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

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

Duration: 1/9/2012-31/3/2014

Second Preliminary Report
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A. Introduction

The AGORA 3D consortium is composed of 4 Belgian federal scientific institutions of the "Nature Pole" and the "Art Pole". The institutions involved in the project are :

- The Royal Belgian Institute of Natural Sciences
- The Royal Museum of Central Africa
- The Royal Museums of Art and History
- The Royal Institute for Cultural Heritage

The goal is to maximize the collections represented in the project. The partners are already involved in several scientific programs using high resolution digitization for scientific purposes. It is necessary to develop these technologies because they are used in many new fields of research in taxonomy, biomechanic, material science, archaeology and history of art. Universities, often developers of these techniques do not have a role as partner in the consortium, but could be considered as suppliers of technology.

A general presentation (poster) of the project is available here. The complete description of the project submitted to Belspo and selected by the international referees is available here *.

*For access to private links, please see AGORA3D CMS.

B. Evolution of the Staff

- Serge Lemaitre, engaged as senior researcher part-time by RBINS stopped his contract with the Agora3D end of March. He is now working full time at the RMAH preparing a new exhibition. He continues to work in collaboration with the project.
- Aurore Mathys, replaced Serge Lemaitre as archaeologist. She continues also to work part-time at the RMCA as 3D technical technician.

The official end of the project is March 31th 2014. Nevertheless, the new staff distribution allows to extend the operational end of the project to June 30th. We propose to extend the contract of Jonathan Brecko and Aurore Mathys like this :

- Jonathan Brecko will be part-time at RBINS until June 30th 2014.
- Aurore Mathys will be part-time at RMCA and RBINS until March 31th and full time at RMCA from April first until June 30th 2014.

C. Work-packages and time-line

The initial duration of the project is 18 months. Agora3D is divided in 6 work-packages :

WP-1 Networking & dissemination

WP-2 Definition of the type of collections and priorities

WP-3 Digitization & Standardization

WP-4 Evaluation of the technologies

WP-5 Tools

WP-6 Accessibility & Sustainability

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 *b: Public Website*

A public website with anonymous access allows the dissemination of the results of the project to a large audience of scientists and non-specialists (task WP1-b).

This website is available now in three languages (French, Dutch and English) and is hosted by RMCA at the following address: agora3d.africamuseum.be.

The website introduces the project and the tools used. It displays some examples viewed in 'Unity 3d' and the next step is to implement an RTI viewer on the website.

WP-1 c*: International Cooperation*

1) Projects:

- COSCH : Colour and Space in Cultural Heritage (Cost TD-1201: 07/11/2012 – 06/11/2016)

This COST Action (COSCH) is contributing to the enhanced understanding of material and helps its long-term preservation. COSCH will provide a stimulating framework for articulating and clarifying problems, sharing solutions and skills, standardising methodologies and encouraging a common understanding, widening applications and dissemination. The action will foster open standards for state-of-the-art documentation of cultural heritage. It will simplify the usage of high-resolution optical techniques, define good practice and stimulate research.

The main objective of this COST Action is to promote research, development and application of optical measurement techniques – adapted to the needs of heritage documentation – based on an interdisciplinary cooperation, on a concerted European level and to offer a novel and reliable, independent and global knowledge base facilitating the use of today's and future optical measuring techniques to support the documentation of European heritage.

Patrick Semal is the official MC member representing Belgium and the Agora3D project. The first Working Groups workshop was organized in Mainz, Germany, on 27 & 28 March 2013. The next one will be at King College, (London, UK) on 23 & 24 September 2013,

- SYNTHESIS 3

Phase 3 of this European project is now accepted by the EU. It is the network of the European Natural History Museums representing 337,204,000 specimens housed by SYNTHESYS partner institutions and in particular 4,058,500 type specimens. SYNTHESIS 3 will start in September 2013, this new project will focus on the virtual collections and associated metadata. Patrick Semal is the task leader for the use of photogrammetry in the reconstruction of 3D models of Natural History Specimens.

2) Visiting Digitization Projects

- Victoria & Albert Museums (AM, 21/06/2013)

We met with Peter Kelleher form the 3D program of the Victoria & Albert Museum in London. He explained the content of the V&A's 3D program. They worked with a Breuckmann scanner and with 3DSom for the creation of photogrammetry models and for interactive application. They advise in favour of video than interactive applications with 3D models and advise us in case of application to have a display showing an already moving 3D object otherwise the public don't interact with the 3D object.

For some models, they explain to have combined several 3d model of the same object but from different technologies in order to have the best model possible.

- Petrie Museum (AM, 20/06/2013)

The Petrie Museum of Egyptian Archaeology (University College London) has also a 3D program called 3D Petrie. The project is focused on 3D imaging research and use of new technologies in the museum. They research the viability of using high quality 3D images of museum collections to engage a range of audiences through the production of 3D models of Petrie Museum artefacts and the development of end-user digital 3D applications with Unity3D (Giancarlo Amati). They work with photogrammetry but also 3D scanners from Arius 3D.

3) Evaluation and Calibration of the Surface digitization equipment

- University College London (AM, 20/06/2013)

We visited the UCL department of Photogrammetry, 3D Imaging and Metrology Research Centre (P3DIM) and met with Mona Hess and Professor Stuart Robson.

This research group carry out investigation regarding the acquisition and understanding of accurate, precise and reliable measurements of a diverse range of natural and man made objects and structures. We had a short review of the project regarding the evaluation of the calibration of 3D acquisition devices.

We are working with Mona Hess, a PhD student at University College London (UCL P3DIM/ UCL

CEGE), for the evaluation of calibration of the scanners. She is coming two weeks to Belgium to work on the practical Assessment of a new metric heritage test object. Short Term Scientific Mission (COSCH Working group 2/ Cost-Action TD 1201).

4) Evaluation of the micro-CT

- NHM, Paris (JB & PS, 22/02/2013)

The Agora3D project submitted a joint application with Antoine Balzeau in order to test the AST-RX platform with a human skull and a small Chlamyphorus skull from the RBINS collections.

The human skull was also digitized with all other techniques (CT, Laser, Structured light; Photogrammetry, and RTI).

- Elettra Sincrotrone Trieste (PS, 2/04/2013-03-05/2013).

Collaboration with Dr Franco Zanini & Dr Lucia Mancini about the definition of the user requirements for a µ-CT scanner dedicated to natural history specimens. The collaboration aims to evaluate the quality of images produced by different systems tested in the framework of the project. Other aspects of the RX digitisation of Natural History specimens - like the effect of the Xray radiations on the DNA analyse - is also a part of this collaboration.

WP-1 d*: Integration in the future federal collections digitization program*

The Belgian Federal Science Policy Office is preparing a new program of digitization of the federal collections. Several technical processes were defined for the different types of collections. 3D digitization is one of the selected technical approaches. A preliminary project was presented to BELPOS in February 2013 in order to apply Agora3D results on case studies from the Agora3d partners but also from other Federal Scientific Institutions. Unfortunately, the project is still waiting the approval by the Accounting Officer.

WP-1 e*: Participation to Conferences and Workshops*

PAPERS

Our Antiquity paper has been published in the June Issue of the Project Gallery:

> Mathys A., Lemaitre S., Brecko J. & Semal P., 2013. Agora 3D: evaluating 3D imaging technology for the research, conservation and display of museum collections. Antiquity Volume 087 Issue 336, June 2013, Project Gallery. http://antiquity.ac.uk/projgall/mathys336/

> *Abstract*— **3D digitisation has already proven to be a powerful tool both for the scientific study of museum collections, and for their conservation and display. This paper compare 3 techniques of digitisation for the Spy talus and present two other photogrammetric models. The preliminary results of the Agora 3D Project indicate that photogrammetry can be a cost-effective technique for the digitisation of a large variety of artefact types, particularly in museums where the equipment and expertise required already often exist.**

CONFERENCES

Belgian Prehistory Contact Group (Bruges, December 8th 2012).

High resolution 3D digitization and scientific imagery of Natural History and Cultural Heritage collections. S. Lemaitre, A. Mathys, J. Brecko, E. Gilissen, P. Mergen, J. Davy, C. Vastenhoud, E. Buelinckx , P. Semal. The poster is available here.

Workshop on Portable X-ray Analytical Instruments for Cultural Heritage (Trieste - Italy, April 29th 2013 - May 3th 2013). Organized by ICTP and Synchrotron of Trieste.

Invited lecture: Recording the Belgian Federal Collections of Cultural Heritage and Natural Sciences. Shape, texture and internal structures with (trans)portable instruments. P. Semal.

The PDF of the 88 slides is here.

Marseilles digital heritage conference (28th October to 1st November).

We submitted two papers :

The first one "Comparing 3D digitizing technologies: what are the differences?" is a paper presenting some of our results.

> ***Abstract*— We tested five 3D digitization systems and one method of 2D+ recording on one object: a human skull from the Royal Belgian Institute of Natural Sciences collection (RBINS). We chose a skull because it has both simple and complex structures and different materials such as bone and enamel within the same object.**
> **The results obtained with the different technologies were compared for 3D shape accuracy, texture quality, digitization and processing time and finally price. Our results show that the structured light scanner provided the best results to record external structures, CT was found to be the best to record internal structures and is also the best for recording reflecting material such as enamel. Photogrammetry is a very good compromise between portability, price and quality. RTI is a method of 2D+ recording and is a complementary technique, using the same equipment than photogrammetry, which can capture small morphological features that are not easily digitized with the 3D techniques.**

The submitted and accepted paper is available here.

The second one "Agora3D. A 3D imaging project in a Belgian museum context using low cost technologies" is a more general paper about the Agora3d project, oriented towards low cost technologies.

> ***Abstract*—Agora 3D is a collaborative project between several Belgian federal institutions which is looking for sustainable solutions for digitization of the Museum collections by evaluating the different techniques available on the market. Many institutions use techniques such as CT, µCT, 3D laser or structured light scanning on a regular basis, but digitizing techniques are constantly evolving. Aside from the above men-**

tioned techniques, we are also testing inexpensive technologies like photogrammetry, Kinect technology, and reflectance transformation imaging (RTI). The project is evaluating which techniques are relevant for the different types of Natural History specimens and Cultural Heritage objects by evaluating data quality, time required for acquisition and post-treatment, direct cost (equipment, staff and running costs), ratio between automated and manual human work and ratio between the relevant scientific information and the size of the 3D dataset. Agora3D endeavours to develop a set of standards and protocols that can be used as a guideline in Museums to ensure optimal, cost-effective and readily applicable methodologies for 3D digitization, definition of data formats, data storage, data analysis and visualization.

The submitted paper is available here.

We submitted also for a conference on museums collections (Gent, November 2013) : "Agora 3d: evaluating the digitization of scientific collections". The abstract was accepted for a 15 minutes talk.

Abstract **- Like university collections, museum collections face the same challenges. How do we preserve all the information a specimen bears for the upcoming generations? How do we make this information accessible to others, fellow researchers and even the general public? 3D digitization of the collection can be one of the solutions to these problems.**

The Agora 3D project, a consortium of four federal institutions (The Royal Belgian Institute of Natural Sciences, The Royal Museum for Central Africa, The Royal Museum of Art and History and The Royal Institute of Cultural Heritage) evaluates several digitization techniques, already used on a regular basis by many universities and museums. Aside from the high end technologies like CT, µCT, 3D laser or structured light scanning, we also test inexpensive technologies like photogrammetry, Kinect technology, and reflectance transformation imaging (RTI). The main goal is to determine which techniques are relevant for the different types of specimens (size and materials) by evaluating the data quality, the time required for the acquisition and the post-treatment, the direct cost (equipment, staff and running costs), the ratio between automated and human work and the ratio between the relevant scientific information and the size of the 3D data-set. By doing this Agora 3D endeavors to develop a set of standards and protocols that can be used as guidelines in museums and universities to ensure optimal, cost-effective and readily applicable methodologies for the 3D digitization, definition of data formats, data storage, data analysis and visualization.

We will aslo participate at TDWG 2013 Annual Conference, Florence, Italy, Monday 28th of October - Friday 1st of November 2013, with a computer demo or a poster.

<u>CONSORTIUM SEMINARS</u>

27/02/2013: **RMCA.** Presentation of 30 minute of the Agora3D project at the CETAF-ISTC Meeting at RMCA.

07/032/2013: **RMCA.** Info-lunch of 1 hour at RMCA, introducing to the colleagues what the Agora 3D project is about.

26/03/2013: **RMAH.** Introducing Agora 3D to the RMAH colleagues.

11/06/2013: **RBINS.** Training course in Biodiversity information (for Sub-Saharan African scientists, university members and students) RBINS. Presentation of the Agora3D project.

24/07/2013: **RMAH.** Agisoft training course for the photographer.

WP-2 Definition of the type of collections and priorities

(1 PM AGORA3D+ 2,5 PM Consortium; T0 – T3)

The preparation of the DIGIT3 Belspo program allowed to each Federal Scientific Institution to define priorities in terms of digitization. The DIGIT 3 program is now following the administrative process before acceptance. The preliminary phase is still pending but Belspo administration is confident to the final acceptance.

We defined 3 different approaches for this phase:

- Developing internal knowledge in each partner for the digitization with photogrammetry
- Sharing the renting or buying of specific scanners like structured light scanner or TOF laser scanner.
- Testing the potential of the 3D digitization on case study collections

WP-3 Digitization & Standardization

Standards for describing the 3D multimedia objects are to be accessed at different levels metadata, data/content level. For multimedia objects, standards already exists, as well as for the content that is to be described represented in the image. Important here is not to necessary create a new standard, but to assess the existing standards, their usability and as needed suggest modifications or additional concepts specifically for the 3D purposes. Based on this finding a specifications document will be drafted for the displaying and sharing of 3D multimedia content in a standard way, depending on its intended usage. Within the metadata things like copyrights, terms of use and citations have also to be considered and provided in a standard way, for further usage.

Metadata

TDWG Biodiversity Standards, opened in March 2013 the Audubon Core Multimedia Resources Metadata Standard for public review for ratification as a new standard (http://www.tdwg.org/homepage-news-item/article/audubon-core-public-review/) . The remarks have been collected by the review manager and transmitted to the experts of the TDWG Multimedia Resources Task Group (MRTG). At the upcoming General Meeting in Florence (October 2013), the task group leader will present the standard and if no further issues come up, it will be accepted as a new TDWG standard.

This standard is currently analyzed in the context of the AGORA 3D project for its fitness for use and adequacy.

Content/data/ represented object

The Standard ABCD (Access to Biological Collection Data, http://www.tdwg.org/standards/115/) has already extended concepts for Multimedia objects, IPR Statements, description of the objects and also a very handy "measurements or fact" that enables to describe the feature of an object and specimen by indicating all details about what is measured, how, the units and the figures or to provide a text describing the feature. The ABCD standard is however centered as to have as unit level a natural history specimen with a taxonomic name attached to it. The features and the concepts of the ABCD schema are thus very interesting to take on board, however in practice they have to be used independently from the rest of the standard, when it concerns non natural history objects.

A further very interesting standard to consider is Structure of Descriptive Data (SDD, http://www.tdwg.org/standards/116/) this standard is at the origin to be used to describe biological specimens in order to produce determination keys. Describing shapes, colors and many other features it would be very interesting to use for the description of the 3D objects.

Further considerations :

Further standards to assess would be the EUROPEANA standards (EDM), they are however so far meant to describe basic metadata of multimedia objects on the EUROPEANA portal and may not be detailed enough for the complete 3D description needed in the context of the project, but definitely to take into account when providing info to EUROPEANA. Due to EU projects like OPEN –UP, mapping tools enable to do the correspondences between the ABCD Schema and the EUROPEANA data model have been implemented and can also be re-used in the context AGORA 3D.

For 2D photograph the technical metadata are also provided by the camera (ie ExiF format). For example in photogrammetry there are as many ExiFs as there are pictures taken and ways should be found to express the technical meta data of the resulting 3D image.

Finally all the systems and gears used to produce the 3D end result, the specification, the methods used, which institutions, which people were involved, modifications follow up … should also be kept and provided as metadata. So that in case of re-use for larger project, the workflow can be reproduced.

WP-4 Evaluation of the technologies

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

We continued evaluating different technologies :

WP-4 a: ***Digitization with CT, µCT and surface scanning***

CT / µCT

Medical CT	CT Siemens, (Termite nest)
µCT (Phoenix)	AST-RX (Human skull)
Transportable µCT	SkyScan 1173 high energy spiral scan micro-CT (fossil)
Transportable µCT	SkyScan 1172 high-resolution micro-CT (insect)
Transportable µCT	SkyScan1272 high-resolution micro-CT (waiting list)

The results of the acquisitions have to be evaluated during the following weeks.

Surface scanners

During this period, we evaluated 7 new scanners from 3 companies and based on 3 different technologies:

Laser scanner:	ScanArm and FARO Focus 3D
Structured light :	Mephisto EX and EOS SCAN, 3D3solutions HDI Advance scanner
Infra Red :	Asus Xtion Live Pro sensor and Primesense Carmine 1.09 sensor with several software's

- FARO (fig.1-2)

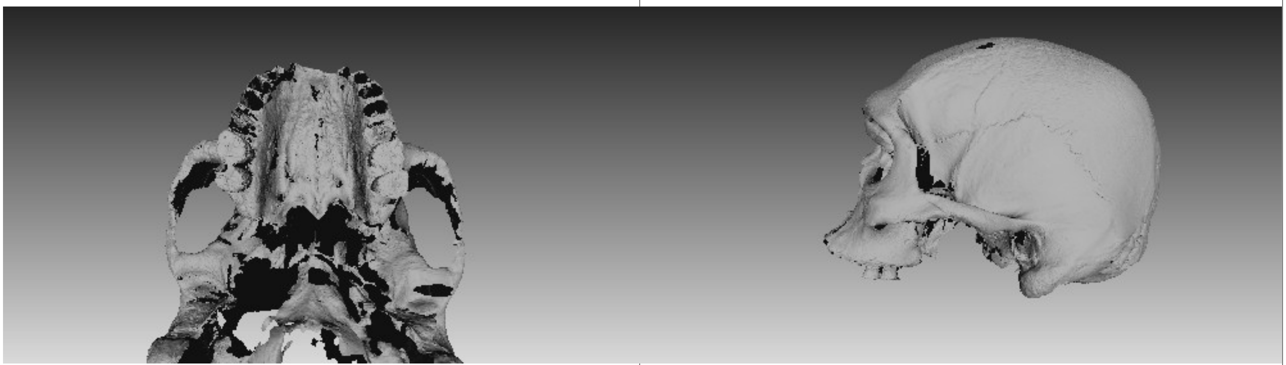
We tested the FARO ScanArm and the FARO Focus 3D which are both laser scanners.

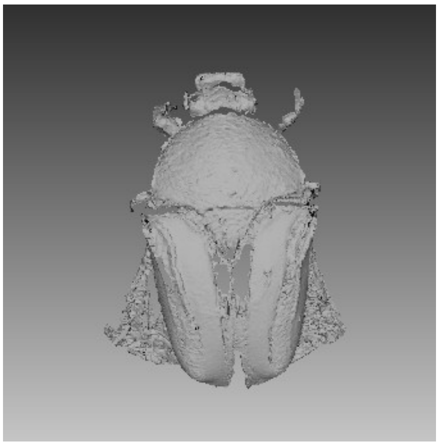
	

Faro ScanArm	Faro Focus 3D

The Faro Arm is a mechanic arm with 6DOF which can scan the specimen by moving around it. It has its own coordinate system. Although the scanners are widely used, the tests weren't conclusive in the framework of Agora3D. These types of scanners are mostly used on less complex and more planar structures. A positive point is that the new Faro Arm manages to scan reflecting surfaces without the need for spraying the object first.

We tried several specimens: sea urchin, bug, coral and a skull. The skull is the only successful one . The result is very precise but more noisy than with other of the evaluated scanner.



	Examples of results obtained with the Faro ScanArm scanner.

The FaroFocus3D is a compact terrestrial laser scanner (TSL). It is a fast laser scanner with accuracy up to 2 mm with a radius range of 0.6 m to 120 m. It records 360 ° in the horizontal plane and approximately 310° in the vertical plane. Only the spot between the legs of the tripod is not scanned during a single recording. This scanner is not accurate enough for small collection objects but is very useful for the 3D recording of buildings, very large structures and field recording. The FaroFocus3D is a very good candidate for the equipment of a common digitization unit of the ESFs. Especially for the recording and monitor the effects of time and pollution on the Cultural Heritage buildings.

More recently, Faro was developing a new 3D scanner technology which is a combination of laser and structured light. This system called FARO 3D Imager is not yet on the market in Europe but needs to be tested because it is probably one of the most accurate systems. The hybrid technology (laser and structured light) seems to be comparable to the DEIOS technology which was developed in the framework of the BELPSO MARS project. This system was the best available but the Spinoff was bankrupted just before the delivery of the prototype to the project.

	Price (€) No taxes
FARO ScanArm	60 000
FARO Focus 3D	35 000

- 4DDYNAMICS – MEPHISTO (fig. 3-6)

This Belgian company has a large range of structured light scanners which go by the name Mephisto 3D Scanners. We tested their products on several different specimens, each with their own specific difficulties, though common in Natural History collections. The specimens we used for the tests were a skull, a tooth, a set of medium large beetles, a sea urchin and a coral.

The Mephisto scanners are constructed in a way that for certain types of products it is possible to upgrade to another higher scanner at any time. Since their scanners consist of a projector and one DSLR camera and/or a machine vision camera, their parts are easily replaced or repaired when needed. We tested a basic system the EOS SCAN and a professional version the EX-PRO. The main difference between these two systems is the extra machine vision next to the EOS DSLR on the EX-PRO system. In the EOS SCAN the Canon DSLR is used for both the texture as for the main geometry, while the latter is produced by the machine vision camera in the EX-PRO.


EX-Pro	EOS Scan

Before scanning a calibration of the scanner is mandatory. It is a fast process that usually doesn't take more than a couple of minutes. When objects of the same size are used or the set-up of the projector and the camera hasn't changed one does not need to calibrate again. To generate a point-cloud of the specimen it is best to use at least three different orientations of the specimen and the number of rotations depends largely on the complexity of the object. The professional EX system is about 10 times faster than the EOS SCAN (1.5 s/scan vs 15 to 20 s/scan). However the EOS SCAN is able to deliver slightly more detail in their scans (maximum resolution of +/- 0.03 mm vs 0.1 mm). Therefore the first is mainly used when a lower acquisition time is crucial, for instance when dealing with moving objects. Although faster is better, museum specimens tend not to move while scanning.

Furthermore the entire scanning process can be largely automated by adding their optional turntable in both systems. This automated turntable can support +/- 40 kg. The main advantage is that separate scans are aligned automatically when using the turntable. Only the different orientations need to be aligned manually by selecting three landmarks on the scans. If needed, custom made turntables can be delivered for large objects . But most of the time it is easier to go round the object with the scanner rather than turning the specimen.

About the object size we can say that there is no real limitation with this system as long as you use an appropriate scaling board. The larger the scaling board used for calibrating the system, the larger the object you are able to scan and vice versa. Although for the smaller specimens they provide a micro add-on lens for the projector to narrow the field of view.

As said before the complete system allows the parts to be replaced. One might think that replacing the DSLR with a newer version will improve quality drastically. But this isn't entirely true as all the components together and mainly the input of the software, which can be installed on multiple computers, is responsible for the delivered results.

An important note is that while scanning one should use smooth light. This means that when the scanners would be used outside it is best to scan in the shade or in a tent, not in direct sunlight.

Looking at the results of the scans we received after the different tests we can conclude that they deliver really nice 3D models. In fact most of the other scanning devices or software products we used (except for µCT) failed to generate a 3D model out of the beetle and the sea urchin. For the sea urchin it was in fact the only time we were able to have the micro-dots of the shell visible which are used for species determination, which is a key factor for a good 3D model of these types of specimens. However the quality wasn't as good for every side of the model, i.e. the micro-dots were only visible for certain sides.

The texture of the 3D models is generated as an albedo map, which means that real colours are shown, not how we see them, influenced by light and shade. However to give the 3D model a more natural look it is possible to add a virtual light setting.

Besides these types of structured light scanners they also adapted their software to work with an infra-red Primesense based 3D scanner (Gotcha, cf. Infra-red sensors). This type of scanner was also tested since it is a low-cost, easily transportable system, which is potentially well suited to generate 3D models of excavations or large objects.

	Price (€) No taxes
Gotcha	1 000
EX-Pro	31635

EOSScan	12185
Micro Add-On	2000
Turning Table with computer remote	5000

- 3D3SOLUTIONS (fig. 7-10)

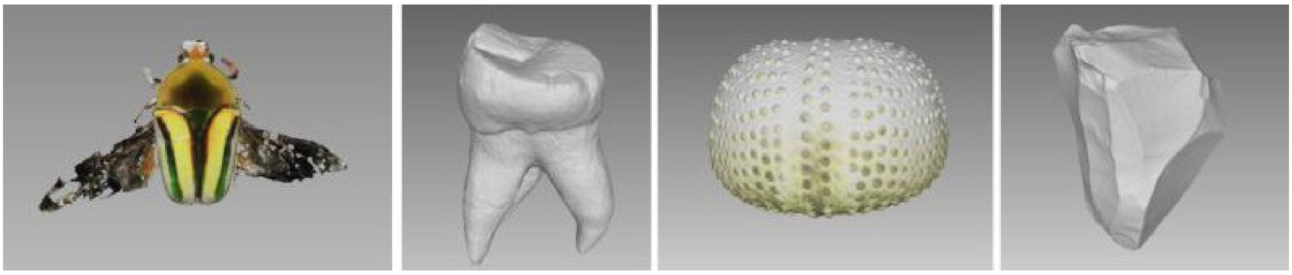
We tested the HDI Advance R3 scanner with colour captor from 3d3solutions.

3D3 HDI Advance scanner
based on the structured light technology

The HDI Advance is a structured light scanner using two cameras with adjustable field of view. There are 3 predefined fields of view, of approximately 200mm, 400mm and 600mm. The 3Mp sensors have approximately 2000 pixels in width. Therefore, for the 200mm FOV you get 0.1mm Point to Point spacing (200mm/2000). You would generally need 20-30 points across a feature to clearly define it. In terms of the size, it depends on the acceptable level of definition required. Although it is not recommended to scan object less than 45mm overall size because it won't obtain a high enough definition.
For each change of field of view, the scanner has to be calibrated with calibration board, which is a simple and very fast process (about a minute).
The accuracy of the scanners depends on factors such as user experience, surface finish, calibration board accuracy, calibration technique, quality of overlapping registration data to name but a few of the main factors. A trained person can achieve about 0.25-0.1mm resolution for the complete project.
The system was tested with 4 different specimens: a tooth, a beetle, a flint nucleus and a sea urchin. Those 4 specimens are relatively smalls (3 of them under 45 mm) and are challenging by their structures or material.
The use of two cameras improve the precision since the scanner has two point of references. The scanner can be sold with monochrome camera or with RGB, we tested the one with RGB camera.
The acquisitions takes a few minutes and can be done by rotating the object manually or with turntable and in both case the realignment is automatic, but the realignment can also be made manually if needed. To scan an entire object like the nucleus (approx. 8cm long) a few minutes and the post process take up to 10 minutes. Each rotation is composed of 8 to 12 scans equally spaced, we did 2 to 3 rotation for each object.
The specimens tested aren't the ideal specimens for the HDI R3 since it doesn't have a micro lens,

and the largest specimen was 8 cm long. Nevertheless we were impress with the result, how it deals with the complex material and moreover we were really impressed with the software and it's realignment capacity. The software could work with a micro scanner but unfortunately the software is not sold alone any more since 3d3solutions has been acquired by LMI Technologies Inc.
Mesh Innovation (the England reseller for 3d3solutions) is developing a micro scanner which would use the Flexscan software. This Macro Scanner will come as standard with one set of lenses, 2mm and 3mm back lit photo lithography calibration boards, Tripod and tripod head. But it would be possible to attach different lens sets to it to achieve different FOV's.

	Price (€) No taxes
HDI Advance R3 (with RGB camera & turntable)	21 000
Macro Scanner	29 000



Specimens scanned with the HDI R3.

- INFRA RED SENSORS TECHNOLOGY (fig. 11-18)

"*Infra Red sensors technology*" or "*Kinect technology*" is the expression we choose to designate motion-sensing captors like Kinect, Xtion and Carmine. Originally used for game on Xbox 360 console, the device was hacked allowing it to be used as a 3D scanner. The technology is quite recent and promising for large objects or for field recording.

The device features an RGB camera and an infra-red laser projector for depth sensing. Several software exist for motion sensing, among them: Scenect, Skanect, ReconstructMe, Kscan3d, and Gotcha.

Gotcha Scanner from 4D4Dynamics

We evaluated the different packages:

- Skanect, Scenect, ReconstructMe and Kscan3D with an Xtion Live Pro (Asus);
- Gotcha software with a Carmine Primesense 1.09.

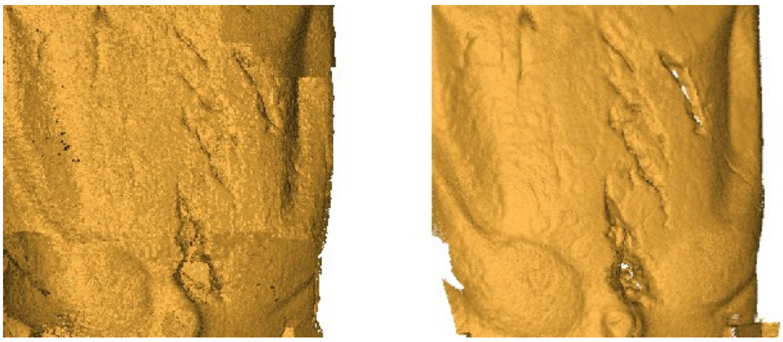
1. Kscan3D v1.0.4.51 is the software developed by 3d3 solutions. Texture capture and static acquisition that have to be manually realigned. The mesh resulting from the capture is correct for that kind of sensor, but it has a very low resolution texture and is time consuming. The ratio between time and quality was poor.
2. ReconstructMe 1.2 was an OpenSource software. It captures point cloud but doesn't capture texture.
3. Scenect 5.1 is an OpenSource software developed by FARO. This system is still very basic and under development.
4. Skanect from Mantcl capture colour and quite accurate point cloud but we had to process the data out of Skanect since in version 1.2 it was very time consuming. In the 1.3 version the meshing is quite faster but the scan is less accurate, the software records less points. The texture is meeting our requirements better.
5. Gotcha is a sensor sold by Mephisto (4dd). It uses a Carmine 1.09 and has his own software. This software allow continuous acquisition similar to as Skanect, but allow as well to realign single records. It also capture texture. The Carmine allows a more precise acquisition than the Asus Xtion Live Pro and the software of the Gotcha is the more complete. Among the downside, the black background of the software interface is might pose problems when recording and realigning scans of dark object.

Kinect technology is a cheap and promising technology, useful for large and compact specimens. It has also the advantage to be transportable.

We use this technology in order to scan large specimens like the mammoth from RBINS (1 week, fig. 15-17), the Moai from RMAH (1 hour), the elephant (2h30) and the pirogue of RMCA (failed). The moai was scan with both the gotcha and the xtion-skanect package. The moai being massive it work really well, while with the mammoth skeleton it is a bit more challenging for the thin bones like the ribs. In general, the point cloud obtained with the Gotcha are good, but the software has trouble processing thin parts and create holes in the mesh for those parts (fig. 16).

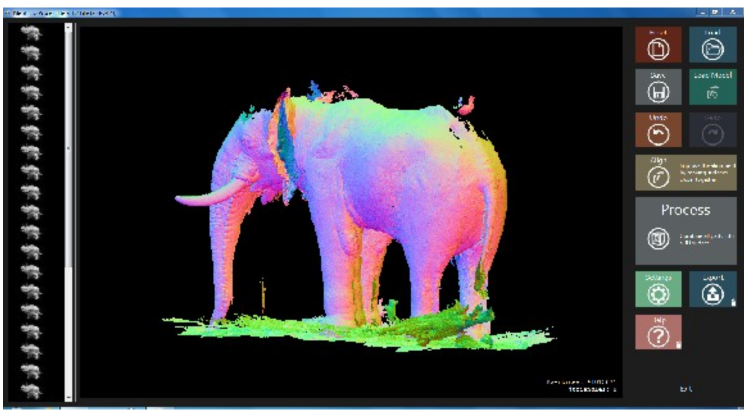
Scapula from the mammoth where the processing software created a hole.

The moai recording is more precise with the Carmine than with the Xtion: the primesense recorded more engravings than the Xtion (fig. 14). Nevertheless the texture from the Xtion Moai was better than the one of the Gotcha package (fig. 13).



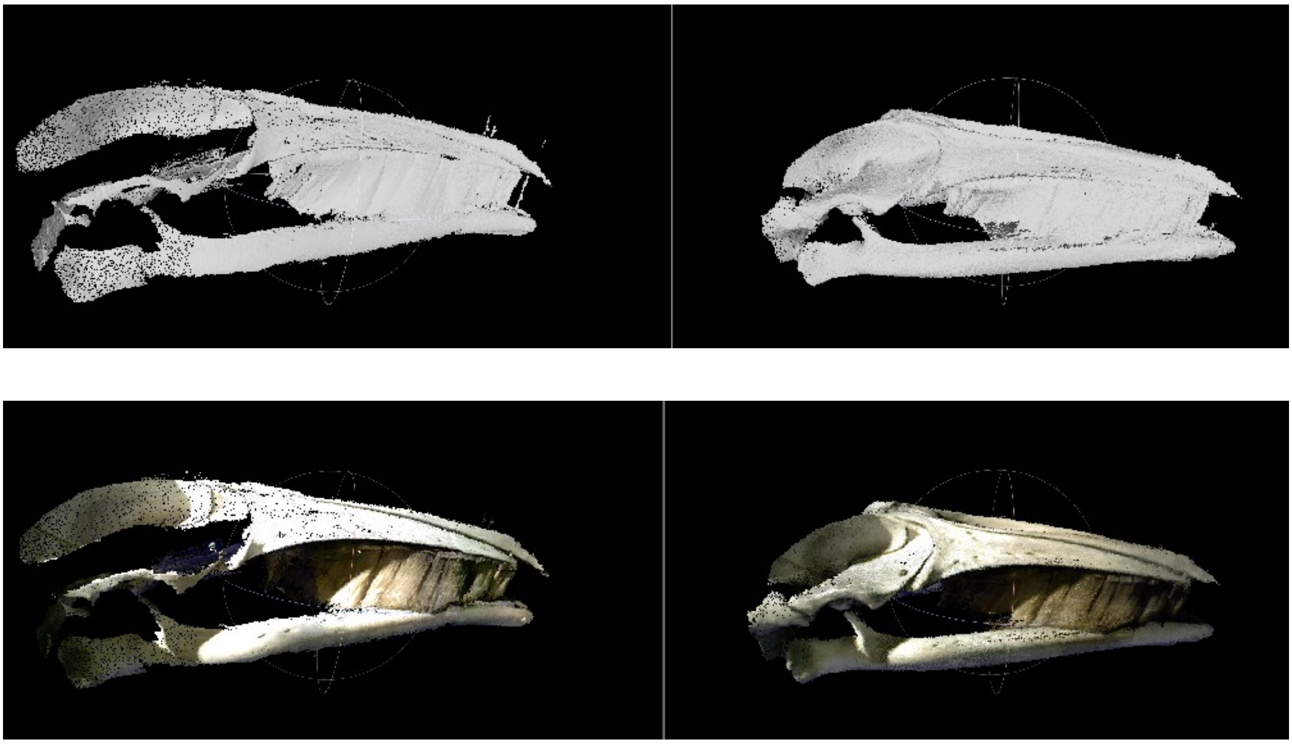
Point cloud of the front of the Moai, scanned with Xtion+Skanect (right) and Carmine 1.09+Gotcha (left)

The elephant (fig.18) and the pirogue were scanned only with the gotcha. The elephant worked fine, but the pirogue did not produce results, probably because there isn't enough detail and reference points for the scanner to locate itself.



Elephant of MRAC scanned with Gotcha

The skull of Petit Rorqual from RBINS was scanned with both Xtion Live pro and Carmine 1.09 with skanect software, in the same light condition. The point cloud with the Carmine seems to be more homogeneous than with the Xtion which created more noise. The colour are better with the Xtion but the detail are blurry, the Carmine colour are burned (light colours overexposed) but the texture is more precise.



Comparison of the point clouds on one scan of the skull of Petit Rorqual with the Carmine 1.09 (left) and Xtion Live Pro (right), both with Skanect software.

WP-4 b: ***Photography, photogrammetry and RTI***

⑤ <u>PHOTOGRAMMETRY</u> (fig.19-25)

We continued our photogrammetry tests with Agisoft Photoscan. We acquired 2 Canon 600D with a macro EF 100 mm f/2.8 lens and a Canon MP-E 65 mm f/2.8 1-5x Macro besides the two EF 50 mm f/2.8 lens, allowing to make recordings of different sizes of specimens. The Canon can be commanded remotely from the computer by EOS software. We also acquired a turntable in order to have a faster and standardized capture of a specimen. We use a perspex plate lifted from the surface of the turntable which creates a shade free, uniform and monochromatic background when illuminated by several lamps. In this way the masking process in the software is severely shortened by using the automated mask function in Agisoft Photoscan, resulting in better 3D models.

By testing different methods, we realised that by taking detailed pictures of an object, Agisoft Photoscan is able to align them as easily as pictures of the whole object. With this procedure more detail is included on the model and usually avoids the issue of masking the pictures. Those more precise models need a higher RAM (32 GB or 64 GB) than we have on our workstations (16GB) at the moment. So only medium resolution models can be achieved for now.

We tested several kinds of specimens from different collection. One of the larger objects we digitized with photogrammetry is the Moai of RMAH (2,73 m). For objects like the Moai we acquired a diffuse flash allowing independent lighting. Normal flash is to hard and flattens the pictures.

Since the RBINS houses a large collection of bones showing cut marks we used a few of these specimens in tests with our 65 mm macro lens to compute a 3D model. Comparing the results of the 3D model of a *retouchoir* (tool used for retouching flints), which has been scanned by an Alicona scanner, we achieve similar results for every angle of view.

We also tested photogrammetry on the alcohol collection of Tervuren (lizard, fish).

Photogrammetry still encounters big issues for flat specimen and plaster (white texture with no detail).

We also compared the result of our metric scaling for size of the objects: we tried to scale the model with an internal scale on the picture, and scale the same model with a calliper. We then proceeded to compare both models in GOM Inspect, and we found a difference between the different method of scaling, the one with the calliper being more precise.

In annex a table with a list of models realised, the number of picture, the results and issue.

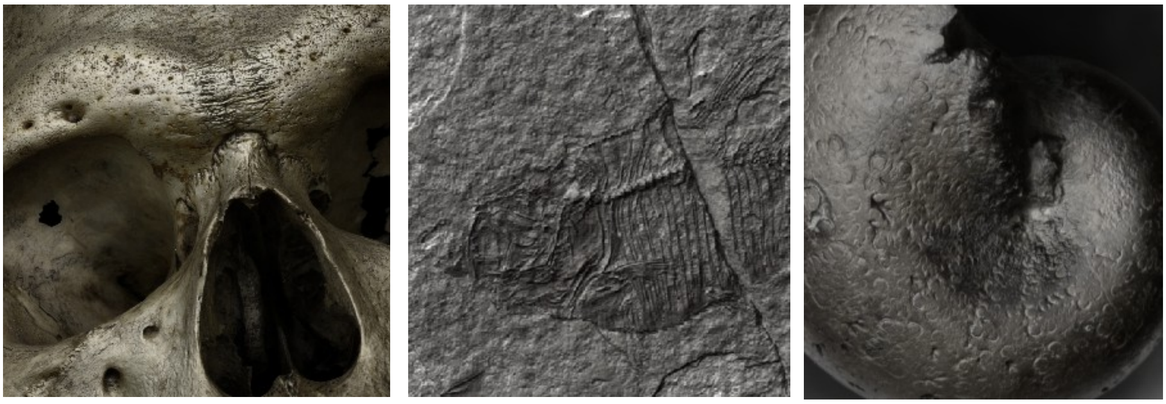
⑤ RTI (fig. 26-28)

Reflectance Transformation Imaging (RTI) is a computational photographic method that captures a subject's surface shape and colour and enables the interactive re-lighting of the subject from any direction. This is not 3D but it allows to enhance small relief of the surface of the specimen.

The principle is very similar to the mini-dome (minus 3D reconstruction): the specimen has to be photographed with light coming from different angle (dome of light). The picture has to include 2 black or red spheres to allow to calibrate the pictures in RTIbuilder software. The result is viewable in a software called RTIviewer, which allow relighting of the specimen by the user with different type of map (diffuse, specular, etc.).

The RTI file is generated by the combinations of several pictures taken from the same point of view with light coming from different orientations. The RTI file resulting “knows” how light will reflect off the subject and has recoded every micro-relief on the surface. It is a complementary technique to other 3D digitization techniques which produces an astonishing level of surface detail.
We worked with the RTIbuilder and RTIviewer from the Cultural Heritage Imaging (CHI) website. But instead of working with a flash, we used LED lights.
We tested several lights (led flash-light, led 30 W, led 24 W, cold light) of different intensity and angle, but the results are quite similar between the different light sources.
We are planning on building our own RTI dome (32 lights with computer control).

We tested RTI on different type of specimens: ammonites, skull, engraved reindeer, tooth, flint stone, cut marks… This techniques is practical to record small details and allow a complete record of the surface with a higher level of visible details than the 3D records.



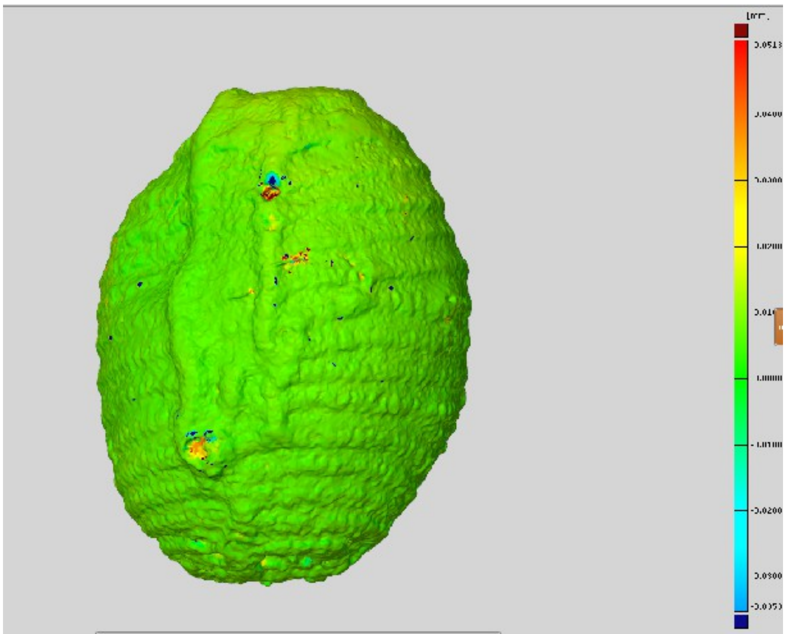
Results of some RTI pictures

WP-5 Tools

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

WP5-a: Comparison between technologies (fig. 29-32)

As said before, we need to validate our first results obtained with the different scanners comparing them between each other. In our previous report we were exploring the possibilities of comparing the mesh with CloudCompare, now we are using GOM Inspect. GOM Inspect allows to compare two meshes to each other instead of one mesh and one point cloud as in CloudCompare. Cloud-Compare was easy to use, but GOM Inspect offers more feature that are useful for comparison like allowing measurements on the mesh or an automatic tool to align that is very stable. GOM Inspect is an Open Source software as well. GOM Inspect allows to compare mesh in .stl or .ply format.



Comparison between the CT model and the photogrammetry model of the termite nest from RMCA.

We also work with visual comparison of the mesh and of the texture. Regarding texture comparison, here are some preliminary results :

- Gotcha => records texture with the shade of the lighting used, not very good
- EOS SCAN / EX-Pro => record the albedo map (absolute colour) which does not look realistic with out a light in the scene
- NextEngine => needs lot of post treatment and has a tendency to go blueish in the holes. Obtaining a good texture is the most time consuming part of the post processing.
- HDI R3 => not enough data to compare
- Photogrammetry => look the more realistic of all without a light in the scene (even if it's not absolute colour) and has the higher resolution
- CT, µCT and FARO don't record texture

EX-Pro (Structured light) NextEngine (Laser scanner) Agisoft Photoscan (Photogrammetry)

In general, our first results show that structured light is the best overall technique to record external surface with absolute texture. CT is useful to record internal structures with good results for reflecting materials such as enamel. However, photogrammetry is a very good compromise between price and quality. It is probably an excellent choice to prepare 3D models for virtual Museums at reasonable costs. Nevertheless, some raw materials are not easily captured with photogrammetry (painted plaster, glass, reflecting surface) and no unique technique can be applied for all Museum collections.

RTI is a complementary technique which can be used to record fine details, especially surface details which are difficult to capture with 3D techniques.

TABΛE I. MANUFACTURE SPECIFICATIONS OF SURFACE SCANNERS.

	CT Siemens Sensation 64	**NextEngine**	**FARO Arm**	**MephistoEX-Pro**	**HDI Advance**	**Agisoft Photoscan standard edition**
Texture	No	Yes	No	Yes	Yes	Yes
Accuracy (µm)	460	≈100	35	50	50-110	Variable Depending camera and lenses
Price €	250 /hour	3000	60 000	30 000	25 000	139 (46 education)
Automatic turntable	n.a.	Yes	No	Yes	Yes	No
Technology	X-ray	Laser scanner	Laser scanner	Structured light	Structured light	Photogrammetry

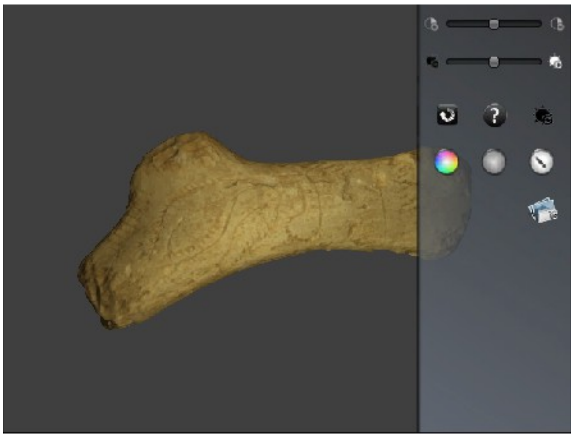
TABΛE II. COMPARISON OF TIME CONSUME FOR A SKULL PER SCANNERS.

(minutes)	CT	FARO Arm	NextEngine	EX-Pro	Photogrammetry
Acquisition	1	20	120	20	30
Process	5	20	/	65	240
Post-process	15	/	480	25	/
Total	21	40	600	110	270
Human time	15	20	480	10	40

WP5-b: Real time rendering

- Unity 3D

We developed a graphic user interface in Unity 3D and some more functionalities like contrast change, automatic movement and displaying picture of the 3d artefact. The next steps are to develop a tool to make measurements in unity 3d and have a fake 3DRTI viewer.



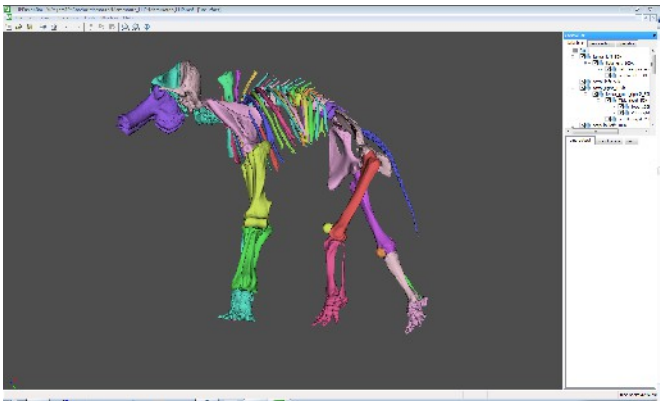
Screenshot of our Unity viewer application.

- LHP FusionBox (fig. 33)

LHP FusionBox is a software developed by the Laboratory of Anatomy, Biomechanics and Organogenesis (LABO) at ULB. LhpFusionBox is dedicated to heterogeneous data fusion. LhpFusionBox is currently being validated in clinical practice.

In our case, LHP is used as a rigging system to reconstruct a skeleton: We scanned all the bones of the mammoth of the RBINS collection and relocate each bone in Lhp. Lhp allows to enter motion capture file to animate the rig.

This process can also be done in most of the 3D animation software (Maya, Blender, 3Ds Max…), we choose to do it in lhp as it is a software dedicate to that kind of thing.



Bones of the mammoth scanned with the Gotcha, replace roughly in LHPFusionBox.