Journal of Information Systems Engineering and Management
2025, 10(31s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Use of RPAS (Drones) for the Inspection of Century-Old Metal Structures: Example of Application on the Requejo Bridge

Rodríguez Elizalde, Rubén (*)
(*) PhD in Architecture and Heritage. Professor at the Open University of Catalonia (UOC), Barcelona (Spain), and at the University Business Centre (center attached to the Rey Juan Carlos University), Madrid (Spain).
Corresponding author: elizalde@aparejadoresmadrid.org
ORCID: http://orcid.org/0000-0003-3314-5129

ARTICLE INFO

Received: 29 Dec 2024
Revised: 12 Feb 2025
Accepted: 27 Feb 2025

ABSTRACT

This article presents a technical analysis of the Requejo Bridge, an outstanding example of metallic engineering spanning the Duero River in Zamora, Spain.

Constructed between the late 19th and early 20th centuries, the bridge was designed to connect the regions of Sayago and Aliste, facilitating communication in an area defined by its challenging topography. The structure masterfully combines functionality and aesthetics, featuring a central metallic arch that supports the deck. Since its inauguration in 1914, it has been celebrated as a symbol of progress and Spanish industrial heritage.

The study focuses on inspections conducted to assess the current state of the bridge, with an emphasis on the use of drones (RPAS). These devices enabled a detailed and comprehensive visual analysis of the entire structure, overcoming the accessibility challenges inherent in historical constructions. The inspections revealed corrosion-related damage, particularly in hard-to-reach areas, as well as aging-related deterioration of the previously applied anti-corrosion protection system. While these issues did not immediately compromise the bridge's functionality, they underscored the need for mid-term interventions to ensure its long-term preservation.

This work evaluates the effectiveness of drones as a tool for inspecting large heritage structures, highlighting advantages such as reduced risks to workers, lower costs and shorter execution times, and the ability to gather detailed data for use in management systems and condition monitoring.

Keywords: Requejo Bridge, drones, visual inspection, corrosion, industrial heritage, civil engineering, metallic structure conservation.

1 INTRODUCTION

The Requejo Bridge, also known as the Puente Pino, is an impressive engineering work that crosses the Douro River. The bridge is located in the province of Zamora, Spain (Fig. 1), and the coordinates that describe its exact position are as follows:

- UTM coordinates (Zone 29):

o X (UTM): 739,444.16.

o Y (UTM): 4,604,980.52.

- Geographic coordinates:

o 41°33'38.42"N.

o 6°07'42.92"W.

It is a metal arch bridge, with a remarkably innovative structure for the time in which it was built (Fig. 2). Its design combines functionality and aesthetics (Pérez – Fadón Martínez et al., 1995), with an imposing central arch, which supports the weight of the deck by means of metal uprights.

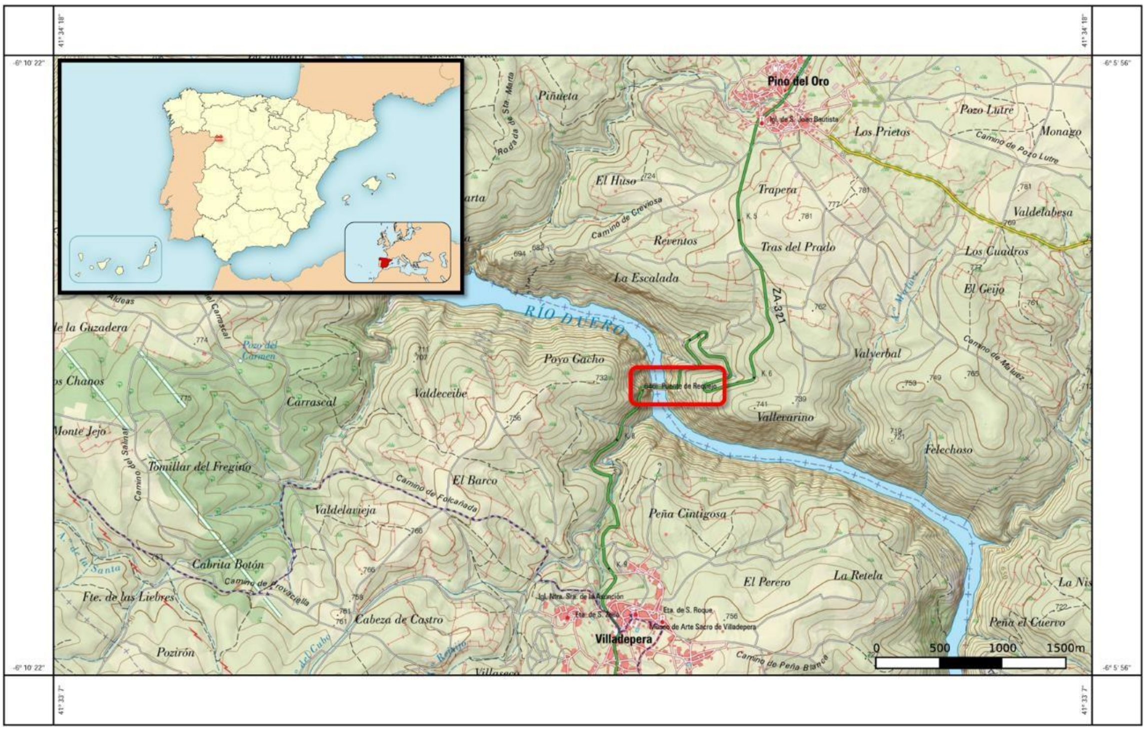

Fig. 1. Location of the Requejo Bridge, on the National Topographic Map published by the Spanish National Geographic Institute.

Fig. 2. General view of the Requejo Bridge, raised downstream (photograph by the author).

The total length of the Bridge reaches 190 meters, rising more than 90 meters above the bed of the Douro.

The Bridge was designed at the end of the 19th century and built at the beginning of the 20th century. Its mission was to facilitate communications between the Zamoran regions of Aliste and Sayago, and more specifically between the municipalities of Fonfría (located in Aliste and which, in 1897, registered 1,347 inhabitants (INE, 2024 b)) and Fermoselle (located in Sayago and which, in 1897, registered 4,569 inhabitants (INE, 2024 a)).

The Bridge was born to cross the banks of the Duero, in an area characterised by the existence of deep canyons and steep landscapes (Fig. 2 and Fig. 3). This, together with its typology and unique beauty, has made the Bridge a visual landmark in the landscape in which it is framed, being today, in addition, incredibly integrated into the Arribes del Duero, an area protected for its high natural and landscape value and of great tourist interest (Hortelano Mínguez, 2015).

Fig. 3. Location of the Requejo Bridge, on aerial orthophotography prepared by the Spanish National Geographic Institute.

Before its construction, the only direct connection between the two towns surrounding the Bridge, Pino del Oro (in the region of Aliste) to the north and Villadepera (in the region of Sayago) to the south (Fig. 1), was through the use of a barge, which crossed the riverbed moved by ropes (Martín Benito, 2015).

The oldest antecedents related to the planning of this Bridge date back to the mid-nineteenth century. Its first promoter was the engineer and future President of the Council of Ministers Práxedes Mateo Sagasta, who, after being elected for the first time as a deputy to the Cortes for the constituency of Zamora expressed his intention to support this new project (Chías Navarro and Abad Balboa, 2008). Years later, Eduardo López Navarro evaluated a different location, approximately two kilometers downstream from the definitive and current location. In this proposal, the grade was considerably lower and a construction solution based on two sections of cast iron was proposed (Ribera Dutaste, 1897; Fernández García, 1914).

Due to the relevance that this Bridge had for the region, all the candidates for the Provincial Council to Cortes promised to promote its construction. However, it was Federico Requejo Avedillo, a native of Sayago, who, during his tenure in the General Directorate of Public Works (Millan García, 2000), managed to study the feasibility of building a road that would connect Fonfría with the road that linked Salamanca and Fermoselle, including the Bridge in this project (Fernández García, 1914). For this reason, the Puente Pino is also known as Puente de Requejo.

The project finally approved, which was drawn up by the engineer José Eugenio Ribera in 1897, faced serious difficulties during its subsequent execution. Initially, no construction company took part in the first auctions, due to the complexity of the assembly (Ribera Dutaste, 1897). In fact, the Asturian company Duro Felguera took over the execution of the work, but, when it came to the assembly of the Bridge, complications forced it to transfer the work to another company, called Montajes. The latter company was the one that began the corresponding works; however, he also had to suspend and abandon them due to technical difficulties. The work finally returned to the hands of Duro Felguera, who, under the direction of the Galician engineer Robustiano Fernández and with the support of local labor, managed to complete the execution of the project (Hortelano Mínguez, 2015) without any incidents or accidents being recorded during the assembly of the arch (Fernández García, 1914). The components of the Bridge were manufactured at the company's main plant, located in La Felguera, in the Principality of Asturias.

The project prepared by José Eugenio Ribera (Ribera Dutaste, 1897; Ribera Dutaste, 1914) proposed the construction of a metal bridge to cross the Duero which, in addition to being the first steel arch bridge in Spain, when it was inaugurated on September 15, 1914, became the bridge with the largest span (120 meters between arch supports) and with the highest height over the riverbed (90 meters) in Spain (Fig. 4). With this work, Jose Eugenio Ribera questioned Eiffel's designs, when he managed to execute a bridge with a lowered arch (Fernández García, 1914), which was lighter than those designed by the French engineer (Fig. 5).

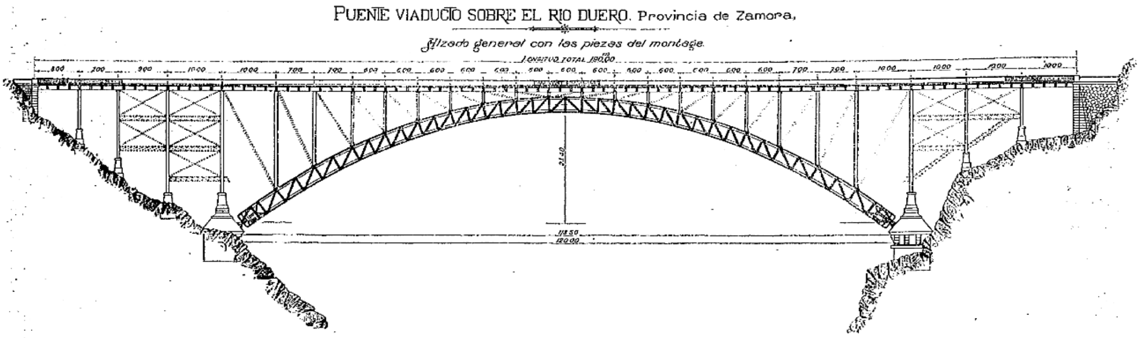

Fig. 4. Elevation of the Requejo Bridge, corresponding to the project developed by the engineer José Eugenio Ribera Dutaste (Ribera Dutaste, 1914).

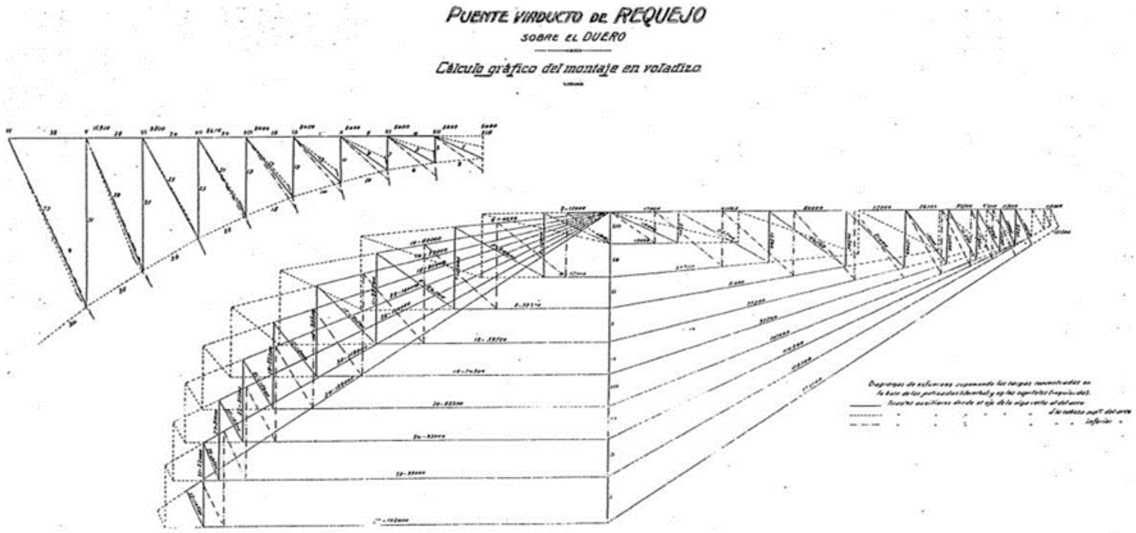

Fig. 5. Graphic calculation of the cantilever assembly of the Requejo Bridge (Fernández García, 1914).

The Bridge houses the ZA-321 regional road, which allows vehicles to cross the Duero. The carriageway of this road is two-way traffic, with only one lane, with no alternative passage in each direction regulated by traffic lights: there is only one priority sign (R-6 sign) in the opposite direction at the access from the east abutment (side of the Pino del Oro municipality, right bank of the Duero River). At the access to the structure from the west abutment (side of the municipality of Villadepera, left bank of the Duero), there is the oncoming priority sign (sign R-5).

The tonnage of vehicles is limited to 15 tonnes, through multiple signs, and speed limit signs at 30 km/h are also available at both accesses to the Bridge (R-301 signs)

The accesses consist of sidewalks that allow pedestrian traffic, which thanks to them can circulate along both sides of the Bridge.

The construction is located in the center of the Douro River basin. This basin is filled by Cambrian and Precambrian materials (IGME, 1982), with the dominant lithology being schists and microglandular gneisses, with quartzite intercalations (Fig. 6). Some of the previous resources (Fig. 2 and Fig. 3) have made it possible to observe the framing of the Bridge within the Duero canyon.

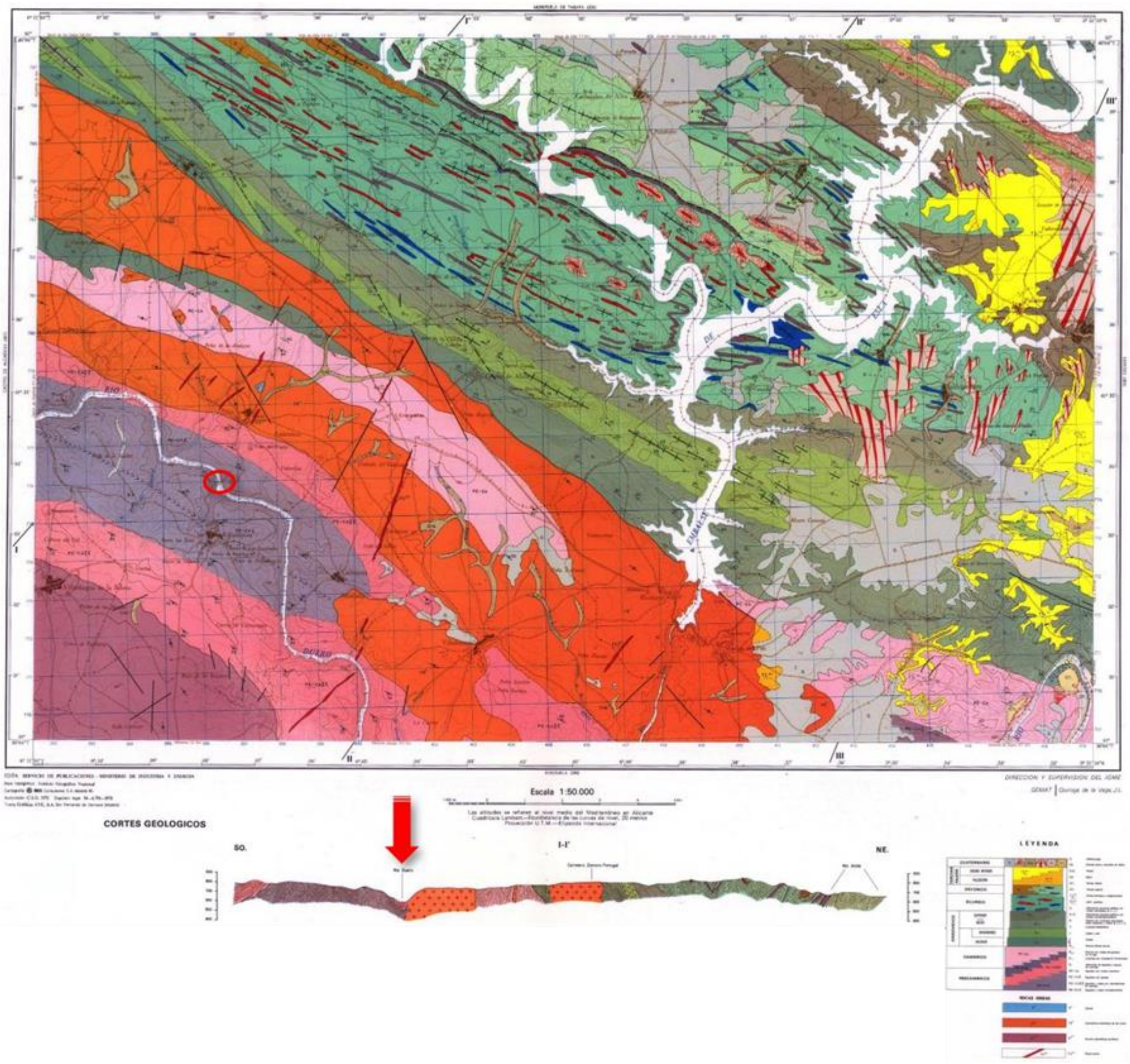

Fig. 6. Legend of geological framework, geological map and section, where the location of the Bridge is marked (Source: Geological Sheet 343 1:50.000, Geological Institute, IGME (1982)).

From the geotechnical point of view, being in the presence of a plutonic outcrop composed of gneissic rocks, the area offers a set of magmatic, migmatitic and gneissic rocks, whose lithological composition is considered favorable. These materials have low permeability, with limited internal drainage due to fissures and active surface runoff.

This is reflected in a high carrying capacity and absence of settlements, which which makes the conditions for construction generally adequate. In addition, it is in an area where the seismic risk is very low (IGME, 1976).

In order to make an orderly description of the elements that make up the construction, in this article the abutment of the lowest kilometer point (in correlation with the kilometer points of the ZA-321 Road that supports the Bridge) has been established as the first abutment, which is closest to the town of Pino de Oro. on the right bank of the Duero River (east abutment; left abutment of Fig. 2 and Fig. 4). The right side and the left side are defined according to the direction of progress of these kilometre points. The subcomponents that are referred to from now on will also be numbered from left to right (Fig. 2 and Fig. 4), also according to the direction of progress of the kilometre points (running along the bridge from east to west: from Pino del Oro to Villadepera).

As already mentioned above, there is a metal arch bridge of the upper deck type, which has a length between abutments of 190 m (Fig. 4), formed by three clearly differentiated sections (Fig. 2): a central section, represented by the metal lattice arch and two access sections to said central section, formed by metal palisades that support the metal deck (Fig. 7).

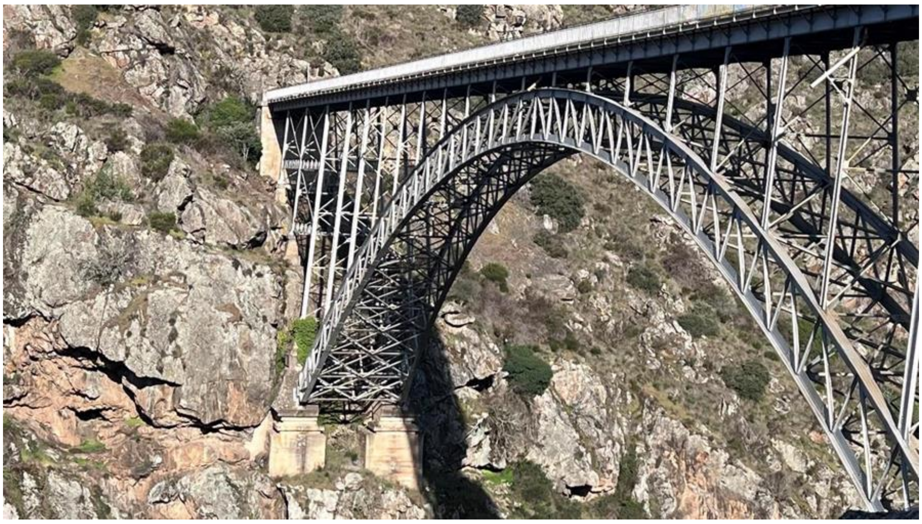

Fig. 7. Partial view of the Bridge, from the south side (upstream side), where you can see the constitutive arch and, in the background, the second abutment, with its corresponding support palisades (photograph by the author, taken with a drone).

The deck, in the central section, rests directly on the arch through metal uprights of variable height from 18.50 m at ends to 0.95 m in the centre of the arch (Fig. 4 and Fig. 7).

The arch rests on four concrete foundations (Fig. 8), the supports being articulated with anchor bar.

Fig. 8. Arch supports on direct concrete foundations in the area of the second abutment (photograph by the author, taken with a drone).

The uprights are supported on the arch by means of platforms anchored with bolts to the main beams of the arch (Fig. 9). This arch has a span of 120 m between supports, being a lowered arch with an arrow of 23.42 m (Fig. 4) and, as already noted, having a height above the sheet of water of the River of 90 m. The arch varies its section from the supports, where it has a maximum width of 8.30 m, to the centre of the span, where the maximum width is reduced to 4.50 m, also having a slope of 1:12 in both elevations of the arch.

In the access sections, the deck rests directly on metal palisades and these, in turn, rest on concrete foundation elements (Fig. 2, Fig. 4 and Fig. 7). The palisades, like the uprights, rest on the concrete foundations by means of platforms, anchored with four bars of 25 mm in diameter.

Fig. 9. Examples of upright supports on the arch, through platforms anchored with bolts, on the upstream side (photograph by the author, taken with drone).

The elements that make up the substructure (uprights, palisades, bracing and arch) are formed by the union of "L" profiles of different dimensions and steel sheets, perfectly riveted.

The deck, whose total width is 6.70 m, is made up of a domed metal slab (Fig. 10), on which rests a layer of reinforced concrete 0.14 m thick, which gives shape to the alternating one-way circulation platform, due to its width of 4.30 m. This platform was built in 2013, thus reducing its weight by replacing the existing one at that time, made up of 0.40 m of macadam and a layer of agglomerate (Llombart Jaques and Rodríguez Bragado, 2014).

The deck rests on concrete abutments, by means of four metal supports formed by three rollers each.

The deck is completed with two overhangs, 1.00 wide, formed by metal sheets that make up the sidewalks, supported on metal corbels. The section is finished with metal railings on both elevations of the deck.

The deck has a horizontal slope, with a 2% transverse slope for the evacuation of water. The road has metal ditches for the collection of water in both elevations of the road.

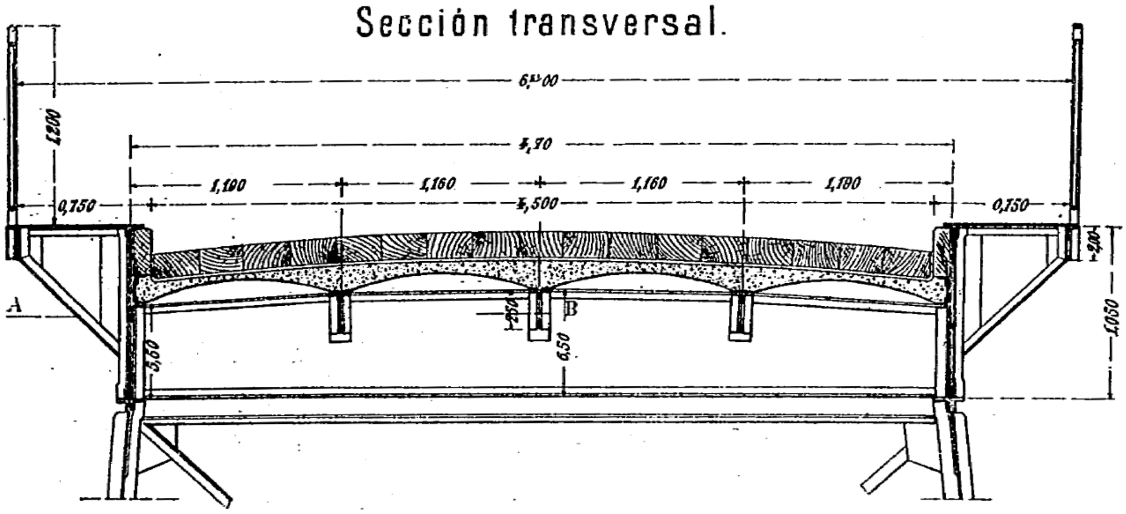

Fig. 10. Cross section of the Requejo Bridge, corresponding to the project developed by the engineer Jose Eugenio Ribera Dutaste (Ribera Dutaste, 1914).

At the ends of the deck, there are reinforced elastomer expansion joints and four manholes that give access to the deck supports on the abutments. Both the joints and the manholes are improvements made during the actions carried out during 2013 (Llombart Jaques & Rodríguez Bragado, 2014).

Its value and recognition is such that it is considered an Industrial Asset of Spain and included in the list of the 100 elements of Spanish industrial heritage (VVAA, 2011). It undoubtedly represents a historical work of notable heritage value that deserves to be maintained.

2 OBJECTIVES

According to what has been seen, the Requejo Bridge, with its considerable height of more than 90 meters above the bed of the Duero River and its design that makes it difficult to access critical areas of the structure, was shown to be an ideal and very interesting case to evaluate the effectiveness of drones for the inspection of metal heritage structures. In addition to the technical challenges, we have already seen that the Bridge stands out for its historical, heritage and aesthetic value, which undoubtedly adds a significant component to the interest of the inspection carried out.

Thus, the objective of this article is to investigate and validate the use of a drone as an advanced tool for carrying out detailed visual inspections of metal structures of heritage value, using the Requejo Bridge as a sample. If its applicability is confirmed, the way in which inspections of complex constructions, improving safety, reducing costs and optimising times.

From the data collected, it will be possible to identify solutions that are not only reactive (repair of existing damage) but also preventive, which extend the useful life of the Bridge while respecting its historical value and functionality. This would culminate the above, as these advanced microtechnological tools could be applied to optimize studies and maintenance.

This particular case is presented as a pilot test that could be applied to other similar structures. The research seeks to extrapolate learnings and methodologies to a broader context, favoring the application of technologies such as drones in future inspections.

Although the technical approach predominates, we do not want to lose sight of the historical and aesthetic importance of the Bridge. It is hoped that this article can also serve to raise awareness of the need to preserve such assets, integrating them into sustainable cultural and tourism development strategies.

3 METHODOLOGY

Structural inspection is a fundamental activity in the conservation of any civil construction. Traditionally, this task has focused on the structural field since its inception. It consists of evaluating, characterizing and monitoring both the construction as a whole and the different elements that compose it. In some cases, this process can be complemented with additional tests that reinforce the diagnosis obtained through visual inspection, depending on the type and scope of the analysis performed.

Recently, the concept of unmanned aircraft or unmanned aerial vehicle, better known as a drone, has been gaining popularity (Cuerno Rejado, 2015). These aircraft, remotely controlled or programmed to operate autonomously, have proven to be versatile tools in various fields (Li and Liu, 2019). Its usefulness has been enhanced by the integration of advanced accessories, such as high-resolution cameras, and by advances in microtechnology, which is increasingly accessible and accurate. These innovations have allowed the incorporation of drones in structural inspection tasks.

In recent years, the use of drones in this type of inspection has made notable progress, with very satisfactory results (Rodríguez Elizalde, 2022). This approach has made it possible to carry out work more economically, quickly, and safely (Seo et al., 2020). For this reason, the use of drones as a viable option for the inspection of structures such as the Requejo Bridge.

Currently, there is a wide variety of drones available, and it is essential to select the most appropriate model according to the characteristics of each inspection (Oñate de Mora, 2015). One of the most relevant criteria for this selection is the method of lifting the equipment in the air, which makes it possible to differentiate between fixed-wing and rotary-wing drones. Although fixed-wing drones are ideal for certain applications, their inability to take off vertically and stay static in the air makes them unsuitable for inspections of older buildings (Elijah et al., 2021). For this reason, the most commonly used drones in this type of task are rotary-wing drones, particularly multirotors. These equipments, equipped with multiple propellers, can take off vertically, stay suspended in the air and rotate on their own axis, qualities that make them perfect for vertical inspections and detailed analyses (Nguyen et al., 2024).

The equipment used to carry out the inspections was a Parrot drone, Anafi model. This device is controlled by a remote console (also Parrot) to which a mobile phone or tablet is attached. For a higher quality of vision, an iPad Pro was used this time.

As noted above, the significant river current of the Duero River together with the geometric characteristics of the Requejo Bridge, which stand out especially for its remarkable height above the riverbed and for the inaccessibility of many of its pathologically delicate areas, were specific conditions that made Requejo an optimal case study to validate the effectiveness of the use of multirotor drones equipped with high-resolution cameras in inspection of metal structures of heritage value. In addition, the historical relevance, heritage interest and remarkable aesthetic value of the Bridge provide a unique context that enriches the results and the transcendence of the analysis carried out.

The starting point of this research was a visual inspection without the use of any type of auxiliary means. Obviously, given the characteristics of the Bridge, this inspection was insufficient. Thus, in order to complement this inspection and in an effort to accurately determine the existing damage to the structure, two drone flight inspections were carried out throughout the structure:

1. On April 7, 2023, a drone flight was carried out in which the two lateral sections were analyzed in detail, focusing especially on the palisades and foundation cubes; and

2. On April 30, 2023, a new drone flight was carried out, in which the central section was analyzed in detail, reviewing the arch and all its uprights, as well as the platform and deck.

On both days, the flight was carried out through both elevations (upstream and downstream of the Bridge), carrying out detailed flights through palisades, arches and overhangs, in order to be able to observe practically the entire structure, being also able to fly under the deck and the overhangs, despite the lack of access between the elements of the structure.

Fig. 11. Multirotor drone, approaching the Requejo Bridge to reconnoiter the palisades of the second abutment, from the upstream side (photograph by the author).

4 RESULTS

Based on the inspections carried out using a drone, it has been possible to identify a series of damages, all of them of a durable nature or caused by vandalism. Some of these injuries are repeated in a generalized way, throughout the construction, and others are much more localized, and are present in a much more punctual way.

Every inspection begins with the analysis of the foundation. In this case, it is recalled that, of the two drone flight operations that were carried out, the first focused on the analysis of the concrete cubes and the palisades on the sides, as well as on the abutments.

It has already been observed (Fig. 8) that, despite their centenary age, concrete foundation elements generally presented a acceptable state of conservation, with some slight deterioration related to the durability of the material and especially to the runoff water. The action of runoff water was also the main injury observed on the abutment walls, where marks linked to dampness caused by the continuous process of surface runoff as it slipped down the wall face were discovered (Fig. 12).

The articulated supports of the arch were in an excellent state of preservation, both the joints and the anchors. On the other hand, the roller supports of the board presented corrosion in the support plates, but the rollers did not show any notable deterioration, except for some slight corrosion in the body of some of them.

Fig. 12. Face of the second abutment, with traces of runoff water (photograph by the author, taken with a drone).

In some of the support cubes of the palisades, the presence of vegetation and organic matter, mainly moss, was located, being especially relevant in the sixth palisade, close to the second abutment (Fig. 13). The presence of vegetation on the concrete elements always denotes maintenance that can be improved. The deterioration of concrete caused by plants is still a chemical attack induced by living organisms. In the case of superior plants, this effect combines a mechanical and chemical action, since the roots generate pressure on the joints or cracks where the plant roots and, at the same time, retain moisture, which intensifies the damage.

The palisades showed, in a generalized way, the deterioration of the protection system against corrosion. In this sense, it was found that the damage was aggravated in the palisades at the ends: in the first palisade, on the downstream side, and in the seventh palisade, also on the downstream side (Fig. 14).

In addition, at the ends of the palisades, punctual corrosion of the components could be observed, which is justified by the fact that they are areas susceptible to accumulating moisture.

Fig. 13. Presence of organic matter and vegetation in the concrete support die of palisade 6, downstream side (photograph by the author, taken with a drone).

Fig. 14. Corrosion in palisade number 7, the closest to the second abutment, downstream side (photograph by the author, taken with a drone).

It was also possible to observe the presence of slight deformations in the L-profiles linked to interstitial corrosion, which is caused by the penetration of moisture between the profiles, which generates the deformation of the parts as their volume increases due to corrosion.

In the case of the last palisade, the seventh palisade, the drone made it possible to discover the loss of the head in one of the anchor bars, in the downstream support (Fig. 15). This loss seemed to be also linked to the corrosion existing in the bar, which must have finally caused it to break.

Fig. 15. Loss of one of the anchor heads in palisade 7, downstream side (photograph by author, taken with drone).

The analysis of the ends concluded with the detection of localized corrosion in some of the braces, this being more pronounced in the area of the second abutment (Fig. 16). Undoubtedly, this deterioration is a consequence of the combined action of oxygen and humidity in the environment, as the metal elements lack an adequate surface treatment for protection.

Fig. 16. Corrosion located in one of the braces of the palisade at the west end of the Bridge, upstream side (photograph by the author, taken with drone).

Continuing with the inspection, the second flight focused on the location of damage to the arch (Fig. 17) and the deck.

Fig. 17. Bottom view of the arch, from the downstream side (photograph by the author, taken with a drone).

During the inspection, it was found that the arch only showed deterioration due to the aging of the anti-corrosion protection system (Fig. 18), showing dots with rust patinas on the upper part of the head of the side beams that make up the arch, as well as point rust in areas where the pieces are joined (Fig. 19).

It was also possible to observe patinas produced by the discharge of water and other liquids through the drainage pipes, which at the time of the visit were not long enough to facilitate the discharge away from the arch (a tube in the center of the arch can be seen in Fig. 7 and in Fig.

17).

Fig. 18. General condition of the arch, in a section between support uprights (photograph by the author, taken with a drone).

Fig. 19. Detail of a section of the arch, with spot corrosion located in the joint areas (photograph by the author, taken with a drone).

On the other hand, the uprights on the arch did show deterioration of the protection system against corrosion due to ageing in a generalised way. So much so, that corrosion points could be observed between elements that made up the upright, such as the sheets and L-profiles (Fig. 20).

Fig. 20. Detail of corrosion in one of the uprights above the arch (photograph by the author, taken with a drone).

Crowning the arch was the deck, which also shows localized corrosion at extended points along its entire length and width (Fig. 21).

A more detailed view shows that the corrosive action is especially located in the joints between the beams and the slab and transverse beams, as well as in the joints of the crosses of San Andrés of the horizontal bracing (Fig. 22).

It is worth noting the corrosion of the existing transverse beams at the ends of the deck, on the abutments, which present high corrosion in the elevation closest to the guard wall of the abutments (Fig. 12 and Fig.

14).

As a culmination of the analysis of the deck, the cantilevers formed by metal sheets that make up the sidewalks, and which were supported by metal corbels, were analyzed. As expected, the impost and all the other elements were not immune to the corrosive action (Fig. 23): in all of them there were traces of corrosion and traces of dyed runoff water.

Fig. 21. View from the underside of a section of the deck, where a multitude of elements with symptoms of localized corrosion can be seen (photograph by the author, taken with a drone).

Fig. 22. Detailed view of a section of the deck, where localized corrosion of several elements can be observed (photograph by the author, taken with a drone).

Fig. 23. View of the impost and the lower part of the perimeter protection railing (photograph by the author, taken with a drone).

On the platform, the existence of corrosion on the railings and on the sidewalks could be observed (Fig. 24), as well as the localized deformation of the handrail of both railings, caused by the loss or theft of the cylindrical stiffeners, and occasionally to the loss of union of the crown cap.

Finally, a slight deterioration of the joints was also observed on the platform due to their ageing, as well as the corrosion of the existing metal beds on the four access sidewalks to the structure (Fig. 24).

Fig. 24. View of the overlying road platform, in image taken from the second abutment (photograph by the author).

5 CONCLUSIONS

The flight of a drone on two different days made it possible to visualize all the units of the Bridge in sufficient detail to determine the existence of injuries and their extent. Thanks to the quality of the camera's zoom, it was possible to observe with sufficient quality and detail points of the structure susceptible to deterioration due to corrosion, which allowed the condition of the structure to be analyzed in detail.

It has already been mentioned that in 2013 an action was carried out on the structure, aimed at repairing the main beams of the deck and replacing the existing wearing layer with a new, lighter slab.

However, no repainting action was carried out: since 1991 the complete repainting of the structure had not been carried out. Then, a three-layer protection was applied (Llombart Jaques & Rodríguez Bragado, 2014).

Taking into account this background, it can be considered that the state of conservation of the structure is adequate and that it does not show serious deterioration or that, in the short term, affect the current functionality of the construction.

The Bridge presents a state of generalized deterioration throughout the anti-corrosion protection system caused by its aging, presenting localized points of corrosion that correspond to points of accumulation of moisture, such as the hidden faces of the crossbars on abutments, support areas of the palisades on their foundation supports, joints between beams and crossbars or metal slab of the panel; or also in the palisades, in the areas where the joint between L-shaped profiles and sheets are joint, where the existence of moisture in the internal area has led to the appearance of interstitial corrosion, which causes the deformation of the profiles due to the expansion of this corrosion.

In fact, some of the corrosion observed may have its origin in the leaks suffered from the deck before its repair and replacement in 2013, so it could be that these did not occur again.

Another additional damage, as a result of the existence of corrosion, is the loss of the head of one of the four anchor bars of the last palisade at its downstream end.

However, it should be noted that, although the presence of corrosion is localized, corrosion has not reached more than 4% of the total surface of the Bridge. This detail deserves to be highlighted, because the existing anti-corrosion protection system in the structure was applied in 1991, more than thirty years ago. This fact is noted because protective treatments of metal elements, based on paints, do not usually have a useful life of more than 30 years. Therefore, the inspection has shown that it is the right time to proceed with this renewal.

The damage observed does not jeopardize the current functionality of the structure, but due to the aging of the existing corrosion protection system and the localized existence of corrosion that has already caused the loss of section and breakage of some components, the renewal of the corrosion protection system is considered appropriate and necessary. repairing and sealing those points where there is a loss of section, and renewing the anchor bar of the last palisade.

Therefore, the structure presents in a generalized way, but occasionally localized, problems of a durable nature that do not put its structural safety at risk, under the traffic limitations that it currently presents (maximum tonnage limit of 15 tons and speed of 30 Km/h).

Based on what has been observed, it is considered appropriate to provide the structure with a new protection system that provides corrosion protection for at least another 25 years, after punctual repair of the defects and/or deterioration observed, paying special attention and detail to the cleaning and adaptation of those areas with corrosion and providing the new protection system with an adequate support base to prevent its loss or failure before its useful life. In other words, preventive actions are proposed, on the one hand, in order to prevent the advance of corrosion and the consequent deterioration of the metal elements; and, on the other hand, palliative actions, surface repair of some metal elements, such as the installation of a new anchor bar in palisade 7 or the replacement of stiffeners in railings.

In any case, the results of the inspection demonstrate that the use of drones is a highly effective tool to carry out a detailed and complete visual observation of the visible, accessible and inaccessible elements of large-scale civilian metal structures. In the case of the Requejo Bridge, the use of drones eliminated the need to use complex and expensive means of access, which would have been indispensable without this technology. Based on the experience gathered, the following conclusions can be drawn:

1. The use of drones facilitates planning by reducing the need for auxiliary equipment for access.

2. The use of drones simplifies field tasks by identifying and assessing damage to structure components more efficiently.

3. The use of drones allows work to be carried out more quickly thanks to the previous simplifications.

4. The use of drones significantly minimizes the risks of impact on the monument during inspection.

5. The use of drones results in the safety of workers by avoiding exposure to risks associated with access to dangerous areas, such as falls from height. In fact, as an anecdote, it can be said that in one of the two inspections carried out, one of the drones was lost as a result of a fall: this justifies the above. It is always better to lose a drone than not to lose the life of an operator.

6. The above benefits contribute to considerable economic savings without compromising the quality of the work carried out.

With the data collected by drones, it is possible to prepare detailed technical reports and generate useful information for integration into management systems and monitoring of the conditions of the structure. This makes it possible to identify urgent intervention needs or to regularly monitor the condition of the inspected elements through recurrent flights. In addition, the experience gained in this inspection can be applied to similar work, opening up new possibilities for this technology in the field of conservation and maintenance of structures.

This study has focused exclusively on the use of drones for the inspection of a large metal element of high heritage value. Images and videos captured with drone cameras can meet Multiple purposes beyond structural analysis, serving as valuable visual documentation.

The integration of additional sensors, such as thermal cameras, could expand the scope of these inspections by detecting non-visible damage or more accurately analyzing the source of superficial injuries. On this occasion, weather conditions did not allow thermographic inspections to be carried out (Rodríguez Elizalde, 2022; Rodríguez Elizalde, 2023), but its future inclusion could significantly enrich the results.

Finally, drones are also useful for reconstructing the geometry of elements through photogrammetric flights, generating two- or three-dimensional data that, after proper processing, allow the inspected structures to be modelled and analysed in detail. Although this aspect exceeds the objectives of this article, it represents another promising application of this innovative technology.

REFERENCES

[1] Chías Navarro, Pilar; Abad Balboa, Tomás (2008). The construction of the territory: Roads and bridges in Castilla y León. *History of Public Works in Castilla y León: Engineering, Territory and Heritage*, pp. 299-414. Available online at: https://oa.upm.es/2848/ (last accessed December 1, 2024).

[2] Cuerno Rejado, Cristina (2015). Origin and Development of Remote Control Piloted Aircraft Systems. In *Drones and their applications to Civil Engineering*. Directorate-General for Industry and Energy of the Community of Madrid (Eds). Pages 15 – 32. Available online at: https://www.fenercom.com/wp-content/uploads/2015/03/Los-Drones-y-sus-Aplicaciones-a-la-Ingenieria-Civil-fenercom-2015.pdf (last accessed December 1, 2024).

[3] Domínguez Torrado, José Antonio (2015). Applications in the management of heritage and cultural heritage. In *Drones and their applications to Civil Engineering*. Directorate-General for Industry and Energy of the Community of Madrid (Eds). Pp. 159 – 170. Available online at: https://www.fenercom.com/wp-content/uploads/2015/03/Los-Drones-y-sus-Aplicaciones-a-la-Ingenieria-Civil-fenercom-2015.pdf (last accessed December 1, 2024).

[4] Elijah, Thato; Jamisola, Rodrigo S.; Tjiparuro, Zenduja; Namoshe, Molaletsa (2021). A review on control and maneuvering of cooperative fixed-wing drones. *International Journal of Dynamics and Control*, 9, 1332-1349. https://doi.org/10.1007/s40435-020-00710-2.

[5] Fernández García, Miguel (1914). Requejo Bridge – Viaduct. *Revista de Obras Públicas* 62, volume I (2031): pp. 423-428. Available online at: https://web.archive.org/web/20160304101422/http://ropdigital.ciccp.es/pdf/publico/1914/1914_to moI_2031_01.pdf (last accessed December 1, 2024).

[6] Hortelano Mínguez, Luis Alfonso (2015). Territorial heritage as a tourist asset in the

[7] "Raya" of Castilla y León with Portugal. *Cuadernos de Turismo*, 36, pp. 247-268. https://doi.org/10.6018/turismo.36.230981.

[8] Geological and Mining Institute of Spain, IGME (1982). National Geological Map, Sheet 368, Carbajales de Alba. Available online at:

[9] https://info.igme.es/cartografiadigital/geologica/Magna50Hoja.aspx?intranet=false&id=368 (accessed December 1, 2024).

[10] Geological and Mining Institute of Spain, IGME (1976). Geotechnical Map 200k - Sheet 28 (Alcañices). Available online at: https://info.igme.es/cartografiadigital/tematica/Geotecnico200Hoja.aspx?Id=28&language=es (last accessed December 1, 2024).

[11] National Institute of Statistics, INE (2024). Alterations of the municipalities in the Population Censuses since 1842. Province: 49 Zamora, Municipality: 49065 Fermoselle: https://www.ine.es/intercensal/intercensal.do?search=3&codigoProvincia=49&codigoMunicipio=065&btnBuscarCod=Consulta+selecci%C3%B3n (last accessed on 1 December 2024).

[12] National Institute of Statistics, INE (2024). Alterations of the municipalities in the Population Censuses since 1842. Province: 49 Zamora, Municipality: 49071 Fonfría: https://www.ine.es/intercensal/intercensal.do?search=3&codigoProvincia=49&codigoMunicipio=071&btnBuscarCod=Consulta+selecci%C3%B3n (last accessed December 1, 2024).

[13] Li, Yan; Liu, Chunlu (2019). Applications of multirotor drone technologies in construction management. *International Journal of Construction Management*, *19*(5), 401-412. https://doi.org/10.1080/15623599.2018.1452101.

[14] Llombart Jaques, José Antonio; Rodríguez Bragado, David (2014). Rehabilitation of the Requejo bridge-viaduct (Puente de Pino). Abstracts of communications, pp. 617-618.

[15] Available online at: http://www.jallombart.com/wp-content/uploads/2022/04/ROP-Puente-Requejo_Rehabilitaci%C3%B3n.pdf (last accessed December 1, 2024).

[16] Martín Benito, José Ignacio (2015). *Boats of passage in the Kingdom of León (From the Middle Ages to the twentieth century)*. C. E. B. "Ledo del Pozo", Benavente, Zamora, Spain.

[17] Millán García, José Ramón (2000). National Leadership and Local Caciquismo: Sagasta and Zamoran Liberalism. *Ayer*, pp. 233-259. Available online at: https://www.jstor.org/stable/41324948 (last accessed December 1, 2024).

[18] Nguyen, Lanh V.; Le, Trung H.; Torres Herrera, Ignacio; Kwok, Nagai M.; Ha, Quang P. (2024). Intelligent path planning for civil infrastructure inspection with multi-rotor aerial vehicles.

[19] *Construction Robotics*, 8(2), 19. https://doi.org/10.1007/s41693-024-00135-9.

[20] Oñate de Mora, Manuel (2015). Typology of Remotely Piloted Aircraft. In *Drones and their applications to Civil Engineering*. Directorate-General for Industry and Energy of the Community of Madrid (Eds). Pages 49 – 58. Available online at: https://www.fenercom.com/wp-content/uploads/2015/03/Los-Drones-y-sus-Aplicaciones-a-la-Ingenieria-Civil-fenercom-2015.pdf (last accessed December 1, 2024).

[21] Pérez – Fadón Martínez, Santiago; Herrero Beneítez, José Emilio; Morillo Rocha, Diego; Martínez Larrad, Daniel (1995). The Ricobayo bridge. The return of the arches. *Cauce 2000: Revista de la ingeniería civil*, 71, pp. 36-43.

[22] Ribera Dutaste, José Eugenio (1897). *Study on the Great Viaducts*. Madrid: Revista de Obras Públicas. Available online at: https://bibliotecadigital.jcyl.es/es/consulta/registro.do?id=40023 (last accessed December 1, 2024).

[23] Ribera Dutaste, José Eugenio (1910). *Catalogue of the works of J. Eugenio Ribera y Cª, a hydraulic and civil construction company founded in 1899*. Madrid: Imprenta Alemand. Available online at: https://biblioteca.juaneloturriano.com/Record/Xebook1-6460 (last accessed December 1, 2024).

[24] Ribera Dutaste, José Eugenio (1914). Requejo Bridge – Viaduct over the Duero, in Pino (Zamora). *Revista de Obras Públicas*, 62, volume I (2035): pp. 471-475. Available online at: https://web.archive.org/web/20110826092622/http://ropdigital.ciccp.es/pdf/publico/1914/1914_tomoI_2035_01.pdf (last accessed December 1, 2024).

[25] Rodríguez Elizalde, Rubén (2022). Structural Inspection by RPAS (Drones): Quality Work with Preventive Guarantee, 4 (2), págs. 1 -11. https://doi.org/10.47363/JEAST/2022(4)143.

[26] Rodríguez Elizalde, Rubén (2023). Thermography Applied to Damage Diagnosis over Monuments and Ancient Constructions. *Journal of Material Sciences and Engineering Technology* 1 (1), 1-6. https://doi.org/10.61440/JMSET.2023.v1.04.

[27] Rodríguez Elizalde, Rubén (2024). Assessment of Architectural Heritage and Historic Structures Through Aerial Thermography. *Revista de Gestão Social E Ambiental*, 18 (10), e08761-e08761. https://doi.org/10.24857/rgsa.v18n10-105.

[28] Seo, Junwon; Duque, Luis; Wacker, Jim (2018). Drone-enabled bridge inspection methodology and application. *Automation in construction*, 94, págs. 112-126. https://doi.org/10.1016/j.autcon.2018.06.006

[29] VVAA (2011). *100 elements of Industrial Heritage in Spain*. TICCIH Spain, Institute of Cultural Heritage of Spain and CICEES.