



# The use of 3D imaging techniques to digitize and visualize Technical Cultural Heritage artefacts

**Reference:** Short Term Scientific Mission, COST TD1201

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**Period:** from 16.06.2014 to 24.06.2014

**Place:** Ecole Centrale de Nantes - IRCCyN, Nantes France

**Reference Code:** COST-STSM-TD1201-18759

## 1 Purpose of the STSM

The 3D visualization of scientific and technical Cultural Heritage (ST CH) artefacts is often difficult due to their complicated shape, glossy metal surfaces and numerous mechanisms that move in different spaces. 2D representations are used to understand the links between the different organs constituting the objects as well as the way the mechanisms run. Still a 3D representation might be required to complete this 2D picture and is a more intuitive way to understand moving parts. New technologies are constantly developed to make these 3D representations much easier to obtain. The objective of this STSM was to get an overview of the different 3D imaging techniques that can be used on ST CH objects and to see which technique fits the best to the artefact considered within this STSM as regards the shape and the surface rendering. The techniques that are the most accessible to end-users (conservation professionals) were further investigated to precise the conditions of a complete survey of an artefact representative of those usually found in our domain of expertise.

## 2 Description of the work carried out during the STSM

As said above the STSM was organized to test different imaging techniques on an object representative of the problematic of ST collections. The aim was to see the possibilities of various technologies to acquire a proper 3D model of a ST CH object. In the following we review briefly the available digitization techniques before selecting the ones that are considered to be the most appropriate to the chosen artefact.



## 2.1 Classification

The digitization technique to use depends on the dimensions of the artefact to be acquired (...<math>1\text{m}^3</math>...<math>10\text{m}^3</math>...<math>60\text{m}^3</math>...), on the accuracy requested, the acquisition time available and the possibility to handle/move the object. Consequently when dealing with digitization of heritage object, it is recommended to combine the techniques (active/passive systems with/without contact) to optimize the acquisition chain (for example: without contact due to major degradation state). Figure 1 gives an overview of the digitization techniques that can be used.

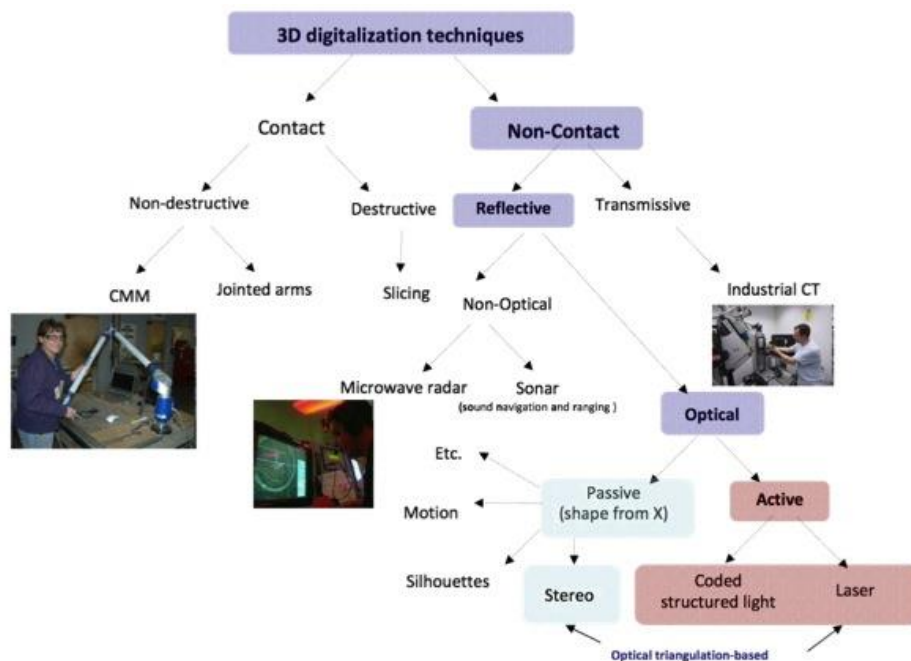


Fig. 1: Flowchart presenting the different digitization techniques (from Technologies de numérisation 3D et domaines d'applications, Boulbaba BEN AMOR, 2009).

Due to the fragility of heritage artefacts, the number of handlings that have to be done in order to get the whole 3D model has to be taken into account. If only one point of view is considered, a stereographic view will be obtained. In practice, it is necessary to combine various points of view and/or various types of scanners.

In the following only the systems employed during this STSM are presented.

### 2.1.1. Passive systems without contact

Used for graphical design, these systems are passive without contact since they capture information with photographic systems or stereoscopic systems. The acquisition tools are cameras and movie cameras.



Photographic systems allow building rapidly 3D models thanks to high definition digital photos. The process associated is:

- Detecting common points between pictures,
- Automatic distance calculations and 3D wireframe modelling,
- Textures application using photography definition,
- Automatic virtual camera or virtual video camera positioning.

The precision of the model depends on the cameras definition: the more the cameras are accurate, the more the model will be accurate.

### 2.1.2. Active systems without contact

Active systems without contact are technologies that generate short waves for measurements (for example: laser). According to the object size to be digitized, there are various solutions:

- “Desktop” laser scan: box containing the scanner. Accuracy = 0.1 mm. It is suitable for only small size objects;
- TMM laser radar. High speed, high accuracy;
- 3D laser scanner. For example from Minolta. They are the most popular and are used in medicine, industrial engineering, archaeology... ;
- X-ray tomographic systems;
- Interferometer with optic fibre;
- Optic measurement system...

## 2.2. **Techniques selected**

Considering the short duration of the STSM (10 days) and the relative availability of different techniques, a selection of two optical techniques was made by the host: photogrammetry (passive system) and handheld self-positioning 3D laser scanner (active system). We also decided to add the preliminary results acquired by the beneficiary during the COSCH Training School held in Warsaw on robotized structured light system (active system) in November 2013.

Trial version of relevant softwares were also provided to the beneficiary with tutorials to test some specificities of these softwares and continue the work carried out in Nantes beyond the STSM. I was also invited in seminars held by the IRCCyN during the STSM around visualization and virtual reality. The aim of those was to see possibilities and new developments in virtual reality and possible applications for STCH artefacts. This topic will not be considered in the report.



As our investigation progressed we saw the importance of replacing the aims of digitization within the process and of not limiting ourselves to technical aspects only. Having an insight on three different scanning techniques was enough to raise questions from the conservation-restoration field. We could see a real need to make a review of these techniques considering also the final use of the 3D model, the study specificity and the accessibility of the technology. A list of potential final use of 3D model on ST CH artefacts is presented in section 3.6. One final need considered especially for ST CH objects is the use of the 3D model to explain “how it works”. That means putting virtually the mechanism in function again, making each part moving with its specific interactions. Here, the reverse engineering seems a good solution (see section 3.4).

### 2.3. The object under consideration

The object chosen is a ring enlarger used to enlarge stone-set rings (Figure 2). This ring roller rolls out the shanks, thus stretching the metal and enlarging the size without popping out the stones or damaging the settings. It regroups specificities of ST CH objects such as: glossy surfaces (plated steel), moving parts and complex shapes (gears) as well as finely worked surfaces (knurling), etc.



Fig. 2: View of the ring enlarger used for our digitization tests.

With such a complicated object we are interested in seeing how much relevant information the 3D model can carry. Can a 3D model be used as an information source like the real object? Should the 3D model be a perfect copy of the reality? In the case of the ring enlarger and its knurled handle what would be the relevance of having sufficient spatial resolution for the knurling to be represented in volume? Would not be the application of a photographic or schematic texture enough? All depends on the final use of the 3D model. If the presence of a knurling on the handle should be indicated, a schematic drawing might be enough. If a real close view or the monitoring of the corrosion development is required, applying a photographic texture should be sufficient. If the study of the wear of the knurled surface is of interest, a spatial high-resolution would be necessary.



### 3. Description of the main results achieved

#### 3.1. Photogrammetry

##### Material

Camera : Nikon® D700

Lens : 60mm Macro focale fixe

Software : Agisoft Photoscan Pro

The first technique tested was photogrammetry. This is a passive system without contact. As said before common points are detected between a large number of pictures. To apply this technique we were invited at Arc'Antique<sup>1</sup> by Christine Riquier-Bouclet (Director). The pictures were taken by photographer Jean-Gabriel Aubert while the processing was carried out by computer engineer Stéphane Jupin.

After an introduction on photogrammetry and the presentation of some case studies we discussed around our object to define suitable conditions for the digitization. A first set-up was made by J.-G. Aubert to have as much diffuse light as possible. Because of the glossy surfaces of our object it was necessary to avoid reflectance during the reconstruction of the 3D model. Pictures were made with a home-made light tent (Figure 3), the object being on a rotating plate and the camera being static. Around 120 pictures were taken – 40 to cover the object under 360° at 3 different camera Z-axis positions. Therefore each picture is covering around 9° of the object. It was possible then to mix the pictures to obtain a sharp picture regardless of the depth of field of the object.

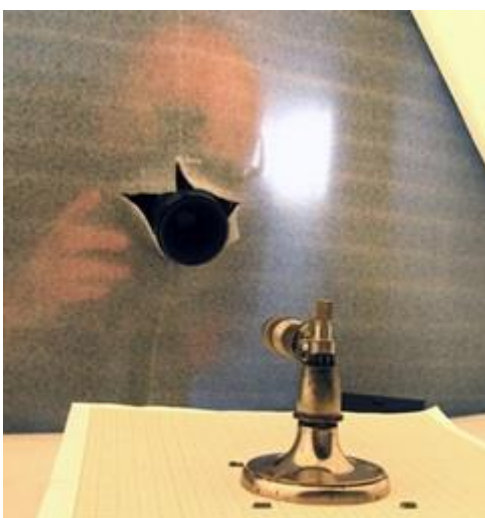


Fig. 3: Home-made light tent.

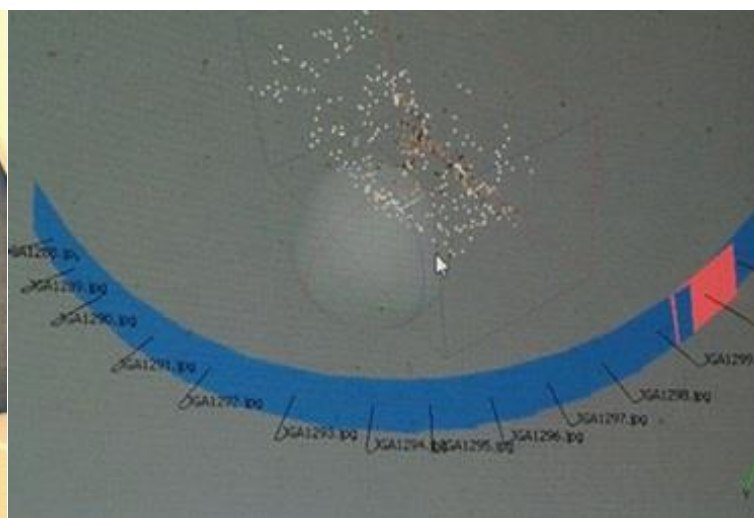


Fig. 4: Alignment of pictures inside the software.

<sup>1</sup> Conservation and research laboratory specialized in the conservation of archaeological and historical artefacts



After the photo campaign, the whole set of pictures (.tiff) were improved with a proper software like “Lightroom®” or “Capture One®”. The pictures were then imported in Agisoft PhotoScan Professional® to create the 3D model. The computer interprets the relative position of the camera and the object. First of all S.Jupin started by testing the 3D re-construction using only 20 pictures. Due to the use of graph paper and a high presence of the behind-scene, the software was unable to position correctly the camera in space. To limit any error of interpretation, we had to select manually the portion of the pictures where the object was. After being re-calibrated the alignment was conducted more easily (Figure 4)



Fig. 5: View of a portion of the digitization with a high resolution texturing.

The software tended then to recognize the position of each single pixel in different pictures. For a proper matching it was necessary to have the same light condition in all directions. If a pixel does not have the same property between the pictures it cannot be easily selected by the software for the reconstruction.

The result obtained after the dense cloud correlation process was very encouraging. Once the cloud was meshed and the texture was applied, the visual aspect of the 3D-model looked very close to the actual surface (Figure 5).

We could observe two major issues with this digitization process:

- The reflectance of the orange graph paper on the object made it looking more orange than the reality,
- A high bumped surface due to a lack of reference pictures and also due to a high reflectance (Figure 6).

The software was unable to replace the white spots in space. This led to the deformation observed.

Knowing that the conditions of acquisition were not optimal, we decided to carry out a second photo campaign. A light tent providing more diffuse light was purchased. J.-G. Aubert took the pictures on the last day of the STSM. S. Jupin offered to carry out the processing of the measurements afterwards. Due to scheduling problems, the results obtained could not be included in this report.

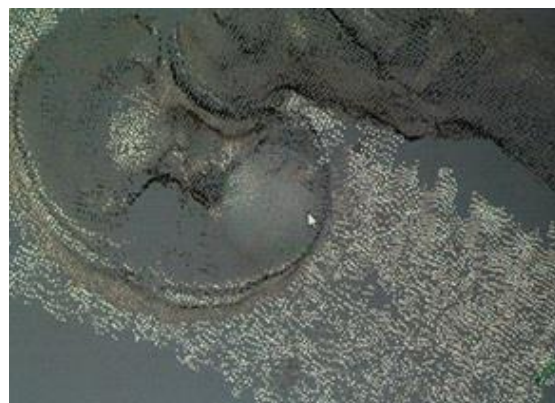


Fig. 6: View of the high bumping volume of the digitization.



### 3.2. Handheld self-positioning 3D Laser scan

#### Material

Scanner: View!scan Creaform®

Software: Vx element

The second method tested is an active system without contact. It is a portable 3D laser scanner, the View!scan Creaform® (Figure 7).

The experiments were carried out at Ecole Centrale de Nantes with Florent Laroche. After a preliminary test we did the acquisition in the dark - the scanner being the only light source. This enabled to limit the reflectance of other light sources on the object surfaces. To scan the object, the View!scan scanner was plugged to a computer, transferring in real-time the data to the editing software "VXelement". This functionality enables the user to see directly the construction of the virtual model during scanning. The scanning rate is influencing strongly the level of accuracy. Our first digitization was performed with a low accuracy of 0.9mm.



Fig. 7: View of the scanning process with the computer screen at the back.

The scanner always acquires data at its highest possibility but the program displays the virtual model as soon as it fulfils the parameters settled. That means that if we scan at 0.9mm (Figure 8), the virtual model will be displayed as soon as the accuracy is reached. If the level of accuracy is changed to 0.2mm all the areas that have not enough points to construct the model with this accuracy will disappear on the computer screen. Therefore the user needs to scan again these portions to have a more completed digitization (Figure 9).

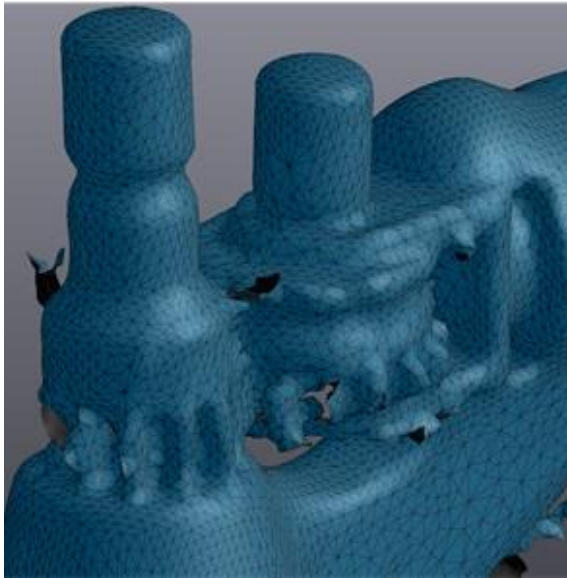


Fig. 8: Detail of the meshed 3D model with 0.9mm accuracy.



Fig. 9: Detail of the meshed 3D model with 0.2mm accuracy.

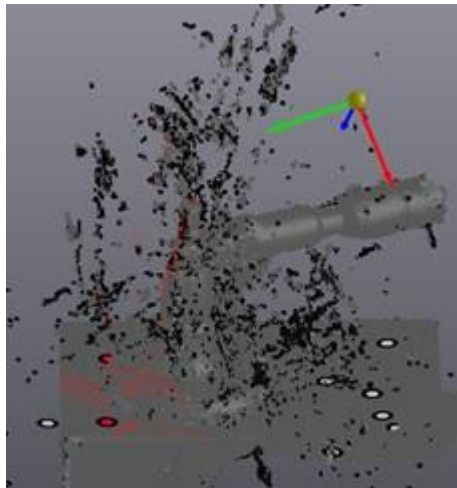


Fig. 10: View of polluting points due to a high reflective surface.

During the scanning a lot of false points were scanned due to the high reflectance of the surface (Figure 10). This pollution could be easily deleted by the software since the points are dispersed compared to the relevant point forming bigger groups with a higher coherence.

With the higher resolution we gained precious details on sharper edges, chamfers, gear tooth, etc. The knurling on the handle could be revealed without being represented completely. A 0.2mm accuracy seemed to be requested to distinguish different parts within the same object. The view!scan device is equipped with a visible light camera to acquire colour information. We made a test to see how a metallic surface could be rendered with such a technique. The result shows a medium grey applied on the whole surface (Figure 11) which is rather different from the real rendering of the metal (Figure 12). We also see the reflectance of the red laser polluting the rendering. We decided to continue the scanning without the colour acquisition.





Fig. 11: Detail of the meshed 3D model with 0.2mm accuracy and textures.



Fig. 12: Detail of a picture of the real object.

We scanned the object in 3 orientations to obtain the volume entirely. The 3 mesh were put together with “Geomagic Studio®” to obtain a unique 3D model. We did not go deep within the data processing, but a proper format (.stl) will be used for reverse-engineering with a CAO software “Catia®” to re-build and add movement (see section 3.4).

### 3.3. Robotized structured light system (TS Warsaw 25-27 Nov. 2013)

This technique was demonstrated during the COSCH Training school jointly organized by the Warsaw University of Technology and the Museum of King Jan III's Palace at Wilanów at Warsaw in November 2013.

For this technique a light pattern is thrown on a three-dimensional surface. The pattern appears distorted from other perspectives than the one of the projector. This new pattern can be used to reconstruct the geometry of the object. The robotized structured light system developed at the Warsaw University of Technology was applied on the ring enlarger. The object was covered with a mat powder to prevent any reflectance. A thin titanium oxide layer was sprayed on the surface (Figure 13).



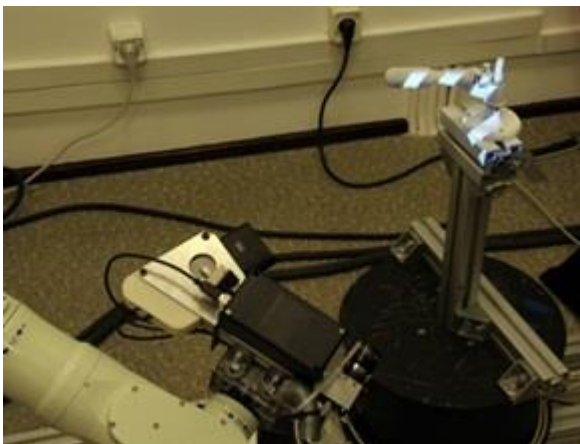
a



b

Fig. 13: Spraying of the ring enlarger with titanium oxide (a) to obtain a non-reflective surface (b).

In addition of being automatized thanks to a robotic arm, the acquisition (Figure 14) enables a very high spatial resolution form (1000 to 10'000 points/mm<sup>2</sup>). Based on the experience of Eryk Bunsch (Museum of King Jan III's Palace at Wilanów) a resolution of 1600 points/mm<sup>2</sup> is considered to be optimal for most of CH artefacts.



a



b

Fig. 14: View of the automatized 3D scanning system with the projection of structured light on the surface of the ring enlarger (a & b).

Thanks to the titanium oxide, we obtained a good digitization of the volume without reflectance. Unfortunately the object was not correctly fixed on his support and he moved during acquisition. Normally the different clouds are correctly placed in the space and no matching is required. In our case all clouds could be seen showing gaps between them due to the movement occurring during the scanning.



Having a high resolution enabled us to have surface details on the 3D model, the gears and the knurling being well represented (Figure 15).

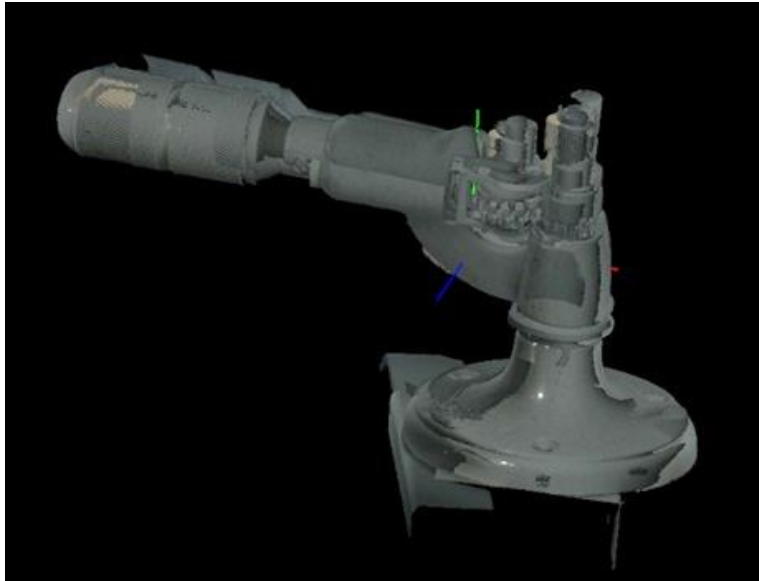


Fig. 15: View of the 3D model with the presence of the knurling and the gears.

### 3.4. Reverse engineering

For this work (in progress), we used the result of the 3D digitization made by the Creaform vew!scan. The STL data will be used for reverse-engineering with a CAO software “Catia®” to re-build each part separately and add movement constraint. The digitized object will be used only as a geometric and dimensional reference to re-draw completely and manually all the parts of the object (Figure 16).

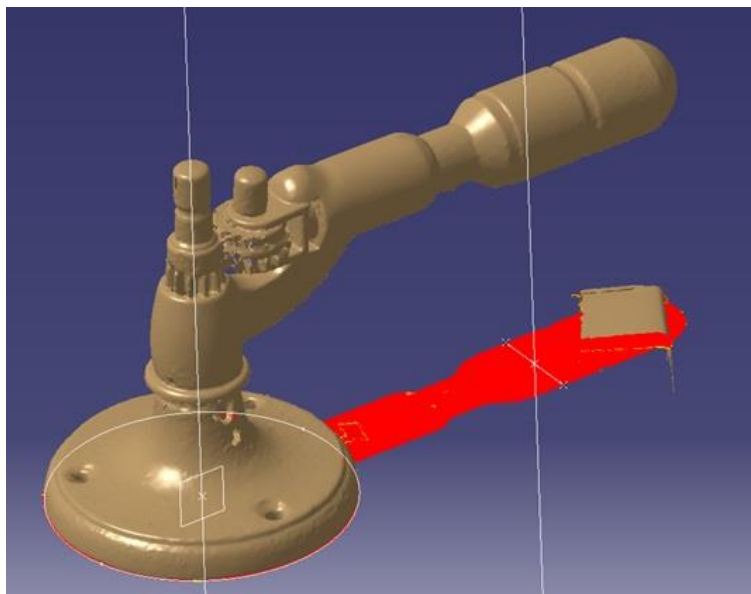


Fig. 16: View of the .stl format imported in Catia® during replacement in ortho-normative coordinate.



The first step of the reverse-engineering is to replace the model in the ortho-normative references of the workspace of the CAO software. To achieve that the user needs to find geometrical references such as plans and axes within the 3D model. The next step is the dismantling and re-drawing of independent parts using the CATIA drawing tool. The scanned object acts like a “ghost” to give relevant measurements and shape.

At the end of the process we obtain an object with a perfect volume non-representative of the reality. We obtain a 3D model that can be used in an engineer’s point of view. All the parts have a certain degree of movement and can move and interact together. This enables us to make demonstration of the use of the object without putting it back in working condition. We can also add in the software materials attributes and launch a simulation to see which part is theoretically under higher mechanical constraint and might fail.

### 3.5. Which results with which techniques?

The three different techniques presented above have their own strengths and weaknesses. For this review we will concentrate more on the possible use of the 3D model produced by each technique than the possibilities offered by the softwares tested.

<b>Photogrammetry</b>	<b>Handheld self-positioning 3D laser scanner:</b>	<b>Robotized structured light system</b>
↓	↓	↓
<p>The high resolution of the texture rendering is adapted for quick visualization and for documentation of the surface. This technique is equivalent to 3D photography.</p>	<p>The scan rate and automatized processing are ideal to obtain a quick 3D model for reverse-engineering. The portability of the tool is another advantage.</p>	<p>The high spatial resolution is adapted for scientific study and documentation.</p>

### 3.6. Which purposes for a digitization of a ST CH artefact?

A non-exhaustive list of potential purposes of digitization applied in conservation is given below:

#### 3.6.1. Documentation of the object at time t

- Capture topological physical volume + textures,
- Deepness of the capture (i.e. inside a 'black box', volume, texture or only skin),
- Definition of movement,
- Description of the technology,
- ...



### 3.6.2. Historical documentation outside object

- Ideal use = enrichment of the knowledge of socio-economic context (i.e. effort of workers),
- History of use = definition of the impact of uses on the life cycle of the object (i.e. wear marks to propose adapted conservation methods),
- Description of technological developments,
- ....

### 3.6.3. Object monitoring/Comparison of the objects at different temporal states: conception state (t -1), actual state (t 0), and future state (t+1)

- Topographic comparison to t-1 (i.e. the original plan, other interpolated model ...),
- Topographic comparison study for signs of wear,
- Topographic comparison for conservation strategy (before/after),
- Degradation monitoring (i.e.: development of cracks, erosion, corrosion, etc.),
- ...

### 3.6.4. Physical object 3D + t (movement) at time t - complete assembly

- Explanation of how it works,
- Re-design parts of an incomplete object,
- Creation of a physical model by digital manufacturing (3D printer, laser cutter, etc.),
- Replacing parts virtually without decreasing real object integrity,
- ...

### 3.6.5. Physical object 3D + t (movement) at time t – simulation

- Stress analysis, mechanical deformation forces,
- Virtual restoration of the dynamic object as incomplete,
- Risk analysis (recovery operation, heating ...),
- ...

### 3.6.6. Operation / Visualization

- Definition of the parts list in old vocabulary + tree assembly,



- Display meta-data from historical documentation,
- Definition of the function - operation explanation,
- ...

#### 4. Future research including collaboration with host institution (if applicable)

- We plan to write an article with Florent Laroche on the methodology to scan ST CH artefacts,
- The applicant and the host should continue the collaboration around the topic of this STSM,
- Florent Laroche is expert for the new HE-Arc SCHEMA-TEC research project about the development of a methodology to represent schematically ST CH artefacts.

#### 5. Projected publications/articles resulting or to result from the STSM

- Florent Laroche and the applicant are planning to write an article on the outcomes of the project in a scientific journal (probably related to computer engineering's),
- Another paper comparing the possibilities of the techniques used is planned in a conservation journal.
- Romain Jeanneret will add the experience of this STSM and future developments in his Master course on infographics in conservation of ST CH artefacts at the HE-Arc CR.

#### 6. Confirmation by the host of the successful execution of the mission

We confirm that Romain Jeanneret from the Haute Ecole Arc Conservation-restauration (HE-Arc CR) worked in our laboratories at Ecole Centrale de Nantes - Research Institute for Communication and Cybernetics of Nantes (IRCCyN) from 16.06.2014 to 24.06.2014.

The visit has been successful and the results are described in this report, which I confirm.

Dr Florent Laroche





## 7. Financial summary

Item	Description	Euros
Travel	Train and plane	380
Subsistence (hotel / meals)	Nantes	720
Total		1100

## 8. Potential interdisciplinary value of research carried out and any other comments

This interdisciplinary work was very interesting. All participants and institutions involved were open to the application of their imaging techniques to ST CH artefacts. Colleagues from the IRCCyN and Arc'Antique that contributed to this STSM are willing to develop more research partnerships. The input from every discipline was very constructive and we saw the awareness and motivation of partners.

Discussions between Florent Laroche, Christine Riquier-Bouclet and myself led to the necessity of writing a chart about the proper treatment of 3D model in the conservation of cultural heritage. This supports very well the development of guidelines for end-users by COSCH WG4.

Romain Jeanneret

16.07.2014