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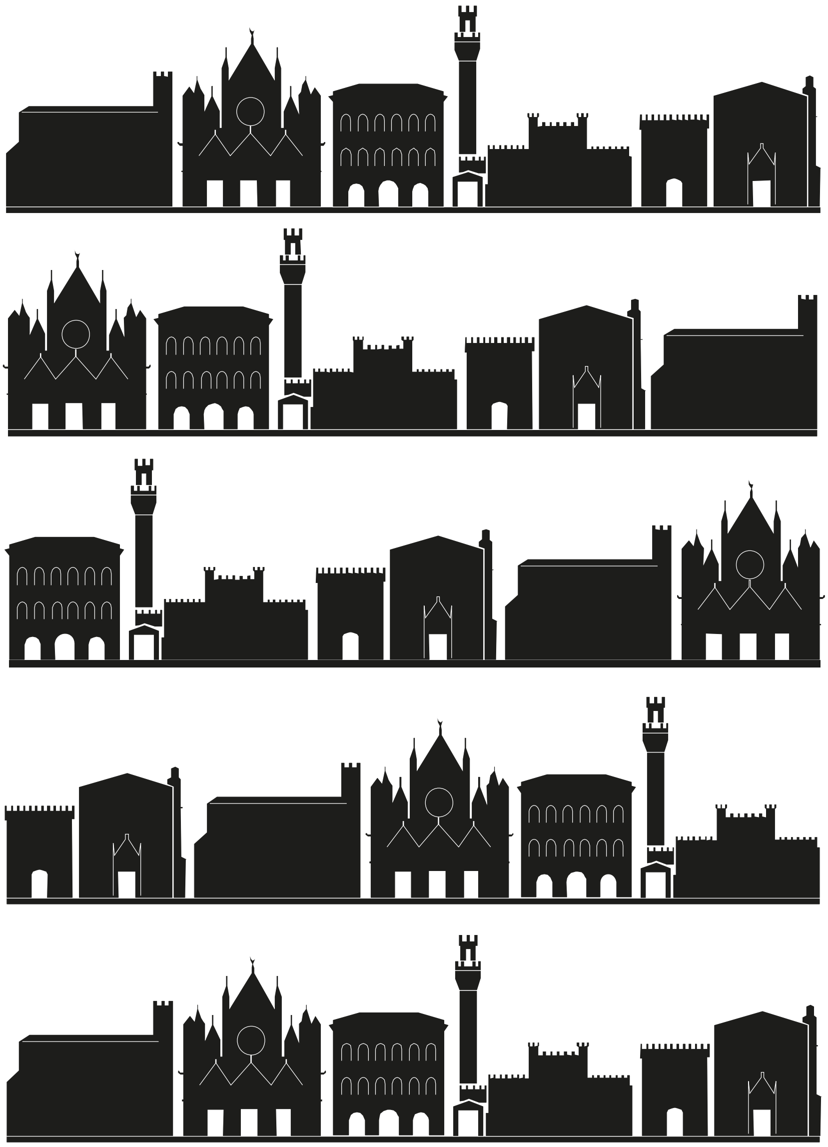

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Computer Applications & Quantitative Methods in Archaeology

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Pompeii, the Domus of Stallius Eros: a Comparison Between Terrestrial and Aerial Low-cost Surveys

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Abstract: The European project 3DICONS enabled the acquisition of numerous architectural and archaeological assets. Different large models were acquired in Pompeii, in particular the work focused on lesser-known archaeological areas, but equally relevant for the analysis of different masonries and stratigraphical superimpositions. Among these areas, special attention has been given to the house of Stallius Eros (Regio I, Insula 6, 13–14), which contains a rich vertical stratigraphy covering a wide chronological period and offers interesting information about the development of this part of the ancient city. In order to provide a more complete and accurate digital replica, the use and integration of two photogrammetric approaches were used to evaluate the accuracy, efficacy, and velocity of the techniques. After surveying the domus using a total station, two interventions, by close-range and aerial photogrammetry, were carried out at two different times to generate a 3D high-resolution model of the ancient house.

Keywords: Pompeii, Close-range photogrammetry, Aerial and terrestrial surveys.

1 Archaeological context

In a report on the works carried out in Pompeii, Maiuri (1929) described with great accuracy the Domus of Stallius Eros (Regio 1, Insula 6, 13–14) excavated in 1926. He analysed the rooms by defining their probable function and created a map of the house, characterized by perimeter walls with different alignments compared to the adjacent houses. Unfortunately the archaeologist, and superintendent at the time, gave no information concerning the stratigraphy of the building.

The Domus of Stallius Eros was included in a group of 30 so-called 'atrium houses' in the framework of the project 'Pompeian Households: An On-line Companion' (Allison 2004). Regio I, with the exception of three large residential complexes—the House of Citharist (I, 4.25), the House of Menander (I, 10.4) and all of Criptoportico and Sacello Iliaco (I, 6, 2–4)—contains buildings of medium size and the best known and preserved manufacturing facilities in the city, in large part built between the second and first centuries B.C. (Pesando and Guidobaldi 2006).

The troubled life of the house of Stallius Eros is clearly visible in its walls. The oldest building techniques alternate with newer masonry, emphasizing changes of use in some rooms and numerous restorations in ancient times. The general layout of the house and the presence of some important constructive techniques among the oldest (*opus quadratum* and the so-called 'Opera a Telaio') in the perimeter walls, indicate a kind of 'frozen' structural domus of the Samnite period (Fig. 1).

According to Maiuri's hypothesis, the domus was completely ruined before the final eruption of Vesuvius. He concluded that the large pile of sand in the rooms around the front hall had rendered this house uninhabitable and indicated that it had been adapted as a private storage area for building materials.

Under the layer of pumice stone, caused by the eruption, there was a dark deposit (as described by Maiuri and only documented in photographs of the excavation taken at the time), representing the state of abandonment of the house before the eruption. According to the final report made by Maiuri after the excavations, room 3 was inaccessible at the time of the eruption. It had been closed for some time and made inaccessible, but Maiuri claimed he found building material in it from adjacent houses that were rebuilt. As in the hall, however, this room also contained finds that may have fallen from the top floor. The relationship between the inaccessibility of this room and the building material (Allison 2004) remains unresolved. The garden area (room 13) was decorated with Fourth Style garden scenes, consisting of various trees and other plants and sphinxes on pedestals, above a lattice socle interspersed with flowers; today the painting has almost completely disappeared.

After excavation in the 1920s, no other in-depth analysis has been undertaken in this area. In the last months, the study of the house has been included in the framework of the 'Grande Progetto Pompei', mainly within the framework of 'Piano della Conoscenza, which is largely based on a 3D survey of Pompeian monuments and on the analysis of the state of conservation of all private and public buildings.

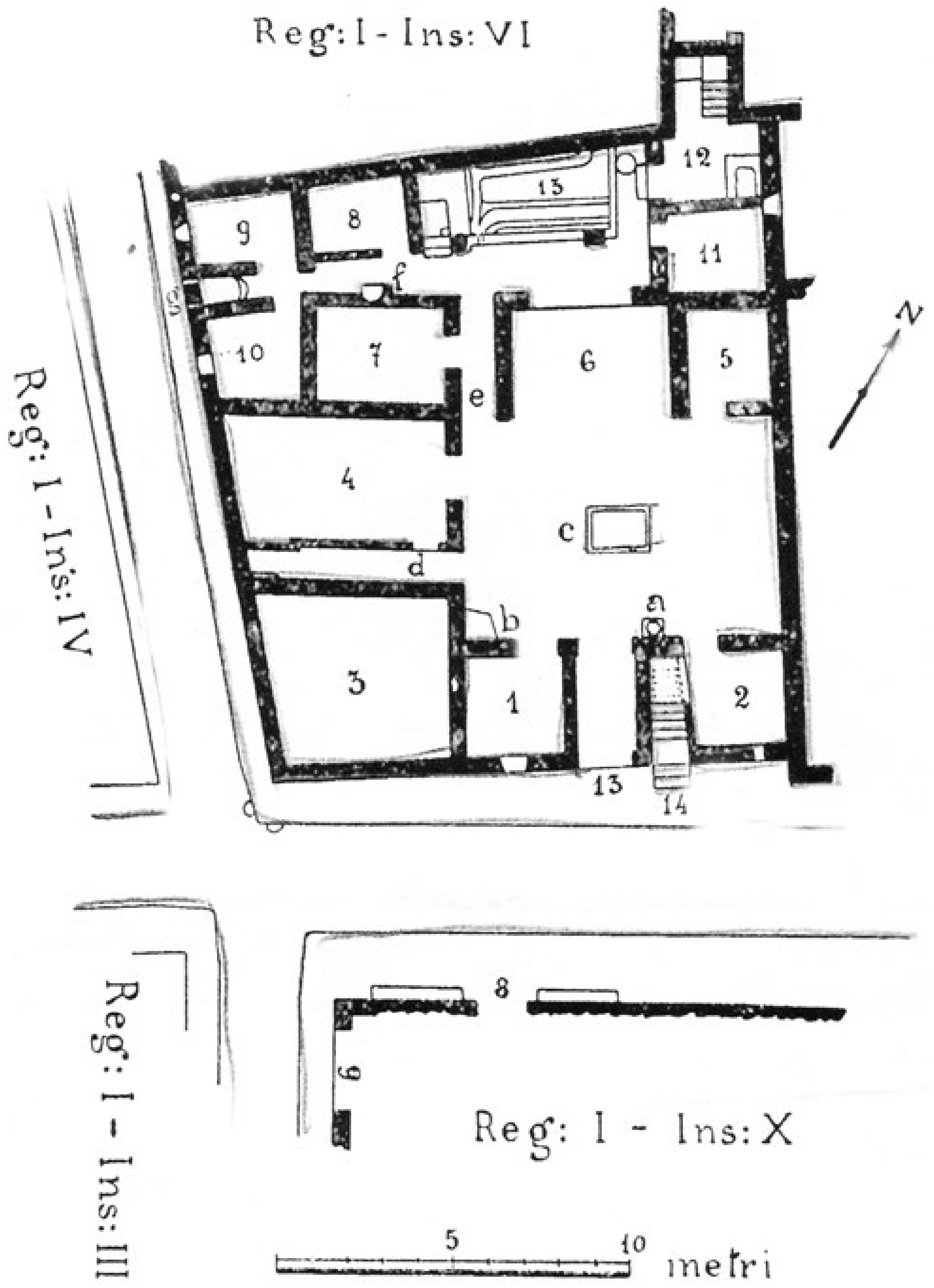

Fig. 1. General map of the house after the 1929 excavation.

2 The surveys

The survey operation was linked to the task of cleaning the domus organized by the University 'L'Orientale' of Naples, directed by F. Pesando, in June 2014. The work consisted in the removal of the modern surface stratum and in analysis of the wall stratigraphy, which is the only available data for the interpretation of the evolution of the layout and, therefore, of the house until the time of the eruption. The domus has a very high perimeter structure, in some parts reaching more than 6 m, and many rooms showing well-preserved internal walls.

In a previous paper (Bosco *et al*. 2015) we showed the survey of the domus by total station and the comparison of this updated map with two 3D models created by aerial and terrestrial close-range photogrammetry (Remondino 2006)

The surveys covered an area about 300 m^2. The 3D final replicas, obtained by close-range photogrammetry, were scaled according to ground control points measured by total station. For the terrestrial model five GCPs were used with a final error of 0.0039 m and 0.801 px. Five GCPs were used for the aerial survey. Due to the ground sample distance, the final error, as predicted, was also higher than the terrestrial survey: 0.370 m and 3.479 px.

Finally, all three surveys (by total station and close-range photogrammetry) were aligned and superimposed in order to evaluate possible differences and variances.

Detailed photo-plans of the walls of each room were extracted from the 3D replicas. This 3D documentation allowed a complete archaeological cataloguing of the walls and provided a basis for the accurate analysis of the structural and decorative decay. This work proved crucial as just after the archaeological campaign, the house was closed to the public and researchers for the reclamation of the area.

The paper focuses on the comparison between the models carried out by aerial and terrestrial close-range photogrammetry. In particular it shows the analysis produced by CloudCompare (www.cloudcompare.org) to test the reliability and accuracy of the two approaches considering the structural study of the building. For these reasons the paper deals with the verification of the accuracy of the two models in order to identify possible vertical decay as bulges and cracks.

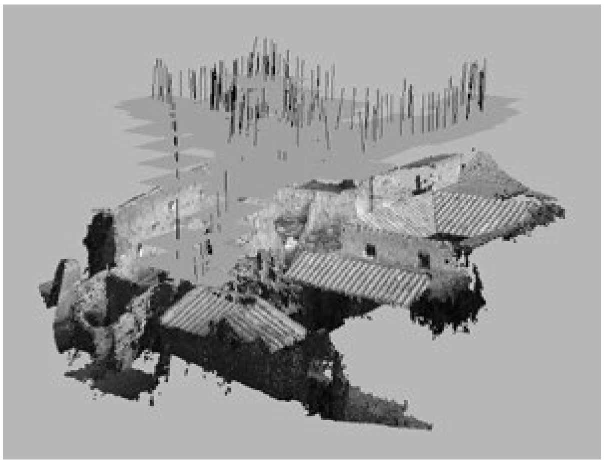

Fig. 2. Location and direction of the photos for the 3D model acquired by drone.

3 Data Acquisition and Post-Processing

About 1500 photos were taken for the terrestrial data acquisition with a SLR Nikon D90 (CMOS sensor APS-C 23.6x15.8 mm; max. resolution 4288 x 2848). The lens used was an AF-S DX Nikkor 18-55 mm 1:3.5-5.6G VR. The process took a few hours and the work of two operators. The distance between the operator and the surface to be scanned was not constant due to the irregular layout of the house, and the pictures were taken parallel to surfaces and around the internal structures at different heights by using a 5 m pole as a support for the camera. Moreover, a panoramic and a closer shot were taken in succession in order to obtain the largest image coverage possible and in the smallest detail at the same time.

After the terrestrial photo shoots, aerial photography by drone was undertaken. This survey method is practical and quick and for these reasons was considered useful for monitoring the progress of archaeological work (Chiabrando *et al*. 2012). The drone flight could only take place in the absence of visitors before the site opened and it was therefore carried out a few days after the terrestrial image-based photogrammetry.

This second survey was undertaken with a low-cost drone (quadricopter Apollo IdeaFly) equipped with a compact camera Canon PowerShot SX 260 (BSI-CMOS sensor 1/2.3" 6.17 x 4.55 mm; max. resolution 4000 x 3000). The camera was mounted on the drone in an upright position, without the aid of the gimbal, which is not adaptable to our camera model, in order to achieve better flight stability even though only vertical photos could be obtained. The flight took a total of about 8 minutes (with the use of two batteries) from a height of about 15 m from the top of the highest wall, and enabled the acquisition of numerous pictures in continuous shooting mode (about one per second). After careful selection to remove blurred and superfluous pictures, about 200 photos were judged useful for the final reconstruction (Fig. 2).

Agisoft Photoscan was used and the two surveys were processed independently according to a well-consolidated pipeline (Bitelli *et al*. 2006). After the alignment and sparse point cloud process, the dense point cloud models were further created and 'cleaned' in order to remove errors such as redundant points and blunders and processed to obtain high-detail surface models. The polygonal models needed repair, either manually or automatically, in order to fix some errors such as holes and incorrect faces and were later provided with high-detail photorealistic textures.

The photogrammetric survey from the ground has enabled the creation of a dense cloud model of about 98.000.000 points and a polygonal one of more than 225.000.000 faces which have been simplified in order to produce a lighter model. The decimation, performed by Geomagic Studio 2013, has provided a good compromise between keeping surface details and a reduction in the number of polygons.

The photographs from the drone produced a polygonal model of about 21.600.000 faces, which did not require a decimation procedure. Low light, due to the early morning hours, has also conditioned the data acquisition. Although less detailed, the aerial model shows the domus in its context (roofs, streets) providing a clear picture of urbanism.

4 Comparison

Because the data acquisition took place at two separate times using two cameras with diverse resolutions, the final models have very different properties. The integration of the two reconstructions in order to obtain a complete view of the context (thanks to the drone survey) and a detailed interior (thanks to the ground survey), provides much useful information for an archaeological interpretation of the house (D'Andrea, Barbarino 2012).

The two dense point clouds were aligned using CloudCompare and a cloud-cloud distance analysis using the Hausdorff distance algorithm was performed. This algorithm, based on the analysis of how far two subsets of a metric space are from each other, simply takes into account the distance from the nearest neighbour.

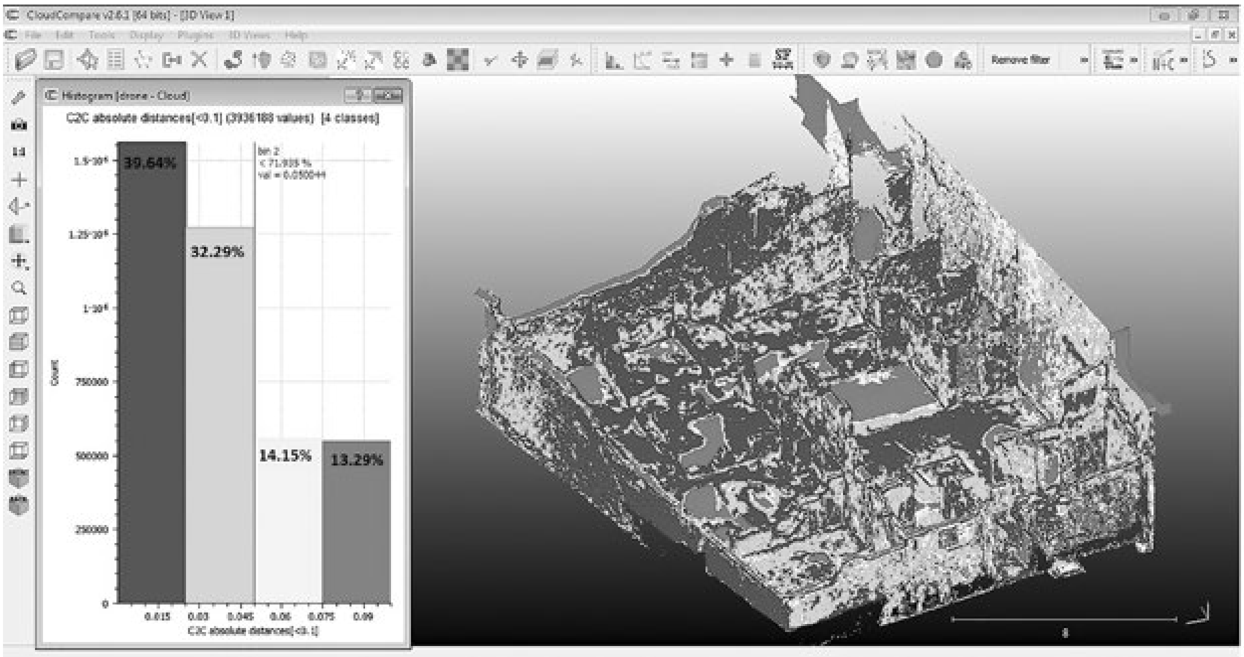

Fig. 3. Analysis of dense point clouds in CloudCompare.

Fig. 3 shows the final results of the overlapping of the two models. For greater understanding four classes have been chosen to identify the variances. The superimposition shows a good alignment: the la distance between the two models is lower than 5 cm in 72% of cases (blue and green colours). The variance in yellow, ranging between 5 and 7.5 cm (14.2%), seems to be localized mainly along the vertical lines of the highest wall where the drone was probably unable to capture the surfaces correctly. Finally the high percentage (about 13.3%) of deviations larger than 7.5 cm (in red) seems to coincide either with parts totally missing in one model (e.g. the crests of the walls) or with areas that were greatly altered during the time that elapsed between the two surveys (e.g. the *tablinum* was reburied and was not visible at the time of the aerial data acquisition).

In order to understand the reason for the presence of widely differing areas between the terrestrial and aerial survey, a specific analysis was performed for the highest wall in the eastern part of the house adjacent to house I, 6, 15. By applying the same analysis on a specific part of the model different results have been obtained (Fig. 4). In 40% of cases there is good overlapping while in 60% the distance is greater than 5 cm. One explanation of this wide variance is because the surface of the wall was barely captured by the drone camera, which can only shoot in an upright position (Fig. 5). Furthermore, as the data acquisition by drone was carried out in the morning before the opening of the archaeological area for safety reasons, the wall, which is particularly high, was still in a shaded area at the time of the flight (Fig. 6). With more sunlight we would probably have obtained better results in terms of the final overlapping. This is seen more clearly by looking at Figs. 5 and 6, where in the former image the surface of the wall is barely defined with many incomplete areas in comparison with the model obtained by terrestrial survey where the wall is complete and well represented.

5 Conclusions

The paper focused on the subject of low-cost digital survey in archaeology, by proposing an integration between two different approaches, terrestrial and aerial close-range photogrammetry. The Structure from Motion (SfM) techniques have been widely tested in archaeology with good and reliable results. The speed of data acquisition and automation in 3D data processing makes close-range photogrammetry a flexible and useful technique in the digital survey of archaeological sites, even those as complex and problematic as Pompeii.

The models obtained through terrestrial and aerial data acquisition show a good degree of overlapping, except for the areas that changed in appearance between the two acquisitions and the areas differently visible by the two approaches.

Considering the low cost of the whole operation and the environmental and timing difficulties, the final results are encouraging and satisfactory. Furthermore, there were logistical issues linked to the presence of visitors and tourists during the day and for these reasons the flight time of the drone was limited.

Even if the numerical analysis of the models has highlighted some limits in the accuracy of the digital models performed in the archaeological area of the Domus of Stallius Eros, the integration of the two approaches provides a more complete and useful model for archaeological research at Pompeii.

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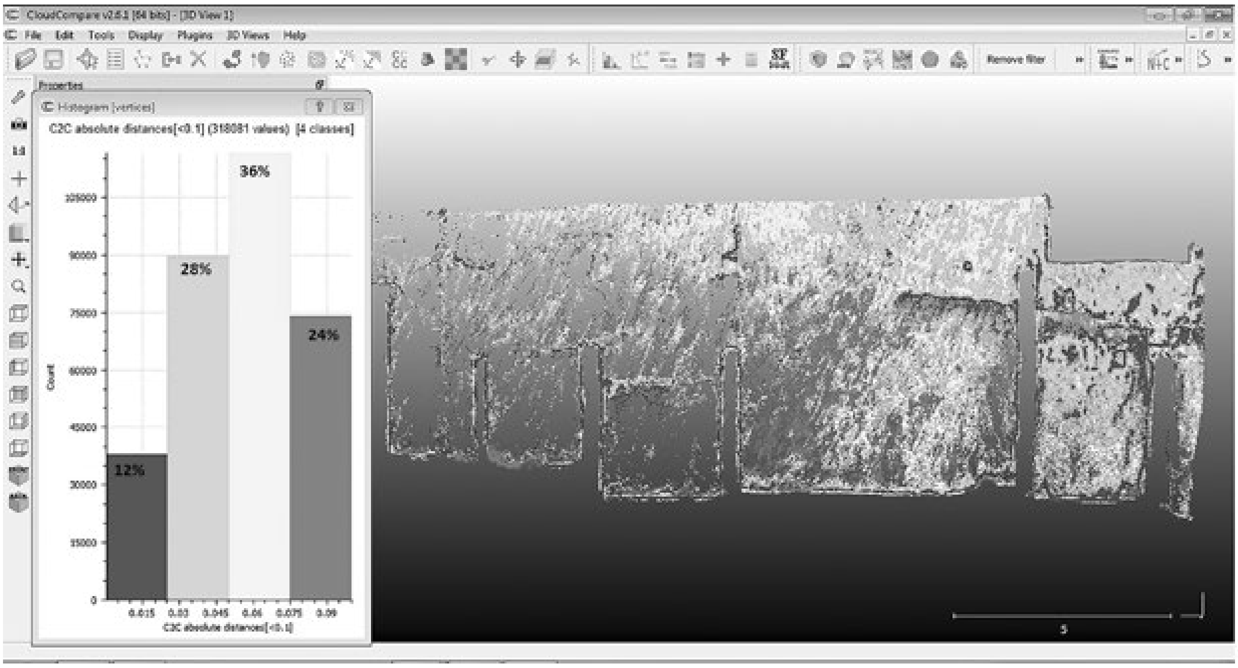

Fig. 4. Analysis of dense point clouds of the east wall.

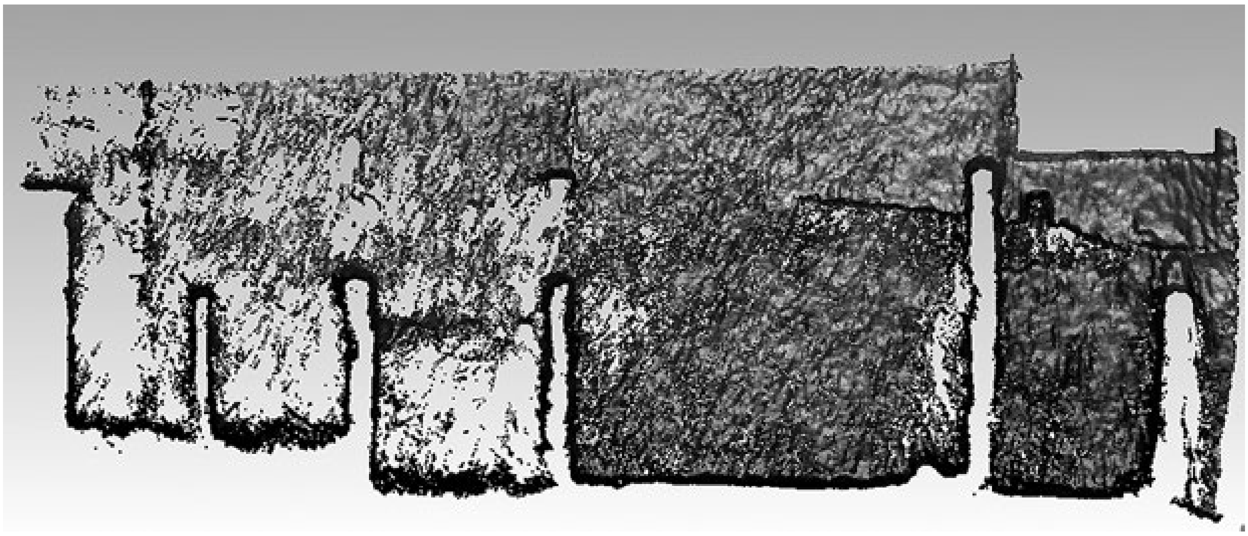

Fig. 5. Vertical surface of the east wall captured by drone.

encouraging this work and providing input to the research and Dr Marco Giglio for providing survey data acquired by the total station. The 3D model, images, and a video of the house of Stallius Eros are downloadable from www.europeana.eu/portal/search.html?query=3D+model+of+Stallius+Eros+Domus&rows=24 (accessed on 15 November 2015).

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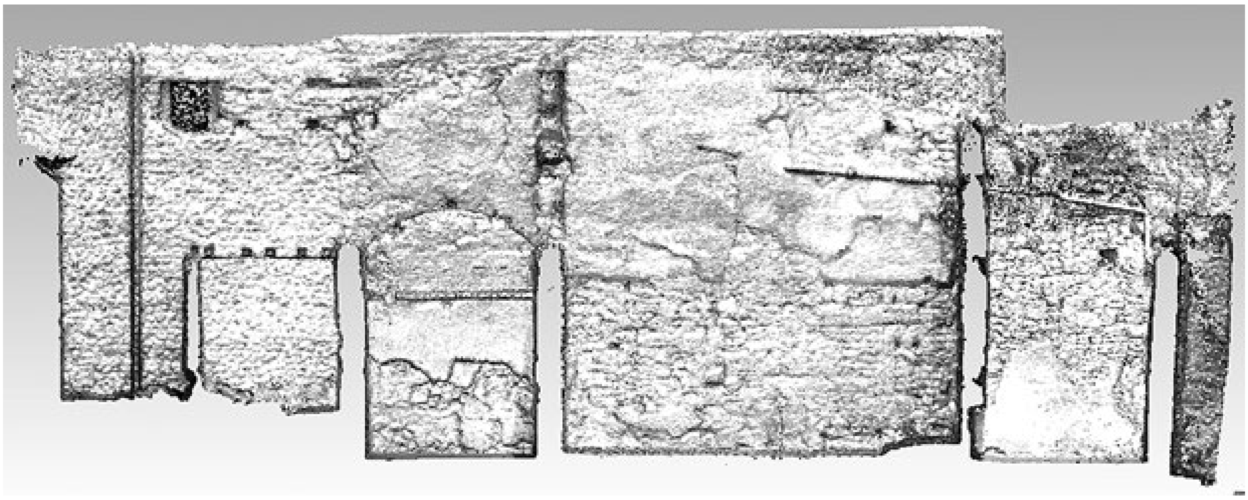

Fig. 6. Vertical surface of the east wall obtained by terrestrial data-capture.

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