Mediterranean Arhaeology and Archaeometry, Vol. 12, No 1, pp. 31-41

GEOTECHNICAL AND METRIC ENGINEERING APPLIED TO BUILDING OF A ROMAN VILLA IN THE VEGA OF GRANADA (SPAIN)

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Received: 6/06/2011
Accepted: 24/10/2011

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ABSTRACT

The excavation of a Roman *villa* in the city of Granada (Andalusia, Spain) has provided major information about the use of geotechnical principles and methods of building a house in the 1st century A.D. The study of the building techniques shows that the inhabitants of the Granada basin had ample knowledge of architectural engineering and its relationship to the geologic characteristics in the area of Granada.

This knowledge was applied by architects to the foundations of buildings to prevent natural risks, mainly rainfall damage to unstable geologic material, a shallow phreatic level, and periodic floods. The architectural design was adapted to these considerations although the building studied is a simple house, more similar to the *pars rustica* of a *villa* than a luxury *villa*.

KEYWORDS: architectural foundation, engineering, geology, Roman period, stratigraphy.

1. INTRODUCTION

The Vega of Granada is a cultivated area that extends over the alluvial plains of the Genil river, and it is surrounded by hills that provide erosive materials and others coming from the periodic overflows of the rivers and streams. These features imply a fertile land with strong farming potential, having a large volume of superficial and underground water furnished by the thaw of the snow on the Sierra Nevada (3482 highest altitude), with many natural springs. The water abundance allowed the irrigation of fields in a natural way, and during the Moorish period the irrigation was organized by means of channels gathering the water from the natural water courses (Fig. 1).

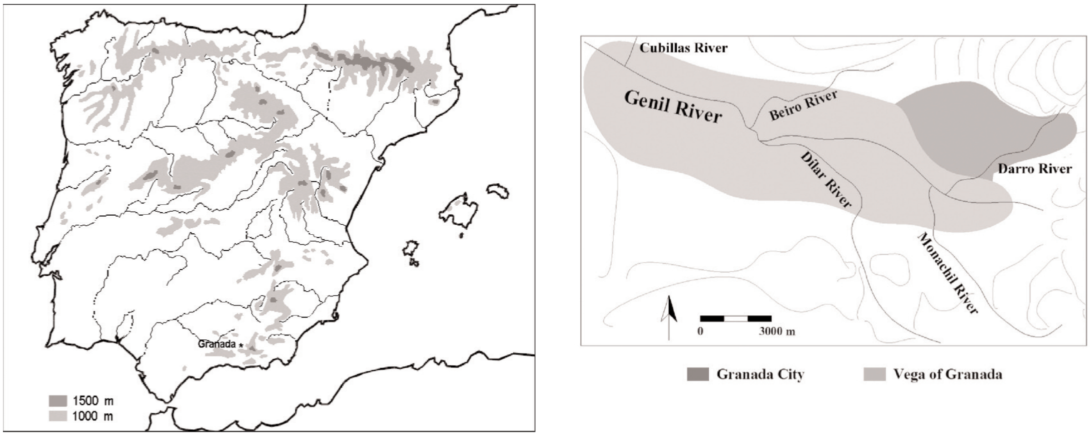

Figure 1. Location of the Vega of Granada.

The farming of this vega was the origin of richness for Iliberris (the Roman name for the city of Granada) from the 1st century B.C. In this period, this area was surrounded by many *villae* exploiting the farming and livestock resources, and located on the edge of a Roman road crossing the entire vega to move the surplus to the Mediterranean coast and to the Guadalquivir River Valley, and connecting with the trade network of the Betic Roman province. During the 3rd and 4th centuries A.D., major economic changes took place due to the crisis of the city (3rd century A.D.), so that some agriculture disappeared, weakening the economy linked to the *villae*. The inhabitants left several buildings, and the remains were used as a burial area during the 4th and 5th centuries A.D., but their ruins remained close to the roadways as previously done in the villages. At present, there is a network of cattle roads named “Cañada Real” surrounding the vega from ancient times near of the location of another known Roman *villae* of this area, and probably constructed over a Roman road having similar features. These *villae* show the same features as others of this period: first occupation in the 1st century B.C., the orientation of its buildings and the use as burial in the 4th century A.D. From then one, silt from floods filled these constructions, that no longer had the same entity that in the past, and the drainage systems were not maintained, causing remains of the Roman period to disappear from view, and this area was used for agriculture for almost two thousand years.

2. MATERIAL AND METHODS

The excavation of an old bus station of Granada (Andalusia, Spain) has yielded important documentation of a Roman *villa* buried under three meters of sediments (Navas, 2008; Navas et *alii*, 2009). The architectonic remains belong to two occupational phases. The first phase contains pottery remains that offer a relative chronology of the 1st century B.C. (Navas et *alii*, 2009). The building was erected over hard foundations, having thick perimetric walls, 1 m wide, with other orthogonal inner walls forming four rooms (Fig. 2). Two construction phases were registered inside the rooms, these having two paved surfaces of different depths. The old pavement was buried due to any periods of flood that deposited a 10-cm layer of lime and clay.

Figure 2. Map of the different rooms.

Three meters from the building, outside, a channel at least 15 m long was constructed with bricks and grey mortar. This channel runs in an East-West direction with a slight slope towards the West, is paved with small stones, and has three minor shallow channels ending in the previous one. These channels were a drainage system for rainwater to a site to be used. (Fig. 3). Rainfall was presumably the only water source because there were not fountains, as this was the starting point for the system with a shallow water sink (10 cm deep). Also, many small channels and streams of water drained from the main channel

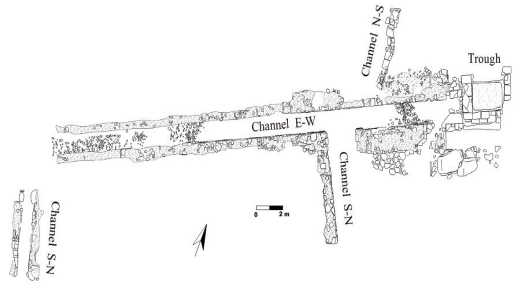

Figure 3. Structure of channels to direct the water.

The second occupation phase took place in the 4th century A.D.: the building was abandoned by the inhabitants and the rubble was used to build eight inhumation burial tombs embedded in the walls. The tombs are dug into the perimetric walls with a west-east orientation (the heads of the dead are oriented to the west with the feet to east). The most important feature is the west-east orientation: most were constructed perpendicular to the perimeteric walls, so that the orientation was maintained, but where the perimeter changed direction, the tombs were constructed in parallel to maintain the east-west orientation. This feature corresponds to cultural reasons, but the different authors do not coincide between them. A discussion appears in the second paragraph of conclusions in the article Navas et al., (2010) Note that in one case, a tomb is linked to another one having the head of a skeleton aligned with the feet of the other skeleton. Inside the rooms, no tomb was built (Fig. 4).

The architectural design of tombs is composed of a gable roof of tegulae with no pottery marks, but tombs for infants were constructed reusing tegulae that had semicircular pottery marks. Each tomb had a

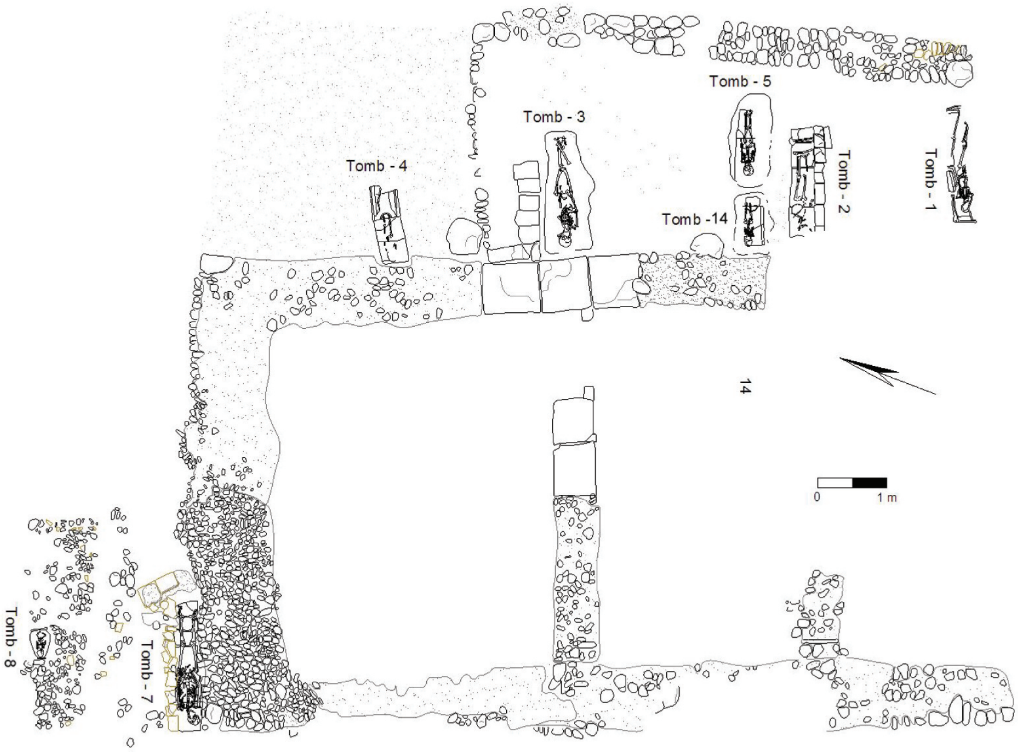

Figure 4. The tombs are located embedded on the external walls.

small plot of land sourrounding it, well delineated by means of pavement with different surface treatments, some apparently used as lanes. Also, it is worth highlighting the use of a small wall and four great stones as architectural features to delimit of the burial spaces.

All the individual tombs contained women or pre-pubescent child remains, this perhaps belonging to a burial area for women and children, whereas the scarce remains of men appear in a communal burial. From an anthropological view, the women do not have their full set of teeth, and existing teeth show a heavy wear, including the complete alveolar bone loss. The teeth of the children have an irregular trait called Carabelli's tubercle (see Navas et al., 2010). With these results, we hypothesise that the people buried in this necropolis belonged to a group with family relationships in varying degrees.

3. STRATIGRAPHICAL ANALYSIS

The information gathered by means of stratigraphic analysis point to different flood events with great quantities of clay alternating with farm soils and rainfall deposits. The width of the layers of silt exceed 1 m, for two major reasons: the increasing deforestation of the hills sourrounding the vega due to the farming of these lands, and the periodic overflow of the Darro and Genil rivers. These features show the consequences of human activities for the natural landscape and the construction of foundations to avoid these natural risks.

The stratigraphic profiles show a sequence of seven stratigraphic phases, enabling us to reconstruct the natural processes that followed the abandonment of the site. This sequence consists of seven stratigraphic phases from the natural layers prior to the Roman occupation to the pres ent time, indicating two major groups. The first group comprises the strata of natural origin, these being the deepest and composed of several soils of organic materials and alluvial deposits, of grey-brown color due to sediments from the near hills, composed of construction materials, ceramic fragments, and fauna remains of small size (Fig. 5).

The second group is shallow, with modern human alterations and having accumulations of recently dumped materials, mainly construction rubble originated from ambitious projects to expand the city in the 19th and 20th centuries, wielding great impact on the vega of Granada. In the shallowest layers appears material remains from the Roman period as gritty flagstones, *laterici, tegulae and imbrices,* having inverted stratigraphic features. These soils are very different from the previous ones due to the different materials used.

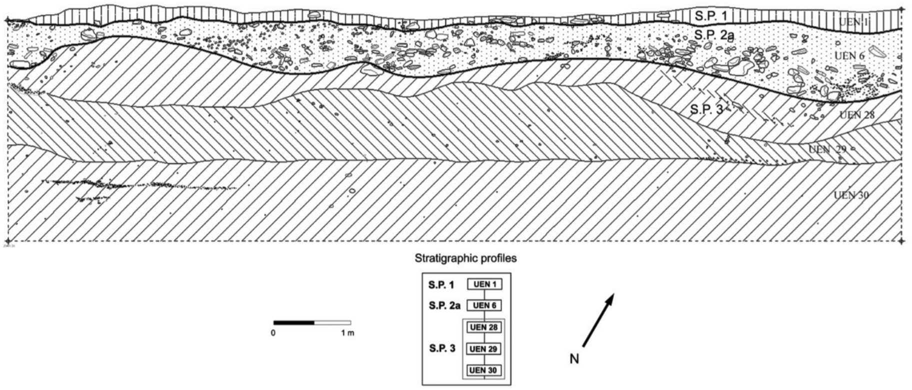

Figure 5. Stratigraphical profile showing the stratum with natural origin.

4. CONSTRUCTIVE TECHNIQUE

The engineering technique applied to build this Roman villa is based on the accommodation of the entire area occupied by the building to construct the foundations by means of a great slab 1 m deep occuping the entire surface. The original natural space had vanished, being filled in with five layers of stones alternating with layers of sand. The two most shallow layers of sand contain a small quantities of mortar composed of sand and lime, having a rosy colour due to the presence of small pottery fragments.

The uppermost layers contain stones 40-50 cm long, rounded by the erosion, but the other layers are composed of smaller stones 20-30 cm diameter with stones of great size located in the corners to reinforce the structure. The most superficial layer of stones is the beginning of the walls (Fig. 6) by means of a soil 3 cm wide of yellow mortar composed by gritty sand and lime, constructed using the entire surface and including the surface under the walls that divide the inner rooms. Next, the walls are preserved only to 10 cm high, and the perimetric walls are about 95 cm wide, built with stones 10-20 cm in size mixed with rosy morter. The inside walls subdivide the inner zone of about 60 cm wide, finished off by great slabs of gritty stone about 60x80x20 cm. (Fig. 6 and 7).

Figure 6. Image of foundation platform.

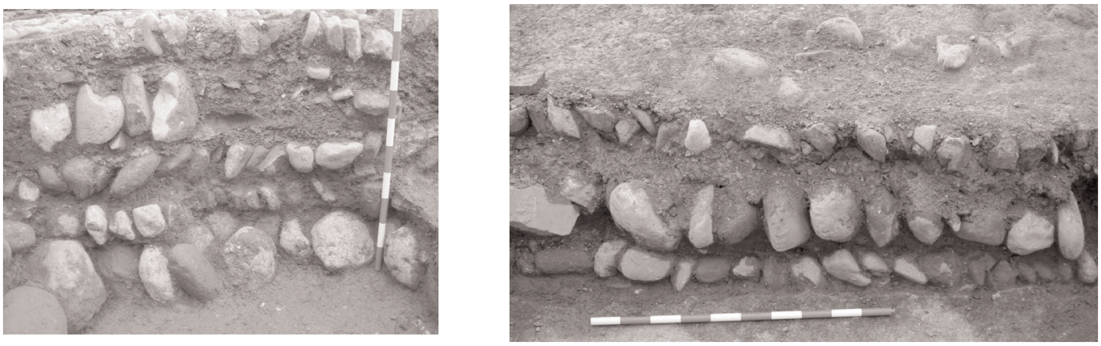

Figure 7. Foundation platform showing the different constructive layers.

Small walls about 60 cm wide and finished off by large sandy slabs about 60x80x20 cm divide the inner zone, forming rooms with similar areas. This area is waterproofed by a layer of rosy mortar composed by opus signinum poor in lime using the half-cane system from the base of the walls. Therefore, this construction system provides a foundation slab resistant to the unstable land, isolating of the moisture because the phreatic level is very shallow in the vega of Granada, and allows the construction of high and wide walls, and heavy roofs. The surface of the foundation is not constant: 11.50x10 m^2 for room 4 and 11.50x6.6 m^2 for rooms 1-3. Also, the N-S perimeter walls do not communicate with the outer zone, indicating that the building has a southern orientation and probably did not have a preserved entrance at this site.

5. GEOTECHNICAL FEATURES

This building, located very near the city and next to a major provincial road, was built in the 1st century B.C., maybe for the exploitation of its rich agricultural potential, but this zone and others similar to it were periodically flooded, requiring great effort to establish profitable lands. Probably, the builders knew the risk of building an architectonic structure over a floodplain with abundant rainfall and voluminous thaws that caused the overflow of the Genil river and other streams flowing into the Genil. This situation raised the phreatic level and produced flooded zones in the land. Therefore, the builders used geotechnical methods and other techniques such as drainage to control the phreatic level, channelling the shallow water or constructing a channel with a stone bottom to avoid the growth of the vegetation that might inhibit the flow of water (Fig. 3).

On the other hand, they could take into accout the risk of earthquakes. We know that the seismicity in the vega of Granada was presumably low in magnitude; according to the data of the Andalusian Institute of Geophysics of the University of Granada, the maximum Ritcher scale magnitude in the period 1955-1999 was 5.1, with only three events in the 4.58-5.10 interval (Morcillo and Esquivel, 2004).

Also, the great walls of the building are oriented south-north for good illumination, as well as for avoid the heatstroke and obtain temperature regulation. In this sense, the width of the walls insulate against the heat and moisture (see Fig. 6 and 7). However, the main drainage channel is east-west, following the level change, carrying the shallow waters to the river Genil. This river receives the flow of smaller channels, storing surface water of the local environment in different directions, forming a complex network of arid land.

Probably, the builders had to make a previous study of the floor and of the underground, keeping in mind the characteristics of natural substratum to design the foundation, this being as important as other architectural elements such as the roof or walls (Fig. 6 and 7). In this way, the edifice was built over a great slab as a transitional element between the substratum and the architectonic structure, thus supporting the stress of the loads and avoiding possible deformations provoked by the differential settling of the land. This slab was constructed as a great platform excavated in the terrain and filled with materials from the environment, using the land as the basic construction material to lay hard foundations and thus establish stable and settled structures. The great slab transmits the loads vertically and horizontally throughout the entire platform, providing strength and rigidity to the materials in order to support the construction of high walls and heavy roofs, thereby achieving great stability.

The form, size, and depth of the foundation are related to the soil mechanics and foundation design, rendering a structure stable and well-levelled without deformations, fissures, waves or cave-ins. This construction system was time consuming in terms of land preparation.

The materials used in the foundations were earth materials and boulders (mainly quartzite with some marble and schist blocks), providing the basis for structures and pavement. The stones were set with great care to achieve the necessary compactness, thus avoiding changes in volume and stress caused by the architectural loads (Fig. 5). Techniques such as alternating layers of sand with layers of stones, the addition of mortar in the shallow layers, and the application of *opus signinum* from the basis of walls provide effective waterproofing. Finally, the quartzite blocks are located at the base, reinforcing the corners and providing strong resistance against loads.

6. ARCHITECTURAL METRIC PARAMETERS

Architectural metric parameters provide important topics for analysing the architectural design (Esquivel, 2008). From prehistory, the use of metric and geometric concepts to build huts has been known in Andalusian settlements of the Chalcolithic period (Esquivel & Navas, 2005; Esquivel & Navas, 2007) as well as the protohistoric period (Esquivel, et al, (2010). In this *villa*, the architectural walls design has two phases. The first phase involves the central rooms of the remains of the *villa*, and in the second phase a room added collaterally to the wall, oriented eastward, and differing architecturally from the earlier walls.

The first phase comprises the construction of two thick parallel walls that form the frame on which two orthogonal walls with less thickness are built, thus shaping rectangular rooms. From a random sample of width in each of the transverse walls (Tr1 and Tr2), the Levene test shows no statistically significant differences between the variances of the two data sets (F=1.792, p=0.202). The application of the t-Student test for independent samples with equal variances indicates no statistically significant differences between the mean width of the two transverse walls at significance level of $\alpha<0.05$ (t=1.037, p=0.317). However, the Tr2 wall shows greater variation (Fig. 8), perhaps because its materials have less width without great sandy slabs as in Tr2 (Fig. 2), and therefore underwent greater deterioration.

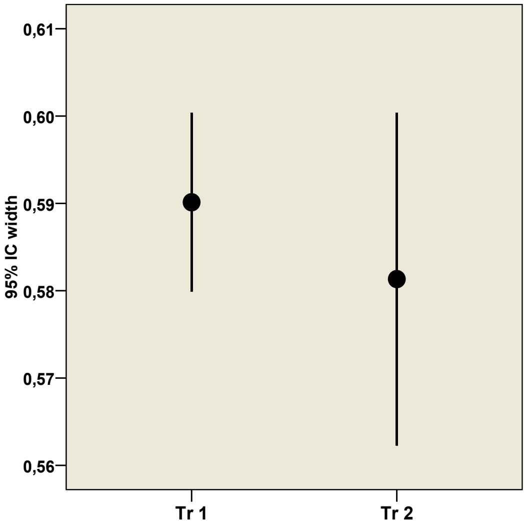

Figure 8. Width of transverse walls using the 95% confidence interval.

This result allows an estimate of the mean width of the two transverse walls by means to the expression (Sokal & Rolf , 1982; Venables & Ripley, 2002):

$$m \in \left(\bar{x} - Z_{\alpha} \frac{\sigma}{\sqrt{n}} , \bar{x} + Z_{\alpha} \frac{\sigma}{\sqrt{n}} \right) \qquad (1)$$

where m is the mean of the population, n the number of elements, σ the standard deviation in the sample and Z_a the Z-value belonging to the normal distribution N(0,1) that corresponds to the selected level of significance α. Using a significance level of $\alpha<0.05$, the resulting mean confidence interval is (0.5780,0.5945) meters, being 2.88% the coefficient of variation

$$CV = \frac{\sigma}{\bar{x}} \qquad (2)$$

(Sokal & Rolf, 1982; Venables & Ripley, 2002), thus indicating the skill of builders to maintain the same width in both transversal walls.

The large parallel walls are oriented in a north-easterly direction, showing some differences in width. For random samples of the width of the 1a and 1b walls, the t-Student test (the previous Levene test shows that the variances of 1a and 1b are equal, F=1.841, p=0.193) indicate that the mean widths statistically differ at $\alpha<0.05$ (t=17.198, p<0.001). The repetition of this process in 2a and 2b walls reflect no statistically significant differences (t=0.628, p=0.605) between the two walls. However, the features of the great wall to the north markedly differ from the previous ones. For a random sample of widths belonging to the best-preserved parts, the result is x=1.267 cm, σ = 0.05, CV=3.9% and the confidence interval $\bar{x} \in (1.236,1.298)$ with $\alpha<0.05$ significance.

The ANOVA test shows statistically significant differences (34 cm) between the great wall and the other large walls (walls 1a, 2a and 2b) (F=403.9, p<0.001) (Fig. 9). The excavation showed that the northern wall belongs to the same constructive phase that the others, therefore these results indicate that the metric features are different to the other, perhaps for being located to the north it was more exposed to inclement weather, protecting the entire village from the cold

7. CONCLUSIONS

In the Roman period, the Vega of Granada was flooded almost entirely, and the construction of buildings posed great difficulties for drying out the land and preparing the new land for agriculture. The Romans appear to have been pioneers using these techniques in the Vega of Granada. Run-off was frequent, and the growth of the city in the 1st Century A.D. caused deforestation and the removal of the plant cover, perhaps for the cultivation of olive trees. Stratigraphic analysis shows many flood periods with sediments of up to two meters deep over 2000 years, implying that the builders of the Roman villae had to deal with frequent floods and the high phreatic level. The farming in the Roman period must have been a major economic resource, given the quantity of archaeological remains of villae with the same chronology of occupation and withdrawal, reflecting a similar operation system.

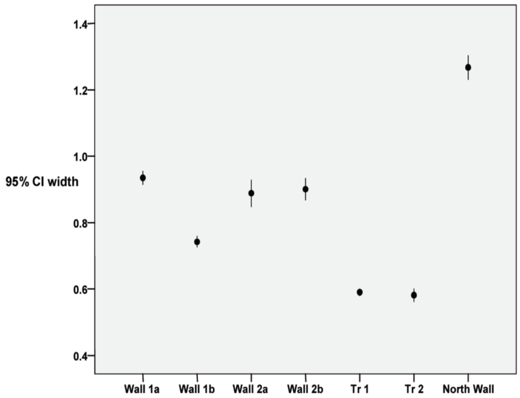

Figure 9. Mean width of walls using the 95% confidence interval. The North Wall is greater wider than the others (see text for details)

The special features of the Vega of Granada during the Roman periods, such as flooding, run-off during rainfall, and the frequent moderate earthquakes require a consistent but flexible construction with good foundations. Furthermore, this foundation system implies substantial geological knowledge and prior work to adapt the land. Also, the construction design included a great slab to provide stability to the building, with large, heavy stones placed in the corners to reinforce the structure, so obtaining great stability.

The metric results point to careful planning to avoid further damage. The main wall is located on the northern side to protect the smaller walls, almost 35 cm thinner than the others and twice the thickness of the transverse walls. The inner transverse walls are almost 60 cm wide, a usual thickness for this culture. The metric features of the walls create floors with rooms that provide more habitable surface area and effective insulation against moisture and cold.

Finally, all the architectural features point to a thorough knowledge of the local geology and meteorology, as well as the geotechnical and the engineering principles to reduce the weathering and seismicity risks. These features were common to all the Roman villae in the Vega of Granada, probably pointing to professional builders with extensive architectural and geotechnical knowledege, probably commissioned to construct, and belonging to a guild having these skills.

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