white or dark; surfaces: transparent, iridescent, reflective; details: hairy, small, …, but also specimens on microscopic plates (Figures 13 to 15). For alcohol based specimens it is better to take pictures in a vertical position as this makes it easier to position them. To prevent floating and moving of the specimen, one can reduce the amount of alcohol inside the dish so the specimen is just submerged. Or one can place glass beads, or grains underneath the specimen so the surface it lays on has more structure. We also found that when the camera isn't entirely stable this creates small movements when the tube of the 65 mm lens is fully extended. If it is fixed properly no such blur exists in the final picture and everything is sharp when viewed at full size (Figure 15).

Figure 13: Focus stack made with the manual method. At maximal size (small highlight in the top right corner) not everything is sharp. This is both due to the continuous lighting and the manual method.

Figure 14: Focus stack of a Trichius beetle made with automatic method, but with just one flash light and ambient LED light. The details are sharper, but the lighting is not as it is supposed to be because there are still some overexposed areas on the elytra.

Figure 15: Focus Stack of a Camillidae fly of approx 3 mm, with automatic stack and two flashlights and softboxes on each flashlight. There are no overexposed parts and everything is perfectly sharp.

Figure 16: A focus stacked picture of a tiny fly (approx. 2 mm) in alcohol showing a blurred effect due to vibrations of the environment. The camera was mounted on a tripod above the light chamber, which caused light vibrations both while taking a picture and when a person was moving. Next to it a picture of a spider with a detail of a pedipalp. This time the camera was fixed to a repro stand, which proves to be more stable. The pedipalp is about 1/3th the size of the fly.

We also tested if in the same way microscopic plates can be photographed as the Canon 65 mm allows a magnification of 5X. After the first test it was clear that this was possible without the need to tweak the set-up. A positive side-effect is that it is possible to change the background with the microscopic plate to enhance the parts one needs to be able to distinguish (Figure 17).

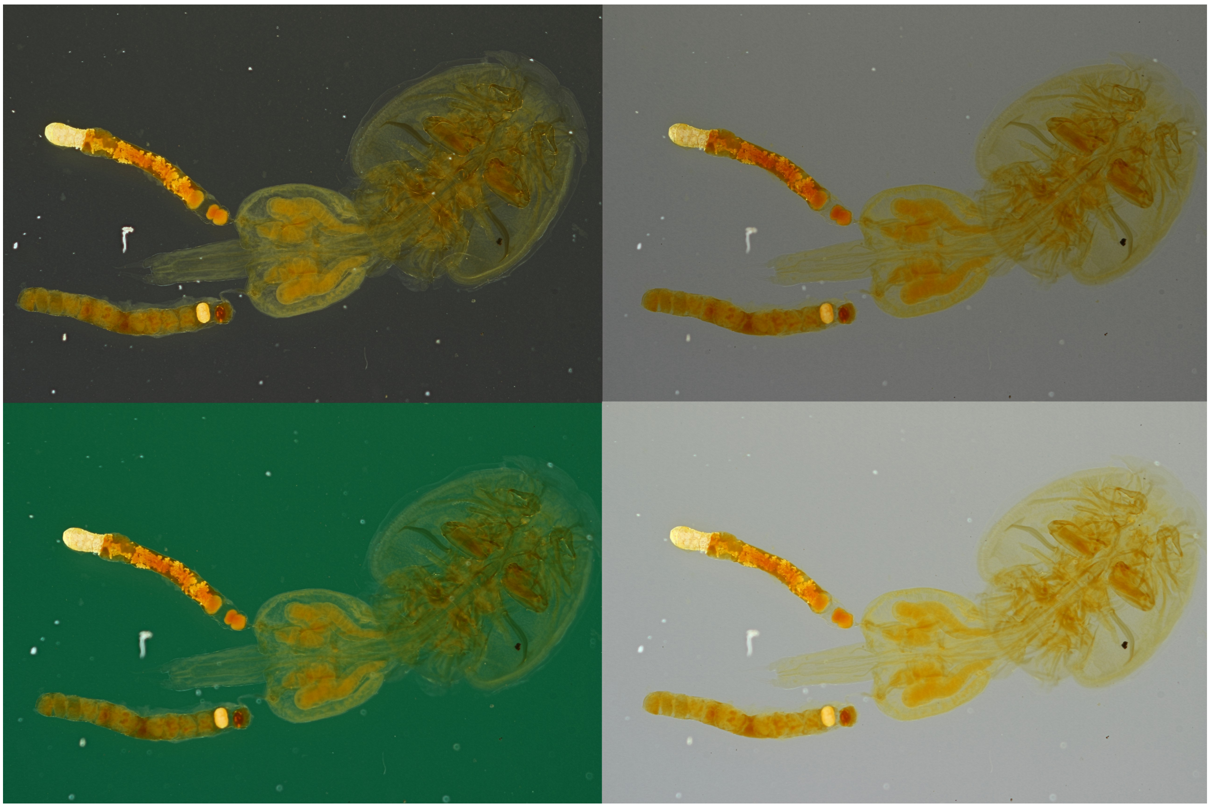


Figure 17: Four images of a microscopic plate with a Copepod. Note that the glass of the plate was dusty and had imperfections. Depending on the background these imperfections are less noticeable. The magnification used was approximately 2x.

Afterwards we compared our set-up to two high end stacking solutions, a Leica MZ16A and a Leica Z6APO equipped with a DCP-500 and DCP-290 respectively. After testing with a small hairy specimen (a Meranoplus ant) and an iridescent beetle of similar size, we came to the conclusion that our set-up delivers a stacked image with the same sharpness as both Leica solutions (Figures 18 to 20). But with better lighting than the Leica MZ16A, which was equipped with two lights controlled by a Leica KL 1500 LCD. The lighting in the end result of the Leica Z6APO and our syste m was more or less similar. The largest differences between the several approaches are the resolution of the pictures and the purchase prices. To get an idea four pictures of the DCP-290 fit into and 1.5 of the MZ16A fit into one picture of the Canon 600D. And you can buy around 11 Canon-Cognisys sytems (see table X) for one Leica MZ16A and 8 for one Leica Z6APO. A small remark has to made, the workstation attached to the MZ16A was not able to process the pictures at highest resolution taken by the DCP-500. To solve this problem one needs to buy a powerful workstation. Regarding the low amount of pixels delivered by the DCP-290, this can be solved by purchasing a newer camera, however, this will have the same price as approximately 3 complete Canon-Cognisys packages. While changing DSLR's would cost only a sixth of the complete package. The comparison the prices are not completely correct as the lights of the Leicas systems are not included in the comparison.

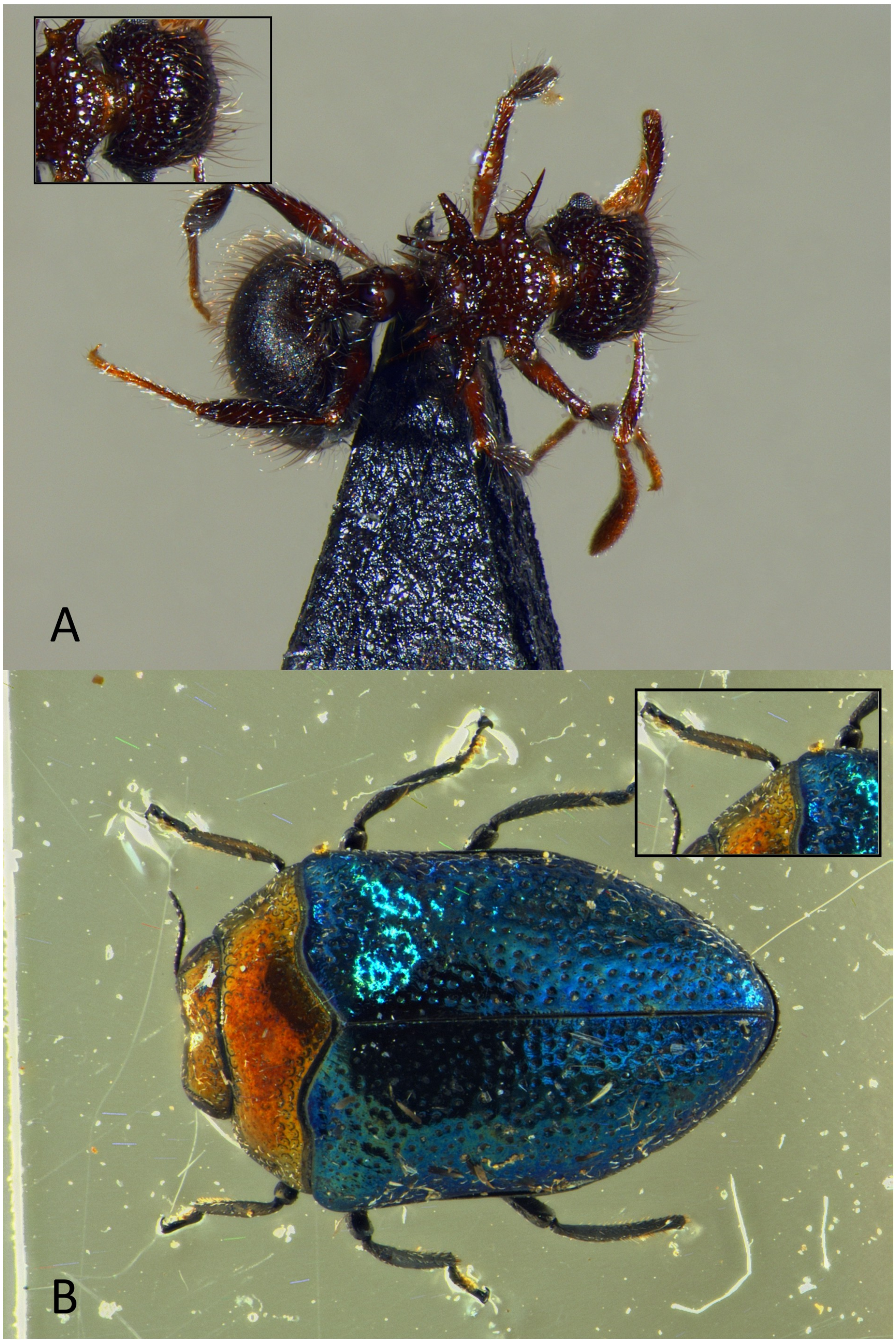


Figure 18: Focus stacking in Zerene Stacker. The small images in the top corner provide a detailed close-up of 518 x 345 pix of the image at 100%. A. Stack of 70 pictures, aligned and combined with PMAX. B. Stack of 41 pictures, aligned and combined with PMAX. The individual pictures of both stacks are made with the Leica MZ16A with DCP 500 camera and Leica KL 1500 LCD lights.

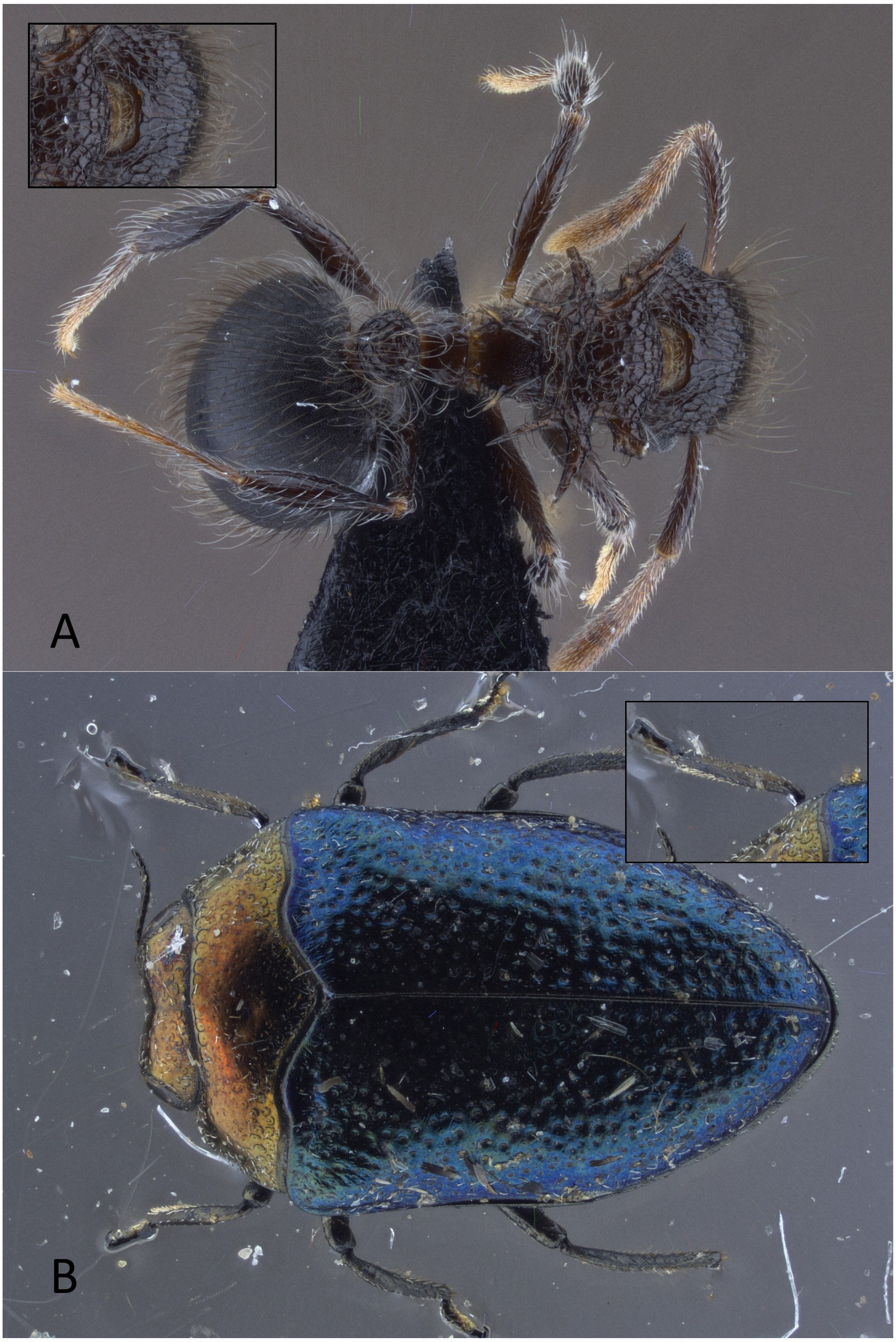


Figure 19: Focus stacking in Zerene Stacker. The small image in the top corner provides a detailed close-up of 518 x 345 pix of the image at 100%. A. Stack of 77 pictures, aligned and combined with

PMAX. B. Stack of 44 pictures, aligned and combined with PMAX The individual pictures of both stacks are made with the Leica Z6 APO with DCP 290 and Manfrotto led light system.

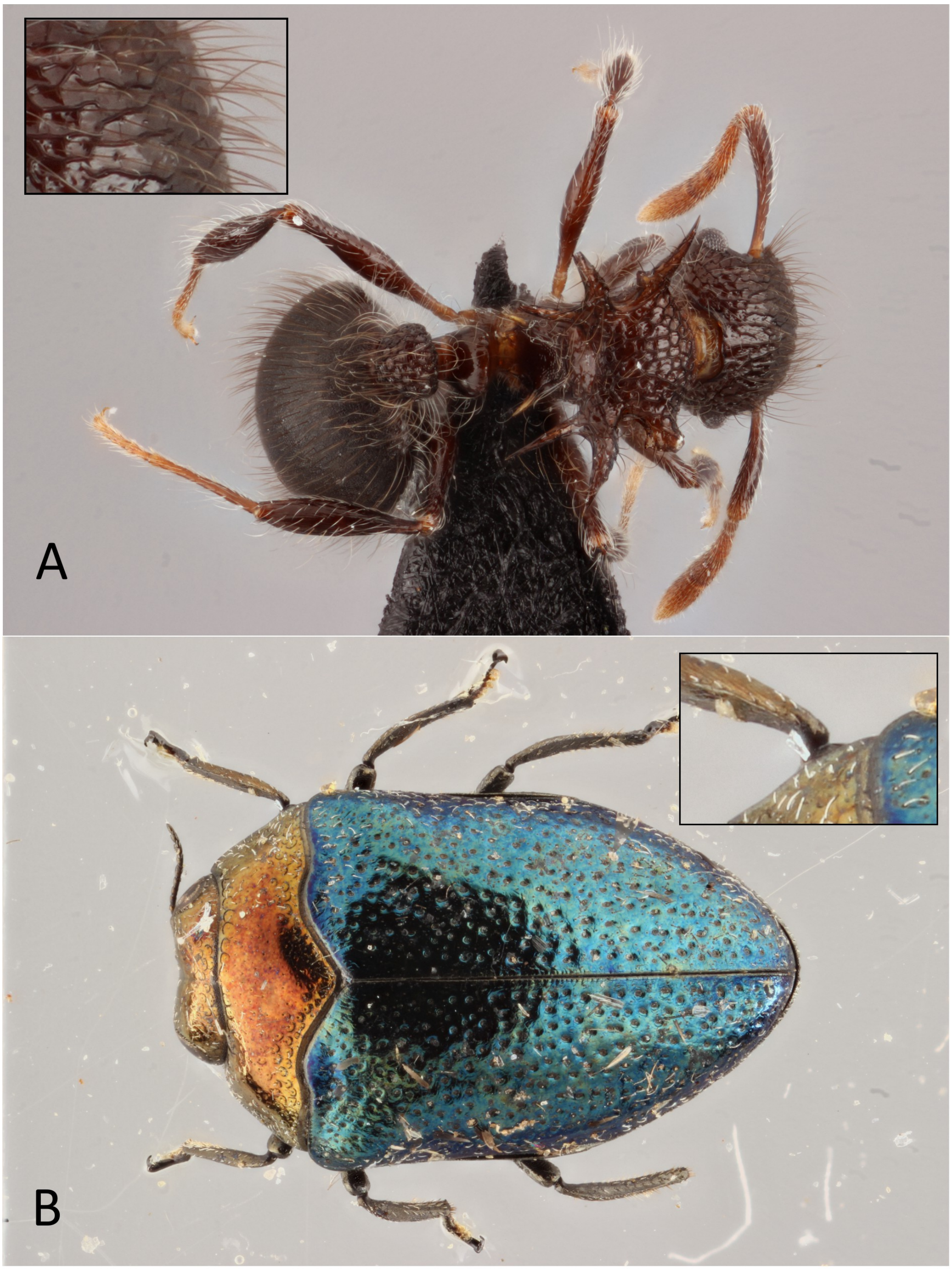


Figure 20: Focus stacking in Zerene Stacker. The small image in the top corner provides a detailed close-up of 518 x 345 pix of the image at 100%. A. Stack of 71 pictures, aligned and combined with PMAX. B. Stack of 41 pictures, aligned and combined with PMAX. The individual pictures of both stacks are made with the Canon-Cognisys setup and double flash lights.

Table X: The complete Canon-Cognisys package without a workstation. Note that when ordering all the photographic equipment with the same dealer reductions might be possible.

Equipment	**Quantity**	**Prices (€)**	**Total (€)**
Zerene Stacker	1	233	233
Canon 600D body	1	449	449
Canon 65 mm MP-E f/2.8 1-5x Super Macro	1	1021	1021
Canon 100 mm f/2.8 EF Macro	1	459	459
Cognisys StackShot	1	599	599
Shutter Speed Cable	1	60	60
Yongnuo Digital Speedlight YN560-II	2	46	92
Remote control for Speedlight	1	20.5	20.5
Foam Board Black/Grey	2	8	16
Extra Battery	1	36	36
Rechargeable batteries AA	4	5	20
Styrofoam Box	2	3	6
Total			**3011.50**

b. Photogrammetry

After testing Photogrammetry thoroughly during the first part of the project, we focused mainly on the other techniques like structured light scanning and image stacking. However there were still some things that didn't work out. One of those things were insects. Previous tests failed to get good models of the test beetles we used. The main problems were misalignment, lacking of legs or doubling fine structures like antennae or eyes. Last month a paper was published in PLoS ONE, discussing the acquisition of 3D models from insects by the use of images. They used a different photogrammetry package called 3DSOM. At the moment 3DSOM is incorporated by BOB Capture, but the program itself stays the same. To retrieve a 3D model with this software it is required to have a printed mat with markers underneath you're object. In this way the software is able to calculate the camera positions. We tried this approach as well and took images of an insect with the mat underneath. Only when we took more than 100 pictures, the software started to compute the pointcloud. However we've tried it several times and each time the workstation freezes. We than used the same pictures in Agisoft Photoscan and even after a single rotation, consisting of only about 30 pictures, the software was able to calculate a pointcloud. During the last half year Agisoft Photoscan has changed a lot. Multiple times a week there are new updates and everything tested and requested well in advance by the AP users, through their forum. After adding the entire dataset a 3D model was computed, which was accurate and showed some detail in the mesh. However, looking at it from a scientific field of view, the models can't be used. But educationally, they look great, especially once they are textured.

-Automating the process

To automate the photogrammetry process we bought at first an automatic turntable. This could be turned on and off by the use of an USB controlled electrical plug. The problem with this approach was that the USB controller when switched on, stayed on for at least 5 sec and consequently stayed off for at least 5 sec when the off switch was chosen. We wrote several macro's to control both the camera and the turntable, but apparently the time wasn't stable as after a few minutes there was a large difference between the clock of the macro and that of the USB controller. We corrected for that as well, but the general work flow stayed complicated because of the unstable USB control program. So we abandoned this project for a moment. Fortunately we have really good programmers at the ICT department. After several trials, they succeeded in creating an interface which controls not only the turntable, but also the camera. And it allows you to set the parameters of the camera without the need to open any Canon software. In this way an operator is only needed to set the parameters and place the object on the turntable.

-Pattern projection

We had mentioned in our previous report that photogrammetry encountered some issue with material without enough detail like white plaster or 3D printed material, even with markers. We tried projecting a pattern and taking pictures of the object with the projected pattern to obtain a better surface model. We tried several different pattern (fig. 21), with the same amount of pictures. One of the pattern had colour lines and increased the number of points of approximately 25%, while with black and withe lines patterns it decreased the amount of point found between 30 and 55%. Even with the 25% increase, it is still very low quality compared to what it is possible to achieve with other more textured materials.

	Alignment points	Increase percentage
No pattern	6825	/
Colour straight lines	8692	+ 27 %

Black and white straight lines	4554	- 33 %
Black and white zig-zag lines	3071	- 55 %

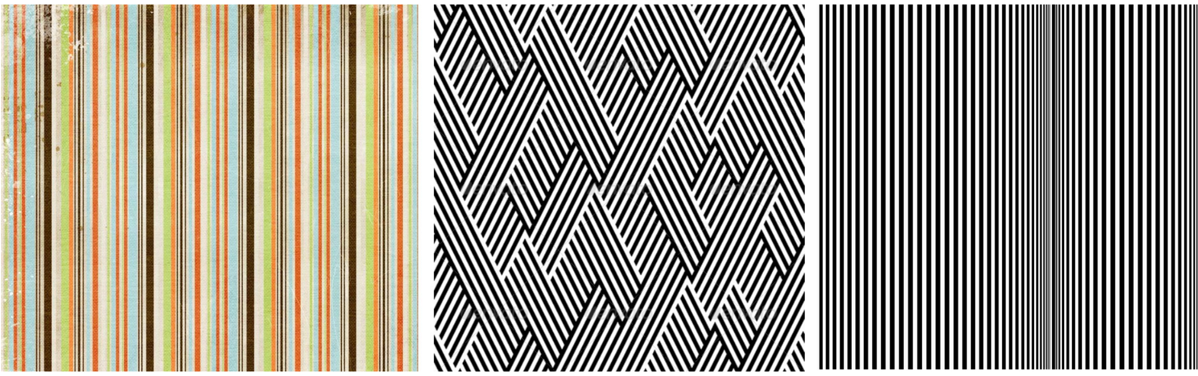


Fig. 21: Patterns tested.

More test need to be run with more patterns, but so far we can say that black and white pattern must be avoided and colour pattern can help increasing the quality of the mesh.

5. MRI (Emmanuel)

Magnetic Resonance Imaging techniques for the study of museum zoological collections

Emmanuel Gilissen, June 2014

Museum collections of fishes, amphibians, reptiles, and mammals have traditionally been repositories for single, fluid-fixed specimens (holotypes) on which most type-descriptions are based. These specimens are generally unsuitable for molecular studies because they have been fixed in formalin. Their value could therefore be greatly enhanced by the use of non-invasive imaging techniques to provide structural information for the study of taxonomy, myology, brain anatomy, functional morphology and also new characters for phylogenetic studies.

With the advent of high-resolution magnetic resonance imaging (MRI) scanners and affordable cost of scanning per specimen, it is now feasible to use these methods for soft-tissue studies of small to medium-sized zoological specimens. As an example, we provide the link toward MRI imaging of a thylacine brain, stored at the MNHN (Paris) and scanned by Prof. Rik Achten (University of Ghent) and Emmanuel Gilissen (RMCA) on a standard medical device (Phillips) at 1.5T. The thylacine is a now extinct marsupial mammal. It went extinct on mainland Australia during the nineteenth century but survived into the 1930s on the island of Tasmania.

The link for viewing the thylacine brain is the following: http://braincatalogue.org/ (please use Google Chrome and go to http://braincatalogue.org/Thylacine). Although the anatomical specimen that we scanned was preserved since decades, now in formalin but in the past probably in various undetermined fluids, and was partly damaged, the main anatomical structures of the brain, as well as the contrast between white and grey matter, are clearly visible. These characters make the specimen available for further studies of marsupial brain comparative anatomy through "virtual dissection".

The application of this technique obviously has great potential. Large stores of fixed material from numerous public and private collections are candidates for nondestructive soft-tissue study, thus increasing their value as scientific resources, especially when the holotype of a taxon is the only known specimen or in cases where rare species are represented by a few extant specimens or in cases where the species is extinct and a handful of specimens are preserved in some museums through the world.

The cost of this technique is 250 €/hour and a scanning a specimen takes approximately half an hour.

Reference

Waller G, Cookson J (1996) *Reconstruction of museum specimens*. Nature 380: 209-210

WP-5 Tools

(7 PM AGORA3D+ 2,4 PM Consortium; T3 – T16)

a. Tools

Several software's have already been mentioned in the previous reports, among them:

- MeshLab

- LHP FusionBox

- GOM Inspect

Other software would be interesting to test more extensively:

- Geomagic versus RapidForm: it would be interesting to see what the differences are between the two software packages when scans are processed into complete 3D models within these software solutions.

- CHISel: this is software developed by a university in Spain, allowing to annotate the models.

b. Analyse of the result

Protocol (use of GOM inspect)

In order to evaluate the results, we choose a set of specimens with different properties. Those specimens were digitised by different equipment and technique. Afterwards each model is closely examine and analyse regarding the original object but also comparing the differences between the models.

Test objects:

- Skull (medium size specimen)
- Sea urchin (small specimen), allows to evaluate precision: the aim was to see if it was possible to see the small punctures on the surface that enables determination of the species
- Neanderthal tooth (small specimen). Allow to evaluate precision and materials acquisition (enamel).
- Flint nucleus. Allow to evaluate precision and materials acquisition (flint).
- Engraved reindeer. Evaluate precision.
- Ishango rod. Allow to evaluate precision and materials acquisition (quartz).
- Beetle. Allow to evaluate precision and materials acquisition (wings, hair, irised structure).

	Structured light	Laser scanner	CT/µCT	Photogrammetry/ Mini-Dome
Skull	GOM Atos Core Breuckmann SmartScan HDI Advance R3 x Mephisto EX-Pro Artec Spider Artec EVA	FARO ScanArm NextEngine Mantis F5 short range	CT Siemens AST-RX	Agisoft Photoscan 50 mm
Flint nucleus	GOM Atos Core HDI Advance R3 x			Agisoft Photoscan 50 mm
Sea urchin	GOM Atos Core Breuckmann SmartScan	FARO ScanArm NextEngine		Agisoft Photoscan 100 mm

	HDI Advance R3 x Mephisto EX-Pro Micro MechScan			
Neanderthal tooth	GOM Atos Core Breuckmann SmartScan HDI Advance R3 x Mephisto EX-Pro Micro Mephisto EOSScan Micro MechScan		µCT skyscan	Agisoft Photoscan 100 mm
Ishango rod	HDI Advance R3 x		µCT	MiniDome
Magritte reindeer	HDI Advance R3 x GOM Atos Core	NextEngine		Agisoft Photoscan
Beetle	GOM Atos Core Breuckmann SmartScan HDI Advance R3 x Mephisto EX-Pro Artec Spider MechScan	FARO ScanArm		Agisoft Photoscan

1) Precision of the mesh

(visual comparison)

We defined as precision of the mesh the level of detail or differences visible to the naked eye.

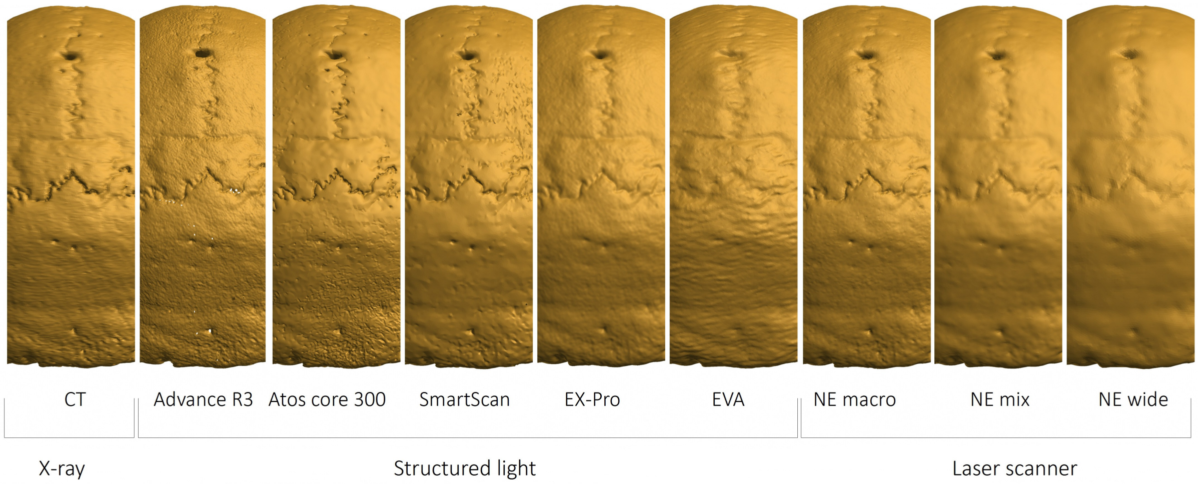


Fig. 22: Back view of the skull digitised with different equipment.

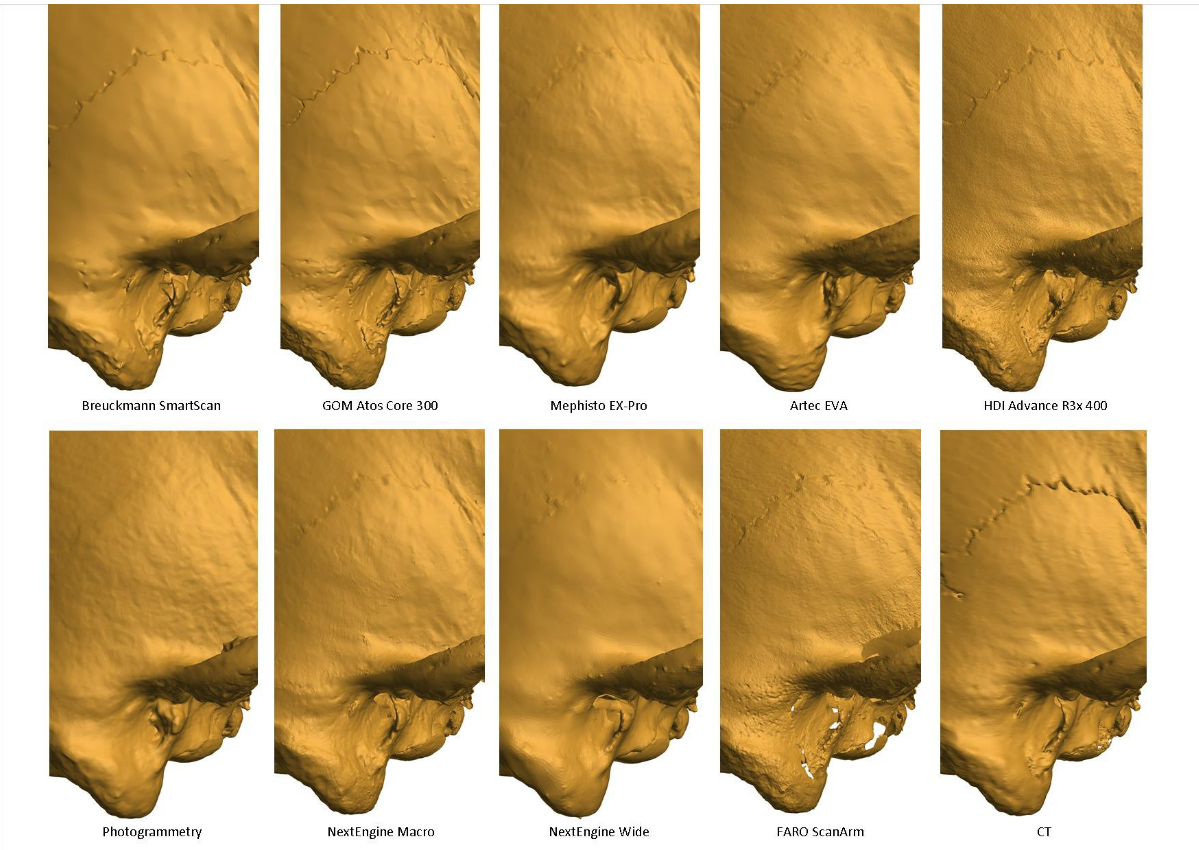


Fig. 23: Parietal view of the skull digitised with different equipment.

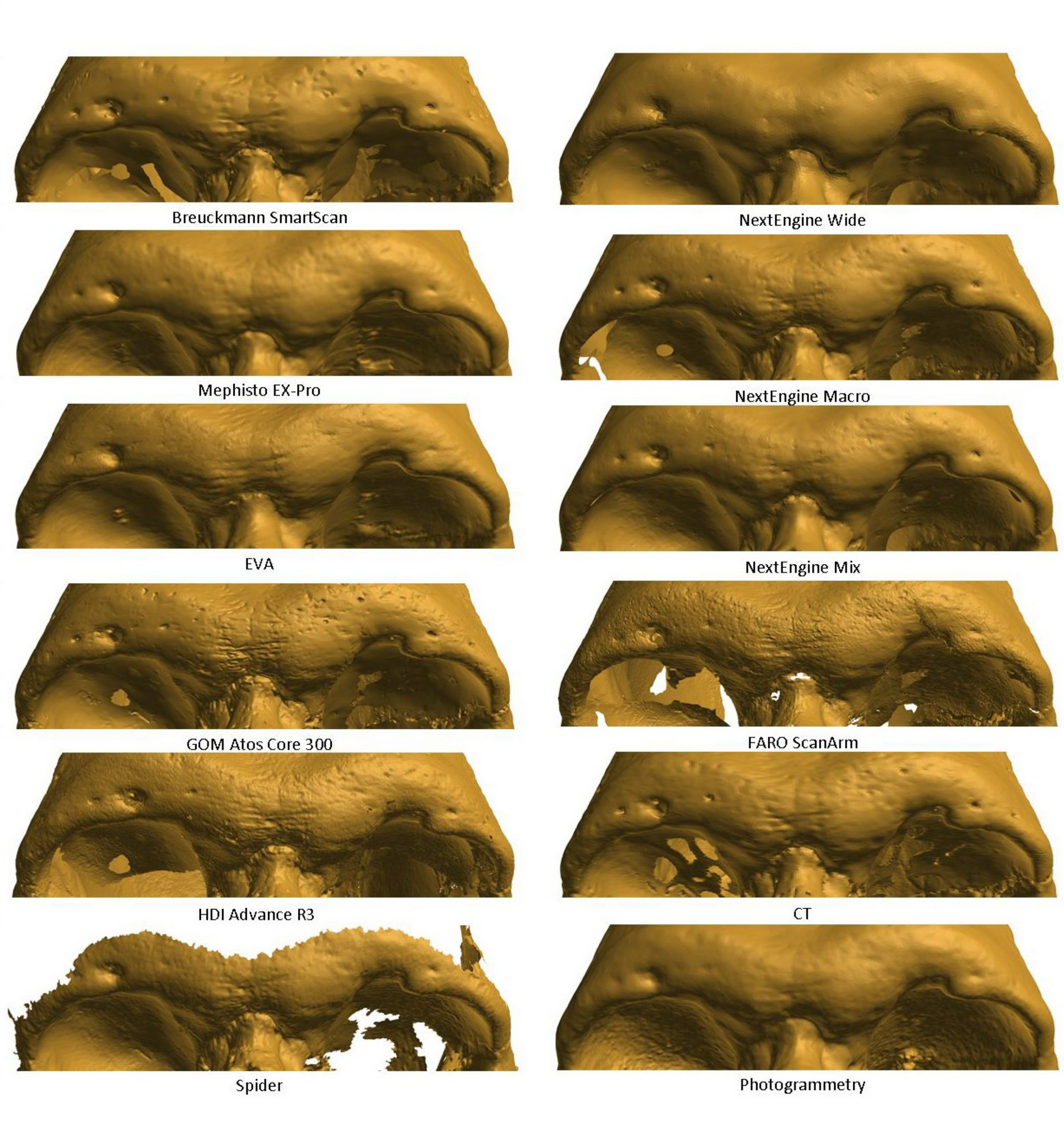


Fig. 24: Frontal view of the skull digitised with different equipment.

This two comparisons figures 22 and 23 shows that after CT, the best equipment to capture sutures are the 2 lenses structured light scanners. On the opposite photogrammetry, NextEngine wide and EVA are the one recording them more poorly.

The frontal view (fig. 24), shows that FARO ScanArm laser scanner has an excellent level of detail for small surfacique data, as well as the 2 and 3 lenses structured light scanners. Again, photogrammetry and NextEngine in wide mode, shows the lowest amount of detail.

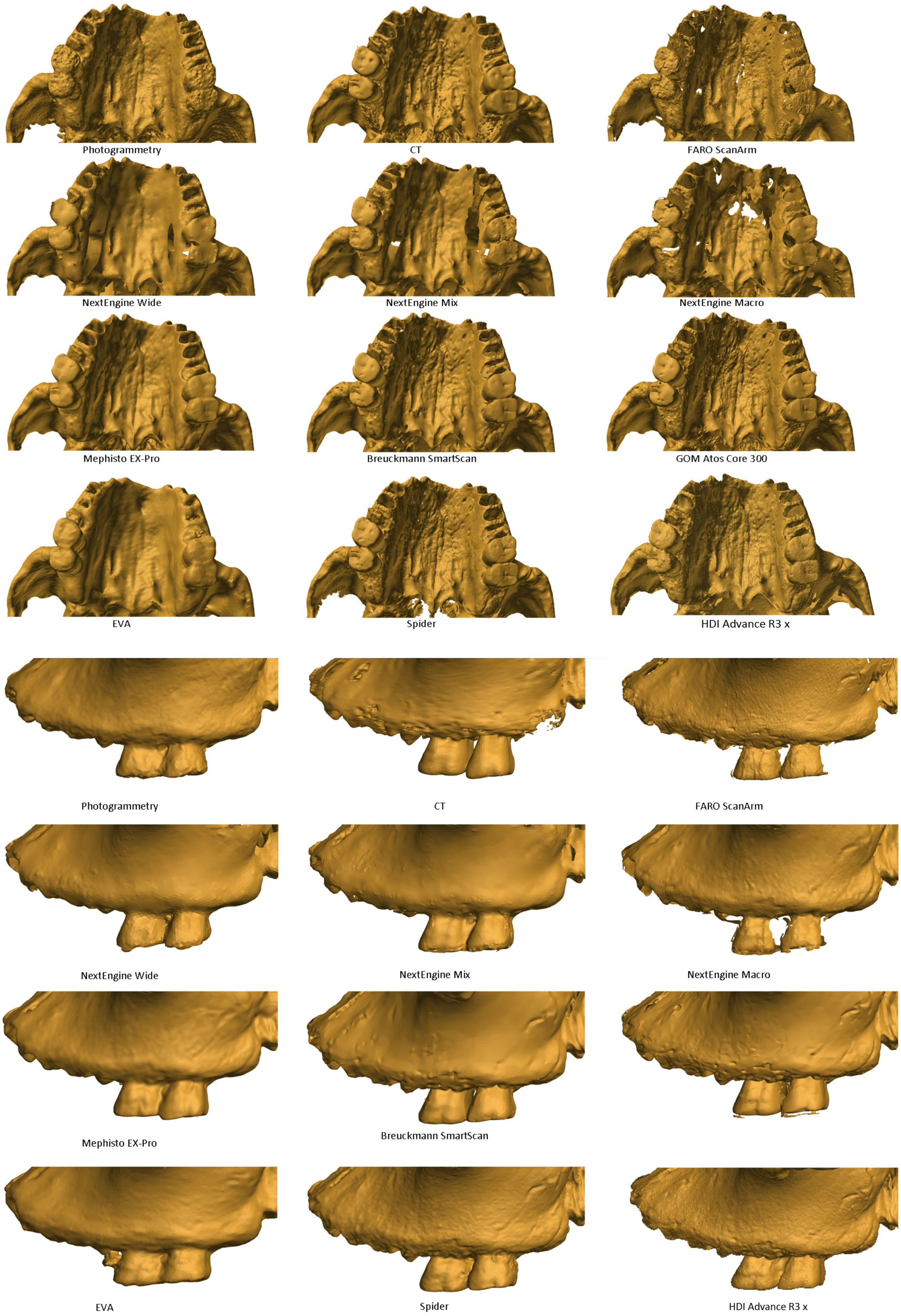


Fig. 25: Views of the teeth, acquired with different equipment.

Regarding teeth acquisition (fig. 25), CT has the best results. Photogrammetry has the most problem with enamel.

Visual comparison of the Spy tooth:

	Vertices
MechScan	*1 454 188*
HDI Advance R3 x	*79 234*
Photogrammetry	*734 681*

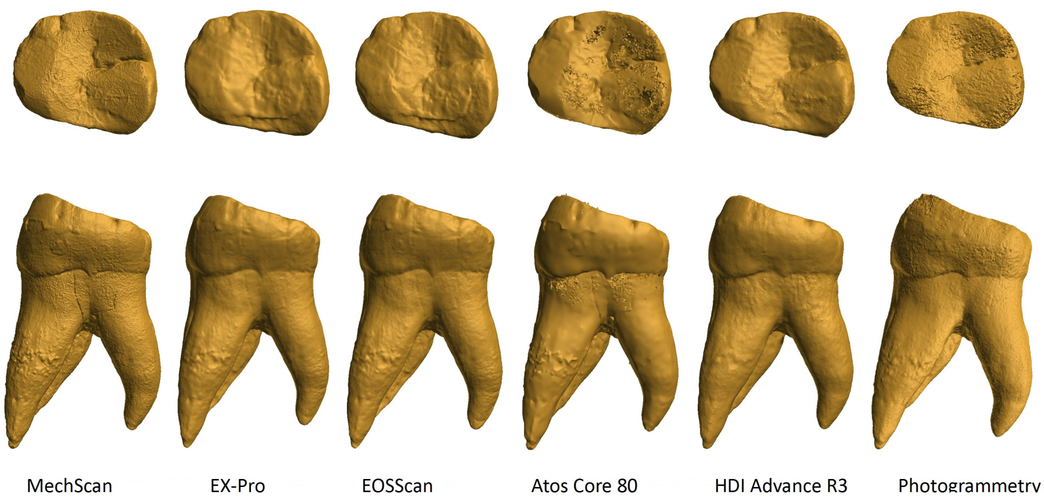


Fig. 26: Molar of the Spy Neanderthal digitised with different equipment.

The visual comparison of the tooth (fig. 26) shows that the MechScan has the best results, while both Mephisto's scanners created artefacts on the enamel that doesn't exist on the real tooth. Atos Core and photogrammetry had some trouble for the enamel and created some noise.

Visual comparison of the sea urchin:

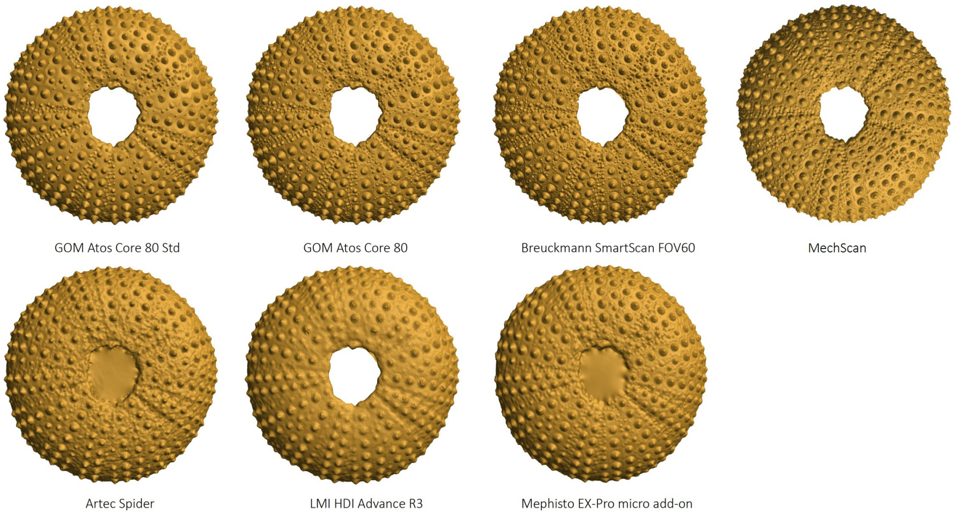


Fig. 27: Sea urchins digitised with different equipment. We were trying to digitise small punctures on the surface.

The comparaison of the top part of the sea urchins shows that there is a difference of quality for the GOM Atos Core measurment between the standard process and the detailed process. The MechScan, the SmartScan and the Atos Core (detail process) are the more detailed.

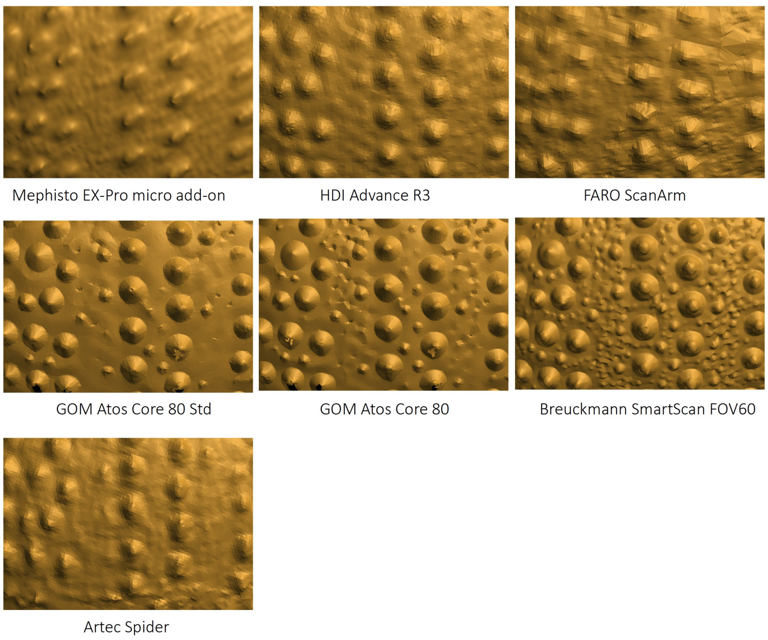
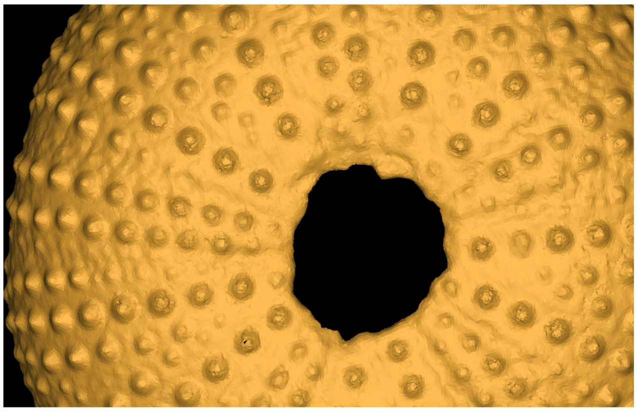
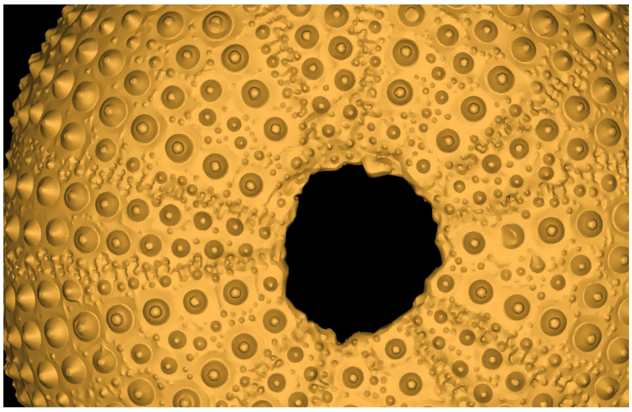


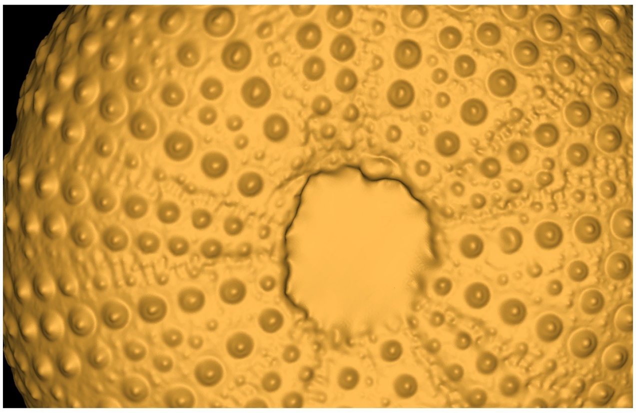
Fig. 28: Detail view of the sea urchins digitised with different equipment. We were trying to digitise small punctures on the surface.



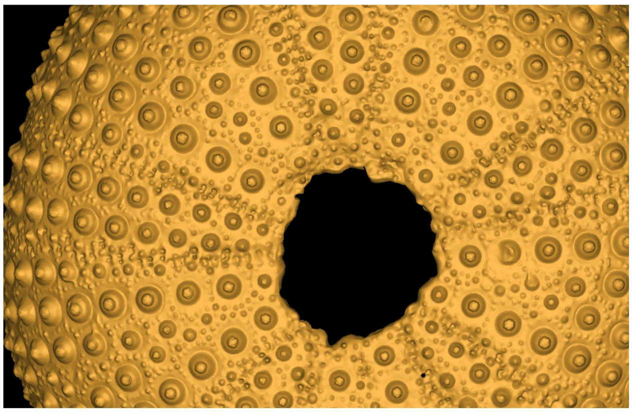
HDI Advance (no macro)



GOM ATOS Macro



Mephisto EX-Pro Macro



Breuckmann SmartScan Macro

Fig. 29: Detail view of the sea urchins digitised with different equipment. We were trying to digitise small punctures on the surface.

The visual comparison from the sea urchin shows that, again, the 2 cameras structured light scanners, with macro configuration, produce the best results. Nevertheless they all still close the small puncture during the meshing.

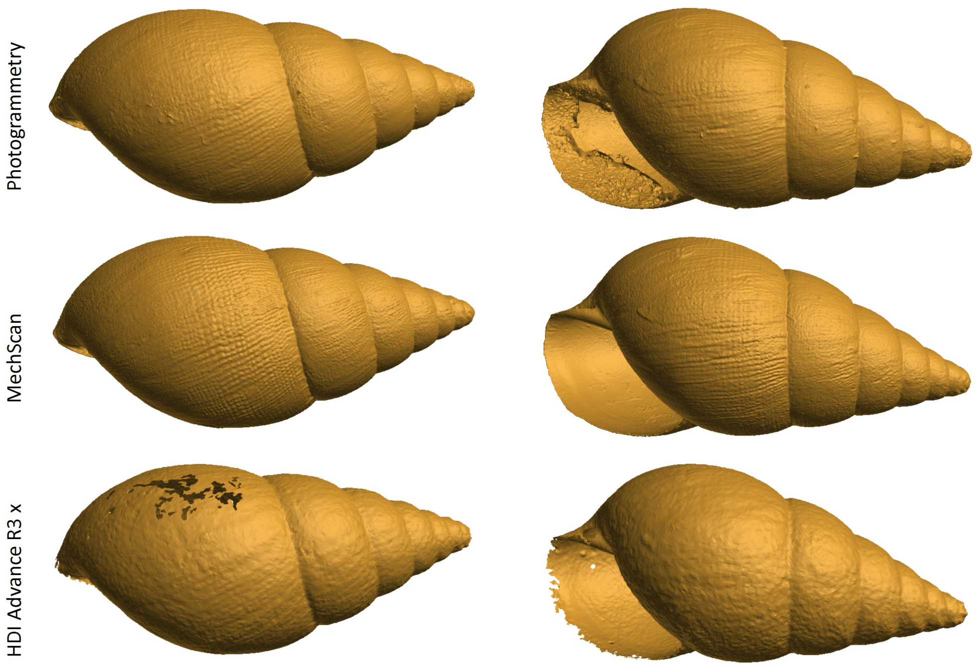


Fig. 30: Shell digitised with different equipment. The photogrammetry model was captured by the 100 mm lens and processed with Agisoft Photoscan. The visual comparison of the mollusc show a similar level of detail between photogrammetry and MechScan for the external surfaces, with still a bit more details for the MechScan. The HDI Advance has a much lower resolution.

Beetle

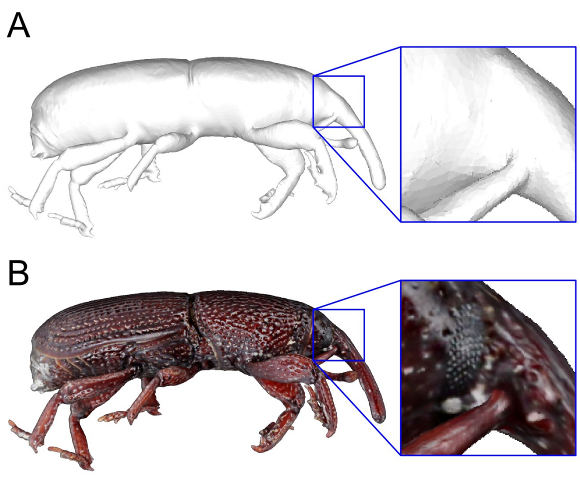


Fig. 31: Results of 3D digitisation of insect in PLOS (Nguyen CV, Lovell DR, Adcock M, La Salle J (2014) Capturing Natural-Colour 3D Models of Insects for Species Discovery and Diagnostics. PLoS ONE 9(4): e94346. doi:10.1371/journal.pone.0094346)

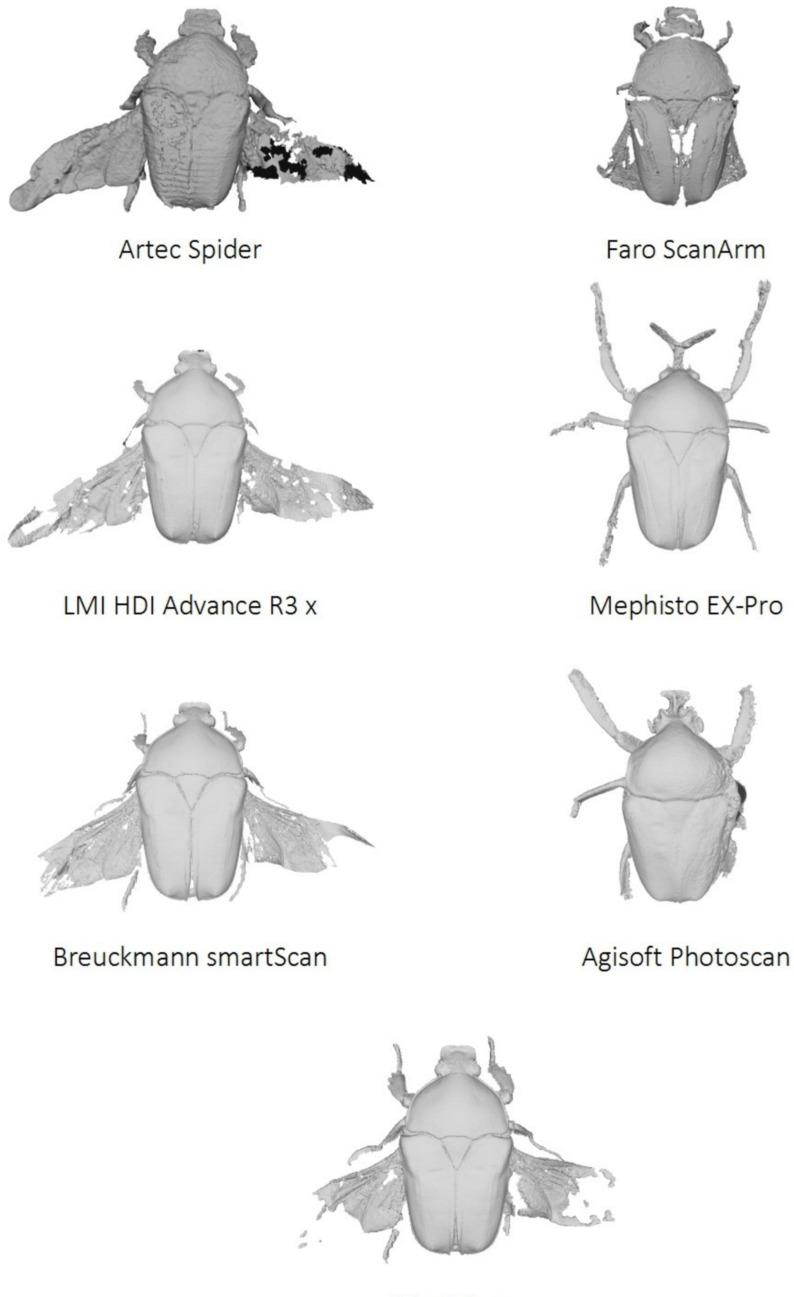


Fig. 32: Result we obtained by digitising beetles with different equipment and technique. The Spider and the ScanArm had the poorest quality. The Spider generated a lot of noise while the ScanArm wasn't able to capture some parts. The photogrammetry model was made using the 100 mm lens and from picture only from the left side which explain the bad appearance of the right side. The model display a general shape but relatively few detail. The Ex-Pro, the HDI and the SmartScan model display a good quality body. The SmartScan and the MechScan are the best ones capturing at capturing the legs.

Specific details differences between equipment:

We examined in detail every model to see the difference between reality and between the model obtain like the example in the fig. 33 display.

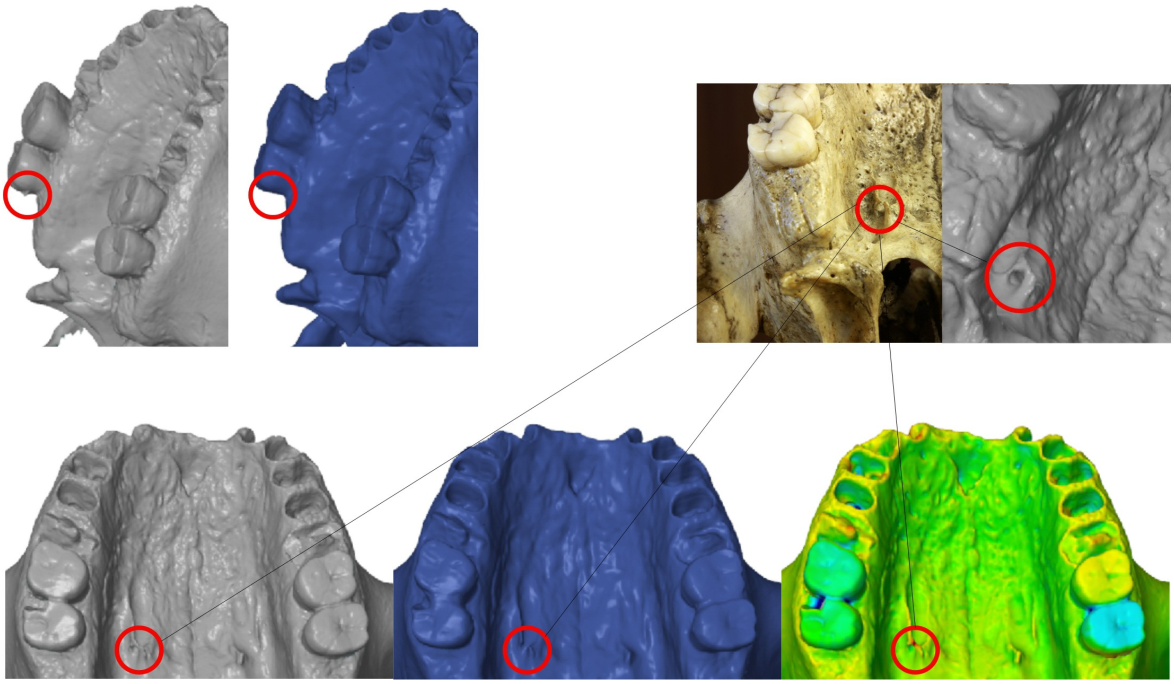


Fig. 33: Artec model in grey, mephisto model in blue. Example of differences visible from one model to an other and in regard to the original data in the picture.

2) Differences between the models

In order to evaluate the differences between the models, we used the GOM Inspect free software and compared the models in order to have value about the standard deviation, mean deviation and minimum and maximum deviation.

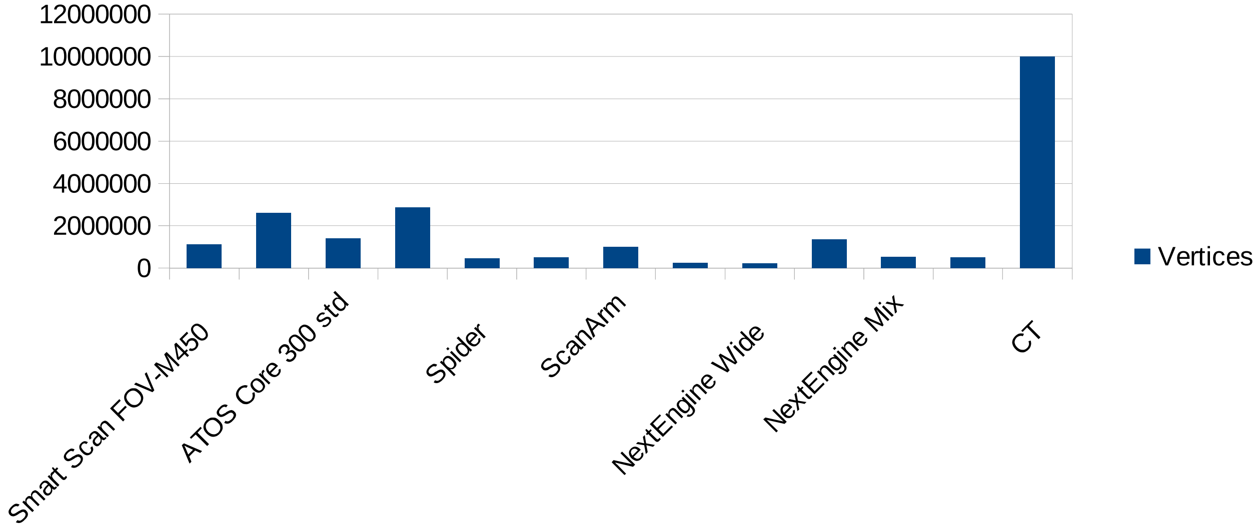
We did general comparisons of the model and local comparison of part of the model to see the local and general deformations.

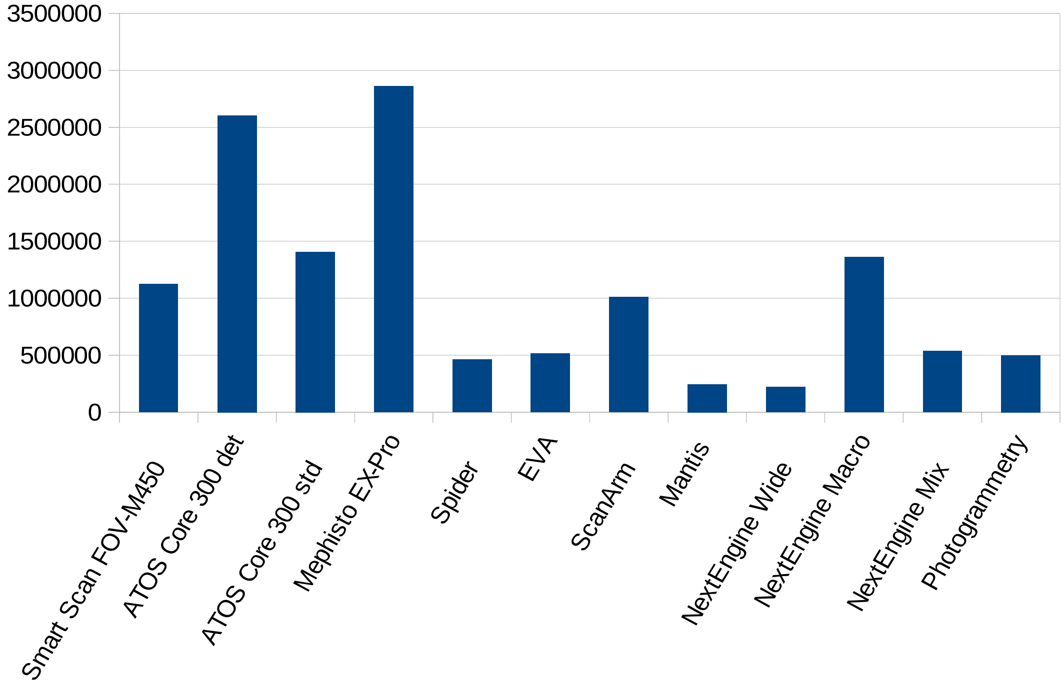
We will present the results only for the skull and the sea urchin.

We are not decimating all the model to have the same number of vertices because it change the accuracy as well. For instance, if the Breuckmann model is decimated to 200 000 vertices, the standard deviation to the original data is 0.001961. For a model like the skull this is a minor difference but still has to be taken into account.

A) Skull

	Vertices	**Complete**	**Watertight**	**Texture**
Breuckmann Smart Scan FOV-M450	1 124 695	yes	no	RGB
GOM ATOS Core 300	2 603 875	yes	no	BW
GOM ATOS Core 300 standard process	1 407 594	yes	no	BW
Mephisto EX-Pro	2 860 746	yes		Albedo
Artec Spider	461 199	no	no	RGB
Artec EVA	512 810	yes	yes	RGB
FARO ScanArm	1 008 768	no	no	no
Mantis	245 591	no	no	BW
NextEngine Wide	220 799	yes	no	RGB
NextEngine Macro	1 361 975	yes	no	RGB
NextEngine Mix	537 371	yes	no	RGB
Photogrammetry	499 952	yes	yes	RGB
CT	9 995 855	yes		no
HDI	2 843 585	yes	no	RGB





CT has more vertices because of the internal structure, this make it not relevant for vertices comparison. Spider and Mantis are incomplete so not relevant as well.

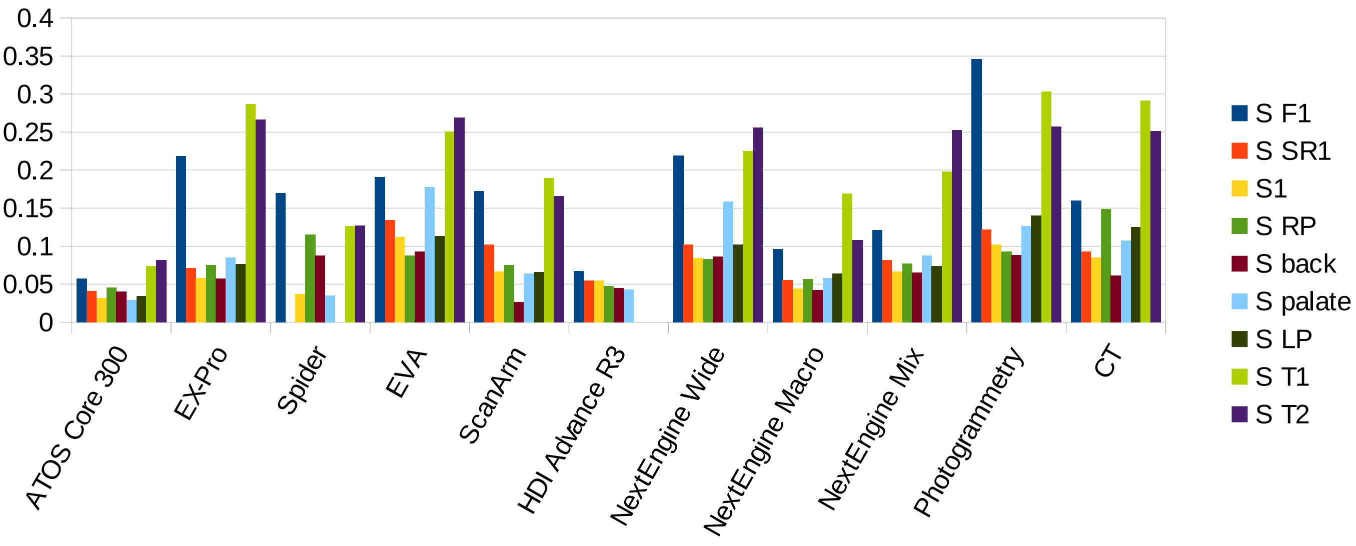
We are not including Mantis in the comparison because is not meshed (and very incomplete). And the model from FARO ScanArm is incomplete, so it is probably not representative of what the scanner can do.

In orther to compare with GOM Inspect, we compared:

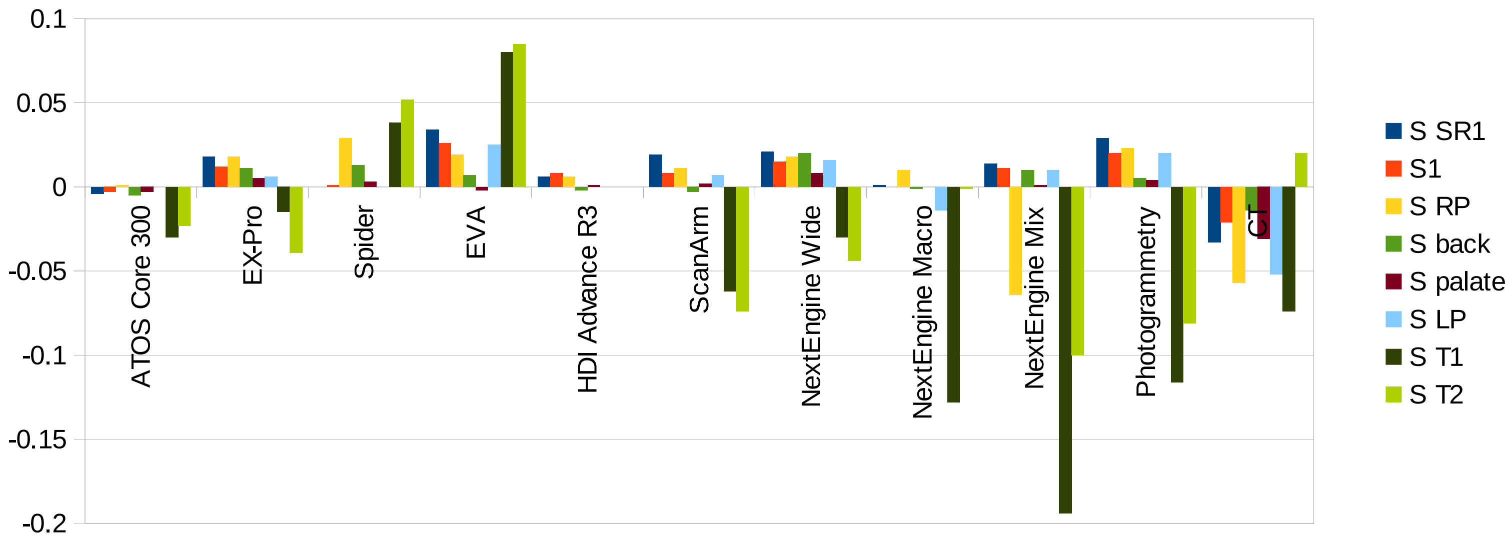
- the general shape of the skull. This allowed us to check if there were no aligning problem, if there was no scaling difference, or any large deformation or artefact.

- then we compared cut sections of different parts of the skull: 5 sections for the bone structures and 2 for the tooth, this allowed us to see the local differences, how similar for one small part were the different measurements. This also showed us that the part with most deviation were the teeth. We mentioned previously that some teeth were slightly moving, this is why we did the same process on the Spy tooth alone. In general, for bone, the two lenses structured light scanner, the FARO ScanArm, the Macro NextEngine and the artec spider have a similar deviation between 0.03 and 0.06, while the EVA, the wide NextEngine, photogrammetry and the Mephisto are more in between 0.07 and 0.13.

- the graphics present the comparison in regard to the SmartScan data. That doesn't mean it is error free, it just allow to give a reference point.



Graphic representing the differences between the models in relation to the Breuckmann SmartScan. S F1 represent the comparison for the full skull, S T1 and S T2 represent the section of the teeth. The teeth section were not measured for the HDI.



Graphic representing the mean deviation of the different section of the mesh captured with different equipement in regard from the Breuckmann SmartScan.

The HDI model of the skull is slightly smaller than the SmartScan model. This might be an issue of calibration, we would need to repeat test.

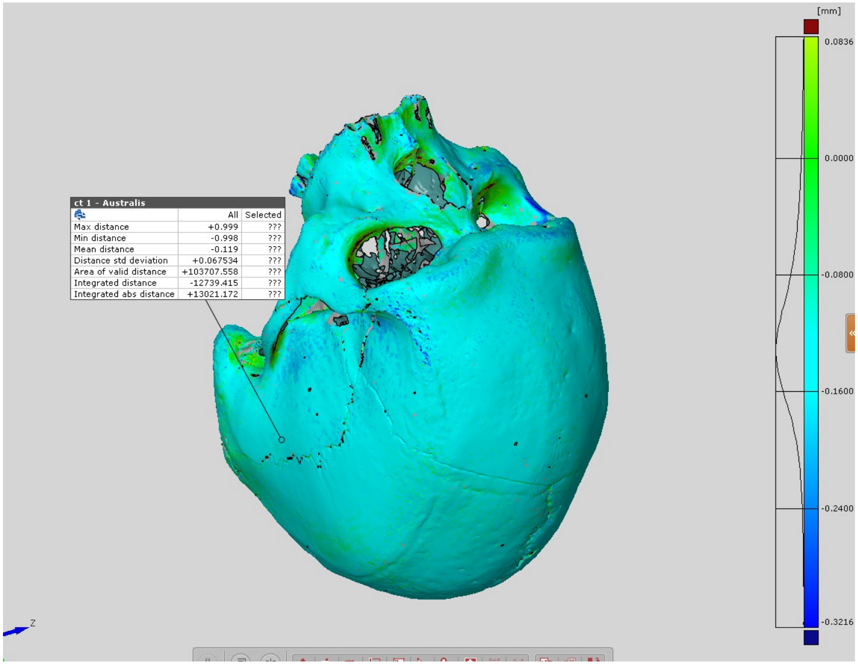


Fig. 34: HDI model compared to SmartScan. The model is generally smaller (of -0.1 mm approximately).

The differences at the suture with CT are always superior as the technique captures internal structures, it goes much deeper.

Some of the teeth of the skull are moving inside the socket of the skull which explains part of the noise on the enamel.

B) Sea Urchin

	Vertices	**Complete**	**Watertight**	**Texture**
Breuckmann Smart Scan FOV-S60	2339115	yes	no	RGB
GOM ATOS Core 80 precision process	422807	no	no	B&W

GOM ATOS Core 80 standard process	243304	no	no	B&W
Mephisto EX-Pro micro add-on	34203594	yes	yes	No
Artec Spider	194730	yes	yes	No
FARO SmartScan	100691	no	no	No
HDI Advance R3	313623	yes	no	RGB

We had the same process for the sea urchin. The results from the Atos Core and from the SmartScan are very close, while the result of the Spider is the most irregular.

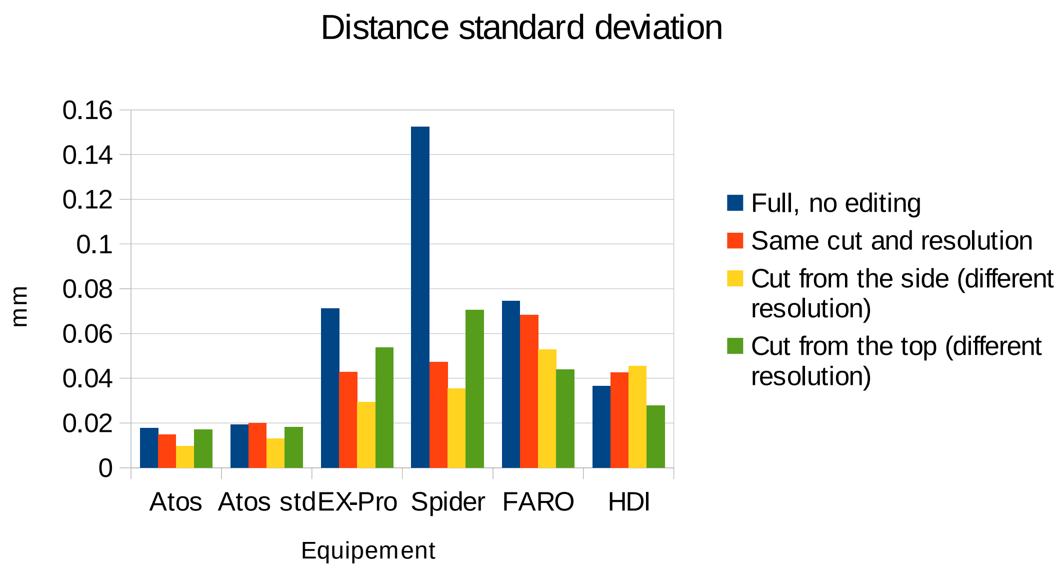


Table of the standard deviation of the Sea Urchin in regard to the SmartScan model.

Our different comparisons show that if the Mephisto models have the biggest among of vertices, that doesn't make them the more precise, the other software's are probably doing a better job at optimising the mesh than the others.

We can also say that the structured light scanners with 2 cameras give best results among the structured light scanners. The Artec Spider has 3 cameras, but as they work with a different principle behind than the cameras scanners tested, the results are not as good, but still better than the one camera scanners. The Artec Spider is also more subject to errors, creating artefacts due to noise than the others technique (probably because of the constant acquisition on the move?). The advantage of the Spider is its portability.

It is harder to draw conclusion on the laser scanner since, except from the NextEngine, we have very few data to go by with.

3) Aspect of the texture

Texture comparison:

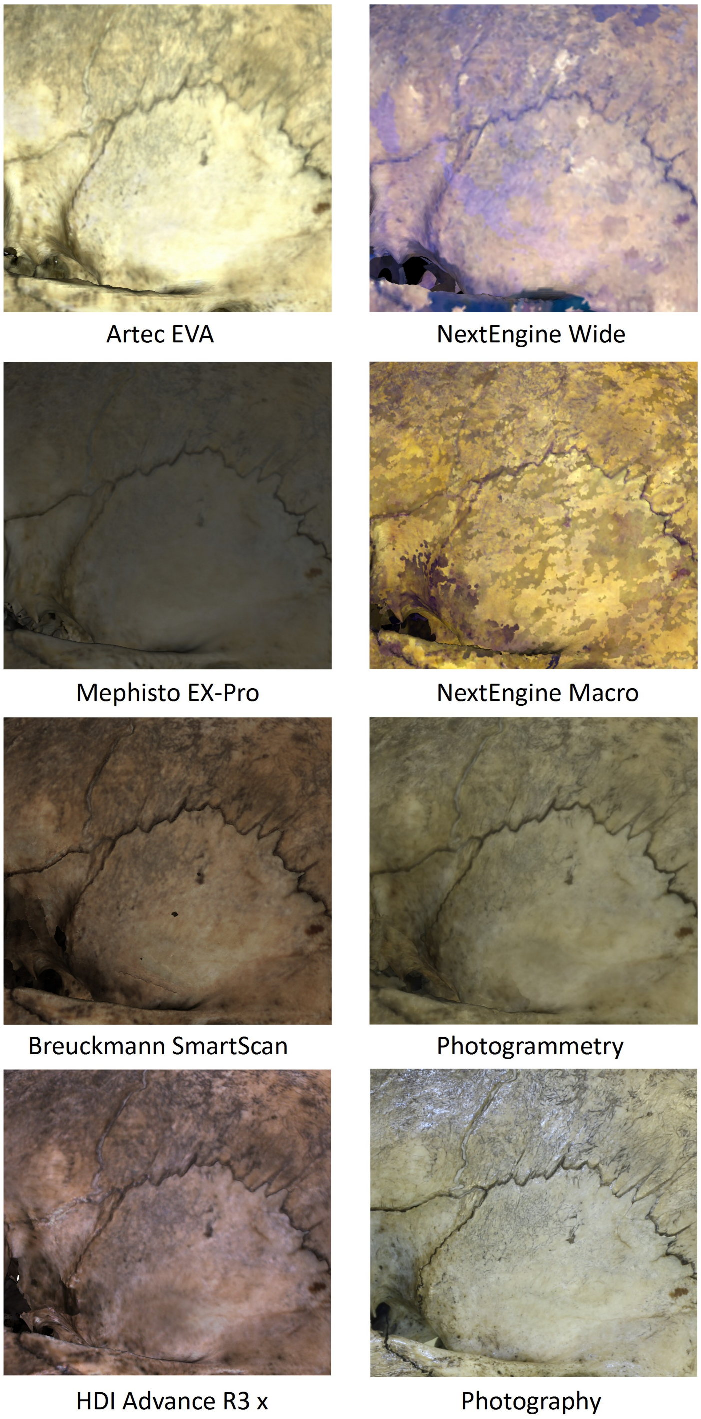


Fig. 35: Texture comparison between the different equipment and the picture.

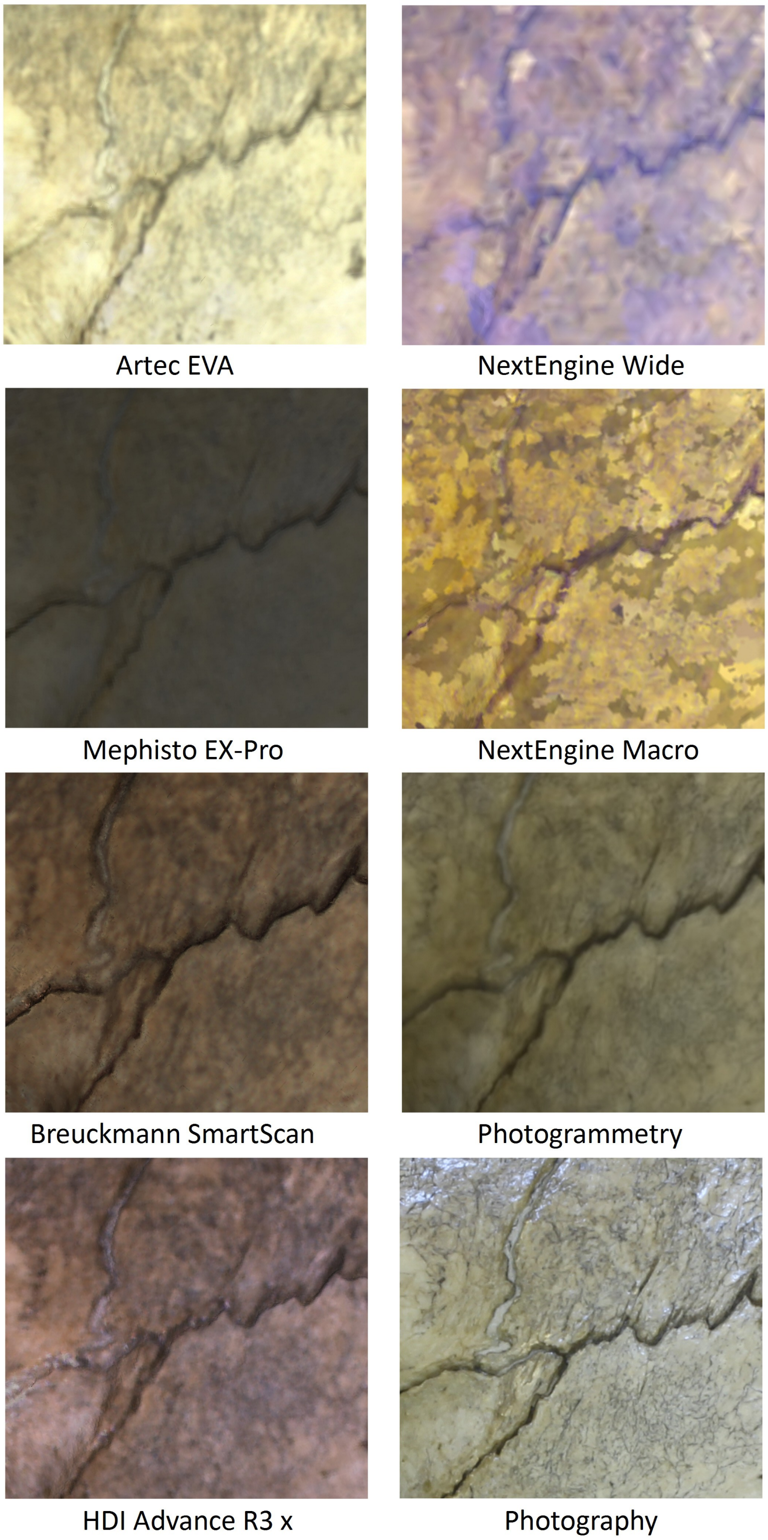


Fig. 36: Detail for texture comparison between the different equipment and the picture.

No filter was apply to the texture to improve them.

Regarding colour accuracy photogrammetry is the more colour accurate, followed by Breuckmann SmartScan, EVA and HDI Advance R3x for the skull example. The NextEngine is the one more far away from reality with some purple/blue spots.

It is difficult to include the Mephisto model in the colour comparison since it's an albedo map.

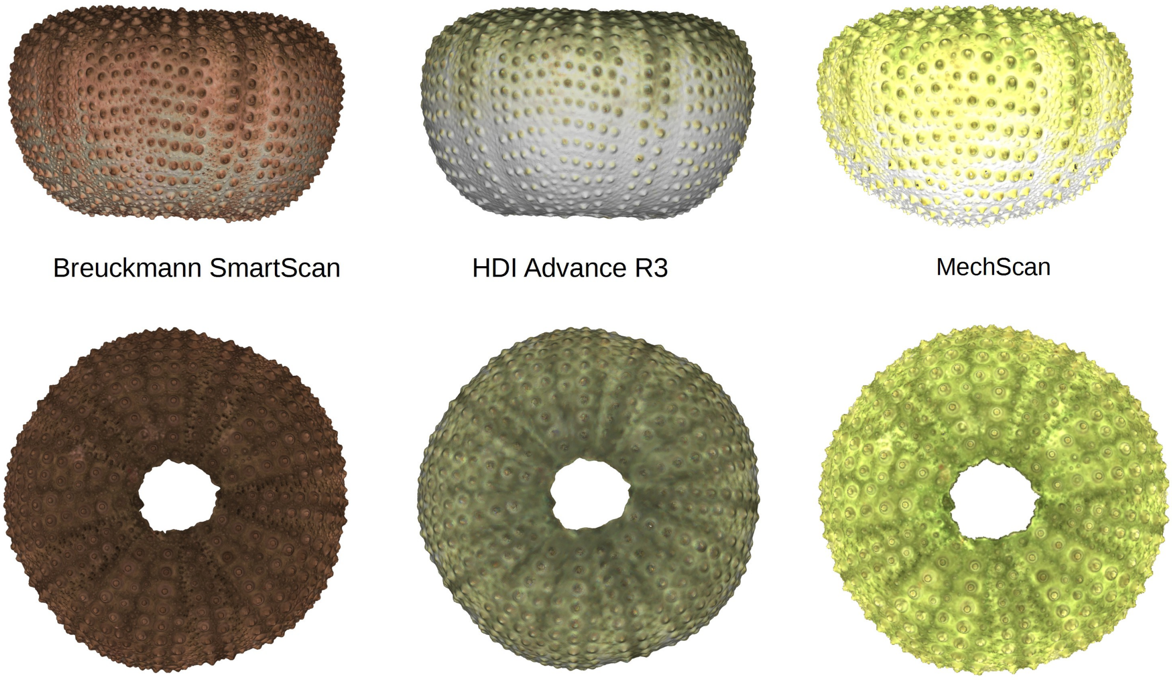


Fig. 37: Texture comparison between the different equipment.

For small specimens the texture (fig. 37) from the Breuckmann in this case is a bit reddish, the one from the HDI is more accurate colour wisely. The MechScan is overexposed.

Fig. 38: Texture comparison between photogrammetry and MechScan.

Fig. 39: Picture of the shell displayed on fig. 38.

Colourwise, the photogrammetry is more close to reality than the MechScan texture. The MechScan texture is greenish in regard to reality and less precise.

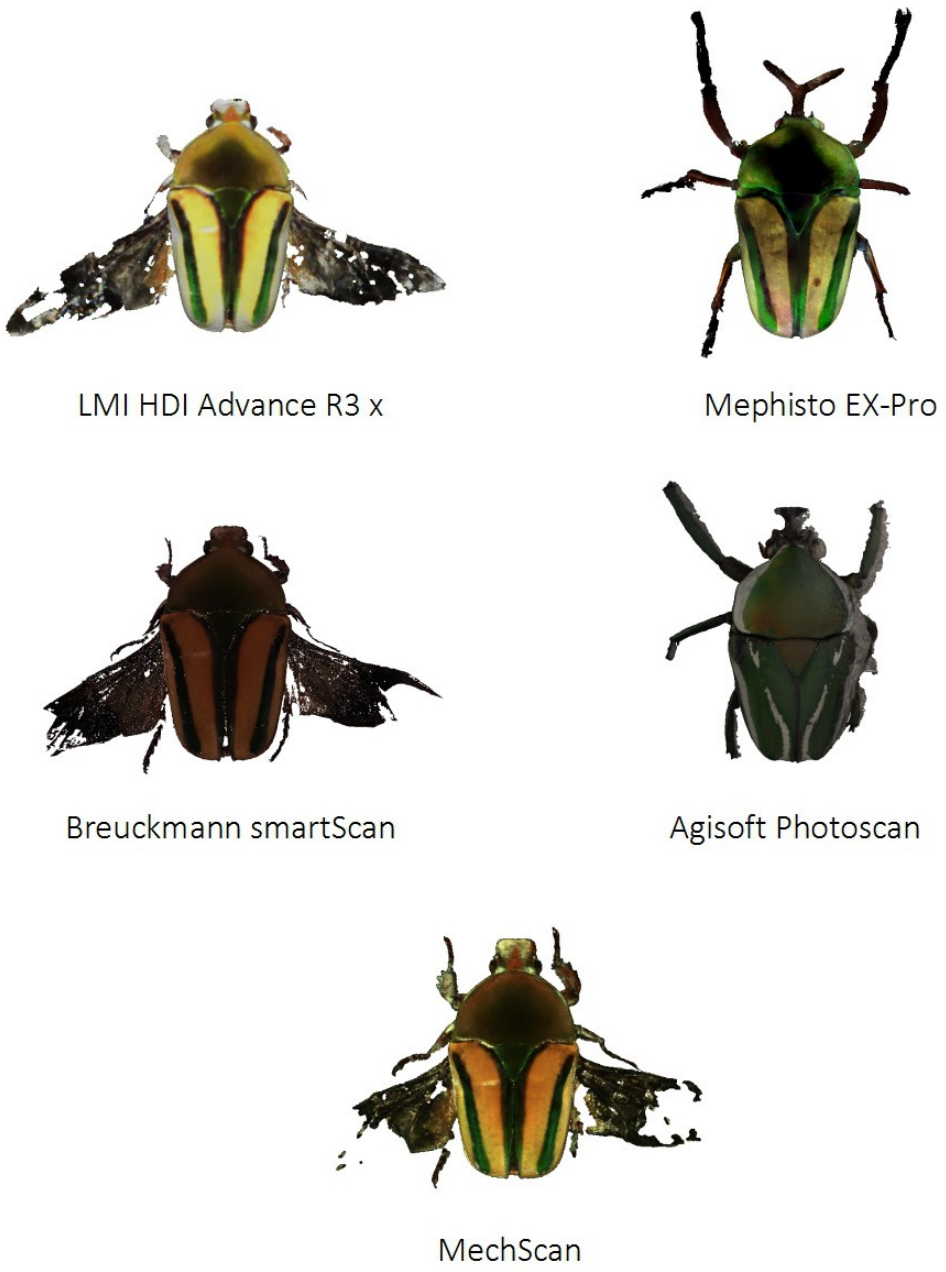


Fig. 40: Different beetles digitised with several techniques. The SmartScan colour is reddish again, while the HDI texture is slightly overexposed. The MechScan result is not overexposed this time.

5) General material analyse

List of material tested:

Materials	**Structured light**	**Laser scanner**	**Depth sensor**	**Photogrammetry**	**CT/µCT**
Alcohol collection	/	/	/	yes	
Ancient glass	/	no	no	no	
Animal skin	/	/	yes	yes	
Basalt	/	/		yes	
Beetles	partly	no	N.a.	partly	yes
Benmoréite	/		yes	yes	
Black glass	no	/	/		/
Bone	yes	yes	yes	yes	yes
Bronze	/	/		partly	
Coral	no	no	N.a.	no	
Dirt	/	yes	yes	yes	yes
Enamel	yes	no	yes	partly	yes
Feathers	no	/	/	partly	
Flint	yes		/	yes	
Fossile	/		yes	yes	
Fure					
Granite	/	yes		yes	
Hématite	yes	/	/	/	
Ivory	/	yes	yes	yes	
Limestone	/	/	yes	yes	
Matte ceramic	/	/	/	yes	yes
Matte gold	/	/	/	yes	
Opaque shell	yes	yes	/	yes	
Oxyded metal	/		/	yes	
Painted plaster	/	yes		partly	
Pearl	/	no	/	no	
Pirite	/	/	/	yes	
Polish quartz	no		/	no	
Polish wood	/			yes	
Reflective silver	/	no	/	no	
Shiste	/	/	/	yes	yes
Sintered glass	/	yes	/	yes	
Sponge	no	/	/	/	
Stuffed bird	yes	/	/	yes	
Textile	/	/	/	yes	/
Translucent shell	no	/	/	yes	
White marble	/			yes	
White plaster	/	yes		no	
Wood	/	yes	yes	yes	

Table showing what materials were tested with each technique and if the output worked or not. Partly is when we get a general shape model, but no detailed enough, at lease not possible to use for scientific purposes.

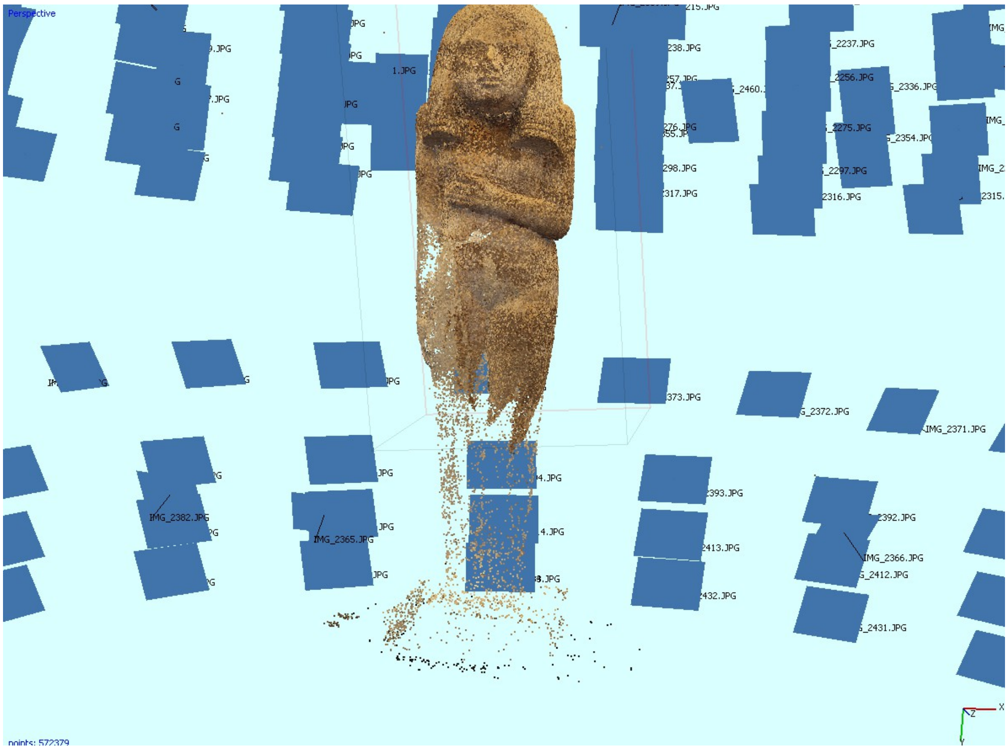


Fig. 41: Dame de Bruxelles (stone and white plaster). The « Dame de Bruxelles » (E.00752) is one of the masterpieces of the Egyptian collection from the Royal Museum of Art and History in Bruxelles (RMAH). The statue is 71 cm in height, originally in limestone, it has been restored with plaster for missing fragments. The model was digitized with photogrammetry using Agisoft Photoscan. As you can see on the figure, the limestone part is superbly rendered but the software was unable to render the plaster part with detail.

Fig. 42: Charles V (painted plaster, KIK-IRPA). Two Charles V bust were digitised at kik-irpa before restoration. They were digitised with a laser scanner (NextEngine) and by photogrammetry. Those bust were made in painted plaster and painted plaster is quite reflective. The model from NextEngine work out fine, with photogrammetry we get results, but the part were the reflection was too strong like the nose only resulted in creating noise on the model.

Fig. 43: Merovingian portable altar (wood and oxyded metal, hight: 12,5 cm, large: 7,5 cm, depth: 2,5 cm, B005717-001). This reliquary from the merovingian collection of RMAH is compose of oak wood and oxyded metal (coper alloy). It was digitised with both photogrammetry and NextEngine with equivalents results.

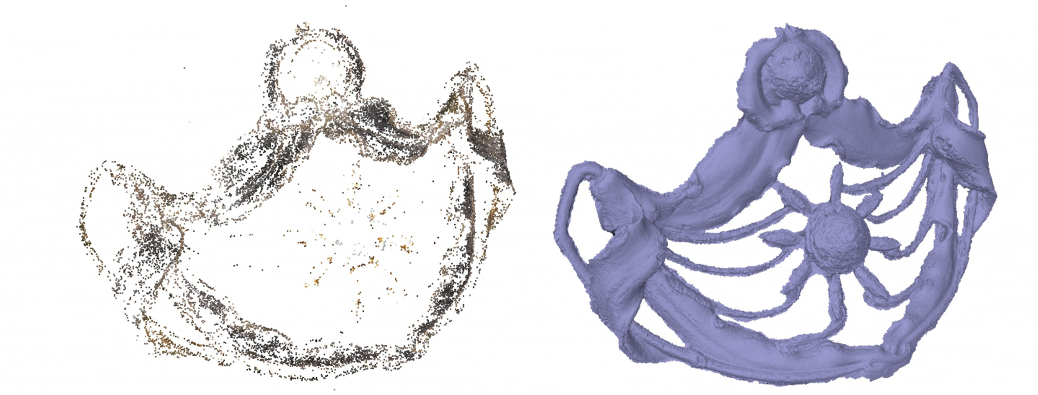


Fig. 44: Art Nouveau buckle (shiny metal, pearl, gemstone). This buckle from the Art Nouveau collection of RMAH is very shiny, we tested a NextEngine and photogrammetry and none of those technique managed to create a descent model out of it.

Fig. 45: Shells (RMCA collections). The shells tested are not properly speaking cultural heritage object, but we can encounter shells in cultural heritage collections. We tried different type of shell: matte, semi-reflective and translucent. The matte and semi reflective work with both structured light and photogrammetry. The translucent shell work with photogrammetry but not with the structured light scanners.

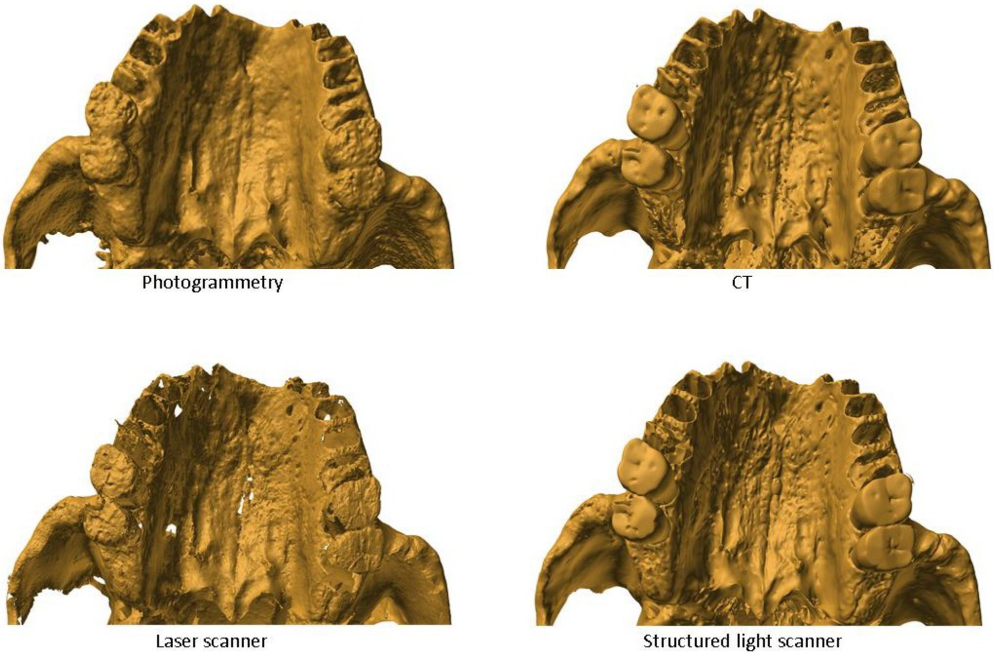


Fig. 46: Skull (bone and enamel). This skull from RBINS has been scan with structured light, laser scanning, photogrammetry and CT scan. A previous paper has already been publish with the studies of the accuracy of the results.

Fig. 47: Vers l'infini et l'au-delà (ivory, bronze, wood, Sc.059, height*: 40,8 cm, large: 12 cm, depth: 7 cm). Picture on the left, 3D model obtain with laser scanner on the right. This small statue of Pierre Braecke of approximately 40 cm high is composed of a wooden based, overcome by a golden bronze and ivory statue. We digitised it with photogrammetry and laser scanning. Photogrammetry captured both the bronze and the wooden part with enough detail, but generate some artefact on*

the ivory part. The results are better with the laser scanners even though there is some extra noise remaining on the ivory part.

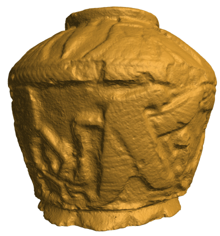


Fig. 48: Egyptian pot (glass paste, E.6169, RMAH). This small Egyptian pot is a few centimetres high and made out of varnished ceramics; It was captured with both photogrammetry and laser scanner. Considering the pot was too small for the techniques used, the results are quite satisfying: the mesh might not be as precise as wished but there is not extra noise of extra holes due to a difficulty to capture the material, which lead us to conclude that varnished ceramics work fine with both techniques.

Fig. 49: African statue (wood, textile) from MRAC (photos Joris Van de Vyver). This statue is interesting because it shows that photogrammetry can display textile on the model.

Fig. 50: Bronze statue from Constantin Meunier (RMFA). Both statue were digitised by photogrammetry in the museum with no specific background or light. The picture weren't masked before producing the model. The software generated the general shape but the surface is relatively noisy due to the reflections, specially the puddler. The models could be improved by a good masking of the picture.

Fig. 51: Stuffed animal digitised with photogrammetry.

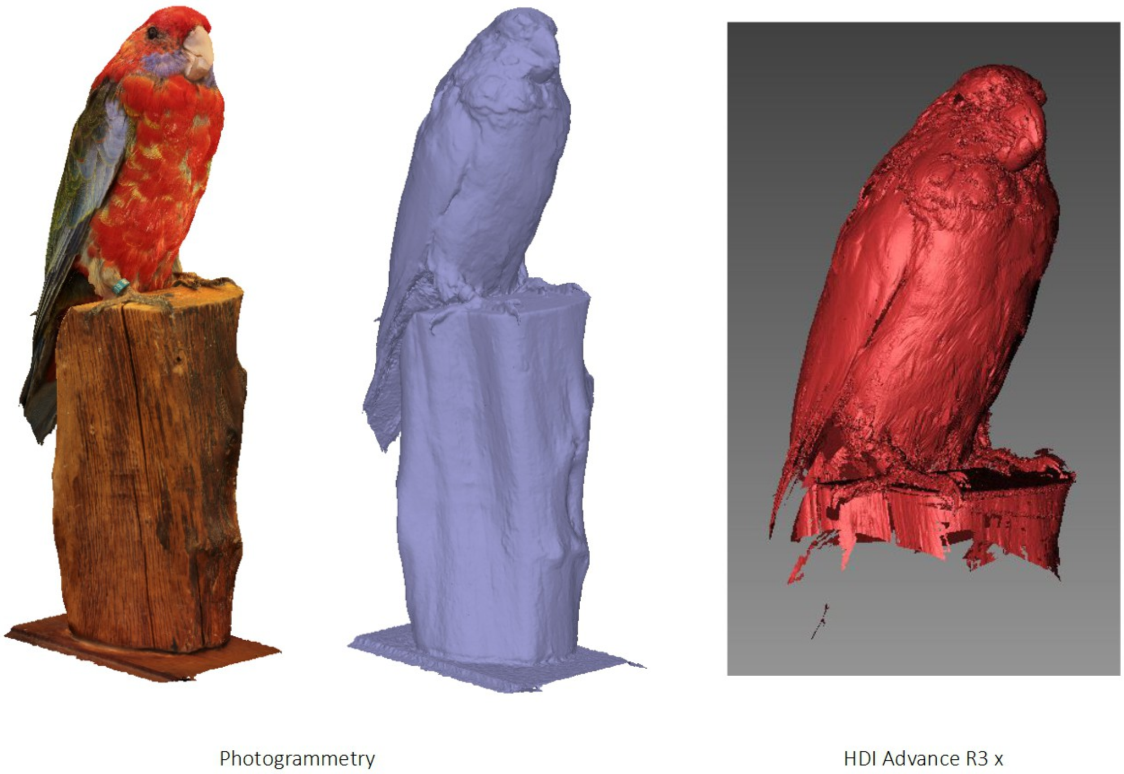


Fig. 52: Parrot digitised by photogrammetry on the left and by the HDI on the right. Both are able to display a general shape, but the photogrammetry lacks detail on the feathers. The HDI model has some detail on the feathers as long as they are close to the body, but if they are isolated, it just generates noise.

- Insects and animals

Insects (fig. 32 & 40) are among the trickiest objects to digitise in 3D. Firstly due to their small size, it is not possible to digitise them with many techniques. Also they are usually hairy, with iridescent or translucent (wings) parts. Except for µCt, up to now, none of the 3D technique tested gave satisfying results (for scientific purposes).

Stuffed animal with fur (fig. 51) don't work with none of the technique because of the hair (tiny, translucent), you can get a result for visualisation purpose but the mesh under the texture will always be very noisy.

For stuffed birds (fig. 52), you can get the general shape for visualisation purpose with both structured light and photogrammetry. With structured light you can have some detail on the compacted feathers, while it will just create noise if the feather is alone.

- Stones

Different types of stones have been tested. Matte stones like basalt, benmoréite or limestone (fig. 41) are easy to capture with all techniques. More glossy stones like flint or granite are possible to capture as well with most techniques but necessitate more captures due to the reflectiveness. Polished translucent quartz on the other hand is more reflective and translucent, it doesn't give good results with surface scanners or photogrammetry but work with µCT.

- Wood (fig. 43 & 45)

Wood thanks to it structure, and as long as it doesn't have a too glossy varnish, works very nicely with all technique mentioned previously. In case of very dark polish wood you'll need to overexpose your picture a bit for the photogrammetry model.

- Plaster

Photogrammetry doesn't deal well with plaster in general. From one hand with white plaster, there is not enough detail on the material which doesn't allow the software to reconstruct a detail enough model (fig. 41). From the other hand, with painted plaster (fig. 42), we faced problems with the reflection of the material. In this case photogrammetry managed to reconstructed the general shape, but some part with too much reflection are reconstruct with a lot of noise. It is the case for the example of Charles the V from KIK-IRPA. The model is relatively good but the nose on the collar where the reflections are significantly stronger displays a lot of noise.

- Metals (fig. 43, 44 & 50)

Like stones, metals have a lot of different aspect, they can be reflective and glossy, matte or oxidized. We tested different objects and our result showed that very reflective glossy metal doesn't work neither with photogrammetry nor with laser scanning. Glossy metal that are not too reflective can work with photogrammetry to create a general shape, but with lit of noise. Matte or oxidized metal on the other hand work fine with both techniques.

- Bone and enamel (fig. 46)

The use of 3D digitisation techniques is not new in anthropology and is already known to work well. Ct, µCT, photogrammetry, structured light scanner, laser scanner and motion sensor can all produce easily models of bones.

Enamel is a tricky material because it is a translucent and reflective material. A laser scanner is bothered by the translucent aspect of the enamel which results in a noisy structure of the model. Photogrammetry, like for painted plaster is troubled by the reflections, which results also in a noisy model.

Structured light deals relatively well with the enamel and CT and µCt give the best results.

- Glass

Regarding glass, most scanners don't see glass because of the transparency, even antique glass with impurity. Photogrammetry is probably the surface technique who can achieve the best result with antique glass, but the software doesn't understand the transparency. But to achieve really good results with glass or transparent material in general, they are only recordable by CT/µCT among the technology mentioned here. It is also worth mentioning that new technologies are being developed allowing to scan transparent materials:

- 3D heating scanning (probably not recommended for museum collections)
- Shape from polarization
- Scanning from Hearing
- Shape from visible Fluorescence induced UV

- Others

Pearl (fig. 44) doesn't work with laser scanner nor photogrammetry, probably due to the reflective aspect (and the absence of detail in the material for photogrammetry).

- General conclusion on materials

From the list of materials tested above, even though we didn't test all the materials with all the techniques, we can conclude that matte material works in general with both laser scanner and structured light. It is the case for wood, most stone (except if there are polish and translucent) and bone, they work with most techniques mentioned in this report.

Plaster, enamel and pearl don't generate good results with photogrammetry, but work with structured light scanner. Laser scanners can deal with plaster but not with glossy reflective material like enamel, pearl or shiny metal.

Material is not the only parameter, lighting conditions is also an issue. As mentioned in the previous report a dark object won't work with photogrammetry unless it is over-exposed and if you use direct flash you won't record any volume. Light can also influence results with other techniques, an overexposed object won't be well captured by structured light. A change of lighting conditions during the scanning can also led to incrementing noise and artefacts.

b. 3D printing

Recently we had the opportunity to go the Rapid Pro fair in The Netherlands (www.rapidpro.nl), which is a fair mainly about 3D printing and 3D scanning, but CNC machines are also on display. As most of the exhibitors at the fair presenting 3D scanners already visited the institution and results are presented above, we will focus on the 3D printing availability. As this industry is booming at the moment lots of 3D printers get manufactured and released each week. As a result, the ones discussed shortly below are only those presented at the fair (which were BeNeLux resellers) and probably already old news. None the less this might give you an idea of what is happening at the moment and what you can get for a certain price range. If you want to get deeper into this material, the webpage: www.3ders.org has tons of information with at least 130 posts about 3D printing related news each month. On that webpage you'll find price comparison table as well, although its a few months behind on updates.

Unfortunately we didn't have the chance to test the different printers and compare printed models to each other and can't say much about accuracy or user friendliness. But as the trend in the next generation of 3D printers already shows, it is better when the set-up is a closed environment. In this way the printing is more stable and less problems arise during the printing. The next step of course is the bigger building volume and a blend of naturalistic colours.

Big Builder

3dprinter4u.com

Build volume: 220 x 210 x 665 mm or 30.7 l

Layer Thickness:

0,05 mm - 0,35mm

Price: 2495 euro

Makerbot Replicator Z18

store.makerbot.com/replicator-z18

Build volume: 305 L x 305 W x 457 H mm

100 microns

Price: 5999 euro

Cartesio

www.cartesio3d.com/

build volume: 400 x 200 x 200 mm or 16 liters

100 microns

Price: 3599 euro

Tripodmaker

www.tripodmaker.com/product/tripodmaker/

build volume: 300 mm diameter x 425 mm Height

Price: 1800 euro excl. VAT

Ultimaker 2

www.ultimaker.com/pages/our-printers/ultimaker-2

Build volume: 230 x 225 x 205 mm

up to 20 micron resolution

Price: 1895 euro

NextDent 30 or 30L (dental printer)

nextdent.nl/3d-printers/

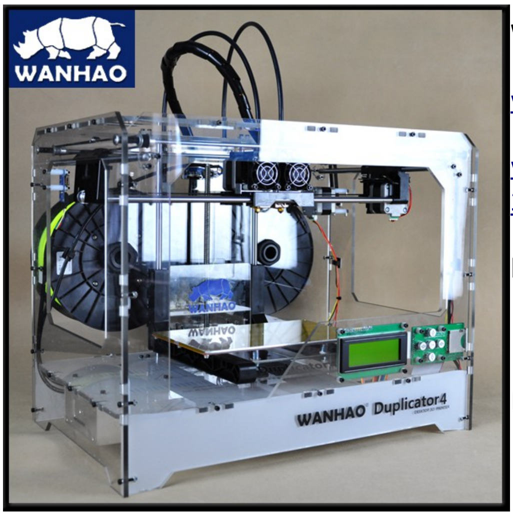
www.youtube.com/watch?v=aU-8-TeREUA

build volume 30: 110 x 62 x 80 mm (l x w x h)

build volume 30L: 110 x 80 x 80 mm (l x w x h)

35 micron precision

Price: ???



Wanhao Duplicator 4x:

www.wanhao3dprinter.com/

www.3dprima.com/en/3d-printer/wanhao-duplicator-4-3d-printer-black-case-with-dual-extruder.html

build volume:225 x145 x 150 mm

100 microns

Price: 1242.75 euro

WP-6 Accessibility

(2 PM AGORA3D+ 2 PM Consortium; T3 – T16)

The High resolution digitization will generates a lot a heavy data files. The consortium has to anticipate this with special attention to the ownership of the digitized data. This work-package will also evaluate the storage technologies in order to guarantee the long term preservation of the data and the access by the scientific community. For RBINS and RMCA, the user requirements of the Agora project will be used for the development of the Multimedia Module of the Darwin collection management system developed by RBINS in the framework of the digit program.

a – Ownership

Each discipline and institution has its usages. It is not possible to define unique rules.

In Natural History, the idea is that the 3D data are a part of the documentation of the collection specimens aas the 2D images and the data and metadata. There is no reason to follow a different workflow of ownership for the 3D data.

b – Storage and long term preservation

Different strategies can be developed at different levels

At the institutional level

Shared folders on RAID5 servers for working copies. This is managed by the ICT of each institution.

Offline backup on 3,5 inches HDD with (re)copy each 5 years. This option is the cheapest one with a price of 40€ /Tb. After 5 years, a new copy is done and it is not needed to buy new HDD. Some docking stations have the possibility to clone HDD without PC.

Inatek station for HDD backup and cloning

At the BELSPO level

A long term offline storage of the data produced by the DIGIT3 program in under evaluation by BELSPO. The files produced by the digitization of the federal collections and archives will be stored in a data centre with an access on demand.

At the European level

The situation is different in each country. At the international level, the initiatives are more oriented by discipline/topic. The major Natural History Museums are members of a consortium which is now working on different projects including the digitization of collections.

Te use of EUDAT (European Data Infrastructure) is one of the possible option but further H2020 calls will clarify the situation.

c – Access by scientific community

Each partner is working with different databases.

At the institutional level

RBINS and RMCA will use DaRWIN as main informations and data databases. Additionally the MARS database is also used for the anthropological and archaeological data.

DaRWIN and MARS are two databases developed in the framework of the BELSPO projects DIGIT5 and MARS.

d – Access by public

Access by specific applications or website(s)

e.g. The museum of Belgian Prehistory and the Palaeolithic Mobile art

Access by the BELSPO dissemination platform

BELSPO will develop a specific platform for the dissemination of the digitized collections.

Until today, it is not defined how the platform will work. One of the challenge is to propose attractive interface for very different types of collections and publics.

One of the idea is to create virtual Museums on specific topics with the digitized material from all FSI but nothing is clearly define yet.

Europeana

For the cultural Heritage collections, Europeana is certainly one of the important diffusion portal but not yet for the 3d Natural History collections.

WP-6 Sustainability

AGORA 3D is now a pilot project for the BELSPO digitization program of the Belgian Federal Collections.

Different digitizations technical lines were defined and the 3D/2D+ is one of them. Even if the aim is to develop shared infrastructures and staff, the funding and the contracts are allowed at the institutional level. RBINS and RMCA decided to collaborate in the digitization of the Zoological types specimens and the published and illustrated specimens. The number of items to be digitized is evaluated to 200 000 specimens and xxx for RMCA.

The evaluation of the digitization cost by specimen shows that the cost changes dramatically with the number of objects to be digitized. We evaluated several 3D digitisation techniques but considering different amount of specimens to be scan. We selected a set of equipment for which we had enough experience, having produced a great number of model out of it, in order to have a good set of data on average time necessary to scan a medium size specimen and a small specimen. We considered here 4 technologies: photogrammetry, X-ray based (Computed tomography and micro computed tomography), structured light scanner and laser scanner.

The equipment used for photogrammetry is Agisoft Photoscan using a DSLR camera. The lens was a 60 mm macro for medium specimen while we used a 100 mm macro for smaller specimens. A medium size specimen has a diameter of 10 to 40 cm, while a small sized one is less than 10 cm.

Regarding structured light we choose the HDI Advanced R3x for middle size specimens while we based our numbers on the MechScan for smaller specimens. Both scanners use the Flexscan software and an automated turntable.

The laser scanner we choose is the NextEngine, we only consider middle size specimens. The NextEngine scanner, used in many Museums, works with the ScanStudio software and an automated turntable as well.

Finally regarding X-ray based technologies, we based our numbers on the medical Siemens CT equipment for middle range specimens while we used µCT for smaller specimens. For CT we use the prices based on a renting service, instead of buying an equipment, but we still process the images ourselves which requires a powerful computer and a dedicated software like Avizo/Amira/Mimics/ORS visual. For µCT we indicated the price of a SkyScan 1173.

	Medium size				Small size			
	Photogrammetry	Structured light (HDI Advance)	Low cost laser scanner (NextEngine)	CT Siemens	Photogrammetry	Structured light (MechScan)	Low cost laser scanner (NextEngine)	µCT Skyscan
Portability	+++	+	++	-	+++	+	++	-
Specimens / week	*50*	*75*	*25*	*84*	*50*	*75*	*25*	*50*
Cost of equipment	*3 500*	*22 000*	*3 500*	*250/h + 1 500*	*4 000*	*45 000*	*3 500*	*240 000*
Staff salary / week	*1 000*	*1 000*	*1 000*	*1 000*	*1 000*	*1 000*	*1 000*	*1 000*
100 specimens								
Time (weeks)	2.0	1.3	4.0	1.2	2.0	1.3	4.0	2.0
Total cost (€)	5500	23333	7500	9574	6000	46333	7500	242000
Price / specimen (€)	*55*	*233*	*75*	*96*	*60*	*463*	*75*	*2420*
1000 specimens								
Time (weeks)	20.0	13.3	40.0	11.9	20.0	13.3	40.0	20.0
Total cost (€)	23500	35333	43500	39038	24000	58333	43500	260000
Price / specimen (€)	*24*	*35*	*44*	*39*	*24*	*58*	*44*	*260*
10000 specimens								
Time (weeks)	*200*	*133*	*400*	*119*	*200*	*133*	*400*	*200*
Total cost (€)	203500	155333	403500	333681	204000	178333	403500	440000
Price / specimen (€)	20	16	40	33	20	18	40	44

Table: Table of the cost in function of the quantity of specimens to be digitised.

(-) = not transportable.

(+) = transportable with suitcases.

(++) = transportable with backpack but need electricity in order to work.

(+++) = transportable in a backpack and don't need electricity in order to work.

We consider the price for staff to be approx. 1000€/week.

The prices include 1 or 2 workstations of approx. 1000-1500 € in order to have a good graphic card and enough RAM (12-16Gb advised). In the case of photogrammetry, you can capture the object in a relative short time, that allows to make 10 acquisition a day and prepare the process file, but you need approx. 3 hours of processing for each model in order to have a descent quality. If you capture 10 objects in one day and need 3h to process each, you'll need 30 hours to process those 10 models. That is 150 hours for one week of capture plus the 38 hours were you are actually working with the computer (taking picture, preparing the photogrammetry mask and batch file), and you only have 168 hours in a week considering week-ends so you will need 2 workstation to keep up. We didn't consider storage of the data in the prices.

By comparison, EU asked to several Natural History Museums some feedback about the previous and running digitization programs. Very few institutions include 3D digitizations:

Biology Centre Upper Austrian State Museum

Subject	**Amount**	**Scope**	€	**Weeks**	*Remarks*
3D museum items	*Digitisation of 10,000*	Scan/photo AND metadata (excl. validation)	250.000	250	Entomology Type Specimen 6-10 high quality detail pictures per specimen, until now we have digitised approx 1800 specimens

Hungarian Natural History Museum, Budapest

Subject	**Amount**	**Scope**	€	**Weeks**	*Remarks*
3D museum items	*Digitisation of 10,000*	Scan/photo AND metadata (excl. validation)	25.000	168	Experience: outsourced, we have digitised crania from Antropological collections

NHMC-Natural History Museum of Crete

Subject	**Amount**	**Scope**	€	**Weeks**	*Remarks*

3D museum items	*Digitisation of 10,000*	Scan/photo AND metadata (excl. validation)	150 (each)	3 items/working day (appr.665 weeks)	Exhibition quality output (>8 MP, 3D techniques, digitally enhanced). ENDEMICS & other valuable specimens, skulls. 5-6 or more photos per specimen, label scans. Estimated number of such specimens ≤200.

Perspectives

More research can be done on the topic, among some of the topic to be further investigated:

- test further the patterns for photogrammetry

- analyse the temperature and light influence on the quality of the measurements

- test the repeatability of the measurement

- test the use of filters or polarising light for photogrammetry for reflective objects

- test multi-spectral photogrammetry

- find a solution to digitise alcohol specimens with surface method and not only MRI.

Nevertheless, we think that the technique which can help us to digitize very difficult objects is the minidome developed by the KUL. Since our first tests, new settings (hardware and software) were achieved and a new settings is now available for our work.

A first version of a multispectral minidome is also under development and open new perspectives for the digitization of Cultural Heritage objects but also for Natural History specimens.

We will evaluate in detail the potential of the minidome with Natural History specimens in the framework of the Synthesys 3 European project which started in March 2014. We have to provide the results for spring 2015.

On the other hand, the AGORA 3D partners and the KUL will submit together a Belgian Research project BRAIN axe 6 application in order to develop a prototype of Multispectral 3D scanner based on the minidome technology. This equipment will be able to combine the advantages of the different techniques allowing to digitize automatically small objects and manually medium size objects of Cultural Heritage and Natural History collections. The collections of the FSI partners will be used as test cases and the needs of scientists will be the source of the user requirements.

If selected, this proposal will also participate to the Belgian input in the COSCH Network (EU COST).