Archeologia e Calcolatori
34.1, 2023, 59-68
doi 10.19282/ac.34.1.2023.07

VIRTUAL RTI APPLICATION ON 3D MODEL FOR DOCUMENTATION OF ANCIENT GRAFFITI: PROPOSAL OF A METHODOLOGY FOR COMPLEX ARCHAEOLOGICAL SITES

1. Introduction

The following work was made possible by the collaboration between the Department Asia, Africa e Mediterraneo (DAAM) of the University of Naples L'Orientale and the inter-university Consortium CINECA, represented by the authors[1]. The project is about the creation of a virtual dome for RTI acquisition and has two main aims: to make possible simple RTI acquisitions in difficult environmental contexts, and to reuse for new research high-resolution three-dimensional surveys acquired for other purposes. As part of a major international project, high-resolution 3D models of the Catacombs of San Gennaro in Naples are available (https://skfb.ly/ozSsA). Among these, the present contribution analyses a frescoed niche characterised by innumerable engravings on the entire surface of the *arcosolium*. The research highlights how the combination of two different open source applications, one made for cultural heritage (RTI Builder), the other one for graphic modelling (Blender), is a valid support for archaeological analysis allowing the reuse of previous 3D data for graffiti identification. It also highlighted how the result of the V-RTI strictly depends on the resolution of the 3D model used. Finally, we underline what are the potentiality and the limits of these applications, to improve methods and practical application in a complex site such as the Catacombs of San Gennaro.

2. RTI methodology

Reflectance Transformation Imaging (RTI), as defined by the non-profit organisation "Cultural Heritage Imaging", which is behind the development of the RTI Builder and Viewer software and of the related methodology, is «a computational photographic method that captures a subject's surface shape and colour and enables the interactive re-lighting of the subject from any direction» in a viewer, revealing details not visible with the naked eye» (CHI 2014). RTI images, in addition to RGB colour information, record surface normals for each pixel; each value, corresponding to a point on the

[1] A.B. and E.M. conceived of the presented research and verified the analytical methods. D.D.L. developed the Virtual Dome and performed the computations. E.M. performed research activities for the state of the art and methodology. A.B. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

object, stores information on the angle of reflectance of light coming from any direction at that point.

The RTI methodology is a reliable and widely used tool for archaeological research, in particular for the analysis of a wide range of artefacts, such as for the interpretation of graffiti and engravings and for the recording of the maintenance phases of objects, paintings or frescoes. It also enables the documentation of particular data that are difficult to visualise with the naked eye and facilitates the recognition of traces and marks on the surface of objects. One of the most widely used acquisition methodology in archaeology is the so-called Highlight Based RTI (H-RTI). It is characterised by its simplicity of use as it only requires easily transportable and low-cost equipment like a camera, a tripod and an external light source.

The H-RTI uses one or two reflective targets (usually a dark-coloured sphere) in each frame at the same position within the image frame to calculate the position of the light directly from the reflection on the sphere (Earl *et al.* 2010; Duffy 2013). It is important for the subject to be illuminated in the round by several light positions with illumination angles between 15° and 65°. For an appropriate acquisition, the camera should maintain a fixed framing while the light source will be moved in each precise angle. By applying this technique in our case study, we unfortunately run into the problem of accidental vibrations transmitted to the camera, which have a significant effect on the framing and compromised the sharpness of the RTI images.

The arrangement of light sources also has an impact on the quality of the acquired RTI data. Ideally, the positions of the lights should be evenly spaced and it is recommended to keel the source of the light at a constant distance from the surface of the subject, i.e., of two to four times the diagonal of the area to be recorded. Through the use of a RTI dome, in which each position of the light is provided by a different illumination source, it is possible to have acquisitions of great detail and precision. The so-called light-dome is equipped with a top hole for housing the camera and LEDs that allow the object to be illuminated from different points equidistant and synchronised with the camera shot. This methodology (D-RTI) is especially suitable for the acquisition of small objects and is, therefore, generally used in laboratories.

One of the main problems, both with the H-RTI methodology and also with the light-dome, lies in the size of the objects to be acquired. Images of larger objects must be acquired in smaller subsections, which increases the difficulty and duration of the process. Furthermore, an optimal H-RTI application requires full control of the recording environment and often the surveying "objects" are located in places that are difficult to reach or where it is extremely complex to plan an adequate RTI acquisition.

Fig. 1 – Elaboration process overview of the 3D point cloud of the Catacombs carried out in the framework of the acquisition project in 2019.

3. Case study

The evocative scenery of the Catacombs of San Gennaro was the location of an international research project focused on the 3D survey of the site, started in September 2019. The activities were funded by the private non-profit organisation GDH (Global Digital Heritage, USA), assisted by the Zamani Project (South Africa) and CISA (Centro Interdipartimentale di Servizi di Archeologia, of the University of Naples L'Orientale). In parallel with the ambitious digital survey activities of the entire hypogeum network, several H-RTI acquisitions were carried out in order to test the methodology for the documentation and analysis of graffiti and engravings (Fig. 1). The huge site of the Catacombs is developed on two non-overlapping levels of underground passages and tunnels and originates from a burial core dating back to the 2nd century CE, which was expanded during the 5th century thanks to the transfer of the remains of San Gennaro. The Catacombs became a place of pilgrimage and a favourite burial site for the population until the Saint's remains were removed in 831. From then on, the site was abandoned until the 18th century, when Naples became one of the destinations of the Grand Tour.

The multi-secular life of the site is perfectly verifiable and "readable" through countless engraved, graffitied, written and painted texts on numerous walls of the Catacombs, both above the decorations of the niches and *arcosolia*, and on portions of bare walls (Bosco, Minucci 2020). These almost completely unpublished "signatures" cover a vast chronological span and represent an interesting tangible mark of the continuous passage of people

Fig. 2 – The niche with the *arcosolium* where the H-RTI acquisition test was performed.

from all over the world. Often, names, signs and dates are superimposed and distributed in such a chaotic manner that their identification and consequent reading are complex or impossible at all.

This context is still very impressive for visitors and represents a real challenge for the researchers because of several aspects. The main obstacle to their survey is the poor lighting, also made worse by the lack of sufficient electrical connections to bring in external light sources. Secondly, the small but highly articulated spaces complicate the acquisition process by requiring more operators and more equipment. Finally, the instability of the ground surfaces on which to fix the equipment often causes blur effects in the photos. Indeed, the tombs, excavated at floor level, greatly complicates the fixing of tripods necessary for acquisitions. Moreover, metal walkways that facilitate the passage of tourists are also very common. Such footpaths, although they overcome obstacles on the ground, cause considerable vibrations, which are detrimental to the photographic acquisitions.

Classical H-RTI methodology acquisition was applied for test on some *arcosolium* burials particularly characterised by graffiti. Unfortunately, it was not possible to respect the ideal angles of light emission, due to the shape of the burial which has a deep arc, thus creating an obstacle to the illumination of the back wall, and also for the narrow spaces, which several times caused camera vibrations and restricted the operators' movements (Fig. 2). The final results were therefore not satisfactory, due to less accuracy and blur in some part/position of the object.

4. The Virtual RTI

The Catacombs project had, however, produced high-resolution three-dimensional surveys of the entire burial complex, combining photogrammetry and scanning acquisitions. Thanks to CINECA's work, it was possible to build a virtual dome in the open source software Blender. The idea is to operate Virtual Reflectance Transformation Imaging (hereinafter referred to as V-RTI), i.e., a hybrid method that combines 3D, virtual manipulation and 2D+ technologies in a workflow, partially carried out *in situ*, that is quick and intuitive (one only needs to be familiar with 3D modelling software) and suitable for the documentation of a wide range of archaeological monuments. The dome was recreated with characteristics reproducing as faithful as possible the real dome, so that the two environments could be comparable, but at the same time it was built to overcome the limitations of the "real" tool. Three-dimensional models generated with SfM, or other technology, are illuminated and then photographed in a virtual environment before being processed in the RTI Builder software. The first step was to

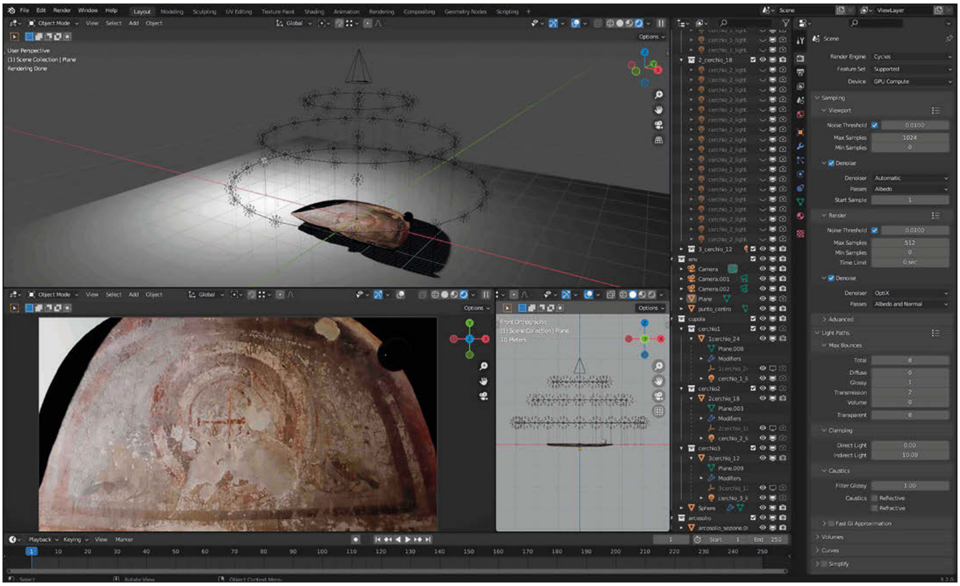

Fig. 3 – Screenshot of the 3D model with the Virtual Dome in Blender (minucci-bosco-de_luca 2022).

import the PLY file of the model into Blender. In the virtual environment the structure of the dome has been created, with three concentric levels of lights equidistant from each other.

The lights are omni-directional point type and have a power of 200W each, with a diameter of 0.03 metres. They were created as instanced copies to provide an easy way of future editing of their parameters. In the largest diameter level 24 lights were inserted, in the intermediate level 18 and the level with the highest angle of inclination had 12 lights. The target object was obtained by creating and positioning a primitive UV Sphere object, with a high level of geometry subdivisions in order to be as smooth as possible and also with smooth-shaded normals. The shader of this sphere was obtained with a glossy BSDF shader with a pure black diffuse colour and a level of roughness of 0.08, in a scale from 0 to 1 (Fig. 3).

The 3D camera was positioned at the centre of the dome, above the highest level of lights, with a focal length of 50 mm and generic 36×24 mm camera sensor, to mimic a real DLSR camera. The render engine used in this setup is "Cycles", integrated in Blender, that allows to set every light bounce to 0 to avoid colour glare and optimise shadows. The target-sphere shadows were also disabled via the Cycles visibility options of the sphere object. By running the *ad hoc* Python script, to simulate the RTI acquisition phase, the system turns off every light and then turns on one at a time, calculates and stores the captured frame, turns everything off again and repeats the procedure for all the other lights. The dome was scalable according to the model dimension and it was possible to "clean" the 3D model to remove obstacles (such as the arch) to optimise the correct illumination of the object under analysis (in our case the *arcosolium*). The activation of the virtual capture process on the wall of the *arcosolium* produced images at a resolution of 3840×2160 pixels, exported in JPEG format with a low compression rate.

5. RTI processing

The resulting images were then processed with the open source RTI Builder software, applying the PTM (Polynomial Texture Mapping) process. The choice of this rendering is linked to the greater availability of filters that can be applied to the finished elaboration in the RTI Viewer. The comparison with the result of the process carried out *in situ* with H-RTI clearly shows the enhancement in the readability of the information, even with the application of the filters that the software provides. The improvement of the data acquisition procedure is immediately visible in the processing phase. Indeed, after the highlight detection within the images, the software carries out the processing and makes it possible to visualise all the light spots detectable

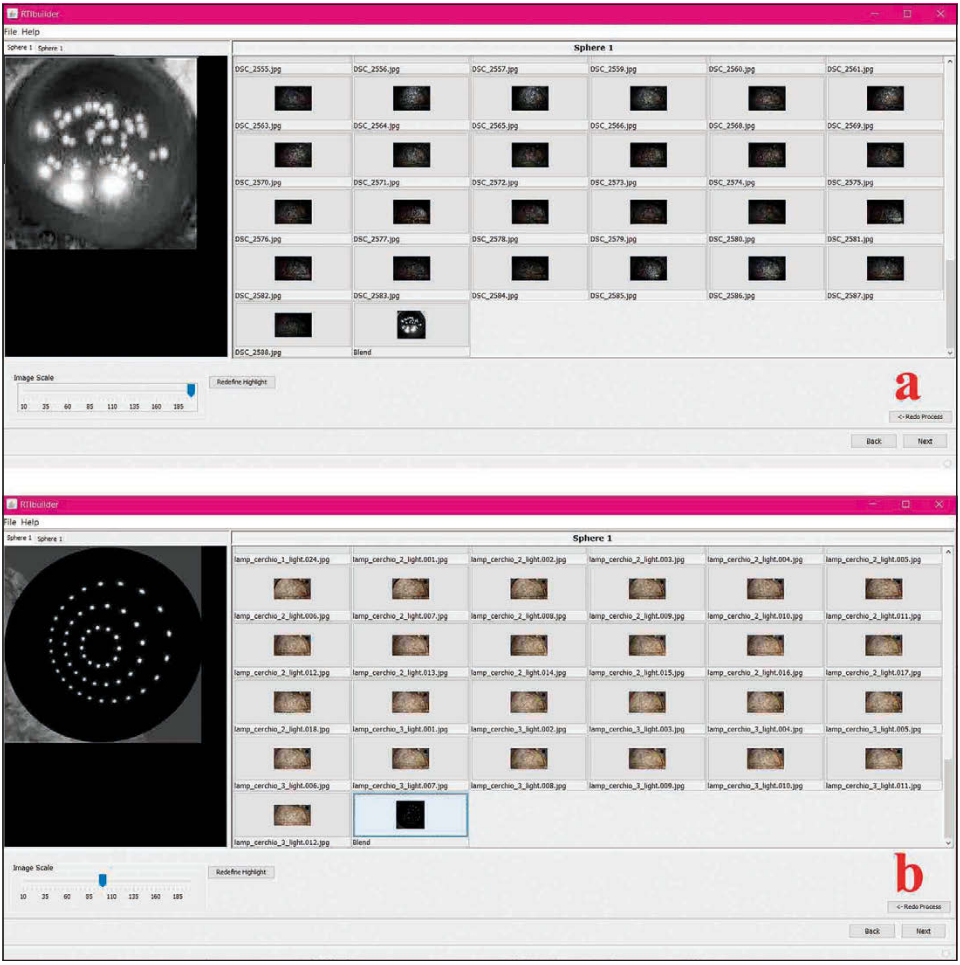

Fig. 4 – Two screenshots of the highlight detection in the RTI Builder software. a) Irregular diffusion of light in the detection of *in situ* H-RTI acquisition; b) Regular light distribution in the V-RTI process.

on the sphere. As shown in Fig. 4, the difficulties and obstacles found in the field resulted in an uneven rendering of the acquisition, clearly visible on the reflecting sphere. On the contrary, the virtual environment allowed a correct and homogeneous distribution of the light source. A marked improvement in visualisation is visible in "Default" rendering and even more so with the application of filters such as the "Specular" (Fig. 5), where the strong shadow seen in the processing from real shots gives way to a palpable emphasising of the micro-reliefs on the surface of the *arcosolium*.

Fig. 5 – Comparison between the Default and the Specular renderings in RTI Viewer on the *in situ* and Virtual elaborations (minucci-bosco-de_luca 2022).

6. Conclusion

In a nutshell, the H-RTI method is recommended for medium-sized and outdoor acquisitions, but it is unsuitable for complex sites due to the specific execution procedures. The use of a light dome in the D-RTI methodology allows for a controlled and stable acquisition environment, thanks to the automatic management of illumination. However, it is suitable for small objects and surfaces and is not always adapted with ease to outdoor acquisitions. The application of Virtual RTI has proven to be a valid alternative that fits into an increasingly consolidated digital survey workflow.

The advantages of the V-RTI are many: (i) since the virtual dome can be scaled and rotated to different positions, the V-RTI methodology is efficient when the object is too large for a traditional RTI acquisition or when this is geometrically complex. (ii) The virtual environment also allows to solve the problems deriving from the shape of the object, which can hinder a correct illumination, and those of the self-occlusion caused by the shadows of the illuminated target sphere that can be found on the surface of the object, thanks to the possibility of "cutting" the 3D replica as required. Furthermore (iii) the V-RTI is very useful in remote contexts, in sites which are difficult to access or where planning an adequate Highlight Based acquisition would be tricky or too time-consuming at a logistical level and where therefore too many acquisitions are not recommended *in situ* (this is the case of the Catacombs of San Gennaro, a vast hypogeum maze characterised by special soft lighting and visited every day by large tourist flows). (iv) The V-RTI methodology also provides greater objectivity than the H-RTI methodology, since it is not necessary to select only one view of the object while in the field. (v) The opportunity to choose different shots in the virtual environment for each detail to be analysed allows for a more reflexive approach to investigations, especially in contexts where it is not possible to repeat acquisitions. Finally (vi) the surface of the objects can be resurveyed and illuminated from different positions after the acquisition of the models, allowing an almost infinite re-investigation in the light of ever new research questions.

Obviously, V-RTI is strongly affected by the resolution of the 3D model being used as a source of information. However, 3D surveying methodologies are, to date, extremely advanced and versatile, guaranteeing excellent data even in difficult environments. The possibility of using polygonal 3D information from any 3D acquisition methodology (photogrammetric, time-of-flight or phase-time laser scanner or even structured light) makes the virtual dome compatible with the most different research pipelines available. The case study made it possible to outline an overview of the methodologies under investigation and to lay the bases for the creation of a comprehensive research protocol for the use of the V-RTI technique. For this reason, the authors are working on making this digital tool available to other research groups, in order to expand the application cases and share possibilities for improvement.

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REFERENCES

Bosco A., Minucci E. 2020, *Rendering RTI ed editing d'immagine per elaborazioni SfM: Confronto tra tecniche e strumenti di visualizzazione per la documentazione di graffiti in contesto archeologico*, «Newsletter di Archeologia CISA», 11, 43-66.

CHI – Cultural Heritage Imaging 2014, *Reflectance Transformation Imaging. Glossary of Photographic and Technical Terms for RTI* (https://culturalheritageimaging.org/What_We_Offer/Downloads/Capture/CHI-RTI-Glossary_v1.pdf).

Duffy S.M. 2013, *Multi-light Imaging Techniques for Heritage Application, English Heritage*, London, Historic England.

Earl G., Martinez K., Malzbender T. 2010, *Archaeological applications of polynomial texture mapping: Analysis, conservation and representation*, «Journal of Archaeological Science», 37, 8, 2040-2050.

ABSTRACT

In the field of Cultural Heritage, the technological advances of recent years have enriched and optimised the possibility of documenting and studying ancient graffiti with a wide range of low-cost and non-invasive methodologies. The most popular are digital photogrammetry SfM (Structure from Motion) and RTI (Reflectance Transformation Imaging) methodologies. The RTI is a powerful tool that, through the use of open source software, enables the documentation of data that are difficult to visualise, facilitating the recognition of traces and marks on the surface of objects. On the other hand, the SfM 3D models are increasingly replacing documentation with traditional photographs. This 'almost excessive' production of three-dimensional models is not often accompanied by an adequate exploitation of all their potential uses. This research aims to investigate the possibility of using a high-resolution 3D model for the implementation of virtual RTI processing, a hybrid method that combines 3D, virtual manipulation and 2D technologies in a fast and intuitive workflow suitable for the documentation of a wide range of archaeological monuments. The process sees the 3D model from the SfM survey being illuminated and photographed in a virtual dome in the open source Blender environment; therefore, the images generated are processed with RTI Builder software.