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### **From simple traces to extended hypothesis, the case of the Cadì Gate at the Alhambra, Granada**

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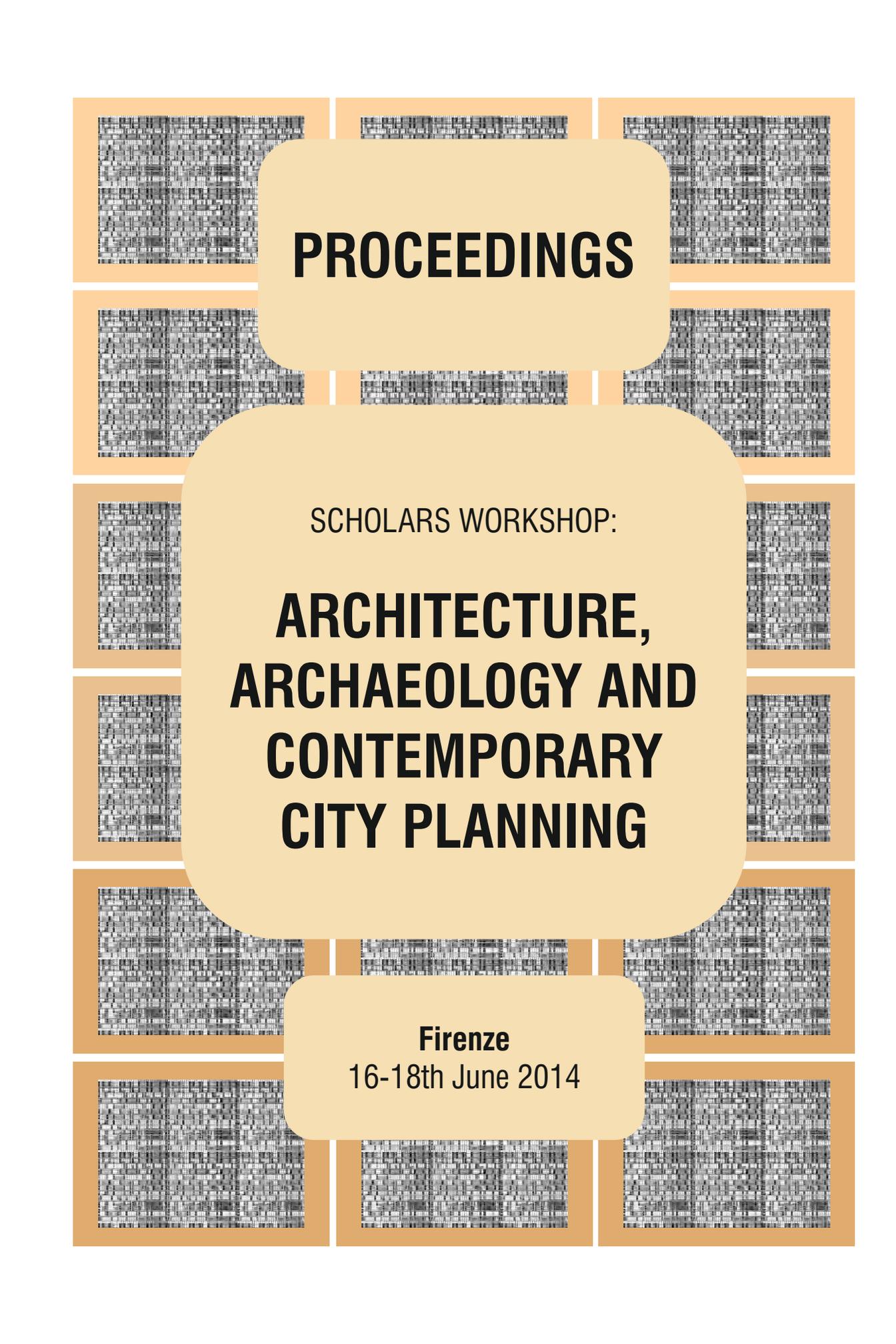
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**PROCEEDINGS**

SCHOLARS WORKSHOP:

**ARCHITECTURE,  
ARCHAEOLOGY AND  
CONTEMPORARY  
CITY PLANNING**

**Firenze**

16-18th June 2014

Firenze  
16-18<sup>th</sup> June 2014

Workshop:

**ARCHITECTURE,  
ARCHAEOLOGY  
AND CONTEMPORARY  
CITY PLANNING**

**PROCEEDINGS OF THE  
WORKSHOP**

**editors:  
Giorgio Verdiani & Per Cornell**

Firenze  
December 2014

Firenze  
16-18th June 2014

**Scholars workshop:**  
**ARCHITECTURE, ARCHAEOLOGY AND CONTEMPORARY CITY PLANNING**

The workshop took place in Firenze, via San Niccolò, 93 at the Dipartimento di Architettura in the Aula Magna placed at the first floor of the palace.

Workshop organizing committee:  
Giorgio Verdiani, Per Cornell, Alessandro Merlo, Gianluca Belli.

The workshop has been realized in collaboration between Architecture Department of the University of Florence, Italy, the Department of Historical Studies, University of Gothenburg, Sweden and MOLA (Museum of London Archaeology, UK)



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# From simple traces to extended hypothesis, the case of the Cadi Gate at the Alhambra, Granada

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**Abstract:** The ruins have always a special fascination over their visitors, moreover, behind the romantic aspects and their poetic “resonance”, often they are a meaningful witness of past choices and readable traces of the previous asset of a town. Granada is well known all over the world for the beauty of its downtown and the presence of the Alhambra monument. The specific combination of European and Islamic Architecture all over the town make it an awesome place testifying a nodal moment in the European story through its buildings. In the town a lot of these elements are clearly readable, but there are also some interesting traces still in need to be investigated. One of these is the so called “Cadi Gate”, a large ruin along the Darro river, just at the feet of the hill where the buildings of the Alhambra rise. The research presented here has been established on the analysis and investigation of the actual state of this ruin, basing the whole approach on digital survey to document the state of the area, passing across a complete digital reconstructive hypothesis based on the geometric analysis using 2D and 3D digital modeling solution. In the presentation the ruins of the “Cadi” will be analyzed and it will be showed the specific approach where the investigation is based on digital tools: starting from the photographic and SfM survey, passing from a complete reconstructive hypothesis based on the geometric analysis of the remains and on a set of architectural references and completing a digital 3D reconstruction of a possible original asset of the ancient urban asset. Starting from the actual “not so clear” condition of this urban element, a better understanding of the ancient Granada will be enriched with a meaningful benefit coming from the digital tools involved in this research.

**Keywords:** SfM survey, 3D modeling, Puente de Cadi, Alhambra, Granada, Bab al-Difaf

## Introduction

The city of Granada is full of monuments and significant architectures, which are known for their beauty all over the world, whose meaning and role within the urban city planning is well known and easily readable.

There are some examples which have not found yet a specific location and a role within the “system” in the city and they are still waiting for a correct interpretation. In major part their “suspended” character is caused by incompleteness of the State’s archival records, by degradation of the monument and also by missing oral testimony, which keeps alive its history and its location in the city.

What people know as “puente de Cadi” is an example of the conditions that we said before. This monument from Ziri period, placed between the Islamic district of the Albaicin and the Alhambra, raises still a lot

of interests among the group of researches. First of all, what is its name? Cadi, Los Tableros or Bab al-Difaf? There are so many names for a single enigmatic monument along the fortifications of Granada.

The interests that revolve around the Bab al-Difaf are many and inherent to many disciplines. But what is most fascinating is the mystery surrounding its origin, its purpose and the morphological aspects that are now lost.

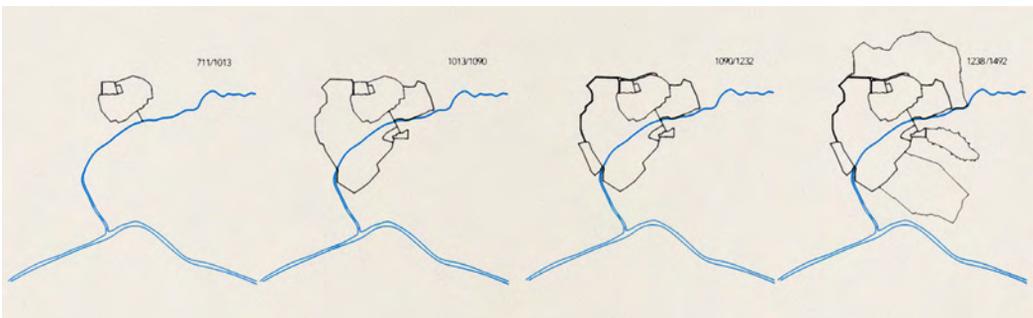
## The city of Granada

At this point, it is important to study and understand the historical evolution of the fortification in Granada. As it’s possible to see from the picture (Fig. 2) the origin of the city reflect the canonical aspect of the medieval settlement with the city placed above a hill not so far from the water. In Granada the relation



between the city and the river Darro was always a very important aspect. In VIII century the connection was made by a fortified corridor called “coracha” in Spanish. With the increase of population and the resources generated by new irrigated fields, the Zirid dynasty was able to consider a new plan for the city in the area adjacent to the old pre-Islamic city. Thus, a large walled area was delimited that was urbanized in accordance with the principles of Islamic law. In addition to producing more comfortable growing space, this expansion had a strategic objective: to connect the emerging fortress of the Alhambra with the town walls, thus preventing any potential enemy attacks from that point. The high part of the city, which had better natural defensive

conditions, was the most heavily fortified and would continue to be the site of the alcazar (fort, castle or palace), the seat of power. It was called the “high city” (al-madina al-fýqà) or alternatively the alcazaba (al-qazaba) to distinguish it from the “low city” (al-madina al-sufilà). The great mosque (aljama) was moved to the lower area and became established in a central and accessible position with respect to the new city design. In this time and exactly for those reasons was build up the Bab al-Difaf. After the Almoravids conquered the taifa kingdoms, Granada became one of the most important cities in al-Andalus, at times serving as its capital. Its governors remained in the alcazaba,





which al-Zuhri described as “the big one” to differentiate it from the small one on the Alhambra hill. In 1125, after the incursion into the southern Iberian Peninsula by Alphonso I the Battler, a new tax was created to reinforce the damaged fortifications of many cities, including Granada.

In 1232, the Nazaridi set up their capital in Granada. Initially, they were established in the alcazar, located in the great alcazaba, the point

Fig. 1 – *The Puente de Cadi with the river Darro on the left and the Alhambra at the top of the hill*

Fig. 2– *The evolution of the fortification of Granada*

Fig. 3– *Areal view of Granada with the evolution of the fortifications and the urban positions of Cadi, marked with a circle*

from which the territory had been governed since the beginning of the Zirid dynasty.

However, a few months later, they decided to create a new city on the Sabika hill, on the left bank of the Darro River, taking advantage of



Fig. 4 – *Plattaforma de Vico*

Fig. 5 – *The ruin of the Puente de Cadi in the Plattaforma de Vico*

a much more secure strategic position. They took over the small alcazaba that had been built there but had to create a new irrigation channel from the river to guarantee their own water supply.

This operation was in keeping with a long tradition of creating palatial cities for the emir, his court, his personal guard and closest advisors to live in dating back to the early days

of Islam. Like this Alhambra and Granada became two juxtaposed, autonomous cities with different functions. In the picture (Fig. 3) it's possible to see the evolution of the city wall above the aerial view of Granada, with the plan of irrigation and wells system.

Granada's complex topography and the compartmentalisation created by the interior walls in different areas are still quite noticeable at the end of the Nasrid period. Consequently, the main streets in each sector were fairly autonomous with respect to the others. There

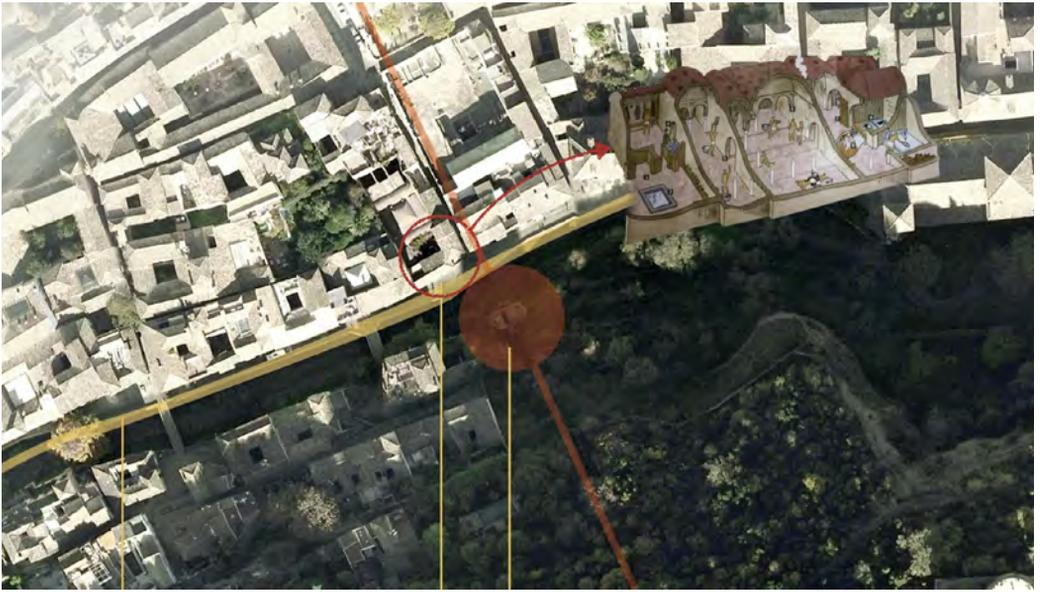


Fig. 6 – The aerial view and cross-section of the Banuelo  
 Fig. 7 – The bridge as it is today and as it was in a photo from the archives of the Alhambra.



was a hierarchisation of streets, indicated by their width and the intensity of the flow of people through them.

These important routes, which were characterised by heavier commercial activity, began at the main gates of their respective walls and ended in a square or at a crossroads. In Granada, due to the eccentric location of the great mosque (aljama), the true centre of communication was at the end of the main city street, Elvira Street, and a small square called Cuchilleros, which were joined by the Baño de la Corona bridge.

This spot continued to be very important until the end of the 15<sup>th</sup> century and would later be converted into a square called Plaza Nueva, which covered the Darro River. The communications within the city walls between the two banks of the Darro were established by

five bridges. One of main document in urban history of granada that known as “Plattaforma de Vico” or “Plano de Granada” dating in XVI century (Fig. 4). It is important to highlight that If we zoom in the image we can discover exactly our monument that at this time is already ruined.

The ruin of this arch starts on the North bank of the river Darro, the original structure should be crossing the river having his second point of support on the South bank. The red circle in the picture indicate the Puente de Cadi.

### The “Banuelo”

Situated near the Darro river in front of the Cadi (Fig. 6) and earlier known as the “Walnut Baths”, the structure may be considered the prototype of the public Muslim bath.

Its entrance had a patio and outbuildings used by the establishment’s keeper. A narrow doorway leads to a hall used traditionally as a dressing room, which is vaulted as is the rest of the construction, and which also presents the characteristic starred and octagonal skylights used for lighting and ventilation.

Next comes a long hall with dividers which served as a cold room, from which an axi-



Fig.8 – *The house standing over the ancient tower in the XIX century (David Roberts, engraving, 1832-34).*

al door leads to the warm room, the largest of all. There is a central covered area with a cloister vault and galleries on three sides over horseshoe arches with splendid capitals, most of which were borrowed from earlier constructions.

The hot room has a similar layout to that of the cold room, but it also provides access to the areas where the basins used for bathing were located. A central opening which was originally closed provides access to the oven room and the attendant's area where the fire was kept burning.

The floor of the hot room has the characteristic inferior hypocaust for the circulation of the furnace refuse which heated the floor and walls. It has been fairly well-preserved thanks to its solid lime mortar construction.

### **The Puente de Cadi**

This research is focused on the remains of a Moorish arch supported by a large tower that is part of the old Moorish walls of Granada (Fig. 7). The ruin of this arch starts on the North bank of the river Darro, the original structure should be crossing the river having his second point of support on the South bank.

It is also curious as in recent times the previous owners of the lot where the Cadi rises built a house over the ruin, but without hiding or changing its aspect (Fig 8). The result was a curious house standing over the ancient tower with a quite unstable look. However this house was demolished in 1920 and the re-

mains were declared a Historic Artistic Monument by the Spanish state in 1931.

Leopoldo Torres Balbás in 1934 provides a description which agrees with its current state. The tower is built with thick walls of rammed earth reinforced with bricks and stone masonry. The design of the plant has a hexagonal shape, long and narrow according to the direction of the river flow, sheltering inside two symmetrical staircases leading down to a door which communicates with the river, but this passage today is closed. Each of these stairs has a loophole for the defense on each side.

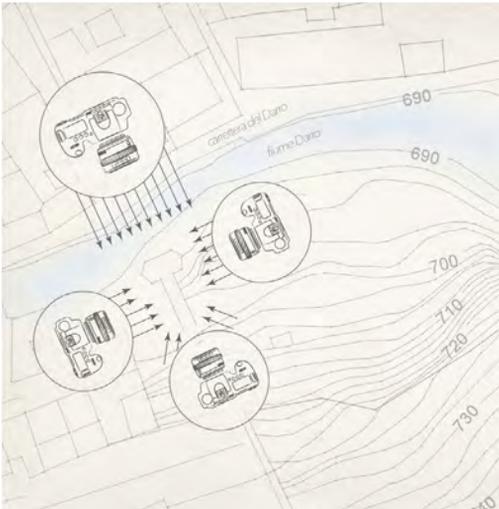
The whole tower has lost its original height, the house built over the top at the beginning of the century probably gave a contribution in the meaning of flattening the remains of this part of the tower, nevertheless it's quite clear that the height of the tower was already reduced at that time.

The fragment of the Moorish arch is built with blocks of sandstone, alternating outgoing and incoming segments decorated with floral motifs, and alfiz. Inside the arch there are two vertical boxes that correspond with the guide gates to close the river. The double guide gate might respond to the need to close the passing but not the course of the river, so a fence would be used, while the other is for a floodgate that could also close the flow of water, either for cleaning the channel either to inundate the valley, hindering a possible enemy incursion.

But little more is known about this gate, raising many unsolved riddles: how was the entire arc? What is the relationship with the other side of the bank? Is it possible to imagine another twin tower? Was this structure providing also access for people along the banks of the river? Was used also as a bridge? Let's see then if digital surveys can answer some of these issues.

### **The digital survey**

Because of the difficult access to the gate and according to the needs of this research the first approach to this building was mainly



photographic, and based on the direct reading of the masonry plot of the structure.

This was done trying to better understand the system of “traces” left in this building, in this way it has been possible to have a clear vision about the possibilities in the planning of its virtual reconstruction.

Since the first inspection of this fragment, the need of a complete and easy to use 3D digital model was immediately taken in count.

The choice to adopt a 3D Photogrammetric survey was done to allow an easy and quick

Fig. 9 – The camera’s position around the monument

Fig. 10 – The point cloud of the survey

Fig. 11 – The process from the point cloud to the 3D model





approach to the monument and its surroundings. So the specific photographic campaign about the Cadi, took care about crossing the river and taking a complete survey of the whole monument, even from the side facing the Alhambra hill (Fig 9).

The planning of this campaign was quite difficult, while the area of the monument is not easy to be reached, the private properties on the border of the river has no access to the Cadi and the very rainy period create two odd conditions: the Darro river in flood and all the plants and tree in a very luxuriance state. So we need to cross the river at an higher point along the canal and then climbing a part of the hill to reach the rear part of the Cadi.

The overall campaign produced a total of almost 6000 shots, all the shots were taken in raw format with a difference of 3 step of exposition, using different lenses stopping them down to have a convenient depth of field in each shot.

Most of the shots were taken on a tripod, in the most difficult positions it was preferred to reduce the working time handholding the camera. One of the main need was to have a good overlapping between the shots from the front, the sides and the rear parts of the building. Because of the idea for the further post processing was aimed to the use of

Fig.12 – *Digital model produced by photogrammetry: Perspective view with the full texture.*

Fig. 13 – *Digital model produced by photogrammetry: Front, top, left and right view.*

Agisoft Photoscan, the new campaign was oriented to produce set of shots optimized for the division in the so called “chunks” inside the software workflow. The possibility to reference different group of pictures into a single alignment creates a basic condition to allow this kind of operation. The group of pictures coming from the front, the sides and the rear parts of the Cadi were aligned into an unique model.

This process took time and long calculation hours, the alternative should be the exporting of single parts to other alignment software to complete the work, but completing the whole task in a single software was in certain way more interesting in the meaning of a better exploitation and exploration of its possibilities.

The first step for the digital process, is to create a point cloud: the point cloud represents the set of points that the software has measured on the photos. As is possible to see from the picture (Fig.10), the result is a really dense point cloud and its already possible to recognize the details of the monument.

The resulting 3D mesh-model was very high quality with a meshes created at the maxi-



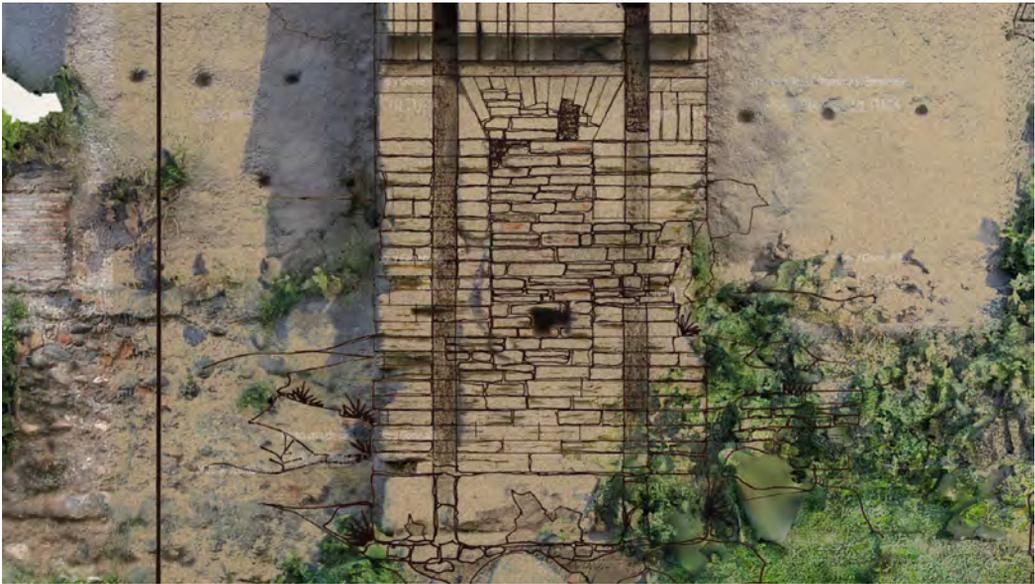


Fig.14 and Fig. 15 – Comparing the previous traditional surveys available in the Alhambra archives with the new digital survey.

taking the advantages of a more complete and versatile set of options for the whole post processing sequence.

The final model, usable for analysis, reconstruction and study was made by 70 million faces, so it is not a model easily usable for multimedia and or real time purposes, but it was characterized by a good balance between quality of the architecture details and the pos-

sibilities to operate with reasonable quickness for the virtual study of this ruin (Fig.11).

The last operation of the digital process is to apply a texture map to the surface of polygons. This map is made by creating a mosaic from all the pictures that we used for the survey campaign.

During this process, it was necessary to build a correct UVmap and the final result is a texture with 268.000.000px (Fig.12 and Fig.13). One of the first use where this accurate model was applied was a simple compare with the

previous traditional surveys available from the Alhambra archives.

This set of drawings were a good documentation about the Cadi ruins and are mainly dedicated to the arch in its front over the Darro river and to its side fronts, in some of these drawings, the presence of overlaid curves, tracing the prolongation of the arch remains makes the drawing even more interesting, showing previous basic investigation processes about the original shape of the arch.

As usual in this kind of drawings, there is a very good graphical quality and all of them are very similar each other, both because the accurate work and the common behaviour to use a previous survey as a base for updates or detail enhancement.

To start a comparative test between the old drawing and the new survey, some selections were in need to be done. First of all a group of drawings was selected according to the presence of a clear metric reference, in this way any risk of error in the scaling process was reduced, then the drawings were compared to check the presence of meaningful differences. In the end, the drawing catalogued as P-000550 (Alhambra Archivo de Planos scale 1:20, author: Pietro-Moreno, Francisco, 1934) (Fig.14 and Fig. 15) and the survey of Arch. Antonio Almagro, LAAC, were chosen for the matching with the new digital survey.

Those simple matches between images was based on the drawing scan and on rendering images produced from the 3D digital survey model, the mode option for each layer where the images were placed allowed obtaining a map of the differences between the old drawing and the renderings.

As expected, the differences were quite modest and not meaningful in front of the state of the knowledge about the Cadi, except for the fact that, with this result, the quality of the old drawings was confirmed, but also the new survey get is final validation for the following steps of the research.

### **The geometric reconstruction of the arc**

As it is common for any historical town, Granada changed a lot along its history, so the ruins of the Cadi now rise with a very transformed context, where sections, paths, levels, buildings have a quite different condition in front of the time of this element construction. So the best thing is to start from the more "solid" evidences coming from the architecture element in itself. As done in the ancient drawing the first process must take care about the main arch, trying to find back the main lines of the missing part of the Cadi. The first reconstruction process was done as a 2D drawing, using a vector layer over a high resolution rendering image produced from the 3D digital survey model. The tracing of the arch was focused on the best fitting of the curvature and checking it back to the "ideal" Moorish arch construction.

The overall process of reconstruction was based on few steps:

- 1). The curvature of the arch is found starting from the traces along its remains in the ruins, this was done using a simple three points arch, identifying a single curvature, in this way it was found a first axis crossing the center of the arch. All the lines generated by the lengthening of each single stone are then projected to the axis.

- 2). Discretization based on the interpolation of the lines coming from the stones, optimization of the curvature according to the new centre and the arch ruin profile.

- 3). Definition of a mirrored set of lines and curves, tracing of the second arch.

- 4). Check of some measurements according to cubit units.

- 5). Optimization of the suggested reconstruction according to the cubit units.

- 6). First definition of the theoretic model of the symmetric Cadi.

- 7). Confrontation with the actual section crossing the banks.

- 8). Completion of the theoretic model.

9). Cubit unit grid aligned on the theoretic model.

10). Final adjustments and optimization of the proposed model according to the cubit grid (Fig. 16).

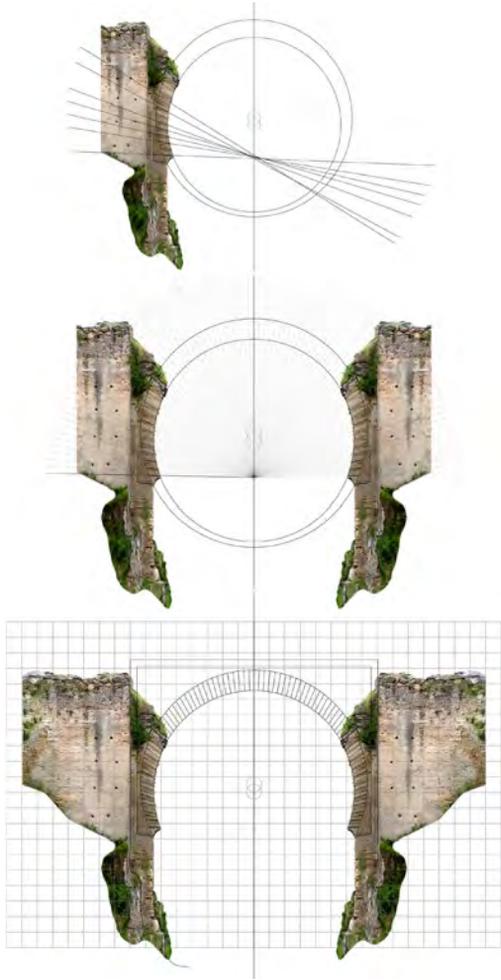


Fig.16 – Graphic scheme of the geometrical reconstruction of the arc

The best fitting grid is based on the cubit measurement unit, adopting 1 cubit equal to 64 centimeters, this creates a main grid made of 21 cubits along the height of the tower, 35 units along its front, according to this grid the arch was 15 cubit large (external profile) and 11 cubit from its impost to the keystone. Extending this grid it is possible to imagine the original aspect of the tower and starting to develop reconstructive hypothesis.

Completing the grid according to a symmetric choice, the plot of the arch come out clear, showing a massive construction, with the second tower meeting the opposite side of the river.

The remains of the arch allow the reading of the original shape, it is clearly an Horseshoe arch, very typical in the Moorish Architecture, this is proved by the angle and curvature of the inner arch profile and by the external, interior profile, defined by the stones and having a divergent curvature as is classic for this architectural element.

### Conclusions

One of the most meaningful result in the geometrical reconstruction is the fact that the second side enters the actual river bank, close to the buildings.

The bank has seen various changes in time and now but, by drawing an imaginary line along the natural direction of the road, it's possible to see that the second part of the arch is exactly along this line.

Along with the archival research, it has been of fundamental importance the collaboration with the LAAC (Laboratory Architecture and Archeology of the city) and in particular with Prof. Julio Navarro y Palazon.

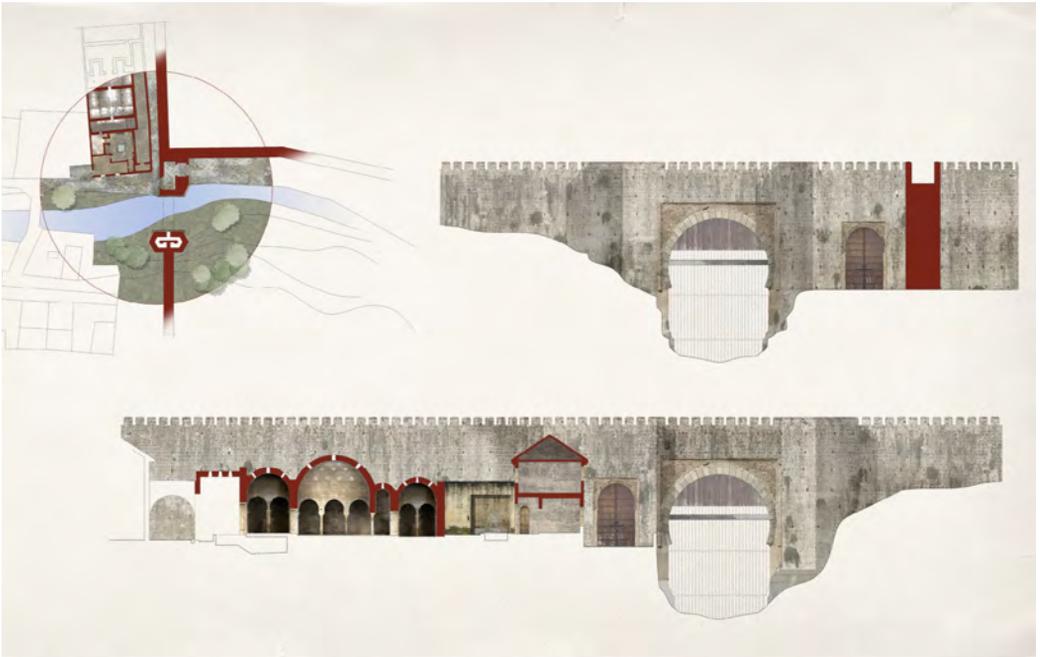
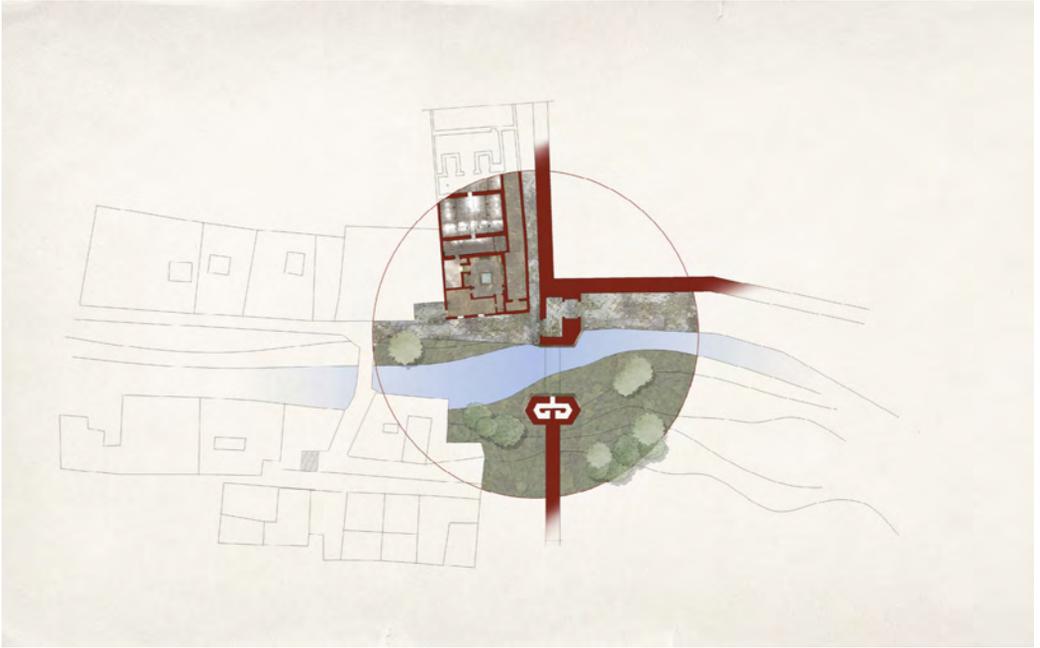
This has made possible to identify and develop a new morphological hypothesis related to the presence of the Arab baths in this area.

So it is possible to imagine the Cadi as a part of a defensive system composed by a double door protecting the urban area, closing the flow of the river and defending the town from possible opponents coming along the banks.

Studying the aerial images of the area it is possible to notice a system of ancient walls connecting the Cadi structures to the main Alhambra fortress, this obviously gives even more meaning to this ruin, opening further questions about the construction sequence and the overall urban system.

This complex set of questions needs well structured information to base hypothesis and enhance the knowledge about these ruins.

An accurate survey is, as it has been



demonstrated again here, the best base to start organizing information and to focus on an “architectural” reading of the remains, spotting on the relationship between urban settlement, logic of the fortified architectures and environment.

While the digital approach to the reconstruction confirms one more time its

Fig.17 – *Graphic reconstruction of the ancient aspect of the area, with its road and the particular relationship with the river Darro.*

Fig.18 – *Hypothetical reconstruction of the entire complex at the time of its completion.*

importance and its capacity to be one of the best “melting” space between evidences and new ideas.

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