Ge-conservación
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Use of geotechnologies in the reproduction and recovery of heritage, ethical reflection and case study

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Abstract: All of us, as well as the objects that surrounds us, are in a permanent process of degradation for the simple reason that we are positioned on the surface of the Earth and interact with the atmosphere that surrounds us. The degradation of all things is an evolutionary process and inevitably leads to non-existence, within a more or less short time limit - at some point in the future, there will in fact be no pyramids in Egypt, no Mona Lisa in the Louvre, no Big Ben in London, at that point, it might consider prudent to have made at least a few copies; or not. We can also consider the hypothesis that, at that point, we have stopped giving importance to the past, only thinking about the immediate future. In this article we intend to present an ethical reflection on the crossroads at which we find ourselves and an example of a restoration that uses technology to "create new ancient art today", but which maintains it our current reality, heritage that had already been lost (in terms of its physical integrity) to the restoration through traditional methods. As a final result of the work of all the experts involved, a CNC-machined stone reproduction was reinstalled in situ to replace the unrecoverable one that was originally situated within a symmetrical sculptural setting. The particularities of the equipment used that allowed this restoration challenge to be resolved are mentioned, as well as the ethical concerns that arose throughout the entire process.

Keywords: restoration, ethics, stone, sculpture, CNC reproduction

Uso de geotecnologías en la reproducción y recuperación del patrimonio, reflexión ética y estudio de caso

Resumen: Todos nosotros, así como los objetos que nos rodean, estamos en un proceso permanente de degradación por la simple razón de que estamos posicionados en la superficie de la Tierra e interactuamos con la atmósfera que nos rodea. La degradación de todas las cosas, es un proceso evolutivo y conduce inevitablemente a la no existencia, dentro de un plazo más o menos corto - en algún momento en el futuro, de hecho, no habrá pirámides en Egipto, ni Mona Lisa en el Louvre, ni Big Ben en Londres, en ese momento, se podría considerar prudente haber hecho al menos algunas copias; o no. También podemos considerar la hipótesis de que, llegados a ese punto, hayamos dejado de dar importancia al pasado, pensando sólo en el futuro inmediato. En este artículo pretendemos hacer una reflexión ética sobre la encrucijada en la que nos encontramos y presentar un ejemplo de restauración que utiliza la tecnología para "crear hoy un nuevo arte antiguo", pero que mantiene en nuestra realidad actual un patrimonio que ya se había perdido (en cuanto a su integridad física) para la restauración mediante métodos tradicionales. Como resultado del trabajo de todos los expertos involucrados, se reinstaló in situ una reproducción de piedra mecanizada por CNC para reemplazar la irrecuperable que originalmente se encontraba dentro de un entorno escultórico simétrico. Se mencionan las particularidades del equipo utilizado que permitieron resolver este desafío de restauración, así como las preocupaciones éticas que surgieron durante todo el proceso..

Palabras clave: restauración, etica, piedra, escultura, reproducción CNC

Utilização de geotecnologias na reprodução e recuperação de património, reflexão ética e caso de estudo

Resumo: Todos nós, tal como os objetos que nos rodeiam, estamos em permanente processo de degradação pela simples razão de nos situarmos sobre a superfície do globo terrestre e interagirmos com a atmosfera que nos envolve. Desta circunstância decorre, que, inexoravelmente, padecemos de processos oxidativos - uma imprecação incontornável que, em simultâneo, nos autoriza as comodidades da nossa natureza terrena. A degradação, de todos, é um processo evolutivo e conduz inevitavelmente à não existência, num limite temporal mais ou menos curto - em algum momento do futuro, não existirão, de facto, as pirâmides no Egipto, a Mona Lisa no Louvre, ou, Big Ben em Londres, etc. – nessa altura, talvez a venha a ser considerado previdente termos feito pelo menos algumas cópias; ou não. Também podemos considerar a hipótese de, por essa altura, já termos deixado de dar importância ao passado, só pensando no futuro imediato, como a maioria dos animais que hoje nos rodeiam. Neste artigo pretendemos apresentar uma reflexão

ética sobre a encruzilhada em que nos encontramos e apresentar um exemplo de uma intervenção que faz uso de tecnologia para "criar arte antiga hoje", mas que mantém na nossa realidade atual património que já se tinha perdido quanto à sua integridade física para além dos limites da recuperação pelo restauro tradicional. Como resultado final do trabalho de todos os peritos envolvidos foi recolocada in situ a reprodução de uma escultura em pedra, produzida por CNC, para substituir a irrecuperável que originalmente se situava num enquadramento escultórico simétrico. São referidas as particularidades do equipamento utilizado que permitiram resolver este desafio de restauro, bem como as preocupações éticas surgidas ao longo de todo o seu processo.

Palavras-chave: restauro, ética, pedra, escultura, reprodução CNC

Introducción

The contribution of Conservation and Restoration in contemporary societies has been to position itself in favor of prolonging the existence of some examples of recognized human mastery, in time and space, delivering to today's descendants the heritage of our common ancestors in the best possible conditions - this apparently simple baton passing, entails, however, many difficulties and responsibilities. One of them is embodied in the ethical discussion surrounding additions, reformulations, reintegrations, copies, etc. which, paradoxically, stands in contrast to one of the most important principles of our code of ethical action, and, is addressed by Appelbaum (Appelbaum 2010) when he says "The conservator-restorer faces complex decisions that are not only technical, but also ideological, affecting the interpretation and authenticity of the work. Heritage conservation reflects the interaction between objects and human beings, requiring consideration of the social context for its adequate protection."

In general, these more proactive options, are not the ones that we consider immediately, although we do not discard them definitively, without evaluating the relative impact of their implementation in a particular case. This position is rooted, first and foremost, in a society in which we recognize that it is on the knowledge gathered in the past (in any area of science, and, whatever the length of the time period considered) that we base the research that enables the development of current and future knowledge – that is, development is also a universal and constant scientific process, which is not limited (nor was it limited) to the living generations; but even this, one day, may change.

Commonly, when faced with the need to restore the function of a given object, Humanity has made use of the technical solutions available at any given time, whether they are used in repairs, additions or restorations, regardless of the ethical argument adopted. This reflection is much more peaceful and welcoming when applied to human artistries that support us in a certain essential function, as is the case with architecture – future use depends on functional recovery. But, in (mostly decorative) works of art, produced for the delight of the observer, which do not directly determine people's existence, we allow ourselves greater philosophical considerations. On the other hand, ethics in the conservation or restoration of cultural heritage has become more relevant only in recent centuries.

This last aspect is quite evident in the variation of criteria throughout the 17th and 18th centuries, in the interventions carried out on classical statuary (Hellenic or Roman), initially recovered archaeologically from the civilizational oblivion determined by the fall of those two empires, and, later, integrated into private collections (personal or commercial - antique dealers) or museums, or both, sequentially. These interventions followed certain aesthetic norms of each era, introducing, altering or removing less consensual elements. It was common to hire sculptors (of the greatest possible caliber) to reintegrate them and allow them to be re-exhibited. This was also a wager on the technical and artistic excellence of the sculptor/restorer, as a way of valuing fractured sculpture - an interpretation that brings Western culture closer to Eastern culture, where, in Japan, the cult of family history was transposed to the restoration of ceramics using noble metals (mostly gold) to fill fractures, the "kintsugi", probably prior to the practices of the modern Italian period described.

Many variations coexist in these interventionist "freedoms", to the point where there were cases in which there was not enough information in the fractured remnant to carry out the effective reconstruction, modifying the original identity with the "updates" introduced, even if the original styles were followed in some way. This was an interventionist position, which could lead the observer to a blunder interpretation, without even preventing him (sometimes, nor even taking responsibility) situations which Marion True sums up in the exclamation "who among us has not experienced the frustration of being misled in the accurate identification of a work of art by distorting or misunderstood restorations?" (True 2003). All of us, regardless of experience, have already encountered a situation like this. In return, this stance, when confronted with current diagnostic methods, produces a great deal of information regarding the history of the evolution of restoration, as revealed by the reports of Orietta Rossi Pinelli (Pinelli 1996), among others, when she states that "the new cult of fragment recovered images that had little to do with the original, because of the alterations that were performed during the ancient restorations".

If during these centuries ethical discussion was scarce, and, experimentation and interventionism dominated, in the following century (19th) the first became influential and prominent, having taken root in opposite poles of two broader currents: classicism and romanticism. As a figurehead of the first we find Viollet-Le-Duc (from whose performance we were recently remembered of in 2019's

fire, by the collapse of the pinnacle of the Notre Dame's church, of Paris, which had been added by him in 1860, in a monument whose construction was concluded five centuries before), which advocates that the knowledge of architecture allowed him to do so. In its opposition, defending non-intervention, even though the situation of complete ruin is reached, were positioned Wiliam Morris and John Ruskin, which began a movement whose obvious principles were proclaimed in the "Manifesto of the Society for the Protection of Ancient Buildings" (Morris, 1996). Later, Cesare Brandi joined this last group having postulated in the "Teoria del Restauro" (Brandi 1977) its ethical position and consequent limits of intervention, in particular, in architecture and painting, a field in which it even questioning the legitimacy of patina removal by saying" (...) historically, Patina documents the very passage of the work of art in time and therefore must be preserved. But its conservation is also legitimated by the aesthetics?". Let us remember that patina is formed after the work has been carried out, based on (and only mobilizing) the outermost layers as a result of use and/or passive deterioration, and, can significantly alter the original aesthetics. In other words, chemically, it is a product of deterioration that can significantly modify the original aesthetic, but it, sometimes, does have some positive return in the future stabilization of the object.

The philosophical currents that guide the practical work of the conservator-restorer today largely derive from those and can be summarized in some positions that we recurrently observe – all of them are situated between the two poles outlined in the 17th century: The one that rejects any type of restoration (let alone copying) and the one that allows it, with defensive arguments about the need for updating. Among them, there are nuances to be described in order to understand the difficulties that arise from each of them.

For some, whatever the state of conservation or degradation, no alteration/enhancement can be introduced after the artistic work has been completed and without being the work of its author. Behold, objects will wither away under our observation, and we cannot do more than preserve the existence of the remainder, at each moment. At the limit, we could today implement a preventive conservation program. It may seem limiting, but it protects copyright and is humble in foreseeing the finiteness of the work in the face of inexorable degradation processes.

Others argue that what should be preserved is the memory we have of the artistic object, since what matters is the impact of the work on the human mind. Therefore, changes can be introduced, but they must not manifestly distort the object, maintaining its connection to the author and the act of its creation. Here the difficulties are related to the combination or prevalence of some of these arguments – especially authorship and context: the authors can be multiple and across several artistic currents, as is the case of many of the largest European cathedrals.

There are also those who advocate that the longevity of the object should be promoted even if (clearly distinguishable) parts are added or de-characterized, since these actions are a mere update of the author's original concept; a very common trend in the appreciation of some religious heritage, although less used as such. Especially because in some cases the deviations aim to introduce a new functionality (for example, museum functionality) or to restore the building to an essential function that was no longer suitable (for example, the complete replacement of roofs).

It can be seen from these perspectives, that the subjective scope of the adopted solution is normally increased whenever the possibility of its conservation or maintenance was overcome by a catastrophic event (natural disaster, impactful accident/incident, etc.) in its results for the object, and, consequently, also in the decision formula of the intervention that is now being carried out will take, as well as in its depth.

From here arise the paradigms that the *corpus* of Restoration Ethics ultimately seeks to reconcile: on the one hand, dysfunctionality enables the adoption of greater depth in intervention, but distances us from historical factuality itself, which has apparently been attempted to be overcome through systematic recording and analysis. The much-recited principle of reversibility, which together with that of adequacy (True 2003) aims to ensure the documented integrity of the original beyond the technical rehabilitation solution adopted at each moment, also follows this need.

For the optimized combination of the virtues stated by the various currents, today's Conservation and Restoration practice also denotes the constant concern of not trying to deceive or mislead the receiving public, highlighting the additions beyond the original, and only disguising to a limited extent the aesthetic discontinuities (pictorial reintegration techniques, p. ex.).

Painting is, in fact, one of the areas most impacted by the latest technological developments, allowing for a deeper analytical knowledge (qualitative and quantitative) of materials, both original and those used in restoration. But also, in sculpture. Interventions in these areas gradually gravitated towards minimal restoration, preferably only structural, preserving as much of the original aesthetics as possible through the reintegration of gaps in an assumed way and moving away from the dubious statements of the past. Thus, gaps today are seen as interferences in reading, as Paul Philippot (Philippot 1996) states when he says "the lacuna, be it in a picture, sculpture or monument of architecture, appears to be an interruption of the continuity of the object's artistic form and its rhythm, since the object's completeness is no longer a necessity (and often the fragmented object has acquired a value in its fragmented state (..) the only aim of the restoration should be to reduce or eliminate the disturbance caused by lacunae in such a way that the intervention can be unmistakably identified as such".

But the greatest ethic paradox lies in the fact that, in the meantime, it is now possible for us to theoretically reproduce any object in series, exposing the difficult consensus recently obtained (which is based on the in-depth analysis of each object, record and common criteria) to new challenges, which, in the end, could make all Conservation or Restoration obsolete.

It is in this ethical discussion surrounding the recent current possibility of being able to reproduce works of art through such different supports as holograms, 3D printing with resins, virtual rendering and augmented reality, NFTs (New Tecnology File System/non-fungible tokens) and also "mechanized copying with computer support" - CNC, the core of our ethical analysis. Today, in fact, we can produce "perfect copies", which reproduce the work of art (in this case, a sculpture), even in its materiality (stone) and with traces of its specific history (small superficial irregularities that result from the deterioration of the original can be digitally recorded by the scan); but, what results is still the object that was lost? And, if it replaces it in its functionality? The intrinsic nature of all these "copies" results in a decisive differentiation with the original, as none of them reproduce the object in its "original historical nature", they are merely representations of it in other distinct realities, and there can be no confusion between the two, and, the observer is informed in advance of the circumstances of the enjoyment in which he embarks.

In fact, none of these realities, in any artistic field, have the same story, or author, or historical materiality, that is, none have the historical-cultural value that we usually attribute to them. The questions that could be raised immediately regarding the legal framework of the authorship of these copies will be dropped, since, we, who are dedicated to historical heritage, are not used to be confronted by authors to claim their rights, and, on the contrary, we assume ourselves, as their posthumous attorneys. For the historical and cultural value, we cannot fail to state that the intrinsic nature of all these "copies" results in a decisive differentiation with the original, as none of them reproduce the object in its creative nature; they are merely representations of the same object in other distinct realities, and, however suitable they may be for enjoying the original work of art from a new perspective, they have no historical-cultural value.

The production of copies, whether to fill gaps (which we referred to earlier) or for cultural dissemination, is a common practice in Conservation and Restoration in a museum context, as is digital recording (2D or 3D, rendering, etc.). The first case has been going on for decades and only aims to make reproductions available at reasonable prices (sometimes with variations in scale, material, etc.) in exchange for some funding and cultural agency for the institution. The second one aims to preserve the original (in the event that it cannot be displayed and is essential for the expository discourse). In order to analyze the issue at hand here, we will also ignore the more or less illicit circumstances in which these practices may also occur and refer only to circumstances that fall within the scope of interventions supervised (directly or indirectly) by national or international cultural institutions – in this way, the ethical issue has been obviated by the execution of copies in limited numbers, distinct materials, good documentation and registration. Until now, these reproduction operations were time-consuming, complex and expensive, and, therefore very limited and in depth considered.

Thus, the most time pressing ethical challenge that we face with the availability of these new resources is to take refuge in the convenient social conviction that we can do whatever we want, to resort to a more convenient solution without ethically analyzing our technical performance. Ironically, only a deep understanding of the context in which the object was originally produced and its physical constitution allows for a more accurate decision, and, this requires ethical consideration in the face of this renewed and increased urgency of immediacy.

Another path is being taken by Creative Conservation, which focuses on maintaining the collective memory of the historical experience or object, materializing them in a new creative reality, but informing and preserving the original context. In these cases, parts of the original object that are no longer "preserve able" are recovered in a new cultural existence, of technical, historical or artistic synthesis, by adopting a proactive and creative attitude towards the ruin of the original material context. Examples of this trend are the recovery of lost fragments of tiles reorganized into a mural based on the original pattern of the tiles themselves (Nogueira *et al*. 2024), or, the transformation and synthesis of multiple historical testimonies into a dramatization made available on video in a museum (Calvi *et al.* 2024).

This is exactly what Munõz Viñas (Viñas 2003) refers to when he says: "Nor is it possible to judge Restoration in the abstract: the same Restoration can be good, acceptable, or painful depending on the circumstances in which it was carried out. There is no such thing as a good Restoration, but rather a good Restoration of a particular object in a particular circumstance. Some readers may conclude that contemporary Restoration theory is saying that anything goes, as radical subjectivism seems to suggest: that since the authentic criteria on which Restoration work is based are subjective, it is legitimate to do whatever the protagonist (the restorer or other decision-makers) prefers. But in reality, it is saying just the opposite. It is saying that the restorer cannot do whatever he decides, what he thinks is best, what he considers most honest, what he has been taught, and that the main criterion that should guide his actions is the satisfaction of the group of subjects whom his work affects and will affect in the future."

We introduce here a case study as a corollary to this reflection, which is intended to express in words the ethical challenges that we are facing, not day by day, not as a position for or against, but rather as the voicing of a challenging situation for conservative ethics.

In this sculptural set of two figures that originally supported symmetrical religious statues one day, the reproduction was obtained from data collected from the only one that was in a good state of conservation, after being inverted symmetrically, to result in the original position of the sculpture that did no longer fulfill the necessary function. The methodological decision was perfectly supported by current ethics, especially in view of its specific preservation circumstances, and, it maintains the original contextualization, but there is a new reality, different from the original, even as it is committed to it.

Figures 1 y 2.- Resulting reproduction from sculpture.

Case study

Introduction to technology

The history of reproduction and replication of sculptures in 3D has evolved significantly, boosted by the advancement of digitalization and three-dimensional printing technology. This practice dates back to traditional molding and copying techniques, but the digital revolution completely transformed the process, making it more accessible, precise and versatile.

Historically, the duplication of sculptures was carried out by direct molding or casting processes, such as the lost wax method. These methods allowed for the creation of physical copies, but could be limited in terms of amount, precision and details, as well as being time-consuming and somewhat invasive for the original works.

With the invention of photogrammetry at the beginning of the 20th century, it is possible to capture three-dimensional shapes using photographs. This process was a precursor to modern 3D digitization techniques, allowing objects to be reproduced at different scales. However, the first photogrammetry methods were complicated and still could not guarantee detailed reproduction of textures.

Starting in the 1980s and 1990s, the first 3D scanners emerged that used laser light and projection technology to capture the three-dimensional shape of objects, including sculptures. In this phase, structured light begins to gain relevance. Structured light projects patterns onto the object, allowing the cameras to capture the distortion of the projected lines, or to, in turn, translate them into a precise three-dimensional model.

The use of structured light and laser scanners allows detailed capture of sculptures in high resolution, opening new possibilities for museums, archaeologists and conservators. An emblematic example is the digitalization project of Michelangelo's sculpture "David", made in the 1990s, which used laser technologies to create a highly detailed digital reproduction of the work. This pioneering work demonstrates the ability of two 3D scanners to capture works of art on a large scale and with extreme precision.

The achievement of 3D printing has revolutionized even more the field of reproduction of sculptures. Beginning in 2000, 3D printing began to be used to create physical reproductions from digital models. The stereolithography technique was one of the first to be used, followed by other techniques such as fused filament fabrication (FFF) and selective laser sintering (SLS).

These technologies will allow the creation of precise reproductions of historical sculptures, from small miniatures to full-scale reproductions. The use of 3D printing also facilitates digital preservation, with replicas being used for display as original works are preserved.

The object

This case study reveals the procedure adopted for the elaboration of a replica of a sculpture in limestone that belongs to Oporto's Cathedral and in a high state of degradation. The set was made up of two symmetrical statues, one of which was not recoverable (on the left). The intervention managed to recover one of the two sculptures with approximate dimensions of 94 cm x 40 cm x 38 cm [Figure 1], which served as a model for the elaboration of the reproduction [Figure 2]. The conservation work was carried out by $CaCO_3$, Conservação do Património Artístico, Lda. and the execution of the elaboration of the reproduction by the company Eduardo Marques & Rosa, Lda.

Technical and scientific resources

— *Optics: Structured light*

The use of structured light to model stone artifacts is an advanced 3D digitalization technique that allows precise capture of the shape and texture of complex surfaces, such as sculptures and other stone objects. This method involves projecting a pattern of light (generally a grid or

stripes) onto the object and, through the distortion of these lines caused by the shape of the object, it is possible to reconstruct a highly detailed three-dimensional model. One or more cameras capture the distortions of the light pattern and the data are processed through specialized software that generates a three-dimensional digital model, precise in the order of micrometers. This modeling of stone artifacts has high precision (it is capable of capturing small details, such as fissures, textures or fine reliefs, with very high precision), and is non-invasive (there is no physical contact with the artifact, which promotes the preservation of fragile or historical objects). Compared with other methods, such as photogrammetry, structured light digitization can be quite fast, depending on the size of the object and the level of detail required, and, versatile for it can be used in a variety of materials and sizes of sculptures. Use in restoration and preservation: Digital modeling allows artifacts to be digitally preserved, and the digital model can be used to restore damaged parts or create accurate replicas.

The operating principle uses two different approaches - see figure 3.

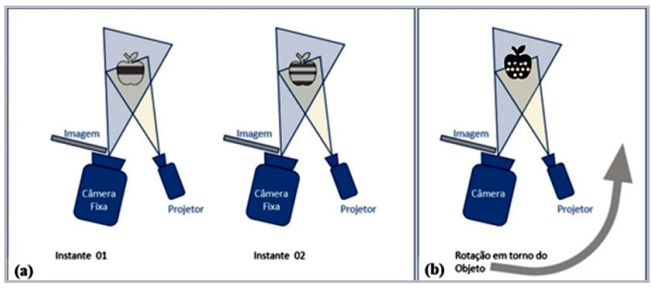


Figure 3.- Two different methodologies for digitalizing objects using structured light.

In Figure IIIa, it is observed that the camera is fixed, as is the object, and, only the two light patterns are movable. In Figure IIIb, the luminous patterns are maintained fixed but the camera and the projector are moving together around the object. In this last approach, it's possible to digitize larger objects, and, still, the deformation of the same luminous projection seen in different positions allows the realization of digitization (Balbino 2021). As various images are captured by the camera, in different positions, they allow the visualization of the same point of the object at different angles (Batlle *et al.* 1998). An example of equipment that uses this operating principle is the FARO Freestyle 3D Objects 3D Scanner [Figure 4], which was used in carrying out this work for the acquisition of digital data prior to the actual implementation of computer-assisted duplication, under specific manufacturing conditions [Figure 5].

• Practical applications:

The use of structured light has been widely referred to in works related to the reproduction and modeling of art objects, not least sculptures, taking advantage of its effectiveness in capturing the detailed geometry and textures of complex surfaces. These studies demonstrate how structured light has been essential for the digital documentation and preservation of art objects, allowing the creation of accurate reproductions and contributing to the conservation of cultural heritage. Below, some examples you will notice:

- 1. 3D Digitization of Sculptures in the British Museum: One of the most successful examples of using structured light to model sculptures was a 3D digitalization project carried out at the British Museum. Antique and valuable sculptures digitized with high precision for digital preservation and subsequent studies, allowing the creation of precise digital replicas (British Museum 2025).

- 2. EU "3D Icons" Project: The 3D Icons project, funded by the European Union, focuses on the digitization of cultural heritage, including iconic sculptures from across Europe. Structured light was one of two methods applied to ensure the detailed capture of shapes and textures of works of art, allowing the creation of three-dimensional models that could be used for study and online display (3D-ICONS 2025).

- 3. Sculpture by Michelangelo – "David": The 3D digitization project of Michelangelo's sculpture David involves the use of structured light technologies to capture the model in great detail. This work was conducted with the objective of creating a complete digital replica of the sculpture, with micrometric precision, being one of the most important references in the use of structured light for Renaissance art (Euronews 2025).

- 4. Study of Roman Sculptures at the Louvre Museum: Another relevant example was the use of structured light to digitize Roman sculptures at the Louvre Museum. This work involves detailed documentation for conservation and research purposes, allowing the creation of high-resolution digital replicas that are used both in virtual exhibitions and in scientific studies on ancient sculptural techniques (Louvre 2025).

— *Image acquisition: Artec Eva portable 3D scanner*

For data acquisition, an Artec Eva portable 3D scanner was used [Figure 4], which is a 3D scanner widely used to capture objects quickly and accurately.

Artec Eva's main features are Structured Light technology, great portability, high resolution, capture speed, software compatibility and versatility in diverse applications (light and easy to handle); it has fast capture speed, facilitating the digitization of objects in motion to capture large surfaces in less time; works with software compatible with

Figures 4 y 5.- Figure 4: The portable Artec Eva scanner. Figure 5 Industrial facility for manufacturing object reproduction

various others 3D modeling and processing software, such as Artec Studio; is adaptable in its application (archaeology, medicine, product design, entertainment and industry) due to its versatility and precision. Thus, the Artec Eva is a valuable tool for professionals who need high-quality 3D digitization, allowing you to capture and preserve the essential details of physical objects – it's technical specifications can be consulted in (Artec 3D 2025).

— Sculptural execution: CNC Quadrix DV 1000

The Quadrix DV 1000 is a CNC machine, installed in an industrial manufacturing facility for replicas [Figure 5], with 5 interpolated axes, developed by Donatoni, is ideal for precise cutting and modeling of materials such as marble, granite and other natural stones. The machine is equipped with a vertical Z-axis path of 800-900 mm and allows the use of 1000 mm diameter blades, providing a 405 mm depth cutting capacity. (Fresator 2025).

This machine stands out for its versatility in different types of cuts, including inclined, curved and circular cuts. It is also capable of performing 2D and 3D operations, such as creating complex profiles and sculptures. With EasyStone CAD/CAM software, the operator can draw and import 2D and 3D files, in addition to using a laser scanning system to capture geometric shapes and surfaces. The Quadrix DV 1000 includes advanced features, the automatic tool change, remote assistance and the Move System, which makes it easier to move parts during the cutting process, increasing efficiency and reducing material waste.

Methodology of use

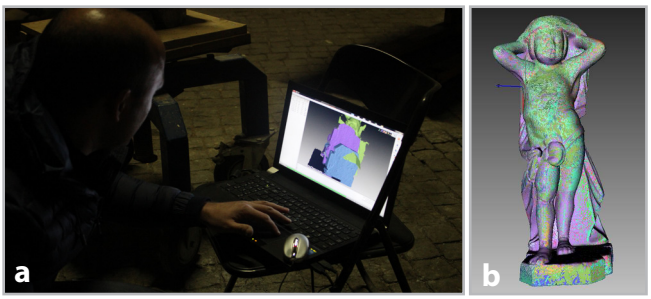
The data acquisition process with the use of the scanner, follow the following steps:

- Object Preparation: The stone statue was cleaned and positioned in a stable and supported manner to avoid movement during capture [Figures 6a and 6b].

- Structured Light Design and Image Capture: A portable 3D scanner emits patterns of light on the surface of the object. The distortions in these patterns caused by the geometry of the object are fundamental for the modelling. The same device records the images of the projected patterns. Analyzing these images allows to calculate the depth and shape of the surface. In figures 6 you can see some aspects of the acquisition of two data sets by the scanner.

Figuras 6 a y b.- Structured light image capture from different sculpture positions.

- Data Processing: The acquired data are processed by 3D modeling software, which reconstructs the surface of the object in a digital model. Figure 7a shows the processing and verification of data acquisition by the scanner, in loco. Figure 7b shows the result of the laboratory process, ensuring the resulting model is suitable to be introduced into the CNC machine. Given the specificities of the project, the model of figure 7b resulting from the acquisition of the original model, was manipulated as it was mirror transformed into the final model.



Figures 7 a y b.- Structured light image capture from different sculpture positions.

- Digital model reproduction: The 3D model, after verification, was reproduced in similar stone using a CNC creating a 3D replica.

The replication process through the use of a CNC machine includes several stages necessary to execute the final model [Figure 10].

The first step is to select the type of stone most suitable for the reproduction you intend to perform [Figure 8]. For this purpose, it was chosen of a "Preto Ruço" block (commercial name), lithological type with chromatic and physical

Figures 8, 9 y 10.- Figura 8: The limestone block of "preto ruço" before modelling. Figure 9: An aspect of the CNC during operations. Figure 10: Final result of the CNC machine operating process.

characteristics most approximate to the lithological type of the original pieces.

After choosing the lithological type, the data modeled from the scanner acquisition will be introduced into the CNC using the PLY format (Library of Congress 2025), a format used to create 3D model data.

Gathered the model software and the CNC block (for material support), the manufacturing process of the reproductin begins. The process, initially, with a diamond cutting disc on the stone block, it will be cropped taking into account the outer limits of the digital model. The result is a rough model, with the existing dimensions of the 3D model obtained from the scanner [Figures 11a,b,c], which will be later perfected with the final resolution.

At the next stage, after the parallelepiped is cut with the dimensions of the digital model, the machine replaces the cutting tool with a precision one [Figures 12 a, b], which will give the model in the details of the resolution of the scanner acquisition.

In figure 12a the "refining" operation is represented with a wear tip, which can be compared to its effect in figure 12b. The effect on the upper part of the reproduction is visible, which resembles the textural configuration and details of the original piece. The final phase of "refinement" of the model in progress.

Finally, as it has been done for thousands of years, the final touch of the stonemason, to retouch the imperfections that the model may present [Figure 13].

As a result, a symmetrical replica was obtained, using the use of structured light technology and numerical control machine (CNC), according to the material chosen, with similar appearance and original details.

Figures 11 a, b, c.- Various stages of stone block cutting on a CNC machine

Figures 12 a, b.- Course and results obtained from the refinement phase.

Figures 13.- Retouch phase by the stonemason.

The use of these techniques allows us to reproduce a historical piece with incalculable artistic value that over time has been degraded and lost, trying as far as possible to preserve the artistic details of the original sculptures.

In figures 14, we can observe the aspects of the final replica sculpture [Figure 14a] and her position in situ [Figure 14b].

Figures 14.- Final reproduction and her reposition in situ

— Operating Gains - Replica Execution Time

Let us make here an approach, which we consider very important, to quantify the execution time of the 3D replica, focusing only on the stages of data acquisition by structured light scanner and execution on the CNC. This temporal quantification is crucial, allowing to quantify the efficiency and planning of operations, or, its cost, quality obtained, rapid prototyping capacity (in product development environments, the ability to raise prototypes quickly is essential) and predictability and effectiveness.

In this specific case, the approximate execution time of each phase are:

Task	Hours
Execution of structured light scanner survey	2
Processing of acquired data	16
Programming of cutting and CNC machines	4
Model execution on the CNC	64
Hand finishing	64
Total	150

— Final considerations on the intervention

The creation of sculpture replicas using structured light and CNC is a fascinating process that combines art and technology. Structured light enables 3D scanning of sculptures, capturing every detail of the original work accurately (Figures 16). This data is then used to create a physical replica using CNC machines, which carve the chosen material following the digital specifications. This method not only preserves the artistic details of the original sculptures, but also allows for the mass reproduction of works of art, facilitating access and cultural appreciation. Furthermore, digital documentation of sculptures can be enriched with metadata standards and ontologies, ensuring that information about the works is preserved and easily accessible for future generations.

The creation of reproductions of sculptures raises significant ethical issues, especially with regard to copyright and the integrity of the original work. Structured light technology enables detailed capture of the three-dimensional form of a sculpture, while CNC machines can reproduce these forms accurately. However, technical reproduction, as discussed by Walter Benjamin (2018), alters the perception of authenticity and uniqueness of the original work of art. The copyright law, Code of Copyright and Related Rights, approved by Decree-Law No. 63/85, is the cornerstone of this legal protection. In the context of replication of works of art, the code stipulates that reproduction of copyrighted works is permitted in certain circumstances, such as for private use, criticism, or education, as long as it does not impair the normal exploitation of the work or cause unjustified harm to the legitimate interests of the author.

However, the creation of reproductions of works of art can raise complex issues related to the author's moral and patrimonial rights, requiring careful analysis on a case-by-case basis. Furthermore, preventive conservation in museums, including that of replicas of classical plaster sculptures, highlights the importance of preserving the integrity of the materials and the physical and chemical stability of the works, which is fundamental to maintaining their meaning and value over time. Therefore, when creating replicas, it is essential to consider not only the technical aspects, but also the cultural and historical impact of these reproductions, ensuring that they do not compromise the original values and the artist's intention. Discussing these ethical issues is crucial to maintaining respect for art and its history while navigating the possibilities that new technologies offer.

Conclusion

In short, the greater circulation of scientific knowledge and the development of new reproduction techniques have made decisions in this area even more complex. More than definitively embracing any of the positions (historical, current or updated) conveyed or in force, we submit this matter for discussion, at the same time as we inform about the analysis carried out. We keep in mind the internal questioning (normally prior to the intervention, which remains even after it: Can we do everything without any criteria? Does it really not matter what material remains persists from the original? All options are possible and ethical acceptable? In what cases do we believe that this methodology respects current conservation and restoration principles? What is the difference between completing an artistic object as an improved artistic recreation without having a record of it and using new technologies to complete what is missing from an object based on another similar work?

In this particular case, the difficulty lay in the fact that the original was too degraded and incomplete, and could not be reattached to its original location due to its fragility (disappearance of almost half of its volume). Unlike other solutions that allow 3D printing but in resin, such as, for example, the case study of the Monument to the Polish Diaspora Bond with the Homeland, (Suchocki 2023), but do not replace the original in situ, in this case CNC allowed the obtaining of a reproduction made of material with identical characteristics and repositioned in the original sculptural context. In fact, resin reproductions, at different scales, can allow flexibility of handling, improve a deep understanding of the object, and even support the planning of complex intervention processes, but, do not replace the object in its original context, thus, they are not part of a restoration process, strictly speaking but rather museology. Furthermore, we emphasize that even in this case where the reproduction is in stone, but manual finishing was necessary.

From the point of view of data acquisition, this technique presents an advantage in terms of time efficiency and the data transformation necessary to obtain the reproduction compared to others that use georeferencing, multiple object and complex targets, which may be more suitable, efficient and of greater value when used for buildings and sites such as those in the iHeritage Project, (Caravello 2024), (Liu *et al.* 2025).

We still have doubts regarding the application of this methodology in the generic resolution of these restoration problems, especially from a deontological point of view.

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