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Surveying Heritage with Affordable Yet Accurate Methods. A Study Case from Agrequipa, Peru

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Abstract

One of the key aspects to keep adequate management and preservation of the built heritage is to maintain an adequate registry of the monuments. In many cases, state-of-the-art technologies are being used to develop accurate and rapid surveys, which utilize sophisticated high-cost equipment. However, in developing countries that possess a rich heritage, many of these technologies are beyond the reach of their possibilities, having to rely on manual, inefficient and inaccurate systems that are still used.

This research shows several alternatives of relatively low-cost techniques that allow a reliable data collection of built heritage, without losing the richness of the details of the historical architecture. To do this, a comparison is made between different methods of manual, semi-automatic and automatic data collection, analyzing their costs and benefits. Subsequently, a comparative survey is carried out using the most efficient and affordable methods, proposing a methodology that leads to the improvement of surveys in historical buildings without this entailing a significant increase in costs.

Keywords

Heritage survey; low-cost survey; point cloud methods

1. Introduction

One of the most important aspects to achieve good management of the urban and architectural heritage is to accomplish an accurate survey and documentation. These measurements will allow developing subsequent restoration, conservation, maintenance, dissemination, and enhancement of the built heritage. In recent years, there has been a growing interest in the use of automated alternative methods that allow adding greater quality and accuracy to the survey of heritage, especially those buildings related to pre-modernist times, due to the amount of ornamentation that accompanies this type of architecture.

In order to carry out better conservation practices, the use of digital documentation such as laser scanners is becoming popular (Petrovic, Meyer, Rissolo, & Kuester, 2015). However, the high cost of these types of equipment and processing, as well as their difficulty of operating, has discouraged its use in developing countries, which, although they possess a great and rich heritage, do not have the means and training to develop these complex and complete surveys. The preferred survey method in these realities is employing a tape measure and then drawn digitally in AutoCAD at best, which implies a great possibility of error because they depend on the ability of who is doing the survey to achieve a reliable record of reality. Even if the measurements are correct they are very time consuming and many details are lost in the process due to the simplification of these graphics.

This paper makes a comparative analysis of different measurement methods, emphasizing its cost and operability, the difficulties of the process but also the advantages and disadvantages of the final product. Many of these alternative processes have the advantage of being developed as a point cloud, which allows file sharing and uses for different purposes (Meschini, Petrucci, Rossi, & Sicuranza, 2014). This research aims to be a contribution to those who are new in the field of photogrammetry and, wishing to improve their surveying methods, have a limited budget for heritage conservation

2. The site

The city of Arequipa, second in importance in Peru, houses a diverse built heritage, both from Spanish colonial and early Republican times, is a relevant example of these processes, leaving evidence of this in its urban layout of and in its unique mestizo architecture is an expression of the cultural richness of the city (Gutiérrez, 2019; Bailey, 2010)

The domestic architecture of Arequipa has followed a process that evolved from adobe constructions topped with wooden log roofs, covered with straw, to those of thick walls, made of a volcanic stone locally called “sillar”, which is a kind of ignimbrite. The vaulted roofs and domes, as well as the ornaments, were typically made of the same stone. Due to continuous seismic events that periodically destroyed the city, several styles are superimposed in the structures of the city. The action of earthquakes destroyed roofs that were just placed (not joined) on top of walls, which easily collapsed to the strength of the geological thrust; The vault was a since it incorporated aesthetically as well as to resist earthquakes (Quiroz Paz Soldán, 1983).

The case study selected for this research is a mansion called "Casa del Corregidor Abril y Maldonado", whose origins date back to the 16th century. Its architectural typology stands out for the use of “sillar” as a constructive material in almost the entire building elements such as walls, pretables, stairs, roofs, floors, niches, arcades, etc. This two-story house is arranged around two patios as it was a common way to spatially distribute and provide light for ventilation to the surrounding rooms. These patios also represented different types of privacy, as the most external one has a social role (and therefore it includes the stairways) whereas the inner yard ad a more intimate function. Nevertheless, the latter is framed by a beautiful arcade. Both patios are connected by an alley and many of the surrounding rooms are covered by vaults. Currently, the Casa del Corregidor Abril y Maldonado, is restored, having a high percentage (65% approx.) of conservation from its original status. (Fig. 1).

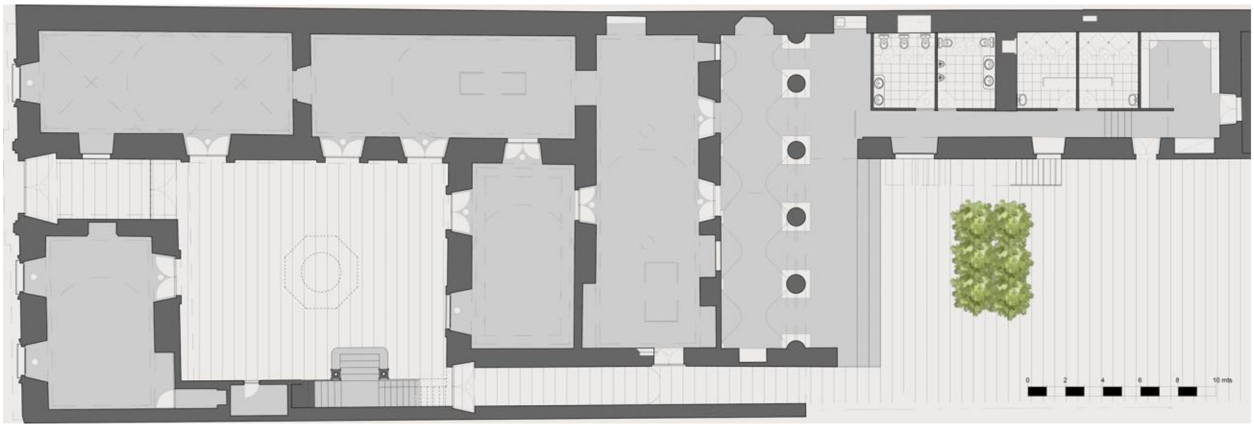

Figure 1. Layout of the Casa del Corregidor Abril and Maldonado, drawn manually in AutoCAD (Rodriguez, 2002)

The main façade of the building which is composed of two stories, made in the so-called a Republican-style, which has fewer ornaments than the Baroque style, yet it includes a wooden balcony and windows with neoclassical ornaments (Fig. 2).

Figure 2. Façade of the building (Zeballos, 2019)

3. Surveying techniques

Peru is a country with a vast built heritage, but which has had considerable mismanagement in its maintenance, due to economic and political situations (Belletich, 2015). The main problem for the protection and conservation of cultural heritage in Peru is the lack of budget. There is not even the minimum necessary to start a process of surveying registration and cataloging, the first step that should be done, in order to undertake a serious work of conservation, restoration, and enhancement of archaeological assets. These neglects are being taken advantage of by land traffickers and robbers that harm the cultural heritage, especially affecting the most vulnerable archaeological sites and architectural places (Baltazar, 2009). Particularly there is a bias between the existing and registered heritage. At best, surveys have been developed using conventional methods, which in many cases have been incomplete, flawed, or expensive and time-consuming.

4. The use of traditional survey methods in Peru

These traditional methods include measurements made by hand, with metallic tape or alternatively, other manual measuring instruments include ultrasonic meter. These later types of equipment work as a “sonar” that emits sound impulses at the ultrasound level, and upon impacting these sound waves with the measuring surface, a return of this sound will be generated. The distance is calculated in relation to the return time of the sound to the equipment. These devices are useful to measure points of difficult accessibility. However, their reliability is not guaranteed as they depend on the consistency of the surface to be measured. The more solid and compact the surface, the more reliable the measurement. Also, these devices have a limited range in terms of maximum distances to be measured, an obvious consequence of the sound wave system that inevitably tends to dispersion. A second stage is, already in the cabinet, to interpret and transcribe the graphic information in a scale drawing, usually drawn in a two-dimensional format in CAD software, and whenever errors occur, oftentimes it is necessary to retake measurements.

Another form of measurement traditionally used in Peru for surveying large archaeological sites and occasionally architectural heritage includes the use of optical levels, theodolites, and the total stations. Unlike the first group, require a higher level of training and experience, since they are the equipment of better performance, but also of greater complexity. Their accuracy will depend on the correct reading made by the operator. Unlike the manual methods, these systems are based on the placement of the equipment at a central point, from which radial measurements are made taken.

An alternative to this method is the 3D metro laser. This technology will have to be placed in a central position from where the fully stabilized and leveled equipment will be ready to take the measurements. From there, the equipment is operated remotely from a tablet and is able to record several points in space, that ultimately will produce a vectorial 3D “wire” which can be exported to DWG, DXF, JPGE, JPG, CSV, etc. formats from the equipment’s software. The advantage of this equipment is that computer files are automatically generated, reducing possible errors during data recording, interpretation, and construction of plans. However, the system requires a lot of practice, as the operator must first establish a fairly organized measurement sequence, and the quality of the result will depend on the ability of the operator and the number of points taken in order to build a reliable model. In the best of cases, the final product will still need a manual retouch as several details are easier to take by hand. Also, it will not consider the intricacy of finer details.

5. Photogrammetry

Photogrammetry is a technique that aims to define precisely the shape, dimension, and position of an object in space; using one or several photographs to obtain coordinates in three dimensions (Quirós, 2014). For many years this technique was analog, today since the emergence of new technologies in camera and computer equipment is mainly digital (Schenk, 2002). The advantages of this system are that it is a much quicker survey method, it is low cost as it does not require professional photographic equipment. It only needs a few technical and human resources. It can obtain a large amount of information (color, textures, details, etc.) There is a variety of software to process the data (various license costs) and the results show significant quality detail.

The disadvantages include that the degree of precision subject to equipment and experience, it requires knowledge of photography and management of specialized software. Also, edited photographs often lose valuable information for the method (contrast adjustment, color correction, etc.) and data processing software is usually time-consuming and it requires a powerful computer to process a large amount of information, especially regarding complex surveys. Another disadvantage is the difficulty to measure the external form of rooftops, as it is an ideal method for surveying interior spaces.

While this method used to employ expensive aircraft flights in the past, nowadays it is carried out with unmanned aerial vehicles (UAVs), popularly known as drones. Later, 2D and 3D computer-generated models can be created, and as they can be georeferenced, they can accurately represent the dimensions and physical features of the measured buildings.

Studies on the use of drones have been carried out in several places in order to create accurate models of ancient monuments, showing the versatility of this process for the creating of point clouds that store the properties of the studied elements, particularly their materials and shapes. This method is excellent to collect information, from large scale landscapes and achaelogical sites to the geometry of a building and particularly of the shape of its roof (Lo Brutto, Garraffa, & Meli, 2014; Brumana, et al., 2013), however, it has difficulty to measure interiors, especially in narrow places. Use of drones is highly recommended for heritage management (Sun & Zhang, 2018) and it can be combined with othey methods of topographic acquisition (Achille, et al., 2015). A careful flight plan should be design to achieve better results for georefecing and producing the model (Barba, Barbarella, Benedetto, & Fiani, 2019).

The reduction in the prices of drones as well as software has allowed the use of these aerial vehicles to become more popular, although their use in Peru is still not very widespread and the rental of these services is relatively expensive compared to traditional methods, at least for medium-size and small surveys.

On the other hand, to our knowledge, photogrammetry using a photographic camera has not yet been utilized in Arequipa since it is a method that is basically unknown for cultural assessment and preservation in this city.

6. Laser scanner

Also known as LIDAR (Light Detection and Ranging o Laser Imaging Detection and Ranging), it consists of a high-powered laser moving horizontally and a mirror rotating around a vertical axis in order to cover large areas, scanning thousands of dots every second (Izgarevic, 2018). Laser scanning also requires a high-end computer that can store and handle large amounts of data and also special software to develop the process.

This is a very time saving and very accurate and reliable technique for surveying historic buildings (Nex & Rinaudo, 2010), as it produces very fine-detailed point cloud models, particularly for façades or interiors, although there is also LIDAR equipment available for aircraft, both manned and unmanned.

Its cost-benefit would be related to the size of the surveyed area as well as its frequency of use, however, in developing countries, whose heritage offices usually operate under low budgets, the cost of a LIDAR scanner as well as the pricey software, not to mention the lack of trained staff to carry out the surveys would make this method definitely out of reach.

Although the use of laser scanner in Peru and in other developing countries is very difficult due to its high cost, there are several documented experiences of its use for heritage surveying in developed countries, both isolated and in combination with photogrammetry using UAVs, having obtained high-quality results in a short time (Achille, et al., 2015; Fassi, Fregonese, Ackermann, & de Troia, 2013).

7. Summary of different surveying methods

As can be seen in comparative Table 1, the manual method is affordable but has low quality and accuracy, particularly for historical buildings. Semimanual methods are better in accuracy but difficult to use and expensive. On the other extreme, the LIDAR method has the best quality and accuracy, but the price of hardware and software makes difficult to afford. Therefore, due to their high accuracy, ease of use, and affordability, three photogrammetric methods have been employed for surveying the house, in order to make a comparison between them. These are efficient and yet affordable ways to acquire data in historical buildings.

Table 1.Comparative methods for surveying historical buildings

Method	Output format	Accuracy	Quality	Ease of use	Affordability
Traditional	Vectorial	Low	Low	High	High
Camera Photogrammetry	Cloud point	High	High	High	High
Camera 360	Cloud point	High	High	High	High
Aerial photogrammetry	Cloud point	High	High	Medium	Medium
Laser scanner	Cloud point	Very High	Very High	Medium	Very Low

8. Surveying the Casa de Abril y Maldonado

8.1. Photogrammetry using a semiprofessional camera

a) Equipment

The equipment used was a Nixon COOLPIX B500 camera, configured in a Preset mode and with a resolution on 16 megapixels. The white balance was set to daily light and the ISO sensitivity was set to 300. It is not recommended to set them in auto mode as they may vary from picture to picture.

As for the computers a desktop with CPU core2quad 2.8 MHZ, Graphic board GTX 770 with 2GB VRAM, RAM 16GB and SSD was used, and also a laptop CPU i7 3610Q 3.3 MHZ, Graphic board GT 650M with 4GB VRAM, RAM 16GB and SSD.

The photographic survey day lasted one hour, from 10:30 to 11:30 AM, on a sunny day with good conditions of natural light, free of obstacles and people.

b) Software

Several types of software were used, as shown in table 2.

Table 2. Software use for image processing in photogrammetry

Software	Affordability	Quality	Ease of use
Agisoft MetaShape Profesional 1.5	Medium	Medium	High
RealityCapture 1.0	Low	Low	High
3DF Zephyr Free	Free	High	High
Autodesk RECAP 2020	Medium	High	High

c) Process

To achieve the reconstruction of the architectural heritage by means of photogrammetry using a semi-automatic camera, a series of technical challenges had to be overcome in the different stages of the process, which we will summarize in two phases.

The first stage was the survey using the camera. The ideal conditions for the photographic record are subject to issues of accessibility to the workspace, access to ceilings, alleys, and others specific to each building; as well as the absence of obstacles such as people, animals, or any other mobile element that obstructs the capture of images.The lighting conditions to obtain the best results are daytime with a cloudy sky, as sunny days with high light contrasts cause poor photographic records during data processing, and that is applicable also to the 360° camera method.

While taking the photographs, it is better to avoid rotating the camera as it will affect the quality, accuracy, and position of the final result since the software positions the image based on coordinates. It is important to generate a sequence of images that share common areas to be overlapped and pictures should be taken orthogonally, in perspective, and at different heights.

The second stage was to process the images. The specialized software for processing photographic data requires that the images should not be manipulated in any way, that is, rotating them, trimming them, adjusting contrast values, color, brightness or any alteration; since it produces loss of valuable information and in many cases, the software simply does not recognize the image file. Images that are discarded usually mostly due to problems such as overexposure, dark surfaces or high contrasts (Fig. 3)

Figure 3. Image processing in Agisoft.

8.2. Photogrammetry using a 360° camera

a) Equipment

The equipment used was an Insta 1x 360° camera, which has two 180° lenses and a resolution of 5.7 K. In the case of the façade, the camera was mounted on a tripod and the photographs were taken perpendicularly at 1.5 meters from it and horizontally at intervals of 1.5 m each, with a buffer area before and after the building. In the case of the inner courtyards, the camera was placed in several locations until the model was completed.

b) Software

The results are uploaded in Matterpoint, an application that can be downloaded both from Apple store and Google Play, and it provides a cloud service which delivers a point cloud and a 3D model.

c) Process

The model is built using the captured imagery and is stored on the mobile device using the Matterport app. For the construction of the 3D model, a sequential workflow must be carried out that is progressively checked on a plan layout (Fig. 4).

Figure 4. Image processing in Matterport.

8.3. AeroPhotogrammetry

a) Equipment

The equipment used was DJI PHANTON 4 PRO drone, configured in a Preset mode and with a resolution of 20 megapixels. For image processing a Dell Precision T5500 Workstation was used.

b) Software

Two types of software were used, as shown in table 3.

Table 3.Software use for image processing in aerophotogrammetry

Software	**Affordability**	**Quality**	**Ease of use**
Agisoft MetaShape Profesional 1.5	Medium	Medium	High
Pix 4D	Low	High	High

c) Process

For the survey of the façade with a drone, it has been experienced performing vertical flights every 2.5 meters, both horizontal flights, and vertical shots. Subsequently, the imagery was processed in Pix 4D as it produced a better point cloud result (Fig. 5).

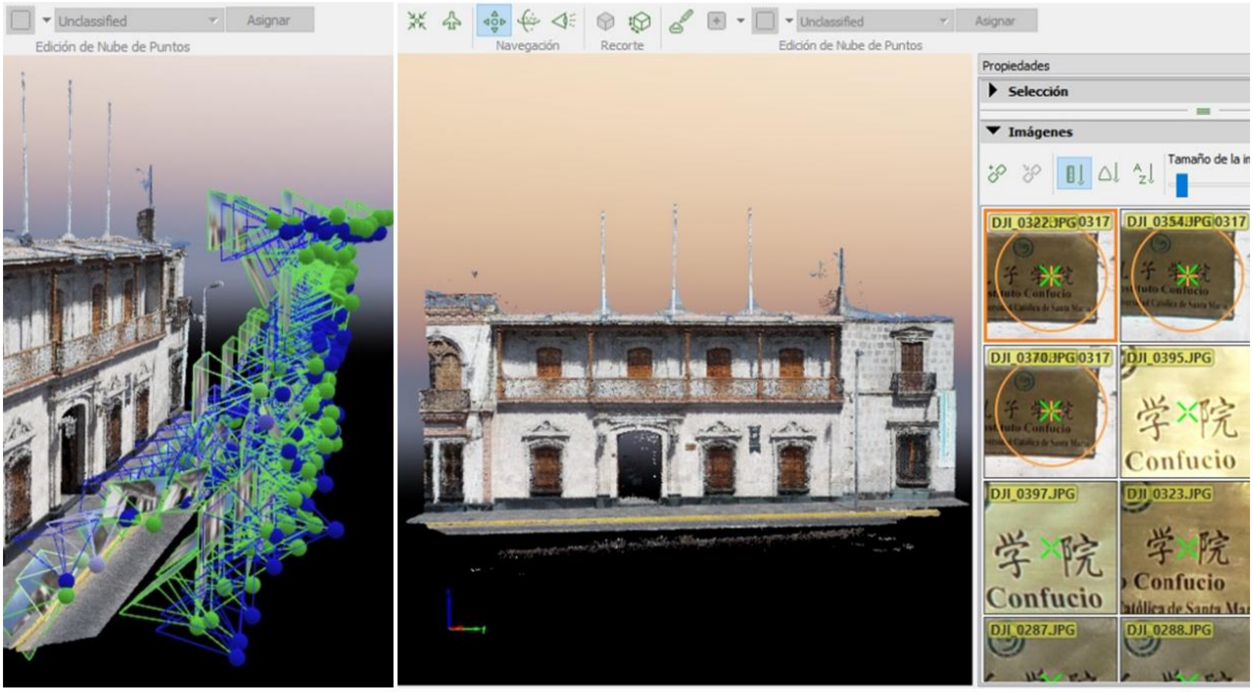

Figure 5. Image processing in Pix 4D.

9. Discussion

The methods used had different performances and qualities of the results. As for the façade, there were results were obtained by a combination of UAV imagery and Pix 4D software, as it was possible to obtain a point cloud of acceptable accuracy and consistency of materials, which can be clearly distinguished (Fig. 6b and 6c). Less accurate results were obtained in the photogrammetry method, which succeeded in showing the volumetry and general ornaments in the façade (Fig. 6a). However, none of these methods was accurate enough to collect fine detail form details, such as metal latticework and other ornaments, as well as cracks in the frontage. To get enough quality of these elements the use of a LIDAR scanner is advisable.

Figure 6. Results of point cloud format in photogrammetry (a) and aerophotogrammetry (b and c).

Also, in the case of Pix 4D, an OBJ file can also be created, which can be easily modified in software like 3D MAX and can be easily exported to AutoCAD, SketchUp, Vectorworks or other vectorial software (Fig. 7).

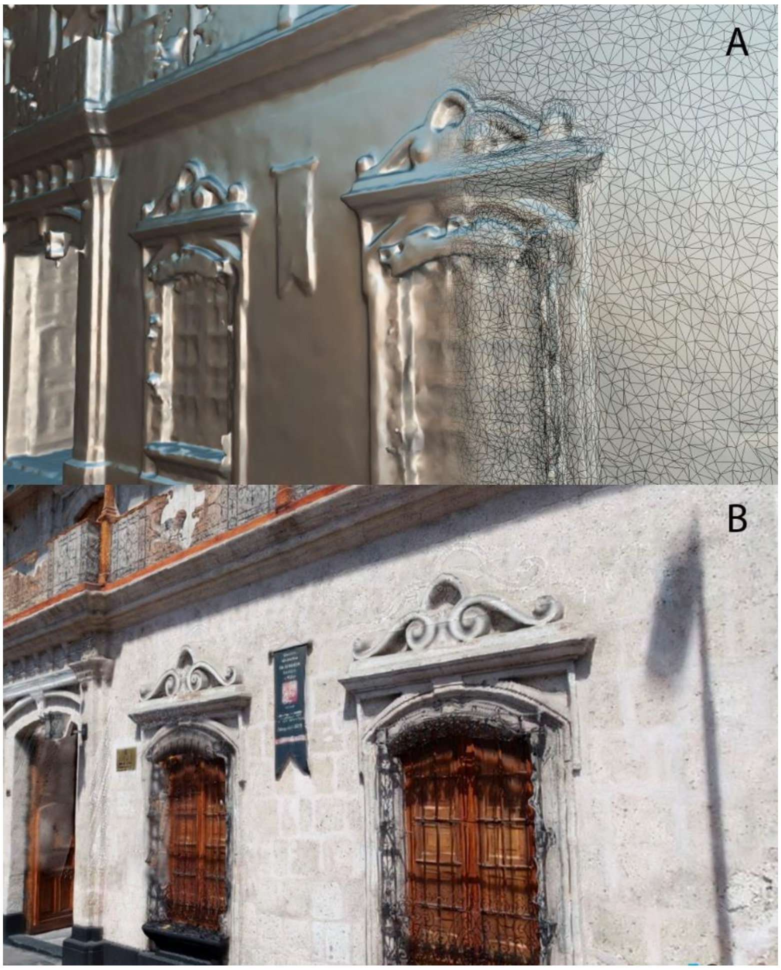

Figure 7. Results of digital format in aerophotogrammetry (a and b). Defects can be observed in the latticework of the handrail.

As for the inner patios, the best results were obtained by the use of the 360° camera, which proved to be both quicker and more accurate than the semiprofessional camera photography, as it reduces errors and blind points. Also, Matterport software can create 360° views than can easily be uploaded to VR glasses for educational purposes (Fig. 8).

Regarding the process of photogrammetry using a terrestrial camera, a series of problems or challenges occurred at all stages of the surveying process. More than 20% of the photographic record has been discarded due to problems of photographic origin, the poor lighting conditions of various spaces; errors of parameter adjustment of the camera in certain lighting conditions or due to obstacles presented at the time of the shot. Therefore, it is advisable to take some extra photographs to avoid various visits to the site.

It is highly recommended to previously plan the photographic record, the position of the photos, the configuration of the camera, carry additional batteries, etc. to minimize time loss at the time of photographing the building since differences in time between shots produce errors in the photometric calculation.

Also, it is important to carry out preliminary tests to adjust parameters in the software to avoid wasting time at the final processing of the photometric model.

Figure 8. Results of digital 3D model in a semiprofessional camera (a) and a 360° camera.

Also, in both methods, vectorial plans can be created in PDF reports, which in turn can be converted to CAD by means of OCR software for further editing and easier distribution.

Also, several problems occurred at all stages of the process; as it was inevitable to discard more than 20% of the total photographic record due to problems of photographic origin, lighting conditions of several spaces or obstacles that appeared at the time of surveying. It is highly recommended to establish a protocol prior to the surveying process which should include the position of the photos, the configuration of the camera, visual angles, etc. It is also to take the pictures in the shortest time possible, as the time difference between shots may be subjected to changes in the lighting conditions, which produces errors in the photometric calculation.

10. Further steps

Being this research a work in progress, the next steps will include elucidating ways to make a proper of these models to CAD, as the totality of agencies in charge of heritage management in Arequipa use this format in their daily work.

Also, from an educational perspective, a 3D reconstruction of past scenarios based in the final model and historical and archaeological research will be carried out, in order to have a better understanding of the evolution of this important colonial monument. These conservation techniques will be replicated in similar cases in Peru.

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