Non-invasive analyses of a multi-stratified archaeological and historical site: the Crypta Balbi case-study

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Abstract. A number of non-invasive techniques were used to study the state of conservation of an important archaeological site in the centre of Rome, the Crypta Balbi (part of the Museo Nazionale Romano), so-called after proconsul Lucio Cornelio Balbo, who in the year 13 BC built here a theatre in the Campus Martius [1]. Excavations are still ongoing, so new relevant archaeological findings could still be discovered. At the same time, this involves that each new finding must be conserved and preserved. To this aim, extensive monitoring campaigns are essential. The reconstructions in Figure 1 and 2 show the structure of the monument during the II century (imperial age) and after, until the 15th century [1]. Figure 3 shows the studied site as it is today. The theatre and the Crypta (a kind of courtyard) are located within the red dotted circles. Today it is close to a tramway in the city centre, that induces air pollution and vibrations potentially putting at risk this unique archaeological site. In order to study its various layers, a number of non-invasive techniques have been used. Among them: infrared cameras for the thermographic analysis, velocimeters to evaluate impact of vibrations, microclimatic parameters acquisition, kinematic analysis, digital video elaboration by motion magnification method. Substantially, this monitoring campaign was based on non-contact investigations in order to eliminate any danger to damage the elements of the monument, which provided useful insights. Thermal images of the monument were captured using a Flir T440 thermal infrared camera. Microclimatic parameters and data of weather stations were collected for correlation to experimental ambient vibration and NDTs data. In particular, air temperature and humidity were monitored by two MSR145 mini data loggers. Seismographs type SL06 SARA Instruments digital recorders equipped with SS02 triaxial velocimeters were used for the vibration monitoring. Each seismograph is independent and provided with battery for the energy supply and with a GPS antenna for synchronization, so that data from different instruments can be compared in the time domain. The instrumentation is very accurate, in fact the sensitivity is 400 V/m/s and the frequency range from 0.2 to 50 Hz, sampling frequency set at 200 Hz. Data were acquired from 10:00 a.m. to 12:00 a.m. Motion Magnification (MM) is a recently developed video processing methodology [2, 6, 5]. MM [2 - 6] acts like a microscope in digital videos, magnifying motions hardly visible with the naked eye, but leaving unchanged the topology of the images.

1. An historically stratified site

The most important element of the site is the theatre of Lucius Cornelius Balbus (13 AC) which included a vast hall (the so-called Crypta Balbi) and an exedra on the opposite side (Fig. 1). The maximum capacity of the theatre was of around 7,000 people and had an overall diameter of about 100 meters. It was quite small in comparison with the major roman theatres of that time, but its importance lies in the fact that it actually represents a unique opportunity to study how the history has modified the architectural and urban environment, through an impressive cultural stratification from the ancient Rome to the nineteenth century. During the centuries, this complex has experienced the alternating of several cultural customs and settlements. Among them the Church of Sancta Maria Dominae Rosae and the hospice of charity of St. Ignazio Loyola and other private constructions. The area of the Crypta was neglected till 1981, when the Italian state acquired the property and finally assigned to the Museo Nazionale Romano in 1983. The monumental complex of the Crypta appears to be the only example of a museum that is able to tell the story of living in Rome from ancient times and until today.

This is not a conventional "museum", but is an entire urban complex of buildings dated back from the 1st to the 21st century (Fig. 2). It is an *unicum*, more similar to an historical book than a museum, as we usually know it.

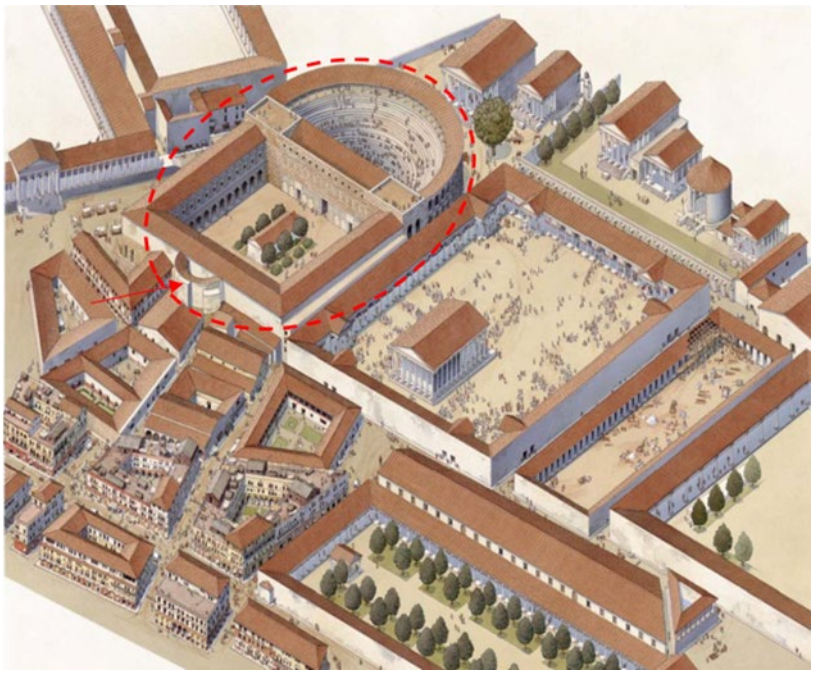

Figure 1. Studied site in the Roman imperial age: close to the theatre a portico (*porticus post scenam*) can be seen. The red arrow indicates the circular exedra, with the half-dome.

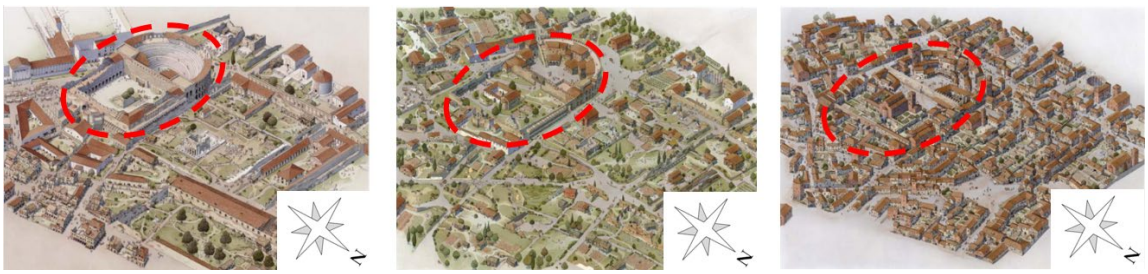

Figure 2. The monument site during the 5th, 10th and 15th century.

This is a unique site where it is possible to follow the evolution of the settlements of the city during the centuries: houses, churches, workshops, simple element of the living spaces as toilettes and fireplaces, large institutional buildings and monuments, since the 1st century (Fig. 3). Every age has left abundant traces in the site: in fact, researches are still going on and new findings are made continuously.

Currently, the Museo Nazionale Romano is fostering the Crypta Balbi as an inclusive cultural attraction site for the entire community to convey to the next generations the sense of a common belonging.

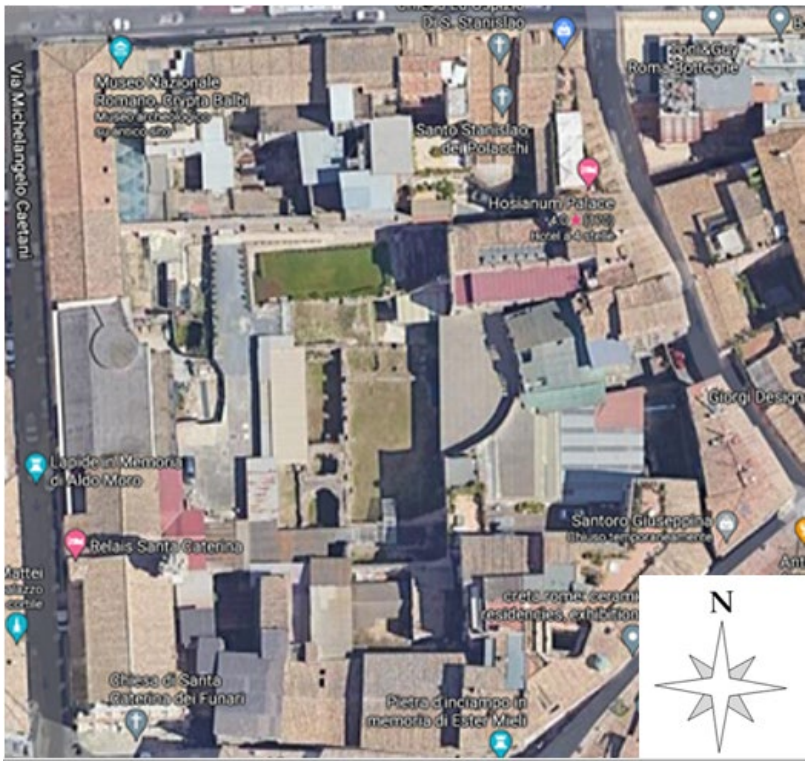

Figure 3. An areal photo of the studied site today; note Via Caetani on the west side, where the body of the Italian statesman Aldo Moro was found in a car.

2. Comparative analysis

Historical monuments in the urban environment are severely affected by anthropic vibrations, air pollution, and other aggressive agents, therefore the health monitoring of those structures is essential to preserve the cultural heritage of these sites. However, if the monument to be monitored is large, extended, and comprises hundreds of minor parts, it is not always feasible to study each element separately. Thus, proper tools have to be selected in order to provide both a synthetic view and, at the same time, a detailed analysis. We have tested these tools in the field, providing some useful results.

This work focused on the comparison between a thermal infrared survey and an analysis obtained from the motion magnification video elaboration. In this last case, small areas of the magnified frames have been colored according to their mean displacement. The color code is the same for the infrared and for the motion magnification images, in order to allow an immediate comparison.

The basic MM version looks at intensity variations of each pixel of the video sequence, revealing small motions linearly related to intensity change of the pixels in the frame. Even the micro-displacements produced by vibrations can be amplified greatly and made available also to the quantitative analysis. Advantages of the MM [7 - 11] are several: no expensive sensors to be deployed on the monument, (that usually is a large one) a reduced amount of camera recording time, a small data

storage requirement. Even the camera need not to be expensive: in fact, the videos recorded at the Crypta Balbi were obtained by a commercial cellular phone with a frame rate as low as 30 fps. Conventional devices are surely more precise, but also more expensive and much less practical. Unfortunately, noise due to illumination, shadows, spurious vibrations, remains a serious obstacle to MM analysis, but nevertheless, satisfactory results in the outdoor environment of the Crypta, using low resolution video cameras, constitute a remarkable starting point for future and improvements. In this case-study, however, the most important advantage was the possibility to examine elements of the structure that otherwise would be very difficult to reach physically or put the operator's safety at risk. Displacements were indicated by a colour code in a single frame of the MM video.

In the following, a small case study on a wall dating back to 16th century is report (Fig. 4).

Figure 4. The studied wall, dating back to the 15th-16th century.

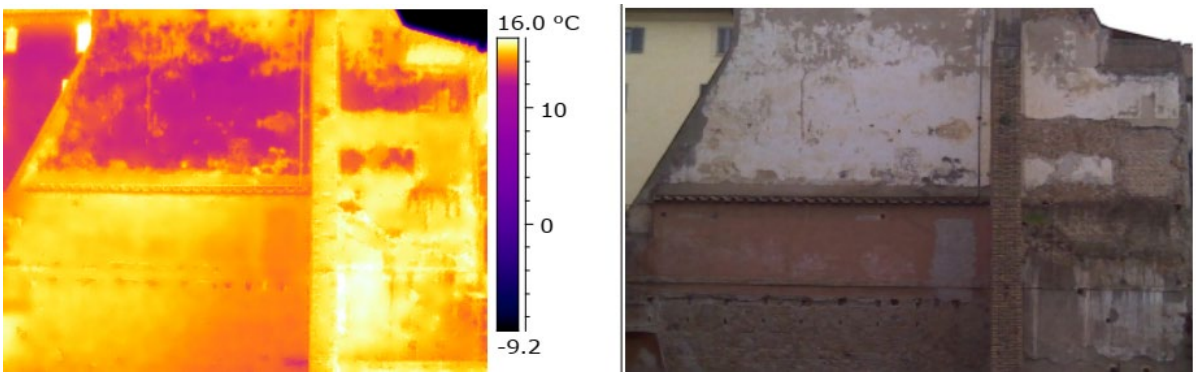

Figure 5. The Infrared thermography of a particular of the wall (on the right the original day light image). Note how the very inhomogeneous medium produces temperature gradients.

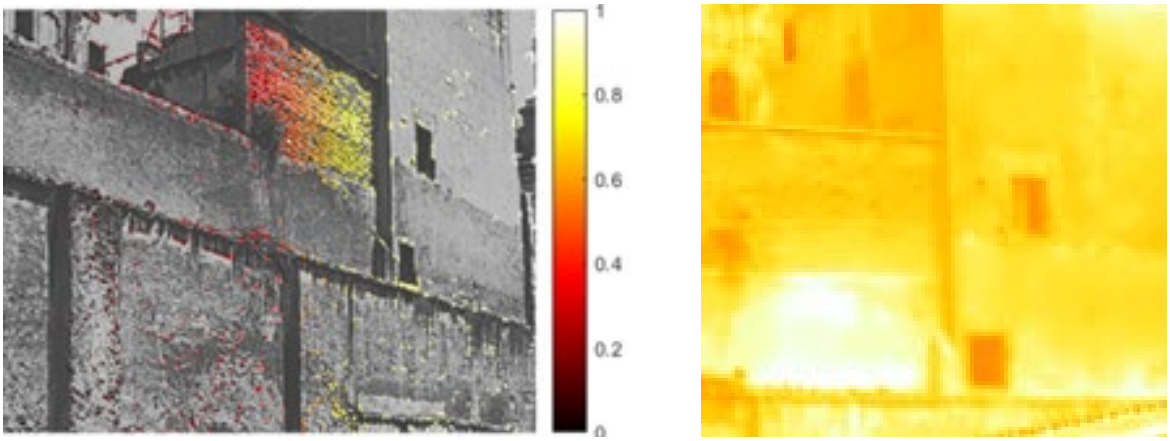

Figure 6. Motion magnification displacement images (on the left) and the infrared thermography of a particular of the wall (right).

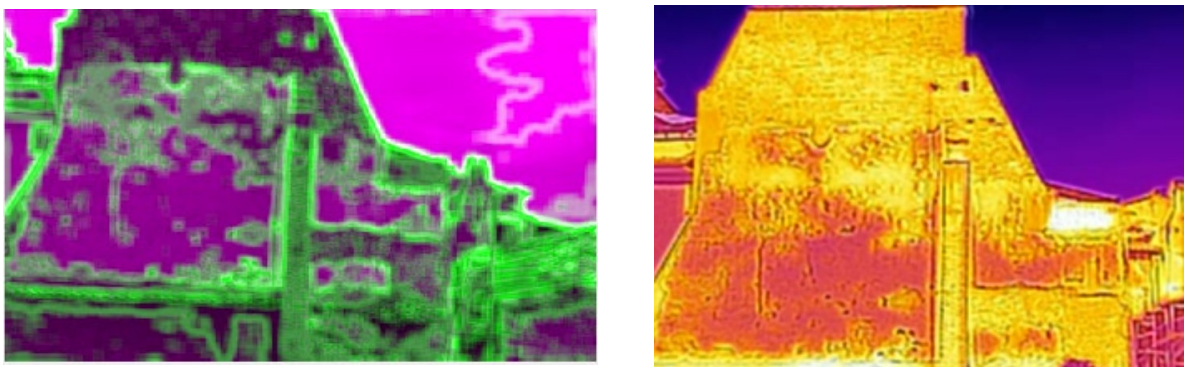

Figure 7. Motion magnification displacements images (left), the green areas undergo large displacements to be compared to the yellow-white ones of the infrared thermography (right). Here the displacements were elaborated by a specific algorithm, in order to get a better graphic result.

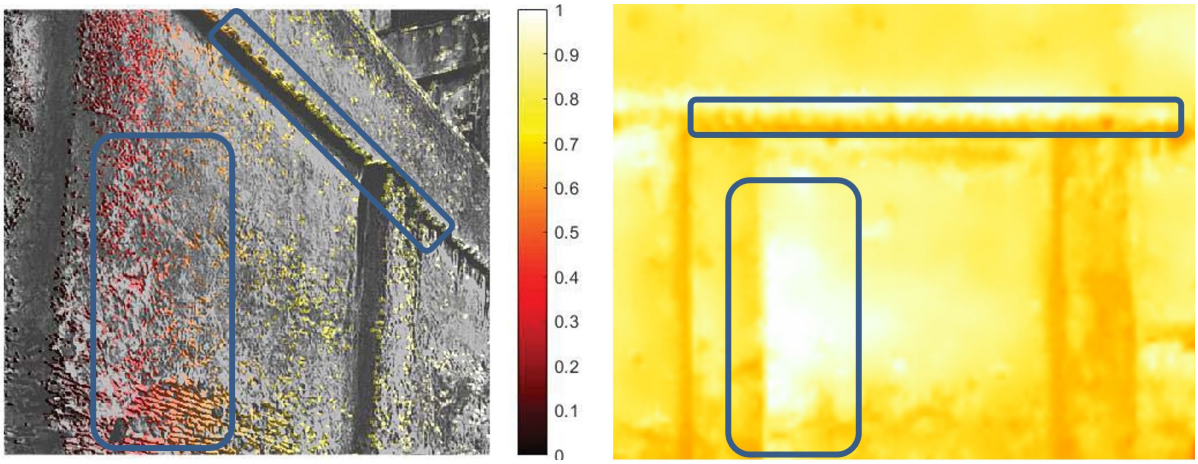

Figure 8. Motion magnification images (on the left) and the infrared thermography of a particular of the wall (right). The point of view is not the same, nevertheless the blue boxes indicate clearly the critical points due to displacements or to the thermal effects (yellow-white).

Areas marked as major displacements do not always coincide with those marked as high temperature, because of different materials and of the modifications undergone during the centuries. However it is interesting that in the majority of cases motion magnification and infrared analysis give similar results. From Figs 5-8 it seems that environmental vibrations may constitute a more important issue with respect to the monument preservation since the edges are more prone to vibrations, although the temperature gradients are to be taken into consideration, too.

3. Conclusions

The Crypta Balbi, a unique archeological complex housed in the Museo Nazionale Romano, was examined using several methodologies, among them the motion magnification, the infrared thermography and the seismographic analysis. In particular, an ancient wall was selected as application example. We report the graphic comparison of the MM and of the thermography applied to the wall, showing that in many cases the critical areas of the structure coincide, therefore they deserve a specific attention.

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