Geodesy, Surveying, 3D Modelling, and AI Virtual Reconstruction in the Archaeological Sites and Monuments of the Former Settlement of Ribeira Grande in Cidade Velha (Santiago Island, Cape Verde)

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Keywords: Archaeological Mission, Cooperation, Fieldwork, Project Definition Criteria, Selection of Documentation Techniques, Generative AI Virtual Reconstruction.

Abstract

The spatial framing of this contribution are the works of geometric documentation that are part of an archaeological mission abroad developed by universities of Spain and Portugal in the historical settlement of Ribeira Grande (now, Cidade Velha) in Cape Verde —a UNESCO World Heritage site, since 2009— in collaboration with the local Instituto do Património Cultural (IPC). The text describes the planning and the establishment of the geodetic network and the three-dimensional modelling of the remains of the Cathedral, with emphasis in the particular conditions of a fieldwork carried out in a reduced number of days, little equipment and with only partial prior knowledge about the work environment. The study also explores the virtual reconstruction of the original appearance of the Cathedral but, in absence of historical expertise, we resorted to generative AI engines to create the views; the procedure to obtain these evocative pictures is presented, as well as a comment about their usefulness.

1. Introduction

It is known that, when it comes to define the way that a documentation work of a cultural heritage element must be done and the results to be obtained, the conditions of both the site and the project play essential roles; often taking preference over the technologies or the needs.

In this contribution, attention is given to some particular features regarding geometric documentation and outreach works in the context of a project of archaeological studies abroad developed by a group of universities from Spain and Portugal in Cape Verde, in accordance with the Instituto do Património Cultural (ICP) of the country. The project takes place in the former settlement of Ribeira Grande (now intermingled among the buildings of a current town, conforming a location called Cidade Velha), which is a UNESCO WH site since 2009.

There are many useful contributions that geometric documentation techniques provide to a research project, from the establishment of the cartographic reference network (geodesy), mapping of sparse elements in a regional area (remote sensing + GIS), recording the site and the archaeologic findings (surveying + photogrammetry), documenting buildings and monuments (ground + drone photogrammetry), 3D modelling of objects held in museums (close range scanning), virtual reconstructions and so on (Pérez et al., 2021).

However, both time and resources drop dramatically when preparing a field campaign in a foreign country of which little information about the survey infrastructure is known, the number of days onsite are scarce (4 days in this case) and the possibility of bringing equipment is limited (to what two common passengers can carry in a commercial flight). It should be added that there is no option to come back and check, complete or correct any part of the fieldwork, hence, it is necessary to return home with the assurance that whatever was done is completely done and error-free. In addition, no matter how detailed the preliminary plan was, archaeological work is always good for surprises and last-minute issues (such as problems with the equipment, accessibility to spaces, adverse weather conditions, etc.) are an ever-present menace; therefore, robust and somehow conservative strategies must be put in place preferentially (Alby, 2021). One final point is that even if the archaeological team may have planned the project to be extended over the next years, the funded is often obtained on a year-by-year basis and, thus, not secured from the beginning. That makes very risky to leave pending tasks from one year to another.

Back at home, the availability of local experts to receive continuous feedback is limited and this can hinder the development of some products —such as virtual recreations— for which regular communication among partners is essential. Therefore, in the current stream of applications of the Artificial Intelligence (AI) it seem tempting to wonder to which extend this lack of expertise can be supplied by generative AI tools.

2. Objective

The aim of this text is twofold:

- On the one hand, it presents guidelines for making decisions concerning fieldwork in the context of research and cooperation activities abroad developed in a short period. This is illustrated in a project in Cidade Velha (Cape Verde).
- In addition, some examples of virtual recreation models developed with the help of generative AI systems and scarce input data were created. The main interest in this matter is to discuss the interaction (i.e., the *prompt*) with the AI engine and the criteria for establishing their usefulness for scientific outreach purposes.

3. Materials and Methods

3.1 Description of the site

Cape Verde is a republic of around five hundred thousand inhabitants distributed in an archipelago of ten islands of West Africa in the Central Atlantic Ocean. Found inhabited by Portuguese in the 15th century, it became a central place of their oceanic expansion in Africa, Asia-Pacific and America, as well as a pass port of the slave trade. With a tropical and arid climate is an example of creole culture. It is considered as one of the most stable, developed and democratic countries in Africa.
Ribeira Grande, founded in 1462, was the first permanent Portuguese colonial settlement in the tropics, situated in the south of the island of Santiago. In the late 18th, the capital was moved to Praia, and the place was renamed as Cidade Velha (i.e, “Old City”). At present, Cidade Velha is a small village with impressive scattered remains of the past, such as the fort of São Felipe, the remains of the Cathedral and the monastery of São Francisco, or the church of Nossa Senhora do Rosário, among others.

Figure 1. Some pictures of Cidade Velha: the village (top), remains of the old cathedral (middle) and historic church — Nossa Senhora do Rosário— already in use (bottom).

3.2 Geometric documentation works

The methods used for the geometric documentation combined GNSS static positioning, surveying with total station and 3D modelling from photographs taken both from the ground and with a drone. These works were done in the context of a research project open to society, which implied that the conversation with inhabitants and tourists was a natural (and most enriching) part of the development. Likewise, a workshop with the staff of the Cultural Heritage Institute to discuss about documentation techniques and results was also carried out (Rinaudo et al., 2023).

One of our encountered disadvantages was that we did not have any contact with local land surveyors, neither had we knowledge about the quality or the placement of the geodetic network or how to get differential GNSS corrections onsite. Therefore, we limited ourselves to somehow “classical” (but robust) methods, in particular, the observation of long static baselines (8 hours) from the closest base of the IGS network situated 200 kilometres away on the island of Santa Maria (also in Cape Verde) that was used to obtain a first set of coordinates to the principal benchmarks in our topographical network. The rest of the bases got coordinated by means of short-static (20 minutes) GNSS observations done with the two GNSS receivers that we brought to the fieldwork (figure 2). In addition, observations with total stations were included to improve the precision of the differences in height. In total, we used two of the days for completing the observations of the surveying network.

Figure 2. Reference network observed by GNSS, distributed for all the areas with historic remains.

In parallel, we documented by means of photogrammetry the remains of the Cathedral, in this case, we obtained photographs from the ground and aerial shots with the help of a drone. In any case, the time slot for the acquisition of the images was limited to the outset of the day in order to avoid cast shadows. Therefore, we started with the photogrammetric record at the beginning of the day and, after that, when the sunlight made unusable the photographs, we continued with the GNSS observations and the total station for the levelling and the capture of the control points for the photogrammetric model.
The third day we took part in an open day and activities with the local actors. Finally, the fourth day, a final three-dimensional model of the area of excavation where the team of archaeologists were working was also done by means of photogrammetry with the drone.

All the data was downloaded and checked every day. Moreover, the 3D models were processed in low resolution so as to verify that all the information necessary to generate them —when returning home— was available.

3.3 Training and exchanges with the local actors

It should be noted that the mentioned outcomes are not the end of the documentation works but a suitable mean to establish collaborative dynamics among the local agents (e.g., the Cultural Heritage Institute, the council, the inhabitants…), together with the foreign research teams with the common goal

of knowing, promoting and protecting the site for the betterment of the community (Santana et al., 2022).

This particular action in Cidade Velha was originally designed as an archaeological project funded by the Palarq Foundation —a private, non-profit organisation created with the aim of supporting missions abroad in Archaeology and Human Palaeontology by Spanish institutions—, hence the different parts it consisted to were the preliminary planning, the excavation, the study of materials and so on. In addition, we implemented this scientific fieldwork with a cooperation action in the institutional frame of the UPV/EHU University Cooperation Office, which funded a set of actions aligned towards the training and collaboration in Heritage tools and new developments applied to the conservation of the rich Cape Verde Heritage. These activities included open days and training meetings with the staff of the Instituto do Património Cultural (IPC) during the period in Cape Verde, as well as the visit by relevant members of the Instituto to Spain and the organization of a series of technical visits and an international workshop.

3.4 Generative AI driven Virtual Reconstruction

Generative AI has proved helpful for virtual reconstruction of missing parts of ruins (Maitin et al., 2024). The possibility to communicate with the engine through a conversational interface (*prompt*) facilitates the task and gives access to users without advanced knowledge of 3D modelling. However, the outcomes must be handled with care, since AI systems find still barriers when assessing cultural heritage values and may provide apparently correct, although fictitious, answers (Spennemann, 2023).

A common procedure to apply AI for virtual reconstruction (Zhang, 2024) starts with a training phase, for instance with sets of images representing complete elements. Secondly, the quality assessment can be obtained either by quantitative evaluation (comparison of the reconstructed result from images that were modified on purpose in order to simulate the deterioration or the missing parts and, therefore, that can be compared with the original images), by qualitative evaluation (i.e., expert consultation) or both.

Our aim, however, was to see which type of images can be obtained without broader knowledge about the element. For that purpose, we resorted to general-purpose engines without particular training in our subject. The procedure used consists of four steps (figure 3).

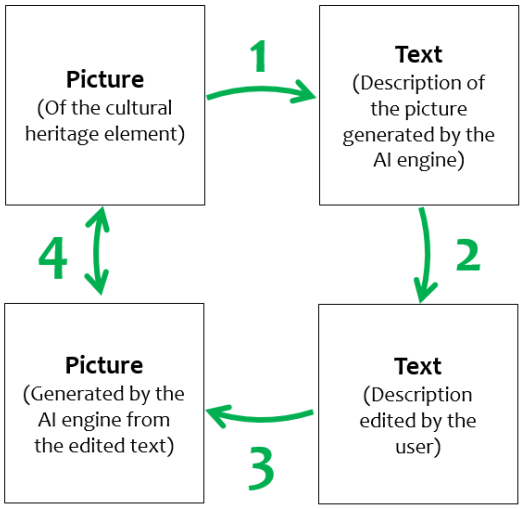

Figure 3. Steps for the generation and assessment of the images generated by an AI engine.

1. Starting with one or more pictures of the cathedral when this element was complete (in this case, we used a drawing issued in 1864. We ask the AI engine to provide a description as complete as possible, emphasizing that the interest lies in the characteristics of the building (figure 4).

2. The outcome is an initial text, that is then edited by the user.

3. After this revision, the edited version is returned to the AI engine as source to generate one or more virtual images of the element.

4. To check the likelihood of the outcomes it is compulsory to conduct a phase of assessment. Depending on the availability of expertise, the evaluation can be based on interviews with experts and contrasting bibliographic sources. When no direct access to expertise is possible, it remains the option of comparing images generated in different moments or by different AI engines and infer that the likelihood of each reconstructed part is proportional to the frequency of apparition of each feature. Nevertheless, the latter approach is very risky because it could tend towards consolidate biases more than towards represent real knowledge.

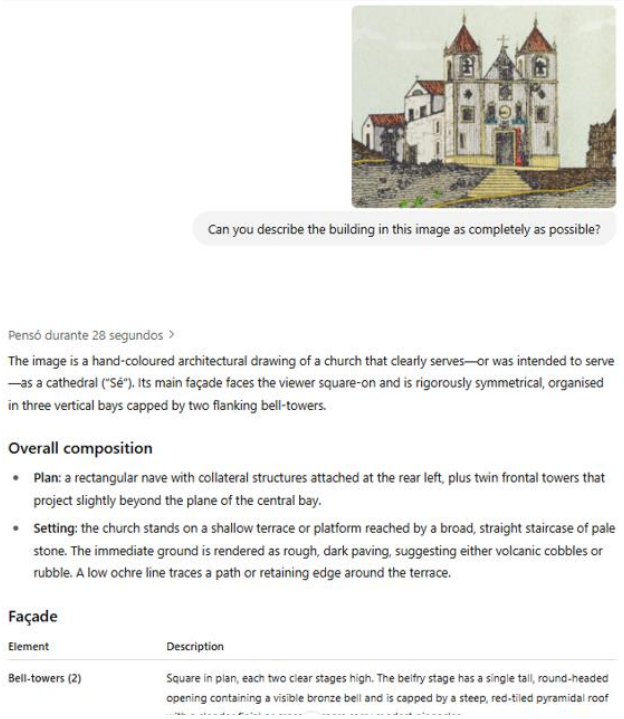

Figure 4. Excerpt of the description of the drawing published in 1864 by Francisco Travassos Valdez generated by ChatGPT.

4. Results

4.1 Documentation outcomes

The results obtained in this first campaign consist of a reference network of stations —and their corresponding descriptive sheets— with coordinates in a global system that are distributed all over the areas of archaeological interest, including at least three benchmarks in each area and interconnection with the adjacent sectors (figure 5).

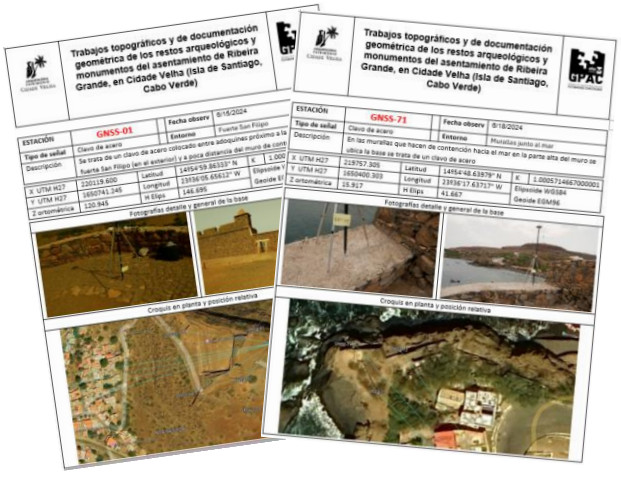

Figure 5. Examples of descriptive cards with the location and coordinates of the benchmarks of the topographic network.

Moreover, the 3D model of the final state of the excavation as a support for the archaeological studies was produced. In addition, a complete 3D georeferenced model of the remains of the Cathedral (figures 6 and 7) was generated as a first example to test possible uses (cultural, outreach, technical… ones) (Reina et al., 2021).

Figure 6. 3D model of the remains of the Cathedral.

Figure 7. Detailed three-dimensional model of a sculpture of the cathedral, mess (left) and texturized (right).

4.2 Virtual views of past appearances

As for the generative imaging for the virtual recreation (figure 8) the systems tested were: Huggin Face (Flux.1-dev), Leonardo, Stable Difussion (3.5), and ChatGPT (with DALL-E).

Figure 8. Examples of non-trained AI generated virtual recreations of the Cathedral.

The results were analysed individually, compared in the set of result and with the images of the standing churches that are considered more similar in the specialized bibliography (Mimoso, 2013). In general, it was very easy and fast to obtain aesthetically appealing, images, however, they also contains many extraneous features; therefore, they should be used with reservations.

5. Discussion

5.1 Soft power and diplomacy of cultural missions abroad

It is widely known that cultural objects and sites have impressive power to mobilise the interest and positive view on a country, a fact that is used in all tourist fairs and world exhibitions, being an excellent example the 3D replica of Michelangelo’s David in the Italian pavilion of the Expo 2020 Dubai (Tucci et al., 2023). Another interesting case is the restoration of the flag of Panamá by the Spanish Institute of Cultural Heritage (IPCE) (Nuño, 2025).

Some works abroad are the result of bottom-up approaches starting from the interest of a group of local actors and foreign researchers that may eventually grow in the aim of obtaining funding. Along the way, it may happen that some institutional interest is born (for instance in national cooperation agencies, foreign affair ministry, etc.) to seize the impetus of the project with varying degree of enthusiasm.

However, we cannot overlook the huge potential of cultural mission in high-level bilateral strategic relationships between countries, where no one ignores that the “culture” is only a nice wrapping of a large package full of many other contents. An example is the French mission in Ethiopia (Endris, 2025), starting with the documentation and immersive tours of Lalibela monasteries that is going to be extended to other monuments.

A controversial aspect of the works abroad is that they may take place in insecure areas and this has given way to strategies of local providers of information that is processed in laboratories in other countries, the case of Gaza carried out by French researcher is a meaningful example of this (Alby & Dellarovere, 2023).

5.2 Challenges, limits and opportunities for geometric documentation works in cultural missions abroad

The availability of satellite imagery, even for remote regions are a starting point for prospection and planning purposes. Legacy systems can be used to monitor changes and detecting elements that may not be evident nowadays (Iranzo et al., 2023), international geodetic networks can be used to obtain precise coordinates and digital elevation models worldwide. Moreover, business enterprises (such as Google) provide good quality orthoimages of almost each part of the world.

Total station surveying is always a most versatile equipment for multiple types of works. Likewise, photogrammetry is now more affordable than ever, with the rapid acquisition from multiple points of view that is available thanks to the use of low cost drones and the easy workflows provided by the software. In cases where the flight of drones is not allowed, telescopic poles may be an alternative.

5.3 Generative AI in the context of Virtual Archaeology

The generation of virtual images did not started with the advent of the Artificial Intelligence, although the widespread access to the easy generation of good aesthetical outcomes have led to the proliferation of uses. Anyway, the well established principles for the scientific use of the virtual archaeology that are in reference documents such as the London Charter (Denard, 2013) or the Seville Principles (López-Menchero, 2013) need to be taken into account. For instance, the AI engines provide no information about the different levels of likelihood in the reconstructed images and this is essential for the scientific use of the images.

6. Conclusions

Documenting is always an essential part of every study of cultural heritage elements and needs to be included in the projects even if the circumstances are difficult with regard to the accessibility of the places, the availability of resources (time, equipment, budget, local knowledge, etc.) or the adversity of the fieldwork conditions.

Using AI engines is straightforward, everyone will be given quick answers that may be very convincing and attractive, but not necessarily correct or usable for scientific purposes, especially if we do not have the knowledge to assess them properly.

Acknowledgements

This project is funded by the PALARQ Foundation; and it was also awarded with a grant of the University of the Basque Country in the call for cooperation in foreign countries (CUD2024); and by CERIBAM Grant PID2020-113198GB-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by “ERDF A way of making Europe”, by the “European Union”.

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