Non-destructive investigation of „The violinist" a lead sculpture by the Spanish artist Pablo Gargallo, using the neutron imaging facilities of the Paul Scherrer Institute

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The violinist, is the title of a lead sculpture representing a musician playing his violin but with no bow in his hand, may be inspired by his friend who was himself a violinist. It is a famous work of art by the Catalan sculptor Pablo Gargallo and one of the icons of the MNAC, the National Fine Arts Museum of Catalonia. The author, Pablo Gargallo is one of the most important sculptors of modernity in Spain, well known for his use of concave volumes and void in his sculptures.

Fig. 1. Four main views of The violinist (MNAC 010972-000), by Pablo GARGALLO. 1920.

The violinist dates from 1920 and is made out of 2mm thick lead sheets, hammered with nails and assembled with soldering on a wood structure. Its dimensions are 55,3 x 31,8 x

21,6 cm and weights 11,9 kg. It is a unique piece which goes out of the Museum in very rare occasions. It was made in the so called "lead parenthesis" a period of 3 years, from 1920 to 1923, in which Gargallo worked with this metal most probably because it gave him the possibility of working with metal sheet in a much easier way thanks to its malleability and softness. This might have been the first of a series of nine sculptures made with lead, all the others being manufactured using a much thicker lead plate with no wood structure.

Let us now have a quick look at its present state of conservation. The 2 mm thick lead plate used by Gargallo makes this a very fragile sculpture, very sensitive to deformation especially when it comes to handle it. When you want to lift it you always have to hold it tighter since its real weight is bigger than you expect it to be.
Changes in the shape and position of different parts of the sculpture occurred during its lifetime of 92 years can be identified by superimposing an old picture of the violinist and a line drawing of its present state. There have been some plastic deformations of the lead sheets due to mishandling, shocks or accidents, in the position of both hands and the flocks of hair, some of which are also broken or showing fatigue symptoms like cracking caused by repeated bending. The tails of the swallow tailed suit which were originally stiff are now completely folded and adapted to the shape of the buttocks and legs.

Related also to the fragility of the sculpture we can observe different places where the soldering is splitting or broken, due to mishandling and shocks. In areas like the right leg or under the right arm we can see broken soldering and deformation of the lead plate from one of the sides of the soldering.

Some years ago we saw for the first time some bumping areas on both legs of the violinist. With time these areas grew larger and higher, and began to open up while a white substance began to show through. A sample taken from the right leg was analysed, the result was lead carbonate. The fine parallel lines that can be seen when looking at a sample of lead carbonate through the binocular microscope shows the way this type of corrosion builds up with every new layer of lead

Fig. 2 Plastic deformation on both legs due to advanced lead carbonate corrosion .

carbonate formed most probably by an increase in relative humidity.

Now there are more areas swelling up and the process seems to be speeding up. We can now find blisters also at the back of the neck, on the right shoulder, on the left heap and between both legs.

The Project

This was the perfect object for a neutron imaging case study. One would quickly think of X-radiography as the NDT suitable to look inside the volume, but the materials used in this particular sculpture make it useless. The thickness of lead may reach a maximum of 7 to 8 mm and the energy needed to go through such thickness of lead would most probably burn out all the information about the wooden structure inside.

In 2010 Mr. Jesus Serrano, president of AEND, Spanish Association for Non Destructive Tests, suggested neutron radiography would be the most suitable technique, but at that time this sounded very much like science-fiction even if I am one of the team of three in charge of the X-radiography department in the MNAC.

Fate wanted me to hear Dr. Lehmann's presentation last march 2011 in Florence at the NDT Congress. His lecture was about neutron imaging of some bronze Buddhas with organic vegetable filling, a subject that had very much to do with our violinist.

I talked to Dr. Lehmann about our need to study our lead sculpture and he encouraged us to prepare a proposal for a neutron study of the violinist at NEUTRA in the Paul Scherrer Institut. Our proposal was accepted and David Mannes was the scientist in charge of the measurements with NEUTRA.

The project was a real challenge both for us (would the results make it worth taking the sculpture to Switzerland?) and for the neutron imaging technique since the inner wood structure would pose a very worrying limit.

From the beginning, the transportation of the sculpture was our major issue given its fragility and the responsibility assumed to take it out of the Museum after so many years.

The sculpture was hold inside a multi-level foam mould with precise contact points. Some rectangular spaces were cut out to contain silica gel bags to keep relative humidity fairly low. We designed a special double crate to reduce vibrations during the trip. A tilt-watch and a shock-watch were placed on the outside of the bigger crate. The violinist arrived at the PSI perfectly safe and sound.

These are some of the questions we would like to answer after the experiment:

1. What are the shape and dimensions of the inner wood structure, in order to evaluate its responsibility in the corrosion attack?
2. Is this structure made in one piece? Are there any joins we can see? Is it made of different parts glued together?
3. Can we get to know how many different lead plates make the entire sculpture? Will we be able to order them according to the manufacturing process?
4. Can we see and measure the thickness of the different lead pieces?
5. What is happening in both legs?
6. Are there any other areas affected by carbonation of the lead?
7. Can we see where the fixing nails are and count them?
8. Can we see the soldering and how the lead plates are joined?
9. Will we be able to differentiate in the images between sound lead and the carbonated products?
10. If so, can we estimate the extension of the carbonate areas behind the lead sheets?
11. And the most important one, was neutron imaging going to give us the answers?

The NEUTRA experiment was planned in three steps:

1. Thermal neutron radiography.
2. Tomography
3. 3D reconstruction.

Neutron radiography is a NDT most useful when it comes to study metal objects, since neutrons can easily go through most metals, and of course lead, although it can be a bit radio activating. The compounds containing hydrogen in their molecules offer a major attenuation of the neutrons which means we might have some problems with the neutron transmission through the wood kernel.

Experimental procedure

First of all we needed to set the different parameters for the experiment and establish the procedure for the acquisition of the projections.

This is the sequence of events.

a) Test radiographies were taken at intervals of 15º turning 180º in order to place the sculpture right in place in front of the neutron beam and to decide on the best exposure time.
b) The movements of the table and the turntable were set in the computer software. For security reasons the sculpture was placed a bit further away from the scintillator to prevent the violin from touching it and break or make the sculpture fall off the turning base.
c) Since the sculpture was taller than the scintillator, it was decided to capture all the information in two runs, one for the upper half and one for the lower one. Each half would make a whole turn of 360º.
d) The final number of projections was decided, according to the radio activation measured after the first 24 exposures, being a total of 1125 projections for each complete turn, so as to compensate for the longer object-scintillator distance and to obtain better sharper images.
e) The exposure time was set to 20 seconds.
f) The shutter in the flight-tube was opened and the sequence of exposures began to be captured with a CCD camera.
g) The violinist gave a concert of 15,6 hours.
h) The total amount of projections-radiographies was 2250.

First results with neutron radiography

The projections obtained are of a high resolution and show quite a sharp image of the sculpture. The wooden kernel, visible for the first time as it is, appears like a dark blob in the middle of the figure allowing the lead plates to be seen only on the silhouette. It is along this silhouette where the features of the *violinist's lead suit* can be studied.

The neck of the violin stands out of the scintillator area in some positions during the experiment and the information missing in those projections makes it impossible for the tomography and the 3D reconstruction to include this part of the sculpture.

The *ImageJ* software has proved to be a most useful tool for the visualization of hundreds even thousands of projections, all stacked in a sequence, helping us to analyse and extract the information contained in them.

Neutron radiographies have proved to be able to differentiate between the lead (metal) and the lead carbonate (corrosion product), which appears in a lighter colour. They can also capture other materials such as wood (probably pine tree), iron and soldering flux (most probably borax).

The projections show some highly attenuated areas either due to geometry or due to the attenuation coefficient of the materials.

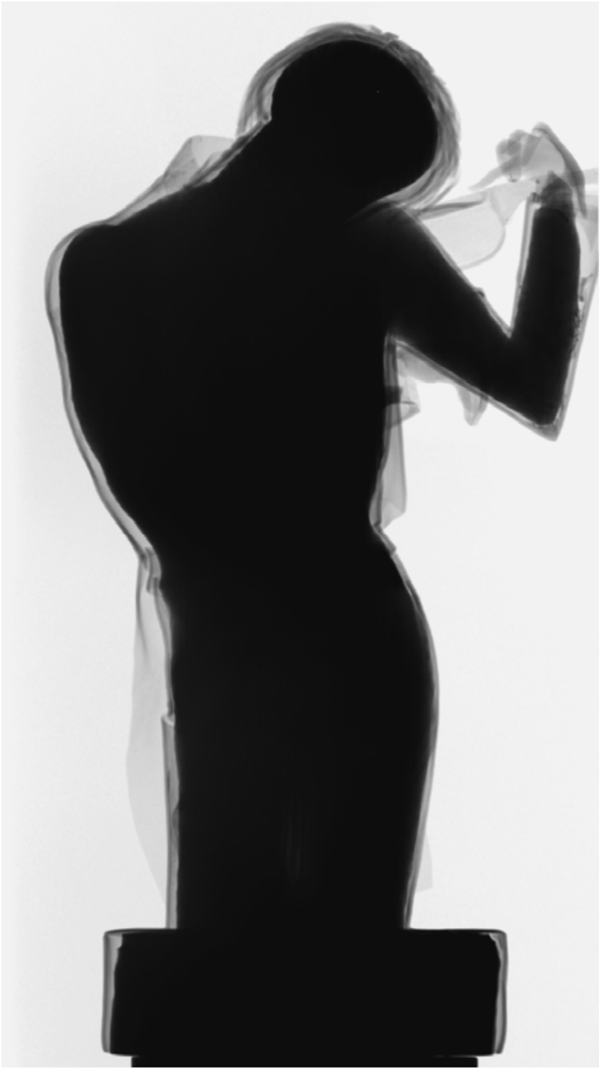


Fig.3. Frontal view of The violinist seen in a neutron radiography. The inner wood structure is very close in shape to the lead sculptutre.

In the first case attenuation occurs:

- in parts of the sculpture not seen on the silhouette of the image, producing a blurred effect in the tomography,
- in parts where the thickness of wood structure is bigger, like the cylindrical base of the figure
- in the cross sections where arm and torso are aligned, i. e. right arm towards the back of sculpture and left arm towards the right side of figure going through torso.

Attenuation due to high attenuation coefficient of the material occurs:

- in spots in soldered areas: flux remains (boron in borax) in folds of suit,
- In spots due to organic materials, like in the chips of wood in the sleeves,
- In the stucco lump in blister on right leg.

The shape of the inner wood structure looks very much like the lead sculpture except in the hands which are made out of lead only.

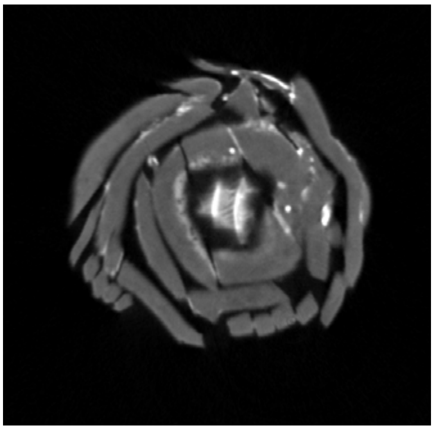
The wood kernel is thinner but not perforated in between the legs (here there is only about 10% transmission of the neutrons).

Where wood is thinner the wood grain can be seen in the images. Thanks to this fact we can now state that the left arm is carved in the same block of wood as the torso.

Tomography

With computed tomography we can obtain three dimensional information from the interior of a sample. It can be done either with X-rays or with neutrons as in this case.

The cross sections are obtained with a special reconstruction software, using the information of every pixel line in the radiographs in a quite time-consuming process.



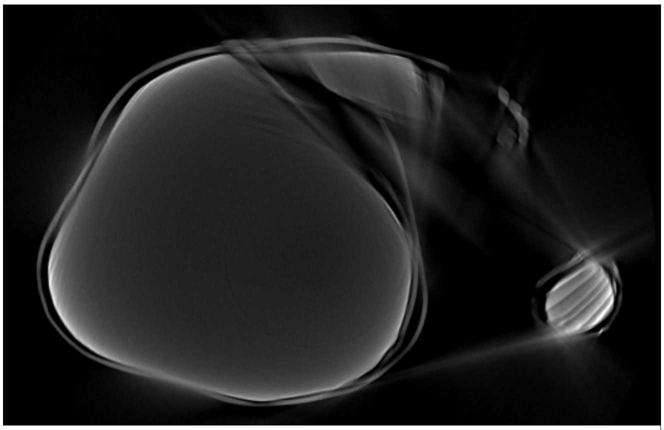


Fig.4. Left: Tomography cross section of the top of the head where soldering, lead corrosión and some grain of the inner wood structure can be seen. Right: Tomography cross secction at the level of both arms showing blurred areas where the information was not properly captured.

The cross sections can be perpendicular to the rotation axe (XY) or parallel to it (XZ or YZ) and contain all the information of the sculpture including all the parts inside.

Despite the blurred areas lacking information, tomography has been very useful to locate the carbonate layers and the fixing nails and solder. It can also be used to find the limits of the different pieces of lead in the sculpture.

Digital processing of the images : volume reconstruction in 3D

A virtual volume can be generated with all the stacks of the tomographic sequences using special 3D software. This volume can be virtually handled and freely moved around in the space. New cross sections can also be obtained to study specific areas. Some parts can be taken away allowing hidden parts to be seen. The volume can be cut in two halves and separated and so on.

Cross sections of the 3D reconstruction will help us clarify the limits of the different pieces of lead that form the sculpture and the way they are overlapped.

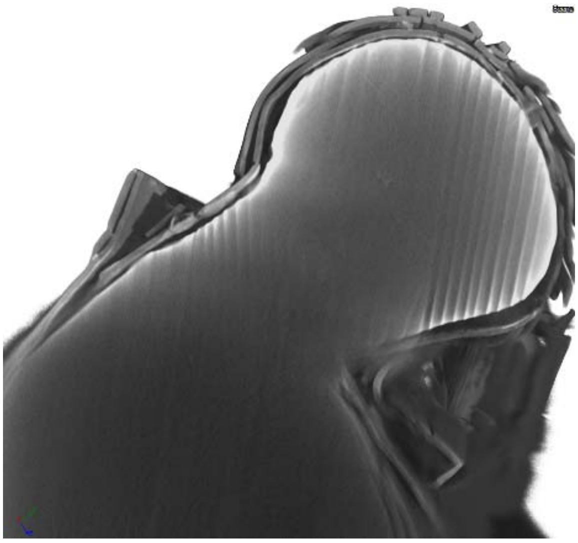


Fig. 5. Detail of the head and upper part of body cross sectioned in the 3D reconstruction. The different lead plates, nails amd some woog grain can be perfectly identified.

CONCLUSIONS

The main results concerning the **materials and manufacturing technique** of the sculpture refer to:

1. shape and dimensions of internal structure
2. identification and exploded view of all the different lead pieces (in progress)
3. location, types and number of fixing nails
4. location and morphology of soldering

The present **state of conservation** has also been assessed in different aspects suh as:

5. location of carbonated areas
6. thickness of carbonate layers
7. dynamics of the carbonation process of lead.

1. Internal wood structure

The internal wood sculpture was carved out of a block of wood made gluing 3 different planks together (vertical joins). The joins are visible in the tomography at different heights all through the sculpture. Wavy carving marks can be seen on the wood sculpture both in radiography and in tomography and make it clear it was carved with gouges, a technique Gargallo used very seldom. Chips of wood are trapped behind the lead plate and in elbows.

The lead plates are really following very closely the shape of the wood kernel: it is like a wood sculpture dressed in lead suit.

2. Identification and exploded view of all the different lead pieces.

Thanks to the 3D software it is possible to separate the lead sculpture from the wood kernel, and once this has been done, each piece of lead can be identified and isolated allowing us to draw an exploded view of the sculpture. This part of the study is still in progress.

3. Location, types and number of fixing nails

A total of 34 iron nails and tacks were hammered into the wood kernel to fix the main plates of the sculpture in places that were afterwards covered by another layer. These nails can be seen in the radiographs, the tomographic images and in the 3D reconstructions. There are 21 nails and tacks and possibly one screw in the head. These nails can fix one to three layers of lead.

4. Low melting temperature soldering

Soldering is an assembling technique that uses low melting temperature metal alloys. Solder material is an alloy of lead, tin and zinc, and thus none of the metals used has a much different absorption coefficient from that of the main metal, lead. The remains of flux containing boron has made it easier to spot in the neutron images where this type of assembly has been used.

Gargallo used low temperature soldering to join different plates of lead in those places that were to be seen in the final sculpture, i.e. on the uppermost layer of flocks of hair, on the attachment of upper disc to the lateral band of the base, on the attachment of legs to the base and on he neck and pieces depicting the wrinkles on the swallow tail suit.

5. Location of carbonate corrosion

Unfortunately there are some places from which no useful information has been recorded, namely the area in between the two legs, and the spaces behind both arms and between arm and chest or arm and violin and shoulders.

Corrosion is visible in all three sets of images: radiographies, tomographic images and 3D reconstructions. We can even see in the 3D images the surface texture of the carbonate layers from the inside.

In tomography the lead carbonate layers appear as a fine white band attached to the inside of the lead plates. They can sometimes be confused by the remains of flux in the soldering. The accurate and thorough analysis of the tomographic images can help us obtain quite an accurate mapping of the areas affected by carbonation and thus estimate the percentage of the total internal lead surface affected which is of about 10 to 15%.

Fig. 6. Mapping of corroded areas on the inside of the lead plates, according to the information given by the tomography cross sections.

6. Thickness of carbonate layers

We have been able to measure both the thickness of the sound lead and that of the thicker lead carbonate layers. The thickness of the lead plates varies from 2,5 mm to 1,5 mm. whereas the layers of lead carbonate appear in all thicknesses from nearly nothing to about 2 cm in the blister on the right leg where no sound lead is preserved.

8. Dynamics of the carbonation process of lead

This study has also helped us understand the dynamics of lead carbonation and why in the case of *The violinist* it has taken about ninety years to show up.

It is clear in the images that the lead plates begin to show symptoms of plastic deformation only when the growth of the carbonate layer has reduced the thickness of the sound lead to a 25% approximately which has happened now. Corrosion has been going on behind the lead sculpture from the very moment it was created in 1920 and with every rise of relative humidity a new fine layer has grown just on the interface with the sound lead. Today there are several areas on the sculpture beginning to swell and that means it will show more blisters in a relatively near future.

The detailed observation of the different images has yielded some very new and interesting information about the sculpture, its materials, its manufacturing technique as well as its present state of conservation. All this information will help us take the next steps towards a successful conservation treatment which will have to be carried out in short.

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