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# Drone analysis of medieval fortifications: the district of Loja in the Nasrid kindgom of Granada (Spain)

The last Islamic kingdom in the Iberian Peninsula was ruled by the Nasrid dynasty during the thirteenth to fifteenth centuries around Granada. It was divided into about twenty administrative districts, and Loja, located in the northern center area, was one of the most important and strategic ones. It had a high density of fortifications of different nature, some of which date back to very ancient times. This contribution is the result of the intense digital documentation that has been carried out on the graphic representation of these assets. They have been completed with the use of Unmanned Aerial Vehicles (UAV) to obtain the necessary graphic information to represent these architectures by means of precise planimetrical surveys, documenting and diagnosing their current state.

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Keywords:
UAV applications in different environments; 3D modeling from UAVs for the visualization, preservation, and sharing of complex architectures; documentation of Cultural Heritage; photogrammetric acquisition procedures; definition of new and unique databases and systems of representation of the Cultural Heritage


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## 1 INTRODUCTION

The Nasrid kingdom of Granada encompassed the mountain areas of the southeast of the Iberian Peninsula, where a natural border was established with the kingdom of Castile between 1232 and 1492. In broad terms, it covered the territory that is now part of the Spanish provinces of Granada, Malaga and Almeria, although its borders with Jaen, Cordoba, Seville, Cadiz, Murcia and Albacete served as a frontier that was altered a number of times over the years. It was divided into about twenty administrative districts, which, after the Christian conquest, remained as part of the Kingdom of Granada until 1833.

One of the most important and strategic ones was the district of Loja, located in the northern center of the Nasrid kingdom, constituting a frontier mountain land crossed by the Genil river valley, flowing between the fertile plain of Granada and the Cordoban countryside. The surface of this area of 73,420.159 hectares around the important city of Loja was the equivalent of only 2.49% of the Kingdom of Granada.

The district came to find itself at a crossroads between the Subbaetic and the Penibetic mountain ranges, in the natural passage towards the valley of the river Guadalquivir to the west, the plain of Granada to the east, the countryside of Alhama, the field of Zafarraya and the Axarquia of Malaga to the south and southwest, and the Subbaetic mountains of Cordoba to the north. From the end of the fourteenth century, Loja district was under pressure from the Castilian border, especially in the area to the north and the west (Malpica Cuello, 1996: 39). First came the conquest of the Subbaetic mountains belonging to Cordoba, which finally fell into Castilian hands during this century. Then came the fall of Antequera in 1410, and, in 1462, Archidona was taken. This led to the reinforcement of the existing fortifications and even the construction of some new ones during the last century of Nasrid rule. At the same time the use of masonry with rows and gravel filling with was becoming increasingly widespread in defensive construction, compared to the limestone walls that were more common in earlier periods. Curved forms that replaced the edges of the angular towers also began to appear, thereby reducing the damage caused by the increased use of firearms.

It had a high density of fortifications of different nature, some of which date back to very ancient times (Jiménez Puertas, 1995: 63-82; Argüelles Márquez, 1995: 83-98; Martín García et al., 1999; Mattei & Jiménez Puertas, 2014). Many of them were reused or built for the purpose of border protection in the Middle Ages, while the defensive system as a whole was completed and reinforced during the Nasrid period. It encompasses the main fortress of this district, the Alcazaba of Loja and nearly a dozen castles of different sizes and states of preservation, as well more than of 20 towers and watchtowers. These structures have survived to our time in different states of preservation (Fig. 1).

This contribution is the result of the intense digital documentation that has been carried out on the defensive architecture of the Nasrid kingdom. This paper aims to contribute to the dissemination of much of this heritage, dealing with its value from a typological, morphological, constructive, materialistic, landscape, territorial or strategic point of view. The first step has always been based on the graphic representation of these assets. To this end, combined architectural survey techniques have been used, from the direct measurement of the spatial dimensions of each element to the use of more advanced tools to measure different parameters indirectly, always avoiding any alterations of these cultural goods. They have been completed with the taking of innumerable photographs from all possible angles with Unmanned Aerial Systems to obtain the necessary graphic information to represent these architectures by means of precise planimetrical surveys, documenting and diagnosing their current state (Fig. 2).

UAV is the main tool of documentation of this heritage. From the first decade of the twentieth-first century, the use of these systems has shown a great potential in the study of the physical nature of the territory, and for the analysis and research of the architectural heritage (Mascort-Albea, Ruiz-Jaramillo & Romero-Hernández, 2014).

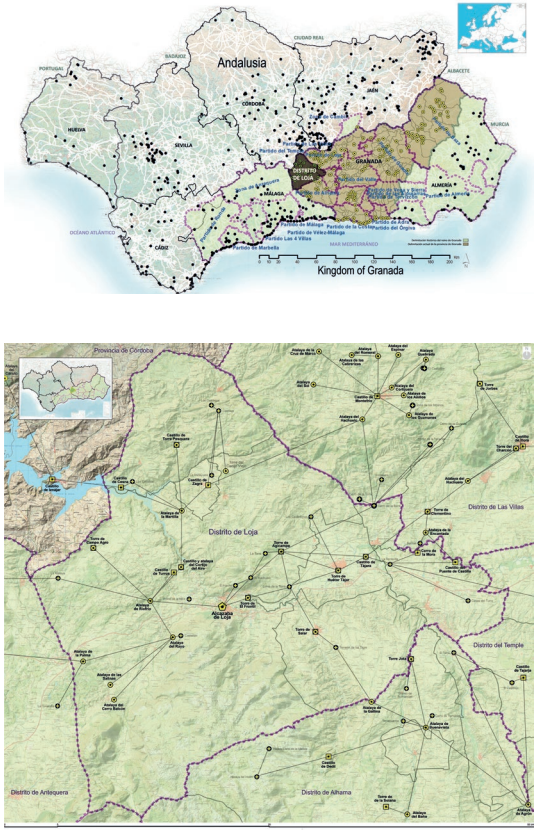


Fig. 1 - (Above). Towers in Andalusia (Spain). (Below) Network of fortifications in Loja district.


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## 2 METHODOLOGY FOT THE DIGITAL SURVEY OF THE MEDIEVAL FORTIFICATIONS

As a preliminary step to its analysis and study, several fieldwork campaigns have been carried out at the fortifications preserved in the district of Loja, both at those with important elevations or only meager vestiges.

For this, a series of terrestrial and aerial photographs with a percentage of horizontal photo overlap of over two thirds have been obtained, by means of a quadcopter equipped with a compact camera. It has a built-in aerial camera, with a one-inch 20 Megapixel CMOS sensor. This is a high-end sensor allowing photographs to be taken with a better quality and definition than consumer-oriented solutions, also resulting in images with much less noise. It has an 84 FOV 8.8 mm lens (24 mm equivalent), f/2.8–f/11, with single or burst shooting up to 14 fps. The remote control has a transmission range of 7 km, allowing control of the drone, tilting of the camera, taking of photographs, the exposure time and modes and video recording.

At the same time, spatial support points have been taken with a total station, with a measurement error from the models of only 0.005% in total, selecting clearly visible indicators in the photographs, which have been processed by entering the coordinates of these points. This has made it possible to generate three-dimensional photogrammetric models, documenting the current state of these fortresses. In those where the upper room has been preserved, additional measurements and photographs have been obtained to correlate the exterior with the interior.

The 3D models, as well as the orthorectified imagd, were obtained using Structure from Motion method / Image Matching (Rodríguez-Navarro & Gil-Piqueras, 2012: 87-89). The software which follows this procedure use algorisms based on the use of each pixel of the image as a point, looking for homologous points in all the images. The set of camera positions, along with the pictures themselves, are used in the construction of the geometry of the model. This process enables to create a photo-realistic texture for the final 3D model. These advanced technical tools for graphical representation enables keeping the maximum reliability and quality of results using a flexible methodology, in order to simplify processes and optimizing time consuming and digital resources (Rodríguez-Navarro, 2012: 100-111).

This process also enables to built-up a terrain elevation model and a 3D digital model of the fortresses. A detailed description and an architectural analysis of the remains can be done along with the on-site observations (Orihuela & Molina-Fajardo, 2021: 6; Almagro & Orihuela, 2015: 287-290).

In a first approach, the inspection carried out seeks to obtain the following basic elements: location; general and detailed maps of the area; public or private ownership; permissions needed and conditions for the access; if the heritage site in inhabited or state of neglect. Subsequently, during this first inspection, a series of photos and drawings are made, and a first documentation of the structure with the following information is carried out:
- Location and topographical relief of the ground. Exempt and isolated or within annexed buildings. Visible and/or accessible around its entire perimeter.
- Main shape: rectangular prism, polygonal, cylinder, trunk-pyramidal, trunk-conical.
- The size and shape of the entrances and staircase, the interior spaces and roof.
- Vertical obstacles such us electric wires and towers, mobile telephony base stations and antennas, trees, other buildings.

Using UAV unit (drone) for taking aerial photographs solves many accessibility problems. Aerial photographs allow a great freedom when taking pictures from any point of view. It is possible to use the same camera for ground shooting or different cameras and then mixing the images with no significant variation in the workflow. In general, however, with a double sequence of pictures, one from the ground and one from the air, it is possible to reduce the post processing needs (Rodríguez-Navarro et al., 2016: 104; 2018).

As a result, two models at different scales are obtained. The first documents are focused on the set of towers, making it possible to obtain orthophotographs of the floors and elevations, as well as sections for those that preserve interior spaces. From these documents, a planimetry is drawn up that allows analysing both the state of conservation, pathologies, constructive materiality of the buildings, as well as the transformations caused by their adaptation to other uses.

Another photogrammetric model has also been developed to study the environment in which the towers are constructed. This has enabled a first documentation that allowed us to analyze other material remains still existing in the vicinity, as well as how it has been affected by natural phenomena and human activity.

## 3 TYPES OF FORTRESSES AND PROCEDURE OF UAV SURVEY

The documentation has focused on the fortresses that nowadays are situated within the district of Loja (Fig. 1). In this chapter follows an overview of the objects studied within the scope of this study. On each of them data has been extracted using the method of UAV and photogrammetric restitution previously mentioned.

### 3.1. Fortress of Loja:

Lawša (Loja) was founded around its alcazaba (Fig. 2) (Spanish for the Arabic al-qaṣbah, 'the citadel'), which played an important role in defending this part of the Nasrid kingdom against Castilian pressure as it guarded the access to the Plain of Granada (Vega de Granada) through the Genil river valley.


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The Medieval fortress was built by the Emir Abd Allāh in 893 as a defence against the attacks of ʿUmar b. Ḥafṣūn, a rebel who rose up against the newly-formed Caliph state. This revolt was put down already in the tenth century by ʿAbd al-Raḥmān III. Its proximity to the border with the Kingdom of Castille became especially evident after the capture of Antequera in 1410 and Archidona in 1462. Finally, in 1486 the city surrendered to the Catholic Monarchs after a grueling siege. The remains that have survived make this site the most significant historical place in Loja, constituting the main part of the urban complex.

Inside the alcazaba, the fortress enclosure (Sp. alcázar, Ar. al-qaṣr, 'the military garrison') covered the summit. The entire southern walls, with five towers of quadrangular shape and masonry walls supported on the edge of the rocky escarpments of the hill, have survived to this day.

3.2. Other fortification in the district of Loja:

These constructions were rural castles of varying kinds (Fig. 3), whose influence encompassed an inhabited territory that it defended, known in al-Andalus with the Arabic word transliterated in Spanish as ḥuṣūn (plural of ḥiṣn). These fortified enclosures used to have several towers that protected the entrance and the main angles, like the one in Cesna, being able to exercise some of them as burŷ al-ʿaẓīm or large tower.

Their function could be to control a communication channel or some strategic resource and, very often, act as a place of refuge for the inhabitants of the settlements organized around an irrigation area or a livestock area with nearby pastures.

Because of these functions, many of these ḥuṣūn are formed like a wide, fold-like enclosure, for the protection of people and animals, and, in the highest and most protected part, they have a main

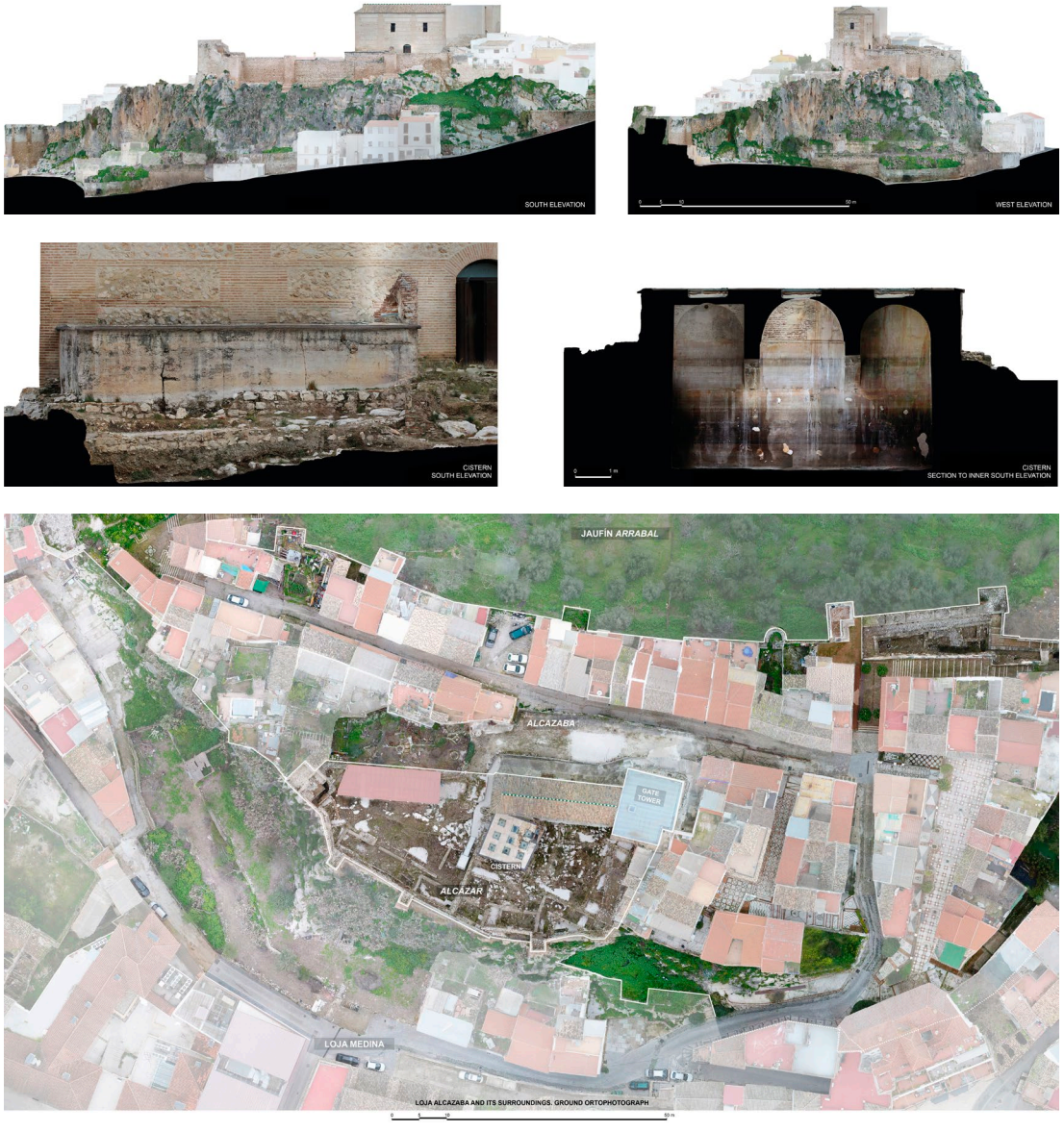


Fig. 2 - Photogrammetric survey of the fortress of Loja and its cistern.


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defensive enclosure. The construction techniques used also show repairs, reinforcements and extensions carried out in masonry on enclosures and earlier structures built in rammed earth.

Castle of Pesquera Tower (Algarinejo):
It is a rural castle or tower encompassed by a defensive enclosure that could have protected a nearby settlement. It is located on the eastern spur of the Pesquera River, which flows into the Genil River in the north-western part of the Loja district, to the south of the municipal district of Algarinejo (Fig. 3). It could have controlled the route by which inroads were made through this valley into Algarinejo, in the municipality of which the Castle of Pesquera Tower is located. During the thirteenth century this area was the target of the raids of Ferdinand III, and during the fourteenth century those of Peter I, when briefly fell into Castilian hands. Once it was integrated into the border area, it finally passed to the Castilians during the fifteenth century, as a consequence of the incessant harassment by the lords of Priego and Iznájar.

Castle of Cesna (Algarinejo):
At present, the Castle of Cesna is located next to the bank of the reservoir of Iznájar, north of the river Genil, at the northern end of the town of Loja in the municipality of Algarinejo (Fig. 3). This border castle had at least two enclosures. In the exterior one some rests of the foundations of the walls and towers survive on all the slopes of the hill. It encompassed the upper enclosure, where remains buried in their own rubble can be found. Because of its proximity to the north-western border of the Nasrid kingdom, it was subject to numerous and frequent Castilian incursions. It was included in the peace treaty between the kingdoms of Castile and Granada in 1439, although from then on in Castilian hands.

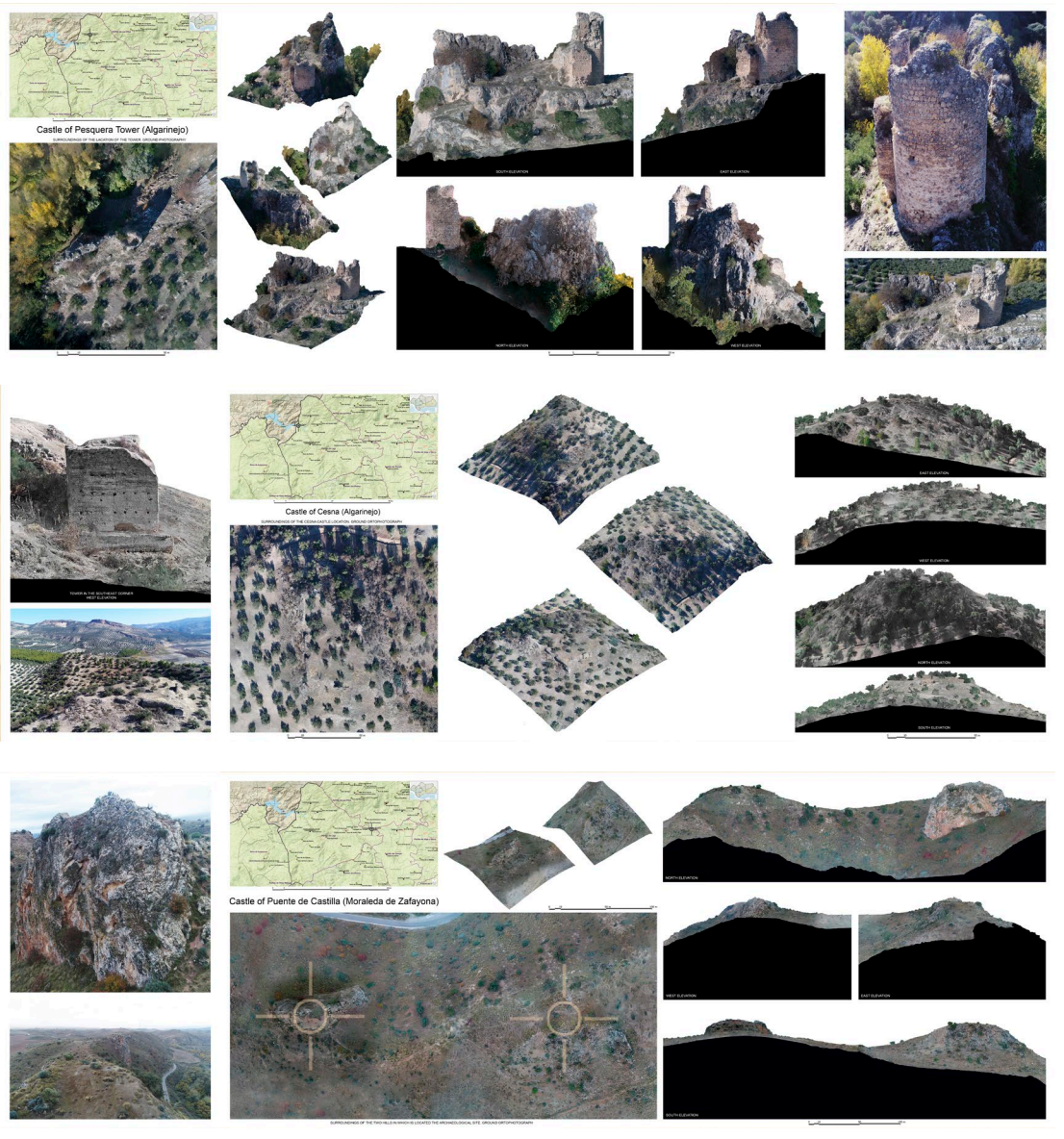


Fig. 3 - Photogrammetric survey of some fortresses in the district of Loja. (From above to below) Castles of Pesquera Tower (Algarinejo), of Cesna (Algarinejo), and of Puente de Castilla (Moraleda de Zafayona).


DOI: https://doi.org/10.20365/disegnarecon.29.2022.9

ISSN 1828-5961



Fig. 4 - Comparison among the farmstead towers documented in Loja.

Castle of Turrus (Loja):
The remains of this citadel are located to the west of Cortijo del Aire, on a hill on the right bank of Riofrío and before the point where it flows into the Genil River. Due to the great thickness of its walls, it has been assumed that it may be a fortified Iberian-Roman settlement, reused in medieval times. It would have consisted of at least two enclosures. The main one, with a noticeably triangular shape, stood on the upper platform of the hill. The west side of the wall and three towers can be seen, in addition to others in the corners.

Castle of Puente de Castilla (Moraleda de Zafayona):
There are remains of a settlement on the two hills that overlook the Puente de Castilla (Bridge of Castile), on the eastern border of the Loja district (Fig. 3). They watched over the road from Montefrío to Alhama and its strategic passage through a ford of the Genil river. On the westernmost hill there are traces of two masonry walls, almost parallel and of low height, running in east-west direction. The promontory located to the east harbors remains that could have formed a fortified perimeter of rectangular shape, consisting of walls and potentially towers, all in masonry, to the east, south and southwest.

3.3. Towers linked to settlements (farmstead towers)

Some rural settlements had to equip themselves with defensive structures, especially when the insecurity caused by the proximity of the Nasrid border to the kingdom of Castile were particularly pressing. Consequently, in some of the farmsteads in the district of Loja, such as Frontil, Agicampe, Huétor Tájar or Salar —the settlements of which have endured in form of a neighborhood, a farmhouse or as fully formed municipalities— a tower has been preserved (Fig. 4). It was the most visible and predominant element of defensive enclosures that often also had walled spaces to protect people, animals, and movable property (Martín García, 2010: 48-54).

This type of towers with an enclosure for protection present great typological diversity in terms of the dimensions of plan and elevation, interior rooms, interior levels, layout of stairways, presence of a cistern or a warehouse.

The walls of rammed earth with lime and gravel content, which allowed for the modulation of prism-shaped towers, were gradually replaced by masonry from the fourteenth century onwards due to Castilian influence. The change towards masonry construction was also born from a need


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ISSN 1828-5961


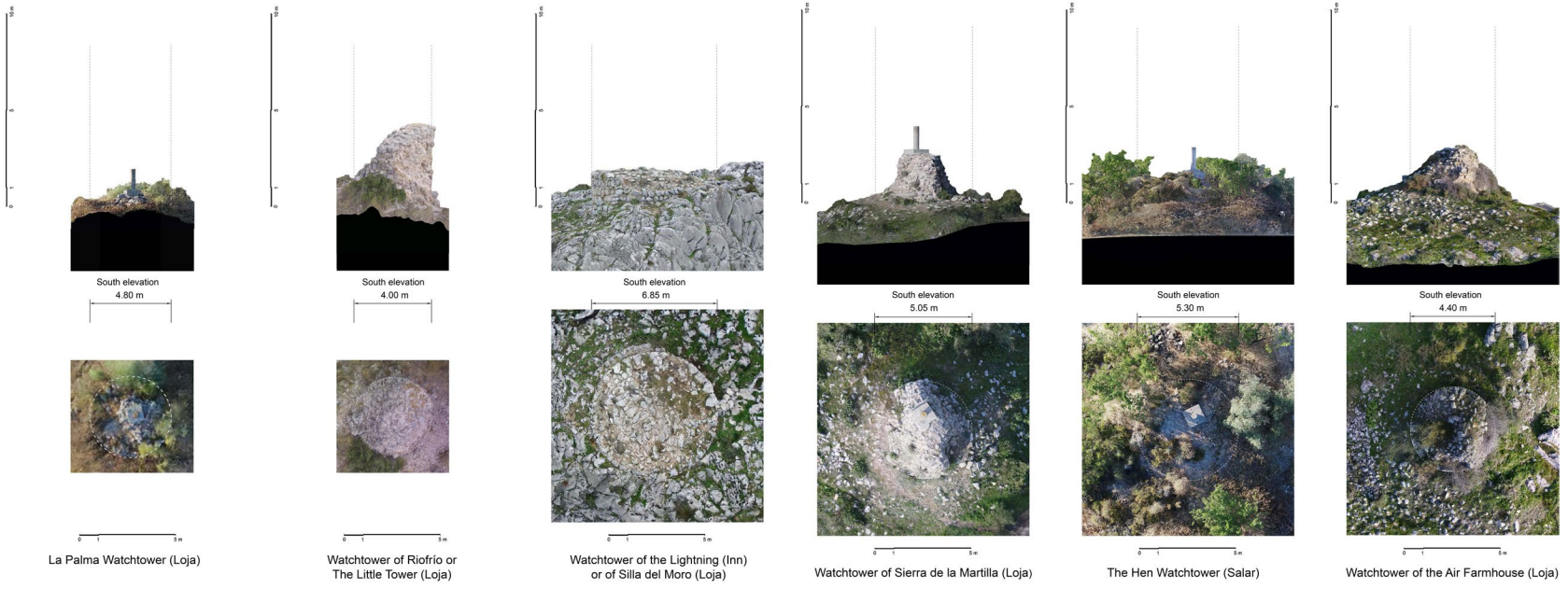


Fig. 5 - Comparison among the watchtowers documented in Loja.

to reinforce the earlier defenses built with earth and facilitate the construction of structures with fewer edges, as those were less vulnerable for the increasingly widespread use of artillery system as a whole was completed and reinforced during the Nasrid period.

Among these items we can highlight the Tower of the Frontil, the Tower of Salar or Pulgar's Tower, the Tower of Agicampe, the Tower of Abor or Campo Agro, the Tower of Huétor, and the Farmhouse of the Towers or Tájara Castle (Fig. 4).

3.4. Watchtowers

These towers were situated in strategic points with wide visibility, enabling communication through smoke signals during daylight or beacons at night. In the Nasrid period this system was reinforced, and new towers were built in locations of special relevance. They are usually built in masonry with gravel filling, with circular base and cylindrical or tapered shape, with the solid base and a single chamber with elevated access for the tower watch, from which the plume of smoke could rise through a hole in the terrace. The upper part was intended for the canopy and, if necessary, to make a beacon.

This network not only allowed the information about what was happening in the district to reach the Fortress of Loja, the system was also connected to other watchtowers throughout the entire Nasrid kingdom.

The watchtowers of which some remains are preserved in the district of Loja do not reach a dozen. They are all destroyed down to the basement, which that could be related to the process of conquest of Loja in 1486, as well as to the first attempt to take the city three years before. Even so, they belong to the typology with the highest number of defensive elements that have been preserved or of which historical references have been found in the district of Loja (Fig. 5).

La Palma Watchtower (Loja):
The cylindrical watchtower, built in masonry with medium-sized stones, is from the Nasrid period and has a diameter of 4.80 m. Its original remains stand 2.20 m high, but a large part of it is buried in its own rubbles, It shows no rests of rendering on the exterior. Nowadays it is crowned by a triangulation station from the National Center for Geograhical Information.

Watchtower at Cerro Balcón (Loja):


DOI: https://doi.org/10.20365/disegnarecon.29.2022.9

ISSN 1828-5961


It was one of the southeasternmost watchtowers of the district of Loja, and visually connected to the Watchtower of El Rayo. However, the more nearby Tower of the Salt Pans would have been impossible to spot, at only 1.25 km to the north. It last remains were destroyed in the first decade of the twentieth-first century.

Watchtower of the Lightning (Inn) or of Silla del Moro (Loja):
It is classified as a Nasrid border watchtower for its building technique. The tower is cylindrical with a diameter of 6.85 m and a preserved height of at most 1.54 m up to a levelling platform with a paw on which it stands, because of the pronounced inclination of the slope on which it is built.

Watchtower of Riofrío or The Little Tower (Loja):
The tower is a Nasrid border watchtower erected on a masonry leveling platform, more visible in the east. Cylindrical and 4.00 m in diameter, it preserves a height of 3.40 m. The structure consists of masonry of medium-sized and large stones, forming rows without gravel filling and joined with good quality lime mortar.

Watchtower of Sierra de la Martilla (Loja):
This watchtower, placed close to the border, was built during the Nasrid period. 2.80 m are left of its cylindrical figure, 5.05 m in diameter. The exterior is only partially visible. It is built in masonry joined with mortar with high lime content and abundant gravel filling.

Watchtower of the Salt Pans or of Fuente Camacho (Loja):
The tower has a circular floor plan of 5.25 m in diameter, built with masonry of medium-sized stones. It must have had a cylindrical shape up to the upper terrace, although its height is currently reduced and divided into segments gradually reduced in size by the curvature of the vault that covers its interior. The watchtower is currently crowned by two chimneys, which give it a remaining height of 5.70 m in total.

The Hen Watchtower (Salar):
This cylindrical masonry watchtower with circular base was built during the Nasrid period. Since the only remains are a 2.50 m artificial mound consisting of a large number of stones from the interior filling and some stones from the eastern façade. Its diameter can be around 5.30 m.

Watchtower of the Air Farmhouse (Loja):
This watchtower, taking up the highest part of the fortified enclosure, would have been linked to the so-called Castle of the Cortijo del Aire, in the Loja district's western half. Built in Nasrid times, it is standing on a nivellation platform. It is cylindrical with a diameter of 4.40 m. It is built in masonry with large and medium sized stones and mortar rich in lime, in irregular rows.

## 4 SPECIFITIES OF THE DIGITAL SURVEY OF THE NETWORK OF TOWERS

For all these towers and castles, graphic surveys have been carried out using UAV. Given that their locations are notably inaccessible, the main problem for obtaining data has been to find and get to the site carrying the drone with eight propellers, remote control with built-in screen and six batteries, as well as a total station.

When it comes to the watchtowers of La Palma, Rayo and Riofrío, the distance and difference in level from the most accessible point by means of vehicles has been considerable. The watchtowers of Cortijo Viejo and Cerro Balcón were described in the 1990s (Martín García et al., 1999: 304 and 314-315), but after prospecting the environment in which they were registered, we were unable to locate their remains. Piles of stones from the clearing of farmlands were found in these environments. Consequently, reconnaissance aerial flights of the territory were carried out at higher altitudes. From these images, the ground orthophotography and the topography was obtained, and contour lines for CAD at 1, 0.5 and 0.1 m height and digital elevation models were extracted. This has made it possible to locate the most probable topographic locations of these watchtowers, based on possible anomalies on the ground, always with other known locations as a reference. This reconnaissance procedure has also been used to try to position some of the towers mentioned in the historical documentation and to which there are references that could help their location. In the latter, it has been possible to corroborate that all visible remains have disappeared because the promontories where they were presumably located have been altered by clearing activities for the construction of buildings and infrastructures or by modifications to the land as a result of intense agricultural practices, where stones have been removed from the surface and accumulated in heaps. However, these flights have always yielded interesting data that have been able to support the argument of the place where they were most likely situated.

## 5 ANALYSIS TO COMPLEMENT THE GRAPHIC SURVEY

Beyond the documentation of these heritage assets, graphic and 3D survey enables the elaboration of a series of analysis which foments knowledge of essential aspects of their conservation, such as their construction, structural and environmental behavior, as well as of their evolution over time.

Excluding works more directly related to historical or archaeological studies based on documentary sources or specific field campaigns, the scientific methodologies applied to the analysis of towers in the Nasrid kingdom of Granada are usually linked to their cataloguing and inventory (Martín García, Bleda Portero & Martín Civantos, 1999), morphological studies (Esquivel, Mustafa & Esquivel, 2019) or construction periods and techniques (Malpica Cuello, 2001). However, the significant development of new computational or technological tools to conduct on-site testing has made it possible to analyse these


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assets from complementary points of view. The introduction of these new components in the analysis methodology has been essential to obtain complementary perspectives that provide more information for a better understanding of the built heritage and its context.

The implementation of geographic information systems (GIS) is an important example of the above. GIS tools can provide relevant information on the territorial dimension of this patrimonial assets, for example, that related to the study of viewsheds, which is a relevant information for understanding the conformation process and evolution of the defensive systems. Analysis at territorial scale must be complemented with the information that can be obtained from each specimen through the application of different techniques and on-site inspection.

This methodology has been successfully applied since 2016 in the study of the towers of the Nasrid kingdom of Granada (García-Pulido, Ruiz-Jaramillo & Alba-Dorado, 2017), being developed along two main lines of work related to in situ data collection. On the one hand, developing photogrammetric surveys through digital image processing (DIP) which, in addition to accurately describing the object of study, become a fundamental support in the following phases of the research. On the other hand, carrying out a series of non-destructive tests (NDT) that enable constructive, structural, and environmental characterisation.

5.1 Analysis of the construction techniques

The knowledge of the construction techniques, together with the information provided by archaeology, allows identifying the historical phases associated with the construction and, in turn, to establish relationships with those located in its surroundings. In the process of identification and characterisation of building materials, in addition to the visual analysis carried out in situ, techniques such as X-ray diffractometry with the Rietveld method (which reveals the mineralogical nature of materials such as mortars) or radiocarbon dating (radiometric dating using the carbon-14 isotope) are used. These laboratory techniques are complemented with computer techniques such as image analysis or infrared thermography, procedures that provide fundamental information to understand the materiality and construction techniques, serving as a basis for rehabilitation processes (Fig. 6).

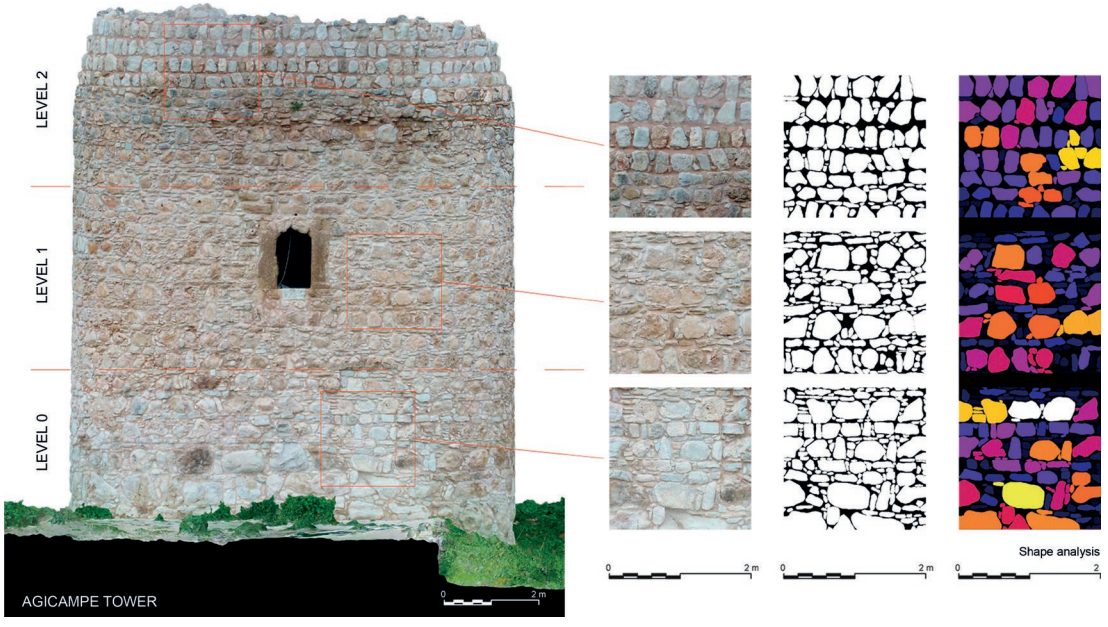
As an example of this a detailed examination of the surface of the exterior walls of the towers has been systematically carried out using infrared thermography (IRT). This technique allows the detection of heterogeneities, revealing construction phases, differences in the materials used, and even distinguishing the typology of the masonry used.under the plastered surface

Additionally, as an important complement to the construction analysis and in addition to the aforementioned in situ tests, remains of wod and mortar samples are taken with the aim to obtain a C14 dating and the mineralogical composition, respectively.

5.2 Structural stability analysis

The investigation of the state of preservation involves applying traditional methodologies to record the pathological processes and degradation that the architectural heritage has suffered over time. In addition to the organoleptic information record of existing damages (material damage, cracks, dampness or collapses and deformations in walls and vaults), the ability to obtain data about the overall rigidity of the structure is added. This information makes it possible to empirically iden-

Fig. 6 - Shape descriptor at the constructional analysis in the Tower of





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tify their state of conservation, as well as to understand their behaviour in the face of events such as earthquakes.

To obtain this information a series of ambient vibration tests have been carried out during the survey of the towers analysed. This has made it possible to obtain direct information on the fundamental frequency/period of vibration and, through this, to determine the homogenised static modulus of elasticity for the entire construction (Ruiz-Jaramillo et al. 2020). This parameter is of great interest to calibrate the structural behaviour of the 3D numerical models created from photogrammetric data acquisition. Once adjusted the mechanical properties, the analytical model has been subjected to both gravity and seismic actions, adopting in the latter case a probabilistic scenario based on the information provided by the current Spanish seismic code (NCSE-02).

### 5.3 Environmental analysis

Everything discussed above refers to the physical remains that are intended to be conserved and protected. Generally, the attention paid to the material remains relegates the analysis of the environmental qualities of the space where the restoration process takes place.

However, the measurement of environmental conditions becomes a substantial part of the methodology for the analysis of architectural heritage. In this way, the parameters associated with natural lighting or ventilation provide relevant information about the original conditions of use of the interior spaces. For this reason, during the development of the research an environmental evaluation were carryied out to environmentally qualify these interior spaces.

Thus, with this objective, several in situ tests were carried out to determine parameters relating to natural lighting (illuminance (Em) in lux (lx)), temperature (ºC), relative humidity (%), as well as air circulation due to the effect of ventilation (m/s). From these data, it is possible to calibrate computer models for lighting or thermal studies that gives a deeper understanding of the environmental properties.

Knowing the interior environmental conditions, together with the information provided by documentary and archaeological sources, would make it possible to discern in each case the specific functions associated with the tower (surveillance, defensive, storage, livestock shelter, residential, etc.). Thus, environmental analysis becomes a powerful tool capable of providing key information during the design phase of restoration proposals to recover these heritage assets, together with its contribution to historical research.

Fig. 7 - Graphical documentation of the Frontil Tower. Its remains are included in the bell tower of the Chapel of Nuestra Señora de la Esperanza (Loja).


### 6 A REPRESENTATIVE CASE STUDY: FRONTIL TOWER

The methodology applied in this project is well represented by the graphic analysis of one of the most hidden and unknown towers in the district of Loja, the Frontil Tower (Fig. 7). Its remains are currently incorporated in the bell tower and in the small chamber of Nuestra Señora de la Esperanza Chapel. This tower, located 2.17 km northeast of the Alcazaba of Loja, stands on a site that would have been inhabited since ancient times, given the existence of an important spring nearby.

This tower of prismatic shape and rectangular floor plan would have been linked to a settlement. Despite its adaptation to religious function, it entailed important transformations. Its structure is


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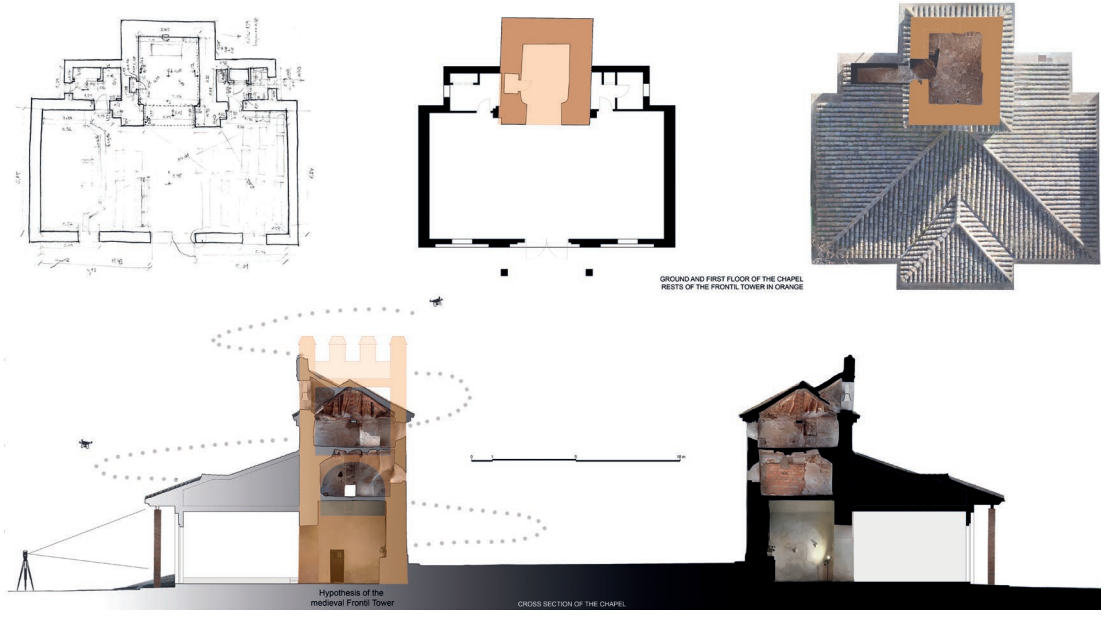
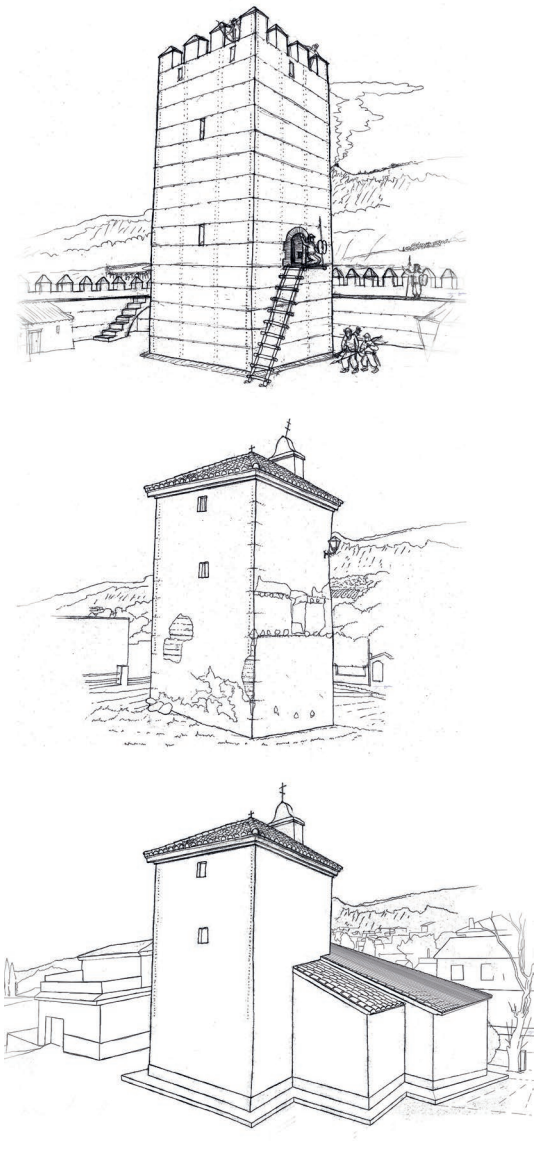
still fully visible in the part that stands as a bell tower, above the before mentioned chamber, a vaulted space attached to the main nave of the chapel, which would have been formed at the base of the tower. Above this space there are two rooms in which the walls of the tower can be analysed. These are built of rammed earth, with a thickness of between 0.90 and 1 m, and are preserved up to a height of over 5 m, while the rest of their elevation has been added as a new construction. The lower room would have corresponded to the ground floor of the tower, as the original access in its northeastern wall, as well as a part of its original vault, has been preserved (Fig. 8).

Although the remains of this tower were already identified in the 1990s (Martín García et al., 1999: 303-304), the users of the present chapel and the general public were unaware of its existence. We describe below the process followed in this case, one of the most complex as the historical construction was covered by a later one, to illustrate the methodology used in the graphic survey and study of these fortifications.

Contact and collaboration with the Loja Town Council and the Archbishopric of the province of Granada, guarantor of this heritage asset, provided us access to the chapel and to the bell tower, as well as the means to enter to all the inner spaces. A sky lift truck had to be used, as well as a portable ladder, by means of which we could access the two upper floors of the tower through its original opening, as these are not directly communicated with the inside spaced of the chapel.

Fig. 8 - (Below) Graphical analysis of the Frontil Tower
Fig. 9 - (Right) Hypothesis of evolution of the Frontil tower (Loja).

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Initially, a detailed sketch of the interior of these two floors and of the spaces of the chapel was made, as well as a complete taking of measurements, following the basic principles of architectural surveying, such as triangulation or measurement of distances correlative to an origin. At the same time, a process of photographic documentation was carried out at the ground level of all these spaces, together with a drone shot of the entire exterior volume of the chapel. This photographic work made it possible to develop a complete photogrammetric model that was referenced with data obtained with a total station (Fig. 7).

Accessing the two upper rooms of the bell tower allowed us to measure, document and analyse the remains of the tower, something that had not been done before. The existence of bare surfaces inside the tower and some traces of construction revealed by the external plaster, made possible to determine the height of the access door, the presence of rammed earth walls and the remains of one of the brick vaults that existed inside the tower, as well as to detect the system and the modulation used on its construction (Fig. 8).

The initial exploration and the architectural surveys carried out, together with the comparison with other typological models analysed, as well as the study of the historical photographs kept in the Archive of Loja corresponding to the time when the chapel was being constructed in 1980, provided the necessary information to postulate a series of preliminary conclusions.

This documentation process allows us to conclude that the tower would have had a solid base or storage space on its socle that would have being disfigured after the conquest of Loja in 1486. Above this first level there were at least two internal communicated rooms and a terrace at a higher level in which a four-sloped roof was placed, reusing the medieval structures. It has also has been found that the chamber of Nuestra Señora de la Esperanza had perforated the lower part of the tower up to its first floor, which would have been levelled with the original entrance, whose opening has been preserved in the western elevation, today embraced by the new building constructed from 1988 onwards. The existence of narrow vertical openings on the northern face of the bell tower, one in each of the inner rooms, is compatible with the hypothesis that the medieval tower may have had at least two arrow slits on this elevation (Fig. 9).

In short, this methodology documentation has made it possible to draw up a first hypothesis about how the initial tower might have been like, raising a series of questions that will have to be resolved in the necessary process of archaeological intervention and scientific restoration that should be undertaken to safeguard and suitably enhance this heritage asset (Trizio et al., 2021).

## 7. CONCLUSIONS

During the last years, the methodology used in various research projects carried out at the Technical Institute of Architecture of the University of Malaga and at the School of Arabic Studies of the Spanish National Research Council (CSIC), has enabled us to document a substantial part of the medieval defensive heritage in eastern Andalusia. This legacy is one of the most endangered parts of the cultural heritage, due to the large number of elements and their geographical dispersion. This has made it remarkably difficult to gain knowledge about them and preserve them throughout history.

Combining techniques for architectural surveys, a documentation at various levels can be created, which is adapted to the different levels of analysis that each case requires. Among these techniques the use of UAV is particularly relevant, considering the accessibility conditions and the need for documenting the surrounding territory in the analysis of these buildings, especially the watchtowers, many of which have practically disappeared.

This project about the defensive architecture of Loja has made it possible by means of the bi- and three-dimensional representation not only to document inaccessible structures but also deepen the knowledge about them and create a solid base for future studies. The data obtained from this research and the various analyses that are presented hav also allowed us to establish hypotheses, both of the original state and of the evolution and transformation of these assets (Fig. 14). These idealized recreations should never be considered as final versions, but as mere approximations that expand the knowledge of these fortifications.

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