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INDUSTRIAL METROLOGICAL TECHNOLOGIES FOR CULTURAL HERITAGE

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Abstract

The work addresses the issues related to the survey of small-sized artifacts made of reflective materials. This is the case of a bronze horse, possibly part of a group with praying figures, kept at the MuVet in Vetulonia. Modern technologies applied during the survey phase encounter difficulties that are hard to overcome in this case. The topic becomes paradigmatic in terms of problem-solving and the adoption of ad hoc technologies. Reflective materials, in general, pose problems on the metric reliability of the three-dimensional model. Therefore, ensuring high reliability for small-sized objects becomes the crucial challenge in order to provide degradation analysis and make the processing details visible. In the case under examination, the representation has realized a reliable model with a deviation of around 0.05 mm, managing to represent the object at a scale of 5:1 with emerged details that were previously invisible even to a high-resolution photographic campaign.

Keywords

Metrology, survey, archaeological findings, Vetulonia museum, blue light.

1. *Archaeological finding contextualization*

Today, the process of digitizing Cultural Heritage has become an increasingly central theme for the safeguarding and enhancement of historical, archaeological, architectural, artistic, and broader Cultural Heritage.
Its purpose should not only be identified in the virtual archiving of the asset but should also include the subsequent use of the digital product, making it accessible to a heterogeneous audience, including scholars in the field for any scientific studies applied to it.

Therefore, technological innovations are fundamental, refined over the years to acquire an increasingly precise and accurate digital model that preserves metric and technical data useful for subsequent analysis and experimentation.
On these topics, the DHoMus research project is presented, started in March 2020 and promoted by the Department of Architecture of Florence in collaboration with the Diocesan Museum of Palazzo Orsini in Pitigliano and the Isidoro Falchi Civic Archaeological Museum (MuVet) with the related archaeological areas of Vetulonia, in Tuscany, funded by the Tuscany Region with the 100 researchers for Tuscany project (Stefanini & Vezzi, 2021).

MuVet collects artifacts from archaeological excavations of one of the most important and rich cities of the Etruscan civilization, the ancient Vatl (Vetulonia). In June 2000, the museum reopened to the public, with the intention of continuing archaeological research by establishing a dialogue with the surrounding area (Aiello, 2020). In fact, near the museum, there are: the Archaeological Area of Poggiarello Renzetti, the urban remains of Costa Murata and Costa of Lippi with the nearby necropolis. With the project *"Così lontano, così vicino. Tutto a Vetulonia, Vetulonia per tutti"*, the objective is to bring the real estate of heritage to the museum and strengthen the connection with nearby sites.

For this purpose, two main phases are realized. The first phase relates to the acquisition of highly reliable data, and the second phase relates to the use of a three-dimensional model that is created for better dissemination and representation of the research carried out on each artifact. This way, the research becomes an attractive feature that can be offered to an ever-wider audience. To achieve this, clear, simple, and direct graphical languages must be implemented and researched, without ever betraying the scientific nature of the data, according to non-simplifying but accessible principles.

For the initial experimentation, the bronze statuette of the so-called *cavallino* analyzed, which according to ministerial cataloguing is identified as follows:

- Card 634
- VET_25 (21.S238-18.025) ICCD_MINP_1562730170 461
- Candelabra cymatium configured as a horse
- Late Classic phase, 4th century b.C.
- Vetulonia, Scavi Città Poggiarello Renzetti Domus dei Dolia, Room G, G showcase 46
- Fragmentary
- h at head cm 8.7; at rump cm 5.8; length cm 11.1

It was found in a small depression in the floor plan at the center of the warehouse-pantry room of the "Domus dei Dolia", along with a group of seven figurative bronze figurines comprising three male character statuettes, two crowned devotees or orants, and an haruspex.
The "Domus dei Dolia", which covers over 400 square meters, is an Etruscan-Roman residential unit from the 3rd century BC, located in the Poggiarello Renzetti district (Vetulonia). It was uncovered during excavation campaigns resumed in 2009, and its name "Dolia" derives from the terracotta jars found there (Grassigli & Rafanelli, 2019).

2. *The choice of the technological protocol to apply*

The choice of the subject of the *cavallino* leads to analyzing its composition in more detail, laying the foundations for structuring a scientific study scaled to the archaeological artifact under examination.
The *cavallino* is characterized by an extreme attention to anatomical details that can be clearly seen after the survey. The delicacy of the melting is evident in the modeling of the mane, hooves, and even the ribs of the chest, which underline the muscular effort of the horse in a rearing position. (Fig. 1) On the horse's neck, the decorative character of the harness with bubbles is observed, and the right arm of its rider, perhaps a dioscurus, is still preserved.
The statuette made of bronze material dimensionally fits into a 12x12cm cube.

The details of the craftsmanship, its small size, and the reflective material of which it is made, become determining and indispensable characteristics in the choice of the most suitable survey system for its digitalization.

The need is to be able to acquire a highly reliable 3D model (mesh) from a dimensional metrological point of view, in order to subsequently carry out degradation analysis and make the microscopic signs of the artifact's creation visible.

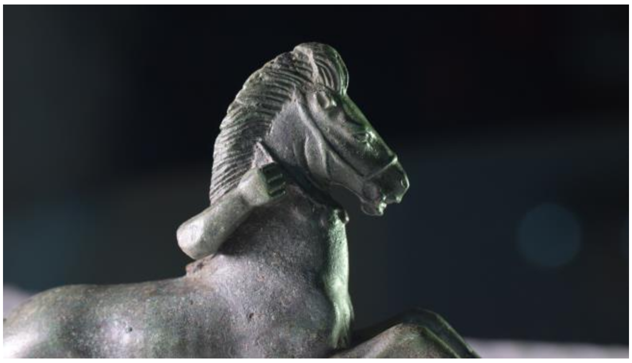

Fig. 1: Photograph showing the bronze statuette of the *cavallino*

The choice of the instrument obviously affects the results. The 3D model to be obtained must be appropriated to the desired output in terms of quality and accuracy of the data metric, as well as acceptability of the texture.

So, the question arises: which technique and instrumentation is best suited to tackle the survey and meet the before mentioned needs?
There are currently several methodologies that are mostly used for acquiring medium/small-sized objects, such as photogrammetry, 3D laser scanning technologies, and structured light scanners.
Photogrammetry, through the creation of photographic campaigns, uses the principle of overlapping at least three common photographs to recognize the position and shape of the detected object, allowing the subsequent creation of a point cloud up to the mesh and the creation of texture with chromatic data. In fact, photogrammetry acquisition by camera, uses a metric reference system to give the size of the object in the photograph. For such a feature, at least 3 frames are required for the software to acquire a correct point cloud. The cloud works by triangulation on a minimum of three points indeed.
On the other hand, 3D laser scanning works with reflected light, as photons are reflected back and forth, those with incorrect polarization are expelled, while those with correct polarization are amplified by the laser, which returns their position in the form of points (cloud). The structured light

scanner, on the other hand, is characterized by light fringes that are projected onto the object to be surveyed and captured by two stereo cameras. The acquired 3D model does not contain chromatic data.

However, it must be observed that the problem of the plasticity of the object, that is, the numerous curves that compose it, becomes a major obstacle for acquisition through both cameras and laser scanners, since in both cases it is not possible to obtain the apparent edge and the metric data is seriously affected. It is quite intuitive that the laser light spot, which is linear, cannot stop at the tangency points of the curve. In the best case, it either splits or just goes beyond the object.

Furthermore, the bronze material of the artifact would have negatively affected the acquisition of points to be, as mentioned, partially reflective.

The same issue arises in the photogrammetric project. The use of a camera and digital image processing software that generates 3D spatial data does not guarantee the metric accuracy required, as with the 3D laser scanner. Another issue is the post-production time required to merge multiple photographic projects depending on the complexity of the object itself. Further more, a good photographic acquisition must be determined by the surrounding light conditions and corrected with spotlights to promote diffused light, minimizing the shadows created.

On the other hand, structured light scanning allows for the filtering of ambient lighting since it works with cold light frequencies (3600-6500 Kelvin) emitting blue radiation. This method reduces interference during image acquisition, allowing for the quick acquisition of a complete and highly reliable 3D mesh model. In this case, the structured light scanner presents itself as the most suitable technology for carrying out the subject's survey under analysis.

2.1 The choice of blue structured light

The choice of tool for the survey it was determined thanks a collaboration with GOM high technologies. GOM is a company within the ZEISS group that specializes in industrial measurement technology in the automotive, aerospace, energy, and consumer goods sectors.

The survey was conducted using a high-speed optical technology, using the ATOS-Q: a blue structured light 3D scanner for non-contact measurement with optical sensors.

It has the ability to acquire more than 8 million points per scan, with a distance between them, ranging from 0.04/0.03 to 0.15/0.12 mm (depending on whether the model is 8M or 12M acquisition points). The scanning is carried out in fixed areas determined by the tool, which vary from 1m x 70cm or 50cm x 37cm. the work in planned by a square of light, proportionally of the object to scan.

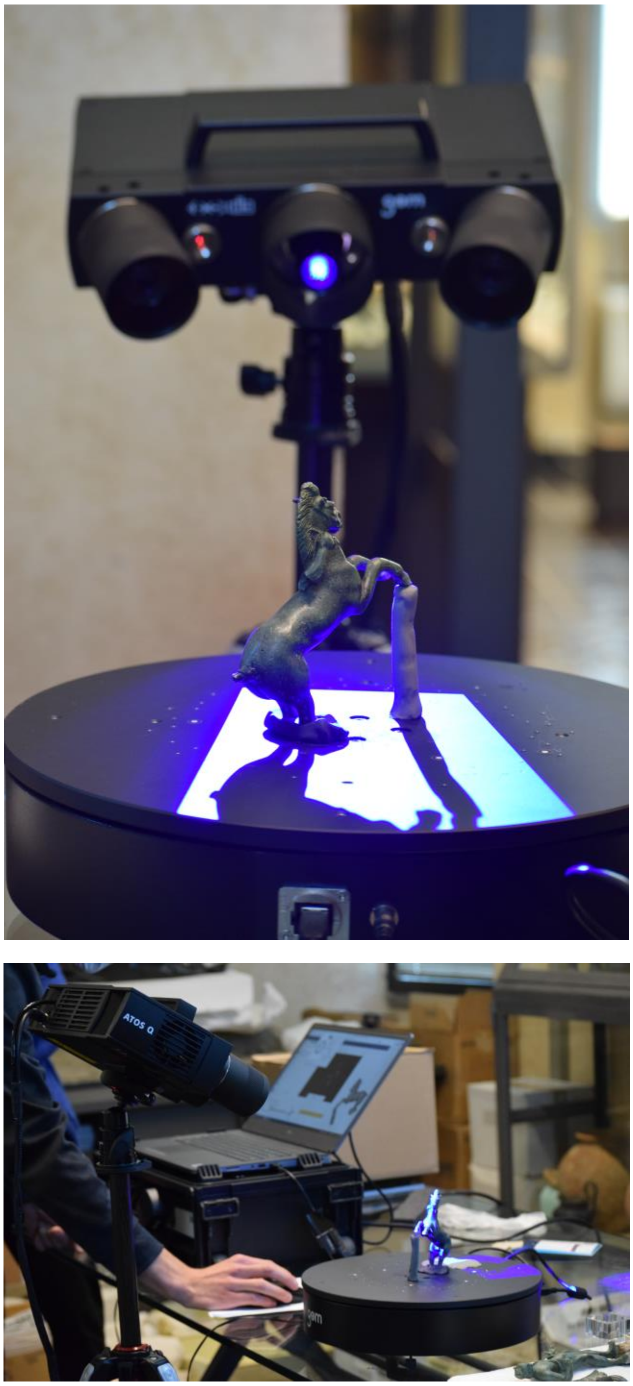

Fig. 2-3: Survey session of the artefact with blue structured light scanner

Fig. 4: Millimeter tags positioned on the turntable, essential for referencing and merging the scans

The compact tool can be easily positioned on a tripod and the object can be placed on a turntable. This allows for the object to be antouched, no opaque material to be used on the surfaces, and a 360° control of the capture (Fig. 2-3). In fact, the instrument allows to register data not affected by the thickness of the dust.
In this case, to do the scan, the tool was kept at a

Fig. 5: Blue light fringes on the surface of the object at high speed, filtering out light interference in the environment

fixed distance of about 50 cm, allowing it to frame the object with the turntable on which it was placed. Millimetric targets (0,8 mm) are positioned on the turntable, which are essential for referencing and combining the scans (Fig. 4).
In this way, the machine acquires a millimetric reference given by the targets and creates a metric network that it uses to reference the measurements made on the surface of the object; an important issue for artifacts is that they are not affected by the placement of any targets.

During the scans, thanks to the Blue Light Equalizer, the light fringes are projected onto the surface of the object at high speed, filtering the light interferences present in the environment, allowing for the creation of uniform light, with measurements taken at rapid speeds, comparable to the speed of light itself (Fig. 5). The high quality of metric data is further provided by the tool which has two opposing optics, based on the intersection method, with the light fringes. In practical terms, it uses the stereo-photographic principle with forward intersection.
Therefore, the light pulses come from two different sources, the distances between which are

Fig. 6: 3D model resulting from scanning with high accuracy and metric reliability, output data

known, and the object is triangulated perfectly, acquiring the metric data. Reaffirming that we are dealing with an object of small size and high plasticity, it is absolutely certain that the chosen instrument has such characteristics that it is better in comparison with both the laser scanner and the photogrammetric method.
Thus, the points acquired with the optical scan are instantly transferred and managed directly by the dedicated software, aligned according to the previously mentioned targets, and subsequently processed to create a highly precise mesh with a deviation of approximately 0.05 mm.

3. *Result*

Having obtained the unique three-dimensional model of the bronze statuette, which guarantees high accuracy and metric reliability (Fig. 6), new readings and analyses of the statuette were possible, such as those related to the details of its manufacturing, which are fundamental for furthering the already initiated studies and for opening new paths towards systems of management and representation of archaeological artifacts in support of the museum. To be precise, the acquisition was done with the ATOSQ 12M instrument, on a measured volume of 100MV and with data density of 0.029 mm.

The mesh model was later integrated with the texture developed with photogrammetric techniques and applied in post-production (Fig. 7). The model obtained through photogrammetry is less reliable from a metric point of view, as it does not allow for capturing all the manufacturing details that characterize the figurine. However, it is acceptable when there is a need for dissemination of the material through digital representation such as videos, holograms, and others, where having a lower amount of information contained in the model favors its management and processing for various final outputs. The two resulting models are then compared. The best resolution is given by the one obtained with the ATOSQ instrument for the before mentioned relief reasons. (Fig. 8).

Thanks to the synergy of the professional figures, involved in the project, such as experts in metrology, archaeologists, restorers, and architects, it was possible to carry out studies on the bronze figurine, hypothesizing its original function and geometric composition, enriching the research (Fig. 9-11). The *cavallino* was probably the top of a candlestick, placed at its upper part as a decorative element. This can be affirmed by taking as an example the candlestick with the top similarly decorated with a knight and a prancing horse, found in Vulci in 1828-1829 and kept in the Vatican Museums.
Regarding the study of geometric spatial relationships, the *cavallino*, viewed from above, is perfectly arranged along the diagonal of a square with a side length of *L*, identifying a module *a*. Similarly, for the elevation, the composition is articulated along the *square root of 2* resulting from the initial square.
Therefore, *L square root of 2* allows the scanning of 4 modules *a* plus *1/4 a*, which match with the final part of the hind legs, the base of the tail, the beginning of the forelegs, the center of the neck, and the upper part of the mane. Although the tail, the final support of the hind legs, and the body of

Fig. 7: 3D model resulting from photogrammetry, post-production data

the Dioscuri are missing to date, everything seems to be balanced according to compositional canons that consider the statics and therefore the distribution of forces in each of its parts. It is interesting, however, to have understood that the bronze fusion made inside a parallelepiped

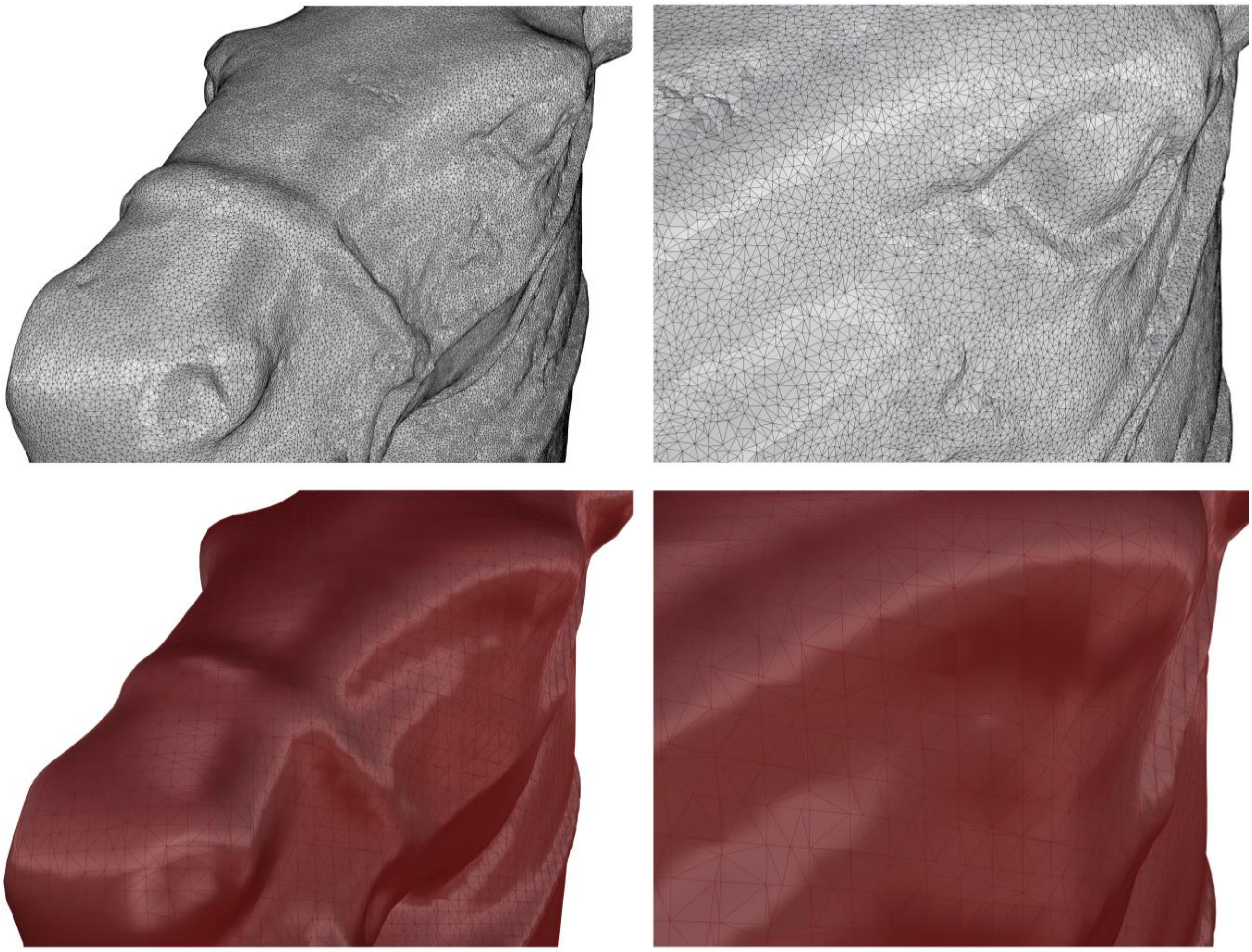

Fig. 8: Exemplification of how curves are acquired near-perfectly from the metric model, unlike those acquired from the photogrammetric model

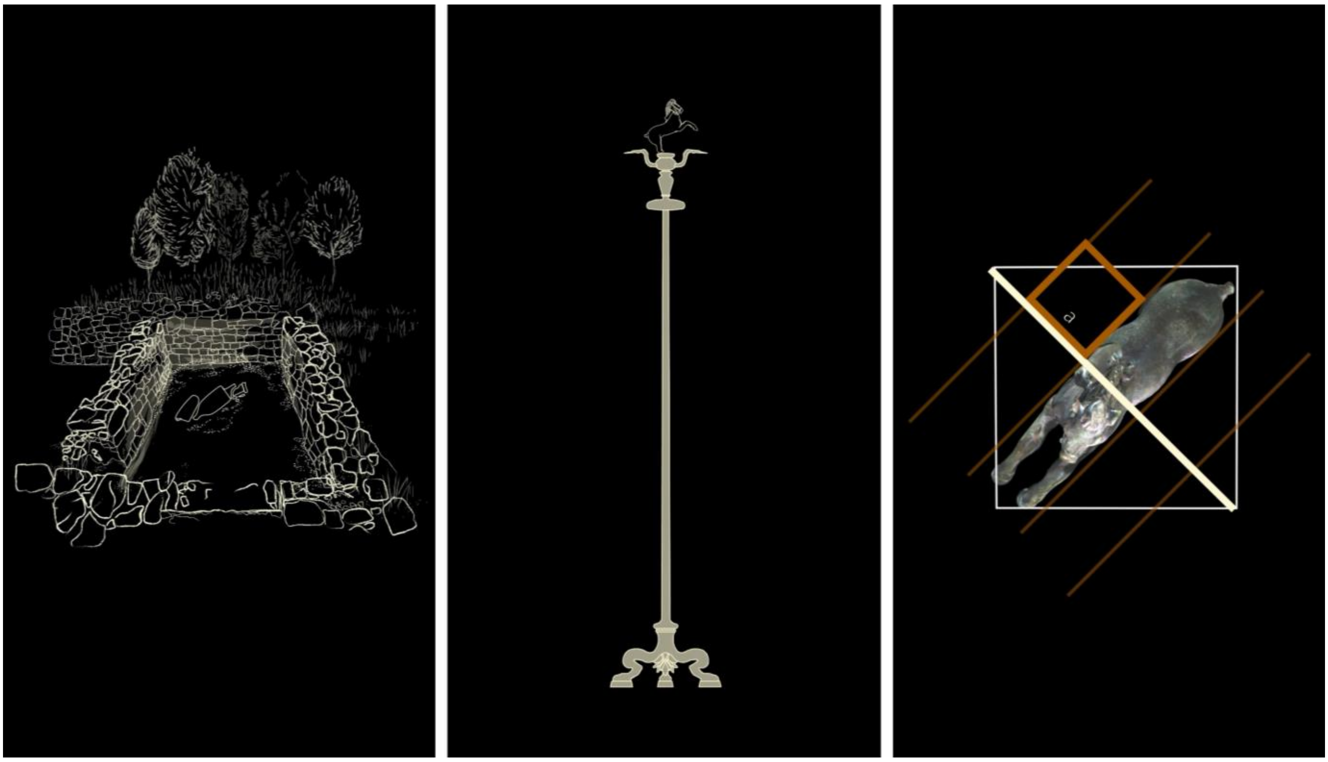

Fig. 9-10-11: Studies on the bronze statuette with hypothesis of its original function and its composition from a geometric point of view

was arranged along the diagonal, and therefore along the largest space available inside a regular solid.
The scholars found the issue interesting, opening a new outlook for the studies on Etruscan Hellenistic period fusions. The survey brought out the details of the horse's rib, the care of the mane and tail, which were not yet visible and could not be admired with the naked eye. The refined workmanship of the object confirms the high artistic ability of the period.

3.1 Divulgation and dissemination

Scientific research, which has been concretized through the study of the most suitable methodology for digitizing the object under examination and developed through the analysis of data acquired with high metric reliability, has taken advantage of the opportunity to experiment with new exhibition technologies in the context of museum communication. Through innovative installations and technological supports, the aim is to disseminate the studies carried out, not only stopping at the showmanship of the three-dimensional model, but also aiming to make them a didactic means of learning for an increasingly wide audience.

Today, museums seek new communication strategies to interact with their audiences using digital solutions that offer a more accessible and immersive exploration of the asset (Lecci, Prodi, Trovatelli, & Vezzi, 2019). Some of these solutions include augmented reality, virtual reality, videomapping, and holographic projection. The application of the latter was made possible thanks to the DHoMus project in the reality of the previously named Isidoro Falchi Archaeological Civic Museum, where the prancing *cavallino* is the main character. Holographic projection is a system that exploits the principle of projection, and in particular, homologous flipping, in which multimedia content (image or video) placed on the holographic showcase support is flipped over transparent surfaces inclined at 45°, the number of which varies depending on whether it is a pyramid or a single fold. The illusionary sensation obtained is that of seeing the reflected scene floating in the air inside the showcase (Fig. 12).
Therefore, the video of the prancing horse (at a scale of 5:1 given the high definition of its details) displayed inside the holographic window allowed for an innovative and dynamic representation of

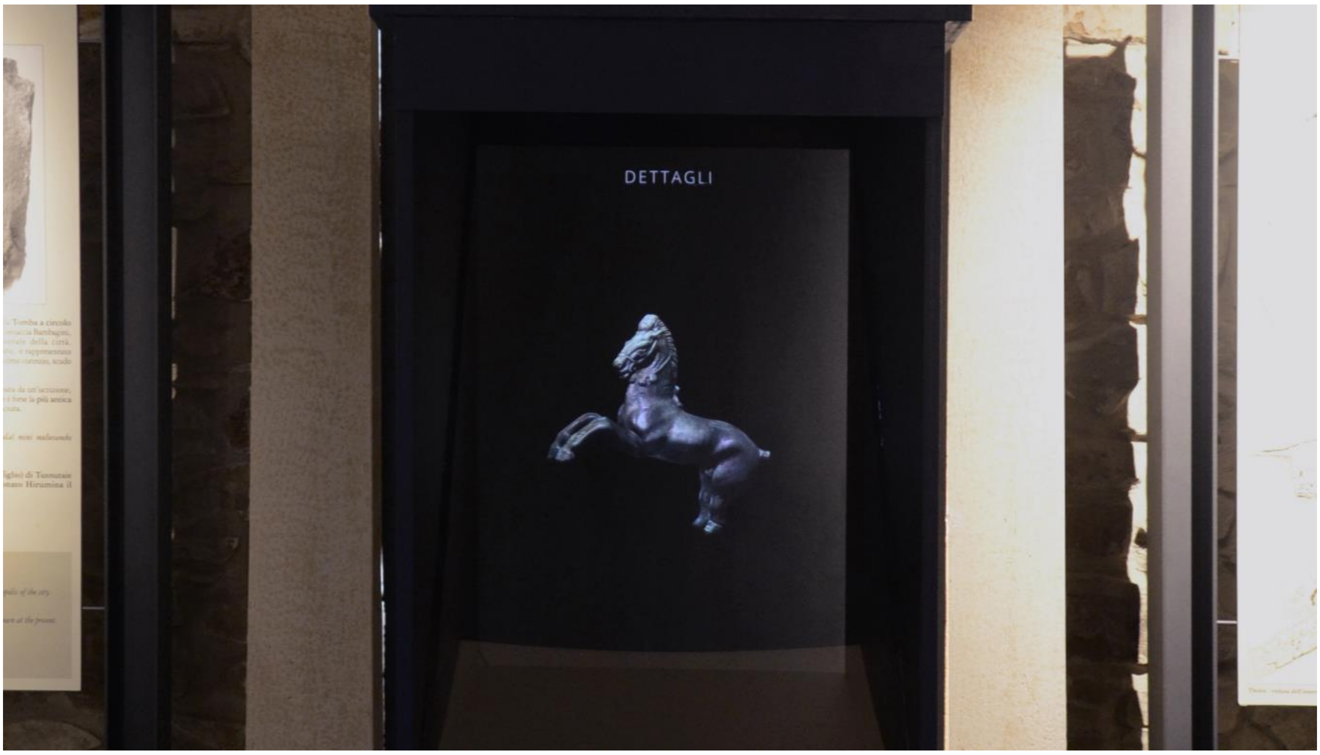

Fig. 12: Divulgation of the analysis of the acquired data, by means of a video in the holographic showcase support inside the MuVet museum path

the archaeological artifact narrative to support the museum exhibition path.

The entire project aimed at redefining the interpretation of heritage involving new technologies must be just one of the points of the development to structure increasingly advanced study methods. The active experimentation of innovative systems continues, which allow for metric reliability of scientific data and aim to solve issues such as the biunivocal correspondence between model and texture while maintaining high chromatic resolution. This is still an open question but could be solved with a new technological protocol, maintaining both mesh and texture resolution. The problem is that once again, we would need to rely on industrial measurement technologies and remodel the use protocols for Cultural Heritage.

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