LOW COST 3D RECONSTRUCTION OF CAVE PAINTINGS FOR THE CONSERVATION OF COLOMBIAN HISTORICAL MEMORY: CASE STUDY INDIGENOUS ROCK ART OF THE SACRED PLACE “PIEDRAS DE TUNJO”

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ABSTRACT:

Anthropic activities are produced by constant human activity in nature which, over time, account for the different civilizations. Rock art allows through pictorial manifestations to capture these anthropic activities, which in many parts of the world are preserved as cultural heritage. Colombia, unfortunately, has an incipient development with the conservation of its cultural and intangible heritage, which has had little progress in recent times, if it is about indigenous cave paintings (Méndez-Vargas, 2019). According to history, the first settlers of the Bogotá Savannah lived in the area currently called "Las Piedras de Tunjo" considered a sacred place by the Muiscas - our ancestors. This area located in the municipality of Facatativá, and is currently constituted as one of the five archaeological parks that Colombia has, is 27 hectares and is located at a height of 2600 meters above sea level. In 1912, Rosales, seeing the spatial richness, stated that these stones should be looked at with interest and carefully cared for, because apart from the rugged beauty of the site, they witnessed important events for Colombia. The pictographs on the rock are now believed to date back more than 12,000 years. Although there are multiple images and videos of the site, this project seeks to approach the 3D reconstruction of an area of the park through SfM photogrammetry (Structure-from-Motion - Westoby, 2012) with a low-cost and easy-to-implement methodology (Santagati et al., 2017; Tavera et al., 2019) to promote historical conservation and Colombian cultural heritage in an indigenous sacred place to democratize it. This work documents different experiments and their results, of the 3D reconstruction using different data sources and software that will allow it to be an input in archeology to better understand the indigenous history of the area that was deteriorated in the 20th century.

1. INTRODUCTION

For more than 16,000 years, Colombia has been inhabited by various peoples who have left as proof of their passage a large amount of evidence, such as roads, tools, dwelling places, sacred sites, human remains, gold pieces, rock art, etc. ., constituting what we now know as Cultural Heritage.
Rock art is known as the traces of human activity or images that have been engraved (petroglyphs) or painted (pictographs) on rocky surfaces (Celis & Contreras, 2004).
Well, this project seeks to contribute to the documentation of rock art in the Archaeological Park 'Las Piedras del Tunjo', through the use of affordable and low-cost 3D reconstruction. For this, the tools available for image processing will be available to carry out the reconstruction of various areas of the park, and in this way contribute to the conservation of the art that our ancestors left embodied in this sacred territory.
Photogrammetry is the science or technique whose objective is the knowledge of the dimensions and position of objects in space, this is done through the intersection of two or more photographs, and the digital model of the terrain corresponding to the represented place. The word photogrammetry means that the measure of what is written with light, derives from the word “frame” (from “phos”, “photós”, light, and “gramma”, tracing, drawing) and “metron”, measure (Nephew, 2007).
3D reconstruction is one of the applications of photogrammetry most welcomed by the different areas of knowledge, and without a doubt it is a fundamental tool for the conservation and preservation of the cultural heritage of any territory.
Known techniques are used, Structure from Motion (SfM), it is considered a high resolution and low cost automated photogrammetric method (Tomás et al., 2016). Also, the Multiview Stereo Reconstruction (MVS) technique is the general term given to a group of techniques that use stereo correspondence as their main signal and also use more than two images (Hernández, 2015).
To carry out the reconstructions, two data acquisition methods will be explored, these are photogrammetric and videogrammetric methods. The latter consists of a data acquisition technique through video capture, and with the help of software, the capture frames are extracted with which the reconstruction tool finally works.

Figure 1. Stones of Tunjo. Rock in the form of a "snake". Own source.

2. STUDY AREA: INDIGENOUS ROCK ART IN THE "PIEDRAS DEL TUNJO"

The West Savannah of Bogotá is very rich in this type of artistic manifestation known as rock art, and precisely, the "lost Tunjo" are located within the vicinity of the Archaeological Park of Facatativá, a municipality located 36 kilometers from Bogotá. The Muisca people that populated this region left their particular way of seeing and understanding the world captured on these immense stones. With more than 60 registered murals, this site, declared a national heritage, is a shameful example of the disinterest of the territorial entities and the population in general to preserve these manifestations.

Our indigenous ancestors left this art embodied in stones throughout the country, and it has remained for centuries in the same place where it was made. For this reason, the environment in which it is found can be considered a true open-air museum. Without adequate protection and awareness, this heritage is doomed to disappear and it is everyone's duty to ensure its conservation (Martínez, Diego; Botiva, 2004).

In the 16th century, with the European conquest of the lands of what is now Colombia, the written and historical record of the events and descriptions of a territory populated by a great diversity of peoples began, by the European invaders. indigenous people who did not develop writing.

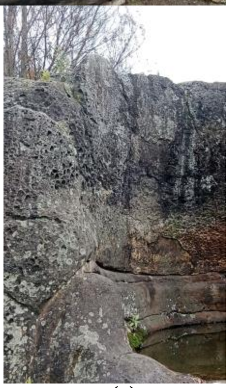
It was not until the 19th century that the indigenous past began to be seen as an integral part of the nationality, however, cave art was not considered relevant at the time. It came to be stigmatized and invalidated as a fundamental piece to understand indigenous organizations, since the first studies were barely carried out. This process of exposure of the indigenous people, full of prejudices, made rock art and its aesthetic modalities and projections be seen as a set of even foreign elements (Greek, Mesopotamian), indecipherable, meaningless and childish (Muñoz, 1995).

At present, there is talk of the importance of our past and government strategies are developed that guarantee its conservation. For this article, 3 areas were carefully chosen that contain some important elements of the sacred place.

They are illustrated in figure 1 as follows:

(a)

(b)



(c)

Figure 2. Study areas. (a) American Rock Art, (b) Petroglyph, (c) Las Moyas

The area of American Rock Art that is illustrated in figure 1 (a), are Pictograms with a variety of forms and techniques that demonstrate the complexity that was acquired over the millennia, and can become a map of evidence of peopling in America.

Figure 1 (b) illustrates the Petroglyph, found in the 14th century between Guasca and Guatavita, this figure represents the wife of the Cacique of Guatavita with her daughter on her back, "fleeing she threw herself into the waters of the lagoon by the offenses of her husband. Statue 3 meters high by 1 meter wide.

Finally, figure 1 (c) shows us "las Moyas". These stones could be used in ancient times for different daily purposes such as personal bathing, washing clothes and food preparation. This rock formation is between 2 and 3 meters high.

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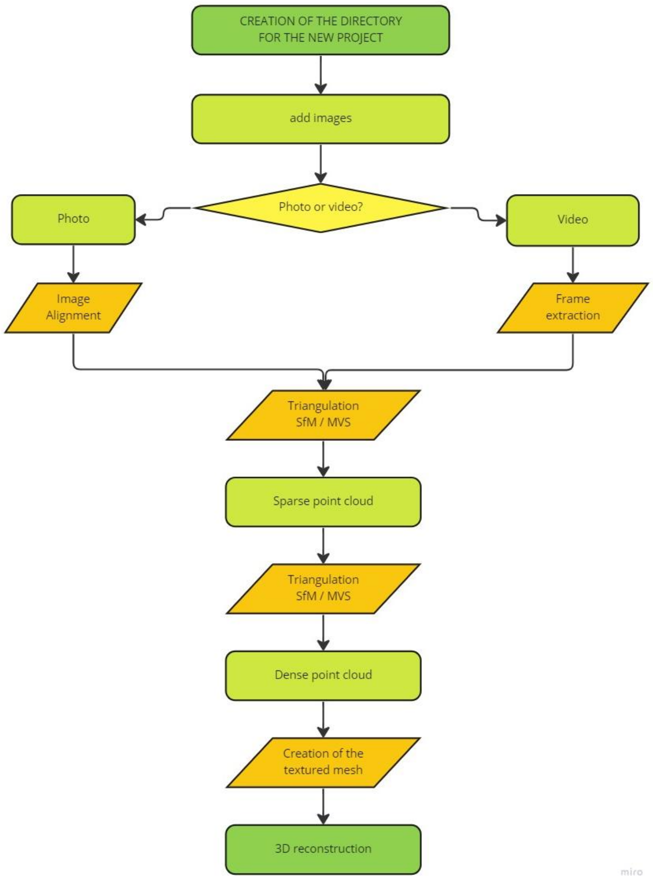
3. METHODOLOGY

To meet the objectives of this project, a workflow is carried out in four phases that describe the processing, carried out in the 3DF Zephyr software, for which the default parameters were left.

First, the alignment of the images (photos) or the extraction of frames (video), for the comparison of points. Then, with the triangulation, the scattered point cloud is generated. Then we get a model with dense cloud of points. Continuing, we generate the continuous surface composed of polygons, in order to color the meshes by projecting the photographic images on the sides of the polygon meshes. Finally, the 3D reconstruction of the object is obtained, and its results are compared.



Graph 1. Workflow for processing the data acquired for the article. Source: self made.

At the time of extracting the final mesh, the data is exported in the ".obj" file extension, also known as "Wavefront 3D Object File", which stores 3D image files compatible with a large part of the processing software useful for reconstruction.

4. MATERIALS AND METHODS

4.1 Data acquisition

Data was obtained from a single capture system, a conventional cell phone camera (Vivo Y33S), which is quite cheap and accessible. Following two different capture methods, there is photogrammetry and videogrammetry, defined at the beginning of the document.

The videogrammetric acquisition method was used for each of the study areas, on the other hand, the photogrammetric method was only used in one of the areas. The distribution is described below as follows:

In the case of figure 1 (a) that illustrates the Petroglyph, data acquisition was by means of the methods described at the beginning of this article. For the photogrammetry, 47 photographs carefully taken around the petroglyph were captured in the field, moving the instruments on an ideal sphere of constant radius and directing the optics towards the center of the statue. Keeping a radial distance of 2 meters from the object and a height of 1 meter above ground level. Regarding the videogrammetry, two videos were captured, one of 44 seconds following a capture criterion equal to the photogrammetric one where the distance restrictions were respected and another of 36 seconds, recorded from different heights and angles. Following equal capture criteria for each method, the data acquisition methods chosen for the pictograms were videogrammetric and panoramic images. Obtaining in the field a 15-second video and 2 panoramic images.

For the acquisition of data in the area illustrated in Figures 1(b) "Pictografías" and 1(c) "Las Moyas", only the videogrammetry method was chosen, being the most optimal due to the shape of the rocks. Obtaining in the field videos of 18 and 14 seconds duration respectively, which document the entire scene.

The photos acquired with the smartphone did not need any development, because the device provided them only in compressed .jpg format, compatible with the software.

For the video format, the smartphone camera was set to the highest possible resolution (width 1920 pixels - height 1080 pixels) and a recording speed of 30 frames per second.

The 360° images are obtained with free access from Google Street View, corresponding to a RicohTheta S camera, which includes a CMOS sensor, for brightness control and contrast correction, a focal aperture of 2.0, a number of pixels equivalent to 14 M, and a resolution of 5376 * 2688 pixels.

4.2 Data processing

For purposes of complying with the processes described in this article, specifically in the methodological part, it was necessary to have a machine that would allow the optimal development of the software. In this case, the computer used is an Intel Core i3 7th Gen, hard drive with a capacity of 112 GB and RAM of 64 GB.

4.3 3D Flow Zephyr Software:

"It's 3Dflow's photogrammetry software solution for automatically reconstructing 3D models from photos – tackle any 3D scanning and reconstruction challenge. It doesn't matter what camera sensor, drone or laser scanner device you're going to use."

This is one of the most complete software used for the development of the objective of this article. Here all the data acquired thanks to the conventional smartphone camera system is processed by the different methods (Photogrammetric and Videogrammetric) stipulated

One of the benefits of this free-to-use software is that it allows you to quickly and efficiently extract frames from a video. The algorithm first extracts all frames and then removes a portion of them based on similarity-based filtering. This function is performed automatically.

5. RESULTS

The data was presented from the graphic and quantitative point of view of the different processes, as follows:

Photogrammetry	videogrammetry ordered sequence	videogrammetry unordered sequence

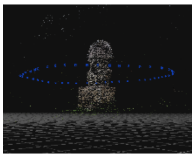
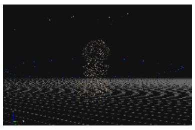
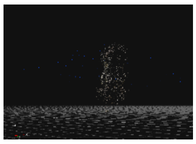

		

Figure 3. Sparse point cloud. (a) Photogrammetry, (b) Videogrammetry with sequence, (c) Videogrammetry without sequence		

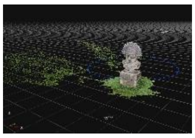
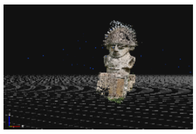
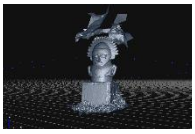
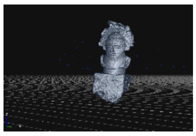

		

Figure 4. Dense point cloud. (a) Photogrammetry, (b) Videogrammetry with sequence, (c) Videogrammetry without sequence		
		
Figure 5. Mesh (a) Photogrammetry, (b) Videogrammetry with sequence, (c) Videogrammetry without sequence		

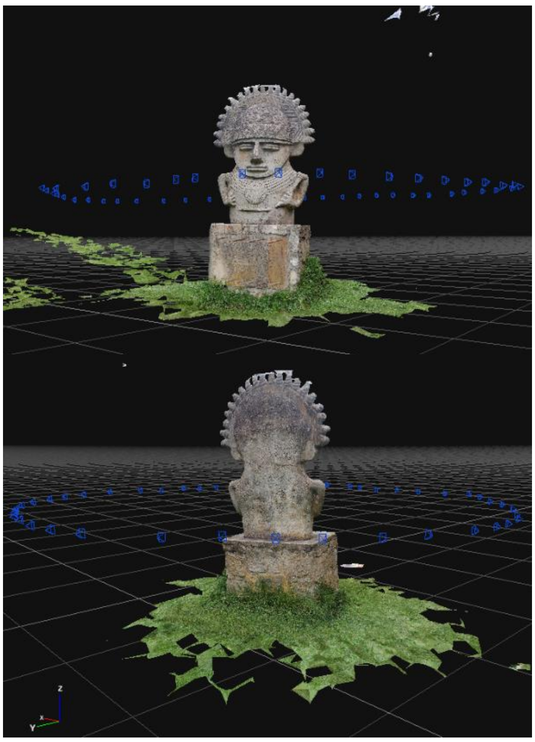


Figure 6. Petroglyph reconstruction, texture mesh. Photogrammetric method.

Figures 3, 4 and 5 (a) show blue dots that represent the position of the cameras at the time of capture. Represent the construction of the sparse point cloud

Figure 6 shows that the reconstruction of the object had quite favorable results at the level of detail, although the upper part of the peaks of the crown was not the best. On the other hand, it is evident that the point cloud also took values from the external landscape, resulting in the reconstruction of a large part of the grassland around the statue.

	Number of calibrated images	Number of densified 3D points	Tiempo de densificación	Tiempo para malla texturizada
3DF Zephyr	47	179603	1 hora	1 hora 30 min

Table 1. Petroglyph quantitative results, photogrammetric method.

The software recognized the 47 photographs, and carried out the corresponding processing automatically with its default settings. It generated the sparse point cloud and the densified 3D point cloud, provided the mesh, and finally returned the textured mesh, took about 1 hour and 30 minutes to complete.

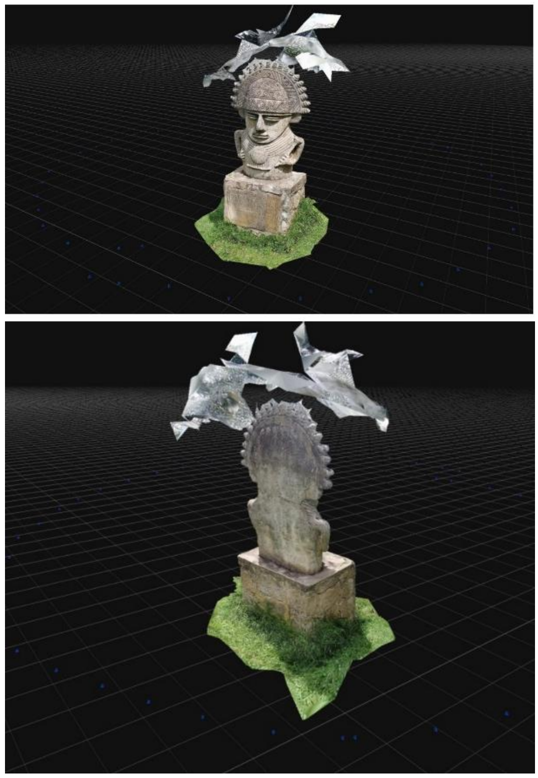


Figure 7. Petroglyph reconstruction, texture mesh. Videogrammetric method with ordered sequence.

Figure 7 shows that the reconstruction had quite favorable results in terms of object detail, however, the upper area of the statue resulted in an anomalous mesh formed around it as a result of the lack of data acquisition from a height. greater than 1 meter above ground level. It is also noted that the software ignored the reconstruction of the exterior landscape considerably.

Number of calibrated images	Number of starting points	Number of densified 3D points	densification time
46	5956	189547	16 minutos
Number of Triangles	**Number of vertices**	**final groups**	**Time for textured mesh**
74762	37424	6665	10 minutos

Table 2. Petroglyph quantitative results, videogrammetric method.

The software effectively and automatically extracted 46 frames from the video capture that was 44 seconds long, approximately one frame per second, as it was the initial setting of the conventional camera.

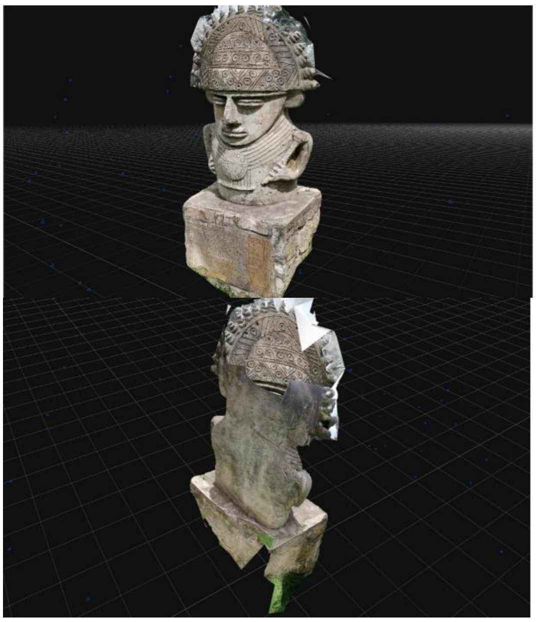


Figure 8. Petroglyph reconstruction, texture mesh. Disordered sequence videogrammetric method.

Without complying with a specific acquisition path, the results of figure 8 curiously gave very favorable results, but only in the front part of the statue, since, due to lack of frame capture in the rear part, the software did not reconstruct it. correctly, as well as the upper part, since it could not reconstruct the crown in a favorable way. In fact, the distribution of blue dots in the images displayed in figure 8 indicates the position of the cameras and the lack of dots behind is evident, which responds to the shortcomings of the reconstruction. One point to note is that he had no problems with the external landscape, so a better video capture could be a good tool for the purpose of this article.

Number of calibrated images	Number of starting points	Number of densified 3D points	densification time
38	3059	125708	12 minutos
Number of Triangles	**Number of vertices**	**final groups**	**Time for textured mesh**
245869	122987	5120	22 minutos

Table 3. Petroglyph quantitative results, videogrammetric method.

The software effectively and automatically extracted 38 frames from the video capture that was 36 seconds long, in fact, it is the only free software that does this. The processing was carried out step by step, where it was possible to designate advanced parameters for each of the steps mentioned in the workflow established for this article. Final product acquisition times were considerably short.

Pictografías

• Method: Videogrammetry (18seconds)

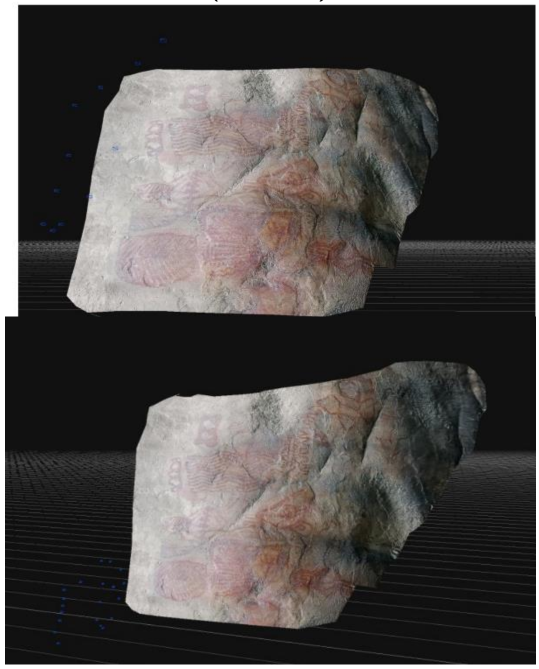


Figure 9. Pictograph reconstruction, texture mesh. Disordered Sequence Videogrammetric Method.

Due to the magnitude of the rock and the fact that it could not be accessed directly, it was decided to capture the video from different angles and heights as much as possible. The distribution of blue dots displayed in the images in figure 9 show the position of the cameras at the time of extraction of each frame. The result, in fact, is very favorable, since it meets the objective of specifically reconstructing this element, and displaying the pictograms correctly and with adequate resolution for their interpretation.

Number of calibrated images	Number of densified 3D points	densification time	
20	6417	8 minutos	
Number of Triangles	**Number of vertices**	**final groups**	**Time for textured mesh**
74831	37456	307	10 minutos

Table 4. Quantitative results Pictography, videogrammetric method.

The software effectively automatically extracted 20 frames from the video capture that was 18 seconds long. It captured 6417 densified 3D points in 8 minutes and finished building the textured mesh in just 10 minutes, being quite favorable for the fulfillment of the objective of this article.

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"Las Moyas"

• Method: Videogrammetry (17 seconds)

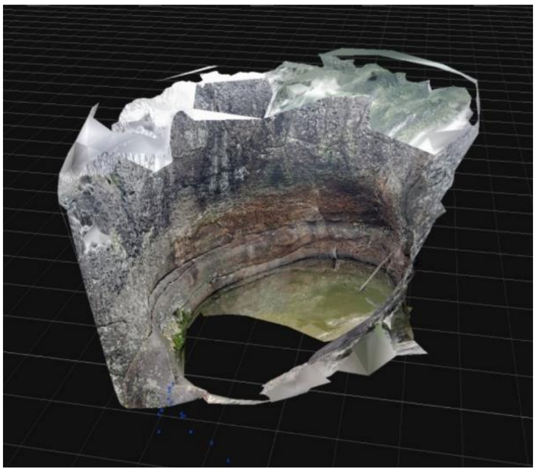

Figure 10. Reconstruction of "Las Moyas", texture mesh. Disordered sequence videogrammetric method.

Due to the magnitude of the rock, since it is more than 2 meters high, and its position, since it can only be accessed from the front, since it is surrounded by vegetation, it was decided to capture video from different angles, trying to raise the camera slightly. atura, to get as much of the scene as possible. Observing the results consigned in figure 10, it is evident that the reconstruction of La Moya was not entirely favorable, since a part of the stagnation is missing, and the upper part is not well defined, this as a consequence of the poor capture conditions. However, despite this, the results are encouraging, if we direct the visual analysis to the internal details of the rock, it is evident that they are good, which means that with better acquisition equipment the results could be very useful.

Número de imágenes calibradas	Number of starting points	Number of densified 3D points	densification time
18	5988	83361	8 minutos
Number of Triangles	**Number of vertices**	**final groups**	**Time for textured mesh**
108814	54462	357	10 minutos

Table 5. Quantitative results Pictography, videogrammetric method.

The software effectively automatically extracted 18 frames from the video capture that was 17 seconds long. It captured 5988 densified 3D points in 8 minutes and finished building the textured mesh in just 10 minutes, being quite favorable for the fulfillment of the objective of this article.

CONCLUSIONS

The resolution offered by the frames extracted from the video capture is lower than that offered by taking pictures frame by frame, however, according to the results obtained, it is evident that it is an effective method for the proposed case study. in this article, since for the reconstruction of the elements, capture alternatives had to be sought, varying according to the magnitude of the rocks to correctly capture the essence of the rock art embodied there.

This initiative could increase your acquisition flow with collective work. People aware of the importance of the conservation of rock art and cultural heritage in general, could without problems, use their low-cost smartphones to acquire data following the methods presented here, and in this way, a better visualization of the park would be obtained. and its rock art.

An interesting alternative for data acquisition could be based on a tour of the park with a Drone, in a way that allows the correct visualization of the large rocky structures.

REFERENCES

Hernández, C. (2015). *Multi-View Stereo : A Tutorial*.

Martínez, Diego; Botiva, A. (2004). *Manual de arte rupestre de Cundinamarca*.

Mendez-Vargas, A. (30 april 2019), *Las piedras del tunjo, templo de conocimiento*. Universidad Central. https://acn.ucentral.co/cultural/3371-las-piedras-del-tunjo-templo-de-conocimiento

Muñoz, G. (1995). Lenguaje de las rocas: Recuperación de la historia cultural Colombiana. *Arte Rupestre En Colombia - Universidad Distrital*.

Rosales, J.M., 1912. Semanario Ilustrado El Gráfico.

Santagati, C., Lo Turco, M., Bocconcino, M. M., Donato, V., and Galizia, M., 2017: 3D models for all: low-cost acquisition through mobile devices in comparison with image based techniques. potentialities and weaknesses in cultural heritage domain, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W8, 221-228, https://doi.org/10.5194/isprs-archivesXLII-2-W8-221-2017.

Tavera, L. D., Páez, A., Rocha, L. A., Dallos, L. A., Gonzales, J. D., and Upegui, E.: SFM photogrammetry as a tool for the conservation of the cultural heritage of Bogotá (Colombia), within the framework of the adopt a monument program, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W17, 363–370, https://doi.org/10.5194/isprs-archives-XLII-2-W17-363-2019, 2019

Tomás, R., Riquelme, A., & Cano, M. (2016). *Structure from Motion (SfM): una técnica fotogramétrica de bajo coste para la caracterización y monitoreo de macizos rocosos Multi-scale Observation and Monitoring of railway Infrastructure Threats (MOMIT) View project*. *November*. https://www.researchgate.net/publication/309611177

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., Reynolds, J.M., 2012: Structure-from-Motion' photogrammetry: a low-cost, effective tool for geoscience applications.