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3D virtual restoration: from photogrammetric and 3D modelling techniques to integration with scientific documentation in a GIS environment

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***Abstract* – The contribution proposed here is linked to the doctoral research being carried out, which aims to develop a 3D GIS (Geographic Information System) platform that can integrate all the software necessary for the elaboration of a scientifically correct virtual restoration and at the same time can contain all the documentation relating to the intervention itself, the analyses carried out and the sources used. The contribution, therefore, will focus only on the specific case of the 3D virtual restoration of artefacts starting from the data coming from one of the case studies investigated, specifically a kotyle from the Etruscan excavation conducted, by the University of Tuscia, in the Monte Abatone necropolis in 2019, to show the potential of this project and possible further developments.**

Key words: Virtual Restoration, 3D GIS, photogrammetry, 3D modelling

I. INTRODUCTION

The aim of virtual three-dimensional restoration is to make the information contained on the artefact more readable and to prefigure a real restoration intervention. Even though it is a restoration carried out not on the real object but on a digital copy, in order to maintain its scientific nature, it must be subject to the principles of real restoration that can be summarised as follows: recognisability of the intervention through a clear chromatic distinction of the parts; minimal intervention in which the operation must not forcibly seek to recover all the parts in an impossible reconstruction of a hypothetical original phase; reversibility of the processes, which in virtual restoration is always possible and, finally, respect for the historical and aesthetic instance of the artefact [1]. While respecting these principles, in some specific cases virtual restoration can, after a careful philological study has been carried out and elaborated, attempt to implement a larger reconstructive hypothesis by trying to restore the work to its original form [2]. The present research is based on these considerations and is part of a more complex doctoral project, the aim of which is to develop a 3D GIS (Geographic Information System) platform for the virtual restoration of any type of work (paintings, mosaics, manuscripts, architecture, statues, artefacts), capable of integrating the software necessary for the intervention, while preserving the scientific nature and all the information generated during the various stages of processing. The steps presented here are based on this need to follow a precise pipeline that can be reproduced by anyone, while at the same time providing all the sources, cognitive processes, analyses and techniques used in the processing, in order to provide a scientifically accurate reconstruction that can be modified over time and verified at each stage. In this respect, GIS was crucial, as it allowed the works to be geolocated when it was necessary to reposition them in their original context, and at the same time to have a 3D model that could be linked to a relational database containing all the data produced and retrieved, as well as the information related to each step. To illustrate this, it was decided to take as an example the processing of a kotyle from tomb 643 of Monte Abatone in Cerveteri, one of the case studies of the ongoing doctoral research.

II. METHODOLOGY

Once these theoretical foundations have been laid, which are essential in order to avoid the creation of historical forgeries, a series of methodological procedures necessary for the creation of virtual restorations can be carried out and developed. The first step is to digitise the work, using various systems such as laser scanners, structured light scanners, photogrammetry or a combination of these techniques.

For the platform development project, the choice fell on the photogrammetric technique as it presents a better and easier management of the textures within the software, a better integrability of both open-source and proprietary software within the platform, respectively meshroom® 2023.2.0 and agisoft metashape® 1.7.6, as well as a reduced cost compared to the others mentioned.

The photogrammetric technique makes it possible to reconstruct a real object directly from photographs of the object itself. Photogrammetry software uses Structure from Motion algorithms to reconstruct the object or scene three-dimensionally, in order to have a three-dimensional model of the photorealistic object corresponding in shape and size to the original [3-4]

The next step is the actual processing using 3D modelling software, in our case Blender® 3.5. First of all, however, it is necessary to have retrieved all the inherent bibliography and carried out, where necessary, various chemical and physical analyses on the object, procedures that are necessary to have all the basic documentation to correctly carry out the virtual restoration.

Using such software, the gaps and shortcomings of the object can be modelled and recreated to reconstruct its original form. However, as described above, one must always have an approach that takes into account the principles of real restoration. Therefore, in the processing, if we want to achieve a result as close as possible to that of a real restoration, we must try to keep the added parts clearly visible and distinguishable from the original [5]. With this in mind, we made use of polygonal modelling, subdivision surface and texture painting techniques in order to reconstruct the missing shapes and parts, as well as colour them in a neutral and immediately recognisable shade. (Fig. 1).

Fig. 1. 3D virtual restoration of the Kotyle in Blender® environment.

Once this work was completed, it was considered necessary to make the cognitive processes and the sequence of actions understandable to anyone, in order to make the result more scientific.

Therefore, to achieve this, the three-dimensional model was imported into a 3D GIS, specifically QuantumGIS® 3.30.2. The decision to use a GIS software was based on the flexibility and power of such a tool, which is not just a container of information, but a methodology that allows the reference geometry, in this case the restored three-dimensional model, to be linked to a relational database that can contain any alphanumeric information. This makes it possible to carry out specific queries within the database and display them on the geometry, as well as spatial analyses on the geometry itself, in order to analyse critical points and extrapolate new information. GIS are very complex tools, used in many different fields, which make it possible to analyse the geometric, spatial and textual data contained in the database in order to obtain new information [6].

Through the QGIS interface, in our case, it was possible to display the restored three-dimensional model by means of a special window. All the information related to the intervention is stored in a relational database created using PostgreSQL® 15.4 and pgAdmin® 7.5. The main element of the database is the general sheet of the Cultural Heritage, which contains all the basic information relating to the identification of the object, its dating, its location and which contains the images of the actual object. Linked to this is the sheet or sheets relating to the virtual restoration intervention, through a one-to-many (1:N) relationship, which therefore contains all the information regarding the intervention carried out as well as the images of the virtual restoration and any reports. Finally, the virtual restoration sheets are associated with those of the sources, the previous real restorations and analyses carried out prior to the restoration itself, again via a one-to-many (1:N) relationship. All this makes it possible to have in a single system both the restored model and the whole mass of data that allow the scientific nature of the intervention to be verified and evaluated, in a combination that allows the reproducibility of the intervention and its possible modification, which may vary when there is an advance in studies that show the need for such a process in order to improve the understanding of the object itself (Fig. 2).

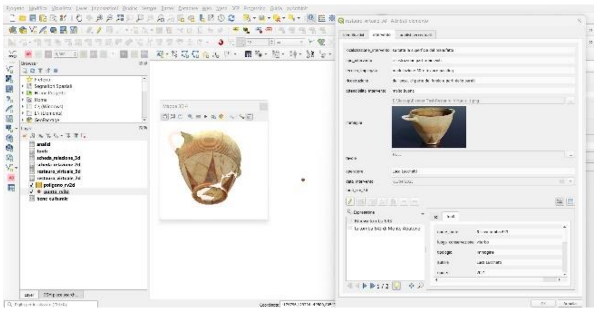

Fig.2. QGIS® interface with the 3D model and the information contained in the database linked to it.

The final step after the virtual restoration work in a 3D GIS environment was the virtual relocation of the virtually restored material. In fact, the kotyle studied is only one of the objects belonging to the tomb excavated in 2019 by the University of Tuscia in the Etruscan necropolis of Monte Abatone. This is one of the most important necropolises linked to the town of Cerveteri, which has many tumulus burials, as shown above all by the excavations carried out by the University of Tuscia in collaboration with the Vanvitelli University of Campania, the University of Urbino and the University of Bonn [7]. The tomb in question is just one of the examples studied in the context of the doctoral thesis and has been chosen as an illustrative case for this paper in order to show the various stages of the elaboration. The tomb examined, of modest dimensions (90x40 cm, only 12 cm depth preserved), dated to the mid 7th century, was carved on top of a larger mound, tomb 73. The small grave probably belonged to a girl and contained a set of grave goods made of various materials, only some of which were found in situ: in addition to the Proto-Corinthian kotyle examined, there was also a bucchero amphora and two aryballoi, one with Proto-Corinthian figures and the other with linear decoration, probably made locally. Fragments of red impasto and part of a "fibula a sanguisuga" were also found in the burial, but were excluded from the reconstruction, partly because of the impossibility of reconstructing the original shape of the pottery and partly because of the impossibility of precisely locating these objects in the tomb. This lack of information is due to the heavy ploughing that has disturbed much of the stratigraphy of the tomb [8]. Therefore, after processing the other materials found and having all the documentation, as well as the photogrammetric surveys of the tomb itself and the context, the original arrangement of the materials can be reconstructed from the excavation data. Therefore, following the surveys, the materials were placed in their most probable position within the Blender® software and via its Blender GIS plug-in, in order to maintain the spatial data produced during the photogrammetric surveys and also derived from the excavation data (Fig. 3).

Fig.3. Rendering of the reconstruction and relocation of the tomb's goods virtually restored.

Finally, the 3D reconstruction of the burial was completed with the repositioning of the burial on the mound, which in turn was geographically repositioned within the necropolis of Monte Abatone, allowing the reconstruction not only of the burial goods but also of the context in which they were found. The location was derived from the excavation information, mainly photogrammetric surveys and photographs, which allowed the objects to be repositioned, as mentioned above, in their probable original location. For the structure of the tomb, the result of the photogrammetric survey was used both for the individual tomb and for the entire mound, which was repositioned to its original location using the Blender GIS plug-in on a basis derived from Google satellite photographs and the relevant terrain data for elevations, all related to the WGS84/UTM32N Reference System (EPSG: 32632), the same as that used for all excavation data on the Monte Abatone site (Fig. 4).

Fig.4. Rendering of tomb 643, which is positioned on top of the mound of tomb 73 within the Blender® environment and geolocated using Blender GIS.

III. POSSIBLE IMPLEMENTATION DEVELOPMENTS

A further possibility starting from this data is 3D printing of both the restoration work and the original model, by means of low-cost prototyping techniques through, for example, the use of plastic filaments, such as PLA (Polylactic Acid), or through products such as resins. The aim is to physically dispose of the restored parts or even the whole object, either for scientific purposes, real restoration directly with the moulded objects or using them as matrices, or commercially, e.g. selling the objects as souvenirs with the museum logo imprinted, etc. [9].

There is also the possibility of a virtual study of the museumization. By reconstructing the museum room and the various display cases available, the lighting, etc., a whole series of studies can be carried out on the artefact and its placement in the room, on the best arrangement of the lighting and the design of the visit routes and, therefore, on the public's enjoyment of the work itself [10]. These types of reconstructions can also be used for popular or scientific purposes through virtual reality visualisation systems, thus opening up the discourse towards multiple scenarios [11]. It is also possible to have a visualisation of objects in augmented reality so as to have access to the original elements at their true scale, using one's smartphone for such a visualisation [12]. This would allow scientific comparisons with the real object or similar types, as well as a freer visualisation of the object and details. All these examples are interrelated because they all start from a scientifically accurate basis, which is one of the main objectives of the PhD project, and thus allow different solutions to be developed, such as those proposed. These solutions are an important step for research, which, as we have seen, is not the main objective of the doctoral project, but they should certainly be taken into account when deciding to further develop one or more of these possibilities in a combination of scientific research and its dissemination, always ready to incorporate possible modifications and new hypotheses.

IV. CONCLUSION

In conclusion, an attempt has been made to show the workflow necessary to produce a scientifically correct 3D virtual restoration by managing all this information through a GIS system. As already mentioned, this paper reflects only a part of the PhD project, which is aimed at creating a 3D GIS platform capable of integrating the different software (photogrammetry, photo retouching, 3D modelling, GIS and relational databases) for the correct practice and workflow of virtual restoration, and at the same time, capable of incorporating all the data and sources used in the processes, in order to provide a reproducible, modifiable and scientifically accurate final data. The project therefore does not stop at the tomb objects presented here, which are used as a case study for the treatment of the material, but also moves into the field of painting, mosaic, sculpture and architecture, with further case studies. However, in order to show the first results of this methodology, it has been decided to present the work carried out on the materials from this tomb as an illustrative case study of a 3D project that is still under development. As will be seen in the course of the paper, the processing of the work involves many separate steps and software, so it is particularly important to have a platform that integrates them and allows the continuous management of data and information, especially in order to better manage the processes and to be able to speed up the transitions from one programme to another. It is also a project that does not stop at individual works but aims to manage all the different types and cases, as mentioned above. An objective that will be pursued in the course of the doctoral research. Finally, this project is not an end in itself and does not exclude further developments such as 3D printing of restored elements, digital recontextualisation of materials, virtual and augmented reality visualisation of objects, their contexts and museumisation. On the contrary, these processes are enhanced and supported by the scientificity and accuracy of the data. In fact, all the examples proposed are objectives that are being pursued in this research and others that are still being developed. Objectives that must always start from a scientifically correct base, but also one that can be updated, modified, and followed at every step, in order to be able to understand not only the final aspects, but also all the logical processes that have led to such a result.

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