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USE OF UNMANNED AIRCRAFT (DRONES) FOR THE INSPECTION OF ARCHITECTURAL MONUMENTS AND ANCIENT CONSTRUCTIONS

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Abstract: The use of unmanned aircraft (RPAS), better known as drones, has been spreading over the last few years with multiple and very diverse applications, including inspections of architectural heritage elements, singular constructions, and old structures. or delicate. This article arises precisely from several routine inspections, carried out experimentally on various heritage elements, and from a detailed main inspection, undertaken on a medieval bridge: the Brandomil Bridge. With the completion of all of them and the information obtained, it will be possible to assess whether the aircraft can serve as a quality tool for carrying out the work that is currently carried out with qualified personnel, the transport and installation of cumbersome auxiliary means and a high economic and time investment, especially in the careful planning of the work. In the same way, there is a very special emphasis on safety and risk reduction: safety and risk reduction towards the monument to be inspected, and risk reduction for the safety and health of workers who currently carry out such tasks.
Keywords: Drones, Heritage, Roman Bridge, Inspection, Heritage Conservation.

INTRODUCTION

Structural inspection is, from the beginning, an essential operation in the field of conservation of any construction, having been applied particularly, and from the outset, to the structural field. In essence, it is based on checking, characterizing and monitoring the construction as a whole, as well as each of the different elements that make it up, and may be accompanied, depending on the type and scope of inspection that is carried out. acometa, of tests that allow to complement the diagnosis made by visual inspection.

The different types of inspection were collected in the different guides developed by the Ministry of Public Works of Spain for carrying out inspections of the road network passing works (VVAA, 2009; VVAA, 2012). Thus, a distinction is made between:

- Routine inspection. This is a basic inspection carried out by non-specialized personnel, generally personnel in charge of maintenance. The Guide (VVAA, 2009) indicates that they are carried out in all passage works equal to or greater than 1.00 m of light. Its objective is to keep track of the state of the structures, to detect apparent failures as soon as possible, which could cause significant conservation costs or, if they are not corrected in time, repair.

- Main inspection. This is a deeper inspection than the routine one, but it is still essentially visual. It must include an examination of all the elements of the crossing work that are visible. For this reason, in many cases it will require the use of auxiliary means that make such observation possible. The need to use these extraordinary means of access (Figure 1) subdivides the main inspections into two categories (VVAA, 2012):

    - General main inspection, which consists of a detailed visual observation of all the visible elements that make up the bridge without the need for extraordinary means of access: it is enough to use simple auxiliary elements.

Detailed main inspection, in which it is essential to use extraordinary means of access that guarantee the possibility of inspection of all visible parts

- Special inspection. This type of inspection, unlike the rest, does not have to be carried out systematically; It arises, as a general rule, as a consequence of the damage detected in a main inspection or, exceptionally, as a consequence of a unique situation. In these inspections, in addition to carrying out a visual examination, complementary tests and measurements are needed, with special techniques and equipment. This level of recognition always requires a plan prior to the inspection, detailing and assessing the aspects to be studied, as well as the techniques and means to be used.

The previous classification criteria has been extended to more areas than those of road structures (Official State Gazette, 2005; ADIF 2020 a; ADIF 2020 b), hence it has been decided to present it here as a starting point.

On the other hand, a few years ago the concept of an aircraft without a pilot on board or an unmanned aerial vehicle arose; These are aircraft that can be remotely controlled by the pilot or programmed and fully autonomous. The incorporation of certain accessories to this equipment, such as cameras for recording or capturing high-resolution images, and the development of increasingly precise and affordable microtechnology (Cuerno Rejado, 2015), opened the door long ago. to the possibility of incorporating drones to carry out this type of inspection.

In recent years, in the field of civil engineering, a multitude of advances have been made and a notable number of inspections framed in the previous classification have been carried out, using drones (Rodríguez Elizalde, 2022 a; Rodríguez Elizalde, 2022 b); The results have been very satisfactory, since in many cases a cheaper, faster and safer job has been achieved (Rodríguez Elizalde, 2022 a; Rodríguez Elizalde, 2022 c), hence the possible application of this tool to the field of heritage inspection (Figure 2).

OBJECTIVES

Based on the fact that the inspection of any construction is essential, as it allows obtaining the necessary data to know, at all times, its functional, resistant and aesthetic state, the main objective of this article is to verify the applicability of drones for the carrying out these inspections in the patrimonial area. The author's experience and the analysis of a detailed main inspection, carried out by him on an engineering monument of great relevance and significance, the Brandomil Bridge, will serve as a basis to verify compliance with the objective established herein.

MATERIALS AND METHODS

There have already been incursions and studies in various fields of application of the use of drones in the field of heritage conservation, especially highlighting the use of this equipment to carry out photogrammetric flights that allow for subsequent modeling and reconstructions (Domínguez Torrado, 2015; Rodríguez Elizalde, 2022 c).

There are many and very diverse types of drones that are currently available (Hernández Correas et al., 2019), so it is important to know in each case the most appropriate type of aircraft for each situation, and particularly for performance. which is analyzed here. Among all the classification criteria, the most interesting for this purpose is the one that attends to the form of support of the equipment in the air. This way, a distinction is made between fixed-wing drones and rotary-wing drones (Oñate de Mora, 2015). There is no doubt that the fixed-wing drone has great advantages that make it suitable for a multitude of applications, but its inability to perform a vertical takeoff and maintain a stable position in the air makes it unsuitable for the inspection of an old construction, unless that it is intended to take images of large surfaces, which is very rare.

For this reason, the type of drone used for the work considered here is usually a rotary-wing drone, and more specifically a

Figure 1: Inspection of the deck of a viaduct that crosses the Rías Bajas Highway (A – 52), near the municipality of A Gudiña, in the province of Ourense (photograph by the author).

Figure 2: Quadrocopter drone approaching for an inspection over the Ponte da Chanca, a railway viaduct located in the city of Lugo that celebrated its 150th anniversary on December 20, 2021 (photograph by the author).

multirotor (Figure 2): they are drones with multiple propellers (always pairs) that take off vertically and have, In addition, the ability to rotate on themselves, which makes them ideal for doing vertical work and maintaining a certain fixed position while suspended in the air, thus allowing accurate analysis.

To verify the validity of the drone for carrying out this type of inspection, the Brandomil Bridge was chosen as a sample, located at the following coordinates:

- 43º 00' 29.0" N.
- 8º 55' 17.9" W.

The Bridge is located in Galicia, in the municipality of Zas, in the province of A Coruña. Save the bed of the Xallas River. This bridge is especially representative because, although it does not currently support road traffic, it was part of the final stretch of the old Camino de Santiago, the one that connects Santiago and Fisterra (Casado, 1969). It did fulfill the mission of fully supporting the passage of carriages along the overlying track until eighty years ago: in the 1940s, a concrete bridge was built to relieve it a few meters upstream (Roseman, 1996). Pilgrims who had disembarked in the ports of Muxía and Fisterra, en route to Santiago de Compostela, traveled through Brandomil, and specifically over this bridge (Suárez, 2022). The width of the roadway overlying the Bridge is 2.75 meters.

The Bridge has four ashlar arches (Figure 3): three of them with the same span (8.20 meters), and the last one, at the southern end of the bridge, with a considerably smaller span (4.30 meters). The piles, with tamajares that go up to the crest (Figure 5), are very thick, around 3.00 meters. The two vaults on the right margin (Figure 3 and Figure 4) have a double thread. Both the vaults and the eardrums and parapets are made of ashlar masonry (Alcaide & López, 2013). Due to its characteristics, both constructive and aesthetic, the date of its construction is dated to the 17th century, although there is evidence of the existence of a previous bridge in this same place (Casado, 1969).

The existence of a fluvial current under the Bridge, such as the Zas River, its geometric dimensions and the inaccessibility of certain areas (the two central piers penetrate the river water), made the Brandomil Bridge a perfect structure to be able to verify the validity of the use of a drone for the inspection of this patrimonial construction. Apart from that, the consideration of the beauty, relevance and historical and patrimonial value of the Bridge would remain, which undoubtedly confer added value to the inspection carried out: its great interest at a historical and archaeological level, and also at an engineering and pathological level reaffirmed this idea.

As discussed in previous sections, for the inspection carried out on the Brandomil Bridge, a quadcopter drone was used (Figure 6 and Figure 7), which was able to approach all the visible areas of the Bridge, whether they were accessible or not.

In the previous images you can see the four-propeller drone used, analyzing in suspension the interior of the smaller vault of the Bridge (Figure 6) and approaching one of the larger vaults over the course of the river for recognition (Figure 7). The equipment incorporated a high-resolution camera with zoom and allowed the capture of the images that are collected later, which could constitute a complete photographic report with the most outstanding observations during the flight.

In addition, it must be taken into account that one of the hallmarks of this bridge is the use of the minor semicircular arch as a guideline for its vaults, as opposed to the common Roman use of the arch. Given the scant arrow of the smallest vault, access to its interior to analyze the state of the intrados was somewhat complicated (Figure 6), hence

Figure 3: General view of the elevation downstream of the Brandomil Bridge, in an image captured with the multi-rotor drone used in the inspection of this article (photograph by the author).

Figure 4: General view of one of the major arches of the Brandomil Bridge, in an image captured with the multi-rotor drone used in the inspection from the downstream side of the Bridge (photograph by the author).

Figure 5: General view of the upper part of one of the cutwaters of the Brandomil Bridge, in an image captured with the multi-rotor drone used in the inspection (photograph by the author).

Figure 6: Multi-rotor drone used in the inspection of the Brandomil Bridge, entering the interior of the vault of the minor arch for inspection from the upstream side of the Bridge (photograph by the author).

Figure 7: Multi-rotor drone used in the inspection of the Brandomil Bridge, approaching the upstream elevation of the Bridge, for the inspection of various constituent elements (photograph by the author).

Figure 8: General view of the downstream elevation of the Brandomil Bridge, in an image captured with the multi-rotor drone used in the inspection of this article (photograph by the author).

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the interest in introducing a drone. It is true that there are gallery points where access can be much more complicated than in this one, since here the width of the vault is 4.20 m and if necessary an operator could access it to carry out the pertinent inspection; but this experience serves to demonstrate that the drone can perfectly perform this function, without having to put the safety of any professional at risk and obtaining perfectly valid results and even better than those that could be obtained by an operator.

RESULTS AND DISCUSSION

In general terms, the Bridge presented an adequate state of conservation. The inspection allowed us to verify the existence of efflorescence, although in a very slight proportion: such lesions were observed in the intrados of some of the vaults and in the elevation of some basin or some abutment. Efflorescence is often concentrated around areas where there is a high concentration of moisture. As it is a river bridge located in the Galician region, it is evident that it is in a location where humidity is high.

The intrados of the vaults is, without a doubt, the most critical point from the pathological point of view and also the most difficult to access for manual inspection. As can be seen (Figure 8), all the elements that make up the vaults are made of granite, with ashlars and voussoirs laid dry, being the rounding of the vertices, characteristic of the alteration of the granite (García de Miguel, 2009), one of the the most notable aspects.

The granite constituting the monument presents, inside the vaults, certain deteriorations as a consequence of the synergy of actions of a diverse nature, fundamentally chemical and biological. Thus, the formation of various black crusts can be observed (Figure 8), presumably linked to the action of polluting agents (particularly sulfur compounds). Along with these crusts, there is an abundant presence of biocolonies (plants), which have grown rooting in the joints that are arranged between the ashlars, especially in the joints of angular points (Figure 9 and Figure 10), which enter into feedback with the phenomena of humidity, efflorescence and runoff water, as reflected in certain observed spots.

Also linked to humidity is the proliferation of small carbonation crusts, detected inside the vaults: in this case, they are crusts due, fundamentally, to the dissolution of calcium carbonate from the mortar placed between the joints of the ashlars. The dark marks of runoff water, observed in some points of the bridge, are linked to this process of development of black crusts.

In this sense, it must not be forgotten that the crusts and, to a much greater extent, the efflorescences are manifestations resulting from the crystallization of salts, which tend to agglutinate around points where there is a high concentration of humidity; This anomaly is triggered by crystallizing the soluble salts present in solution in the porous system of the factory (García de Miguel, 2009).

In principle, the damages previously collected are not damages of a structural nature, but damages related to the durability of the construction materials. When talking about damage that is related to the durability of the material that makes up an element, reference is being made to injuries that arise from the interaction of the deteriorated material with the environmental conditions imposed by the environment in which the element is installed. In other words, the durability of a material can be understood as its ability to resist the action of the environment, which includes all chemical, physical, biological attacks, or any other environmental process that tends to deteriorate it.

In other words, they are not injuries

that affect the integrity of the monument in the short term, but they can lead to more serious damage, such as alveolization or even sandblasting of the stone material, if they continue to develop. The particular detection of efflorescence, on the one hand, shows that a process of chemical degradation is taking place, although it is not very dangerous; and, on the other hand, it issues a warning that considerable internal mechanical stresses may be being generated, due to the crystallization processes of the salts.

This section is closed, repeating the presence of rooted vegetation in the joints between the ashlars (Figure 9 and Figure 10). Due to the humidity, and given the susceptibility of the granite to attack of a biological nature, the drone was also able to record films or mottles, resulting from the accumulation of plant microorganisms, moss-like or similar (Figure 9 and Figure 10).

However, and although none of the damage compromises the security of the monument, the drone allowed the location and diagnosis of such injuries, taking into account that many of them were not visible from the position of a passerby. In addition, the inspection with the unmanned aircraft made it possible to have graphic documents that, in subsequent inspections, will make it possible to assess the evolution of the damage and thus estimate the relevance of a possible restoration intervention.

CONCLUSIONS

The results of the inspection carried out show that the use of an adequate drone allows for a detailed and complete visual observation of all the visible, accessible and inaccessible elements that make up a monument of a certain entity. With this tool, it is not necessary to resort to extraordinary means of access, as they would have been if the multi-rotor aircraft were not available.

Therefore, in light of the experience gathered here, the following can be concluded:

1. The drone simplifies planning work, since it reduces the planning and acquisition of auxiliary means of access.

2. The drone simplifies field work, with a view to identifying and assessing deterioration of each of the constituent elements of the monument.

3. The above simplifications allow you to get jobs done faster.

4. The drone reduces a considerable part of the risks affecting the monument. The Brandomil Bridge preserves its primitive form which, like any construction, needs care for its adequate conservation. The drone has proven to be a very effective tool in this regard, not coming into contact with the monument at any time.

5. The drone reduces all kinds of risks to the safety of the workers who must collaborate in the inspections, given the danger inherent in the use of certain auxiliary means to access certain elements of the structure: with a drone, no worker has to, for example, exposing yourself to the risk of falling from a height.

6. The five previous points justify a considerable economic saving, which does not imply a decrease in the quality of the work.

With the data collected with the drone, as exemplified here, a complete technical report of the inspection carried out can be generated in the office, in addition to providing the pertinent information with a view to incorporating it into a management system and obtaining the indices. status, of each of the elements and of the construction as a whole, to assess whether some kind of urgent action is required or to verify, through a regular check of the injuries detected through

Figure 9: General view of the smaller arch of the Brandomil Bridge, seen from the upstream side, in an image captured with the multi-rotor drone used in the inspection, where the abundant presence of rooted vegetation can be observed in the multiple elements (photograph by the author).

Figure 10: General view of one of the major arches of the Brandomil Bridge, seen from the upstream side, in an image captured with the multi-rotor drone used in the inspection, where the abundant presence of rooted vegetation can be observed in the multiple elements (photograph by author).

periodic flights, the evolution of said injuries.

It goes without saying that the experience of the experimental inspection carried out for the elaboration of this article can be extrapolated to many other works of the same nature, which opens up an infinite range of opportunities for these small ingenuities that, without a doubt, have come to stay and to change the way you inspect singular elements.

FUTURE LINES OF RESEARCH

This article has focused exclusively on the use of drones in the field of inspection of heritage elements. The images, and even the videos, that are captured with the cameras incorporated into a drone can be used as visual documents for multiple other purposes that go beyond the inspection analyzed here.

The incorporation of other sensors, of a visual or thermal nature, can be used to locate invisible lesions or better understand the origin of visible lesions for which no explanation can initially be found. In this case, the scope of the special inspection would already be entered, in accordance with what was seen in the Introduction, using indirect tests that would not cause any deterioration to the monument under analysis (Figure 36).

The drone can also be of great help in the geometric reconstruction of an element from the photographs obtained in captures made in photogrammetric flights. For this, extensive knowledge is required in terms of data collection that is beyond the scope and objective of this article, since it is necessary to obtain measurable data (whether two-dimensional or three-dimensional) and the subsequent processing of the data collected for the modeling and reconstruction.

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