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The masonry of the *Terme di Elagabalo* at the Palatine hill (Rome). Survey, analysis and quantification of a roman empire architecture

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ABSTRACT
The NE slopes of the Palatine and the Colosseum valley area have been the place of a long archaeological research; here the continuous urban development produced an overlap of architectural complexes distributed over time. The huge amount of archaeological documentation produced during research is managed by an intra-site GIS. For ancient walls analysis we have introduced the use of image-based-modelling photogrammetry in order to create a very detailed 3D documentation, marked by an increasing and progressive high-level-autopsy, linked to a DBMS dedicated to ancient structural features. In this procedure we also decided to compare two different approaches to check results of both: one based on taking brick measures directly by hand, the other taking same measures on photogrammetric elaborations by GIS. Through this methodology, counting measures and dimensional aspect of wall facades features, we can evaluate specific aspects of the ancient construction yards for each period; we can also refine the chronological sequences of the architectures and verify the contextual relationships of the surrounding buildings in order to formulate wide-ranging reconstructive hypotheses.

Section: RESEARCH PAPER

Keywords: Rome, archaeology, ancient architecture; 3DSurvey; GIS

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1. INTRODUCTION

The area of the northeast slopes of the Palatine hill that faces the Colosseum valley has been the subject of a long archaeological research since 1986, carried out by the Department of *Scienze dell'Antichità* of *Sapienza*, University of Rome (Figure 1). During more than 30 years of excavations, the material remains of major building and monumental interventions have been unearthed, testifying an environmental and topographical continuum where the development of diversified urban systems has involved a complex physical overlap of structures and architectural complexes distributed over time [1]-[4]. Today the actual floor and appearance of the zone reflects the aspect reached during the 4th century C.E with some main differences: first of all, the first big excavations made during 19th century included the destruction of many medieval remains; secondly the building during the fascist regime of two new large streets, *Via dell'Impero* and *Via dei Trionfi*, caused the dismantling of the *Velia* hill and the destruction of several roman monuments, like the *Meta Sudans* fountain and the basement of the famous *Colossus*. The target of this investigation was to reconstruct the ancient topography and to restore the connection between the Colosseum valley and the Palatine hill; the research had to take into consideration the previous literature and studies about the zone and the huge amount of data produced during annual stratigraphic excavations: dealing with this purpose, we had to use IT tools for data collection and management, articulated into distinct chronologies and graphic outputs able to reproduce the ancient spaces and their transformations over time, on a small and large representation scale.

Finally, in several zones of the investigated area previous digs carried from XVII to XIX centuries compromised the stratigraphic earth basins, making difficult to read the archaeological record: here, in order to obtain other keys of interpretation, we decided to implement the stratigraphic and

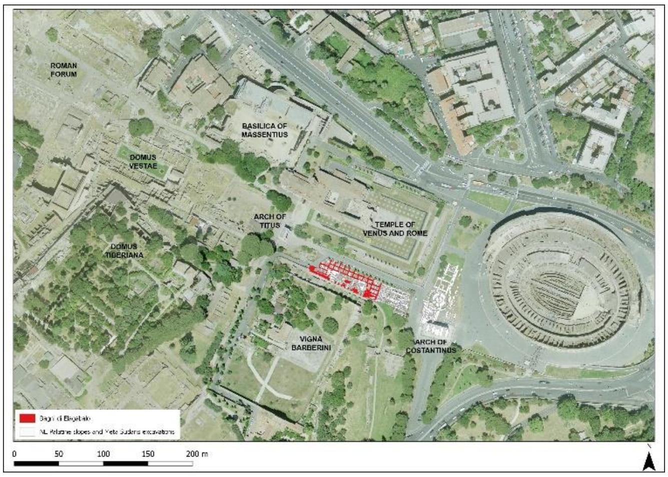


Figure 1. The investigated area in the historic centre of Rome.

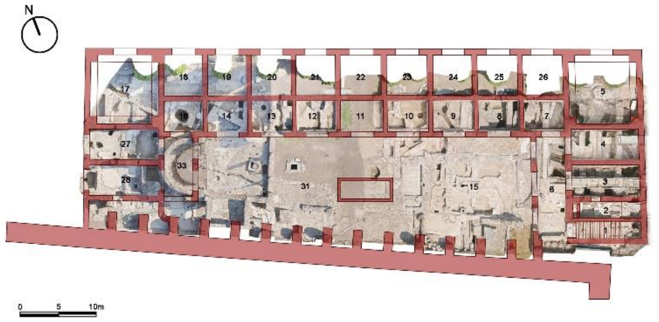


Figure 2. General plan of the Terme di Elagabalo complex: the Severian phase is highlighted in red.

detailed analysis of ancient architectures, according to the most current research criteria.

In section 2 we will discuss about the archaeological framework; in section 3 we will give a brief description of data management methods, techniques and procedures; in section 4 we will illustrate our particular approach for the structural analysis of ancient walls; in section 5 we will give some quantitative data about constructive features of the ancient walls. Finally, in the concluding section, we will account the preliminary results of our research.

2. THE ARCHAEOLOGICAL FRAMEWORK

An area of about 4500 square meters has been excavated reaching a depth, were possible, of 8/9 meters, chasing the millenary history the city, from first settlement to modern age, including all kind of evidences like medieval spoliations and modern or contemporary interventions. In order to reconstruct the original geomorphology, we have conducted also geophysical investigations tools such as ground-penetrating radar and resistivity [5]-[7].

To make an extreme synthesis of the main results, starting from the remains of Iron Age huts, found along the slope, we move on to an early urban planning witnessed by the presence of two sanctuaries dating to the Roman Kingdom (8th-7th century BCE) located along both sides of the ancient road leading to the Roman Forum: one of them can be identified with the *Curiae Veteres* and has been frequented until the affirmation of Christianity.

The installation of a residential district, along the road, is documented since the archaic period: subsequently this area has been periodically rebuilt in the following centuries, until Augustus age. In this period, at the meeting point of five of the new 14 city zones planned by the emperor, the first *Meta Sudans* fountain was built, in front of the *Curiae Veteres* which were also reconstructed in monumental shape during the years of the emperor Claudius. The real break-up here happened in conjunction with the great Nero's fire: after this disaster Nero decided to carry out in this area a deep urban transformation that would end with the realization of his majestic palace, the *Domus Aurea*. In the years between 64 and 68 CE a total reorganization of the road system was made, with a regular and orthogonal shape, according to the guidelines dictated by the palace project. In the Colosseum valley the new architectural complex was characterized by columned porticoes around an artificial pond over which the Flavian dynasty later will build the Colosseum; the Palatine hill slopes were regularized by artificial terraces on arcades while the new climbing way to the Forum was flanked by arched porticoes. The urban planning of Flavian emperors, focused on restoring a public dimension to the urban spaces occupied by the *Domus Aurea*, can be emblematically summarized, together with Colosseum building, in the reconstruction of the *Curiae* and of the *Meta Sudans* fountain, both burned in the fire. The area will be modified again by Hadrian with the construction of the Venus and Rome Temple and, a of a long building flanking the porticoes on the other side of the street going to the Forum. After another catastrophic fire, at the end of the 2nd century CE the area was rebuilt again by the Severian dynasty: in close connection with the monumental project of the new Palace of the emperor, the whole front of northeast Palatine's substructures was heavily transformed while the constructions at its feet were completely dismantled and replaced by a new courtyard building, commonly called *Terme di Elagabalo* (Figure 2). Inside this monument, in the 4th century CE, a large banquet hall was obtained, with gardens and fountains and a small bath in the backyard. Finally, with the construction of the Constantine's Arch and the restorations at the Venus and Rome Temple the ancient urban history of the area was completed [8]-[11].

3. ARCHAEOLOGICAL RECORD COLLECTION: METHODS TECHNIQUES AND PROCEDURES

The huge amount of documentation produced in front of such a complex stratigraphic sequence required the development of a data storage and management system, dedicated to contextualize information and capable of proposing new elements useful for research. The entire archive is therefore managed by an intra-site GIS (designed since 2001), used for data-retrieving, spatial analysis and for the elaboration of archaeological themes and/or reconstructive models [12].

The historical sequence reconstructed for the excavation areas was therefore contextualized in a wider urban historical framework, traced through the study of previous bibliographies, archive data and historical cartography. The archaeological records collected during these operations were linked to a general map developed in a GIS environment, made up of several distinct layers combined into a unique reference system by overlay mapping procedures: the vector cadastre of Rome, the digital cartography of the Municipality plus several rectified aerial photos and satellite images.

Over this base-map we have georeferenced several historic cartographies, in raster and vector format, such as Nolli's *Nuova*

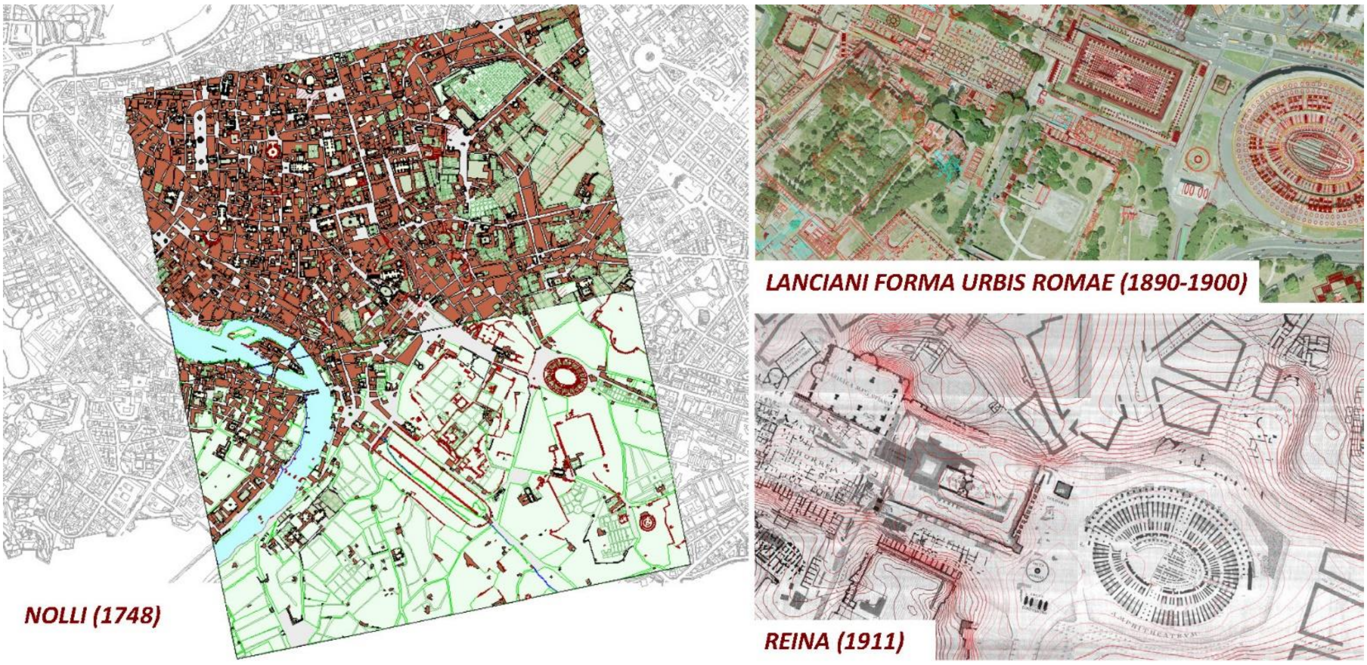


Figure 3. Collection of historic cartographies reproducing our investigation area in different periods of modern age (E. Brienza and M. Fano).

Pianta di Roma (1748), some sheets of Lanciani's *Forma Urbis Romae* and the cartographic atlas *Media Pars Urbis* made by V. Reina in 1911 (Figure 3) [13], [14].

We have updated the territorial study producing a Digital Elevation Model in order to compare the current state with ancient surfaces: this was produced by interpolation of the altimetric data available at the *Geoportale della Regione Lazio* (Figure 4) *[15]* and subsequently recalibrated on the basis of the altimetry detected during the annual topographic campaigns; it is an additional basis where to place stratigraphic evidence of structures and infrastructures (ancient roads, sewers, terraces) connected to the original morphological configuration; here we can verify, using the deepest stratification data, our environmental reconstructions for the most ancient periods.

In fact, using all the data collected from stratigraphic and geoarchaeological investigations, from surveys and historical cartography, two digital terrain models have been developed: one related to the Augustan age and the other suggesting the situation after the 64 big fire and Nero's massive interventions. Those DTMs are the basis of virtual urban scenarios, modelled in a 3D environment, that can be navigated following a diachronic exposition and associating each monument to its period, with the option to converse interactively with each architecture in its specific temporal version [16].

Over the years this system has been implemented in software, for the advent of new IT products, and in the stored contents: in our spatial database, today, digital and analogical documentation (in particular handmade archaeological detailed drawings and on-paper archaeological forms) are managed together, in order to maintain the integrity of the research archive and its history (Figure 5) [17], [18].

To have the best results in this operation a memorandum of agreement has been approved by the Sapienza, University of Roma, the Kore University of Enna and the I.S.P.C.-C.N.R. (Institute of Sciences for Cultural Heritage of National Council of Research), institution that since 2007 has collaborated with the research carried out at the Palatine hill and the Colosseum valley, in particular in 3D surveying and integrated geophysical

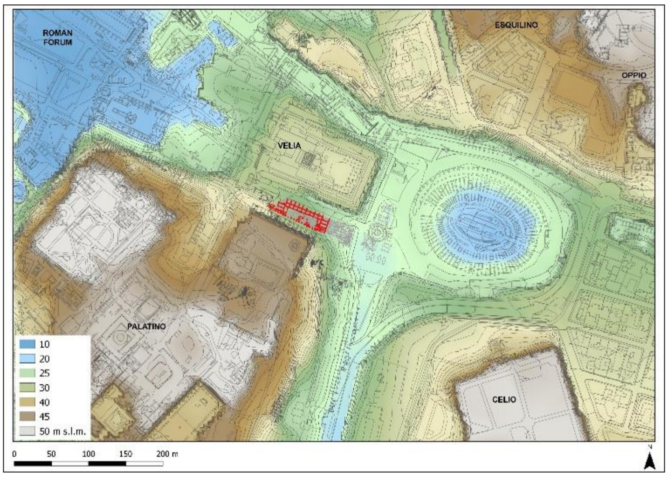


Figure 4. The new Digital Elevation Model produced from the data of the *Geoportale della Regione Lazio.*

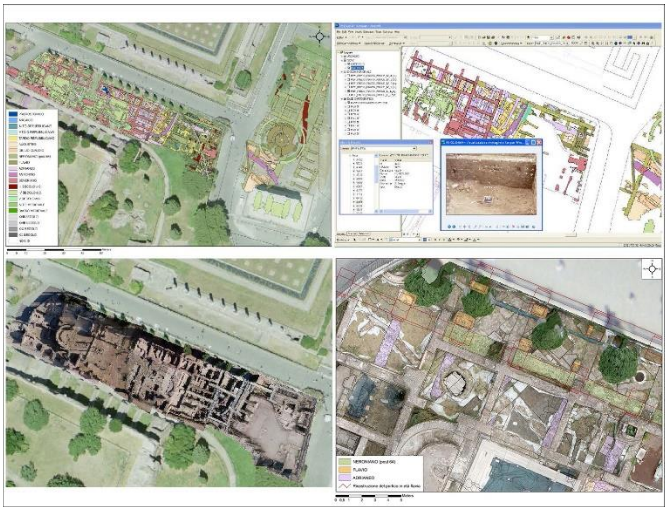


Figure 5. Intra site GIS: data management.

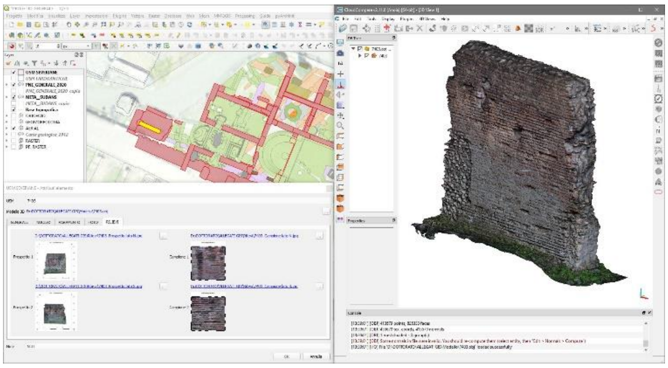


Figure 6. Intra site GIS: 3D data management.

prospecting [19], [20]. During these years a big amount of raw data has been preserved in two different repositories, while only final elaborations were shared by the research group: since 2019 we have finally started to unify the separate archives in a single spatial database, for investigation purposes but also for deontological instances in order to leave a complete and single testimony of all activities carried out in this important archaeological place site during these decades.

Our intention is focused on giving access to the scientific community but also to interested people, not only to the data (both synthetic and in-depth format) but also to the analysis system itself: paying great attention to the issues of open-data, ArcheoFoss [21] and public archaeology [22] we have tested the migration of the entire dataset and its interrogation criteria and tools to an open-source web-GIS platform, using web-oriented DBMS like *PostgreSQL* + *PostGIS* and GIS software like *QGIS Server*+*LizMap*).

In this digital environment, starting from the general site map, it is possible to decompose the single architectures into their structural contexts and features and verify the cognitive process for each one of them: passing from photos to 3D models, then to elevations, wall-samples up to the general synthesis of file-cards and records of ancient structures (Figure 6).

4. STRATIGRAPHIC ANALYSIS AND AUTOPSY OF ANCIENT WALLS

The study of ancient architectures today can adopt survey tools able to detect objects in 3D with a certain precision and quickly: through these tools we have produced ortho-photo-plans that, gradually, have joined the traditional 2D documentation but we have also proposed three-dimensional sequences of excavated stratigraphic sequences as well as the reproduction of some ancient artifacts, suggesting their virtual-digital restoration. In the study of ancient walls, the use of new *image-based-modeling* photogrammetry techniques based on *Structure From Motion* (having accuracy and photographic texturing) brought us to the realization of a new detailed 3D documentation of the ancient walls [23]-[30]. A 24.2 megapixel Canon EOS D200 reflex camera, with image stabilizer and a focal length of 18 mm, was used for the photos; in addition, a tripod and a telescopic rod were used to ensure better quality; an average of 30-40 shoots were taken for each acquisition not to burden the processing times. We have produced 3D models of the structures, adopting three approaches based on differentiated analysis scales: a general and less accurate one (mainly *aerial*), for architectural complexes (Figure 7) [31]; a second one, more accurate, for sectors and rooms of ancient buildings (*close-range*); a third one of in-depth analysis of the walls and samples, using a maximum resolution and accuracy approach (*very-close-range*, Figure 8).

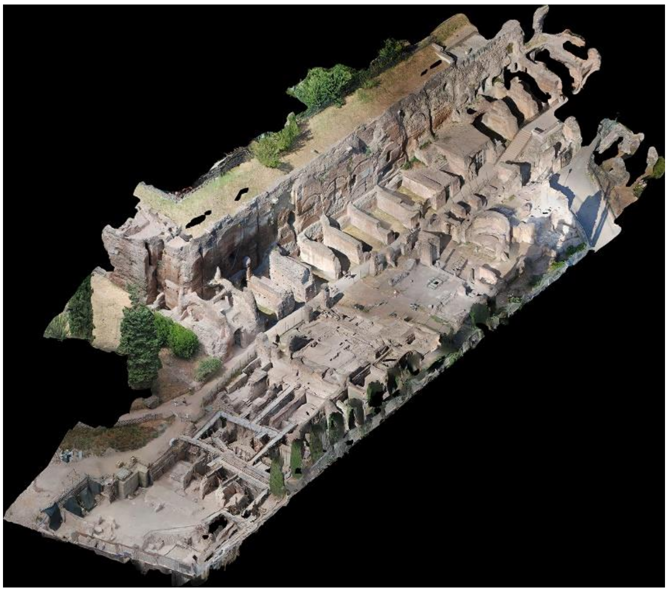


Figure 7. Aerial 3D survey of the architectural complexes (G. Caratelli and C. Giorgi).

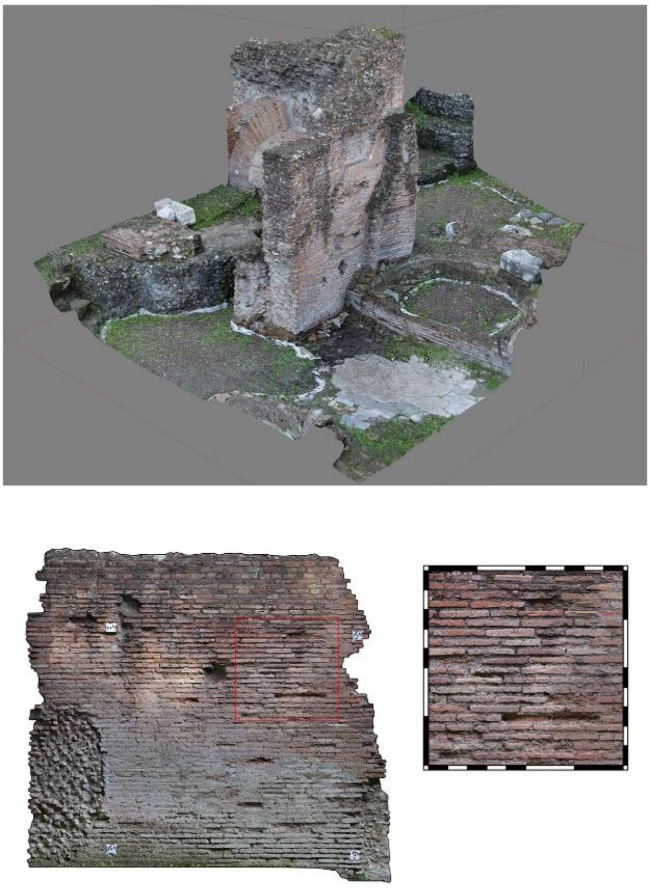
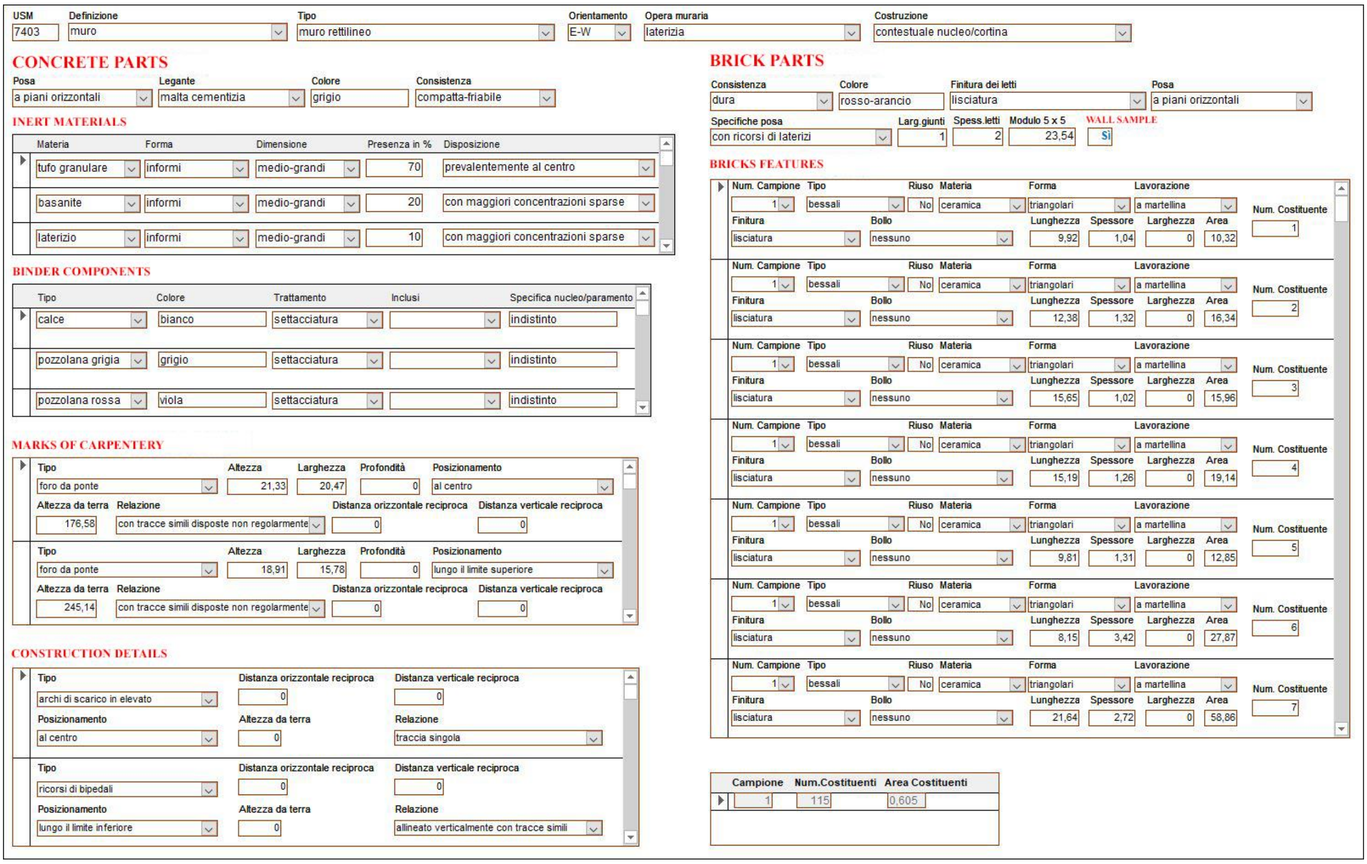


Figure 8. Very-close-range digital photogrammetry of ancient walls.

In this last case each wall was taken up completely, maintaining a constant distance: particular attention was paid to have a maximum accuracy survey of 1sqm area samples, taken from facades, maintaining a maximum distance of 1 m, in order to obtain images with a high level of detail; in this way it was possible to use very-high quality orthophotos, having an average



USM	Definizione	Tipo	Orientamento	Opera muraria	Costruzione
7403	muro	muro rettilineo	E-W	laterizia	contestuale nucleo/cortina

CONCRETE PARTS

Posa	Legante	Colore	Consistenza
a piani orizzontali	malta cementizia	grigio	compatta-friabile

INERT MATERIALS

Materia	Forma	Dimensione	Presenza in %	Disposizione
tufo granulare	informi	medio-grandi	70	prevalentemente al centro
basanite	informi	medio-grandi	20	con maggiori concentrazioni sparse
laterizio	informi	medio-grandi	10	con maggiori concentrazioni sparse

BINDER COMPONENTS

Tipo	Colore	Trattamento	Inclusi	Specifica nucleo/paramento
calce	bianco	settacciatura		indistinto
pozzolana grigia	grigio	settacciatura		indistinto
pozzolana rossa	viola	settacciatura		indistinto

MARKS OF CARPENTERY

Tipo	Altezza	Larghezza	Profondità	Posizionamento	Altezza da terra	Relazione	Distanza orizzontale reciproca	Distanza verticale reciproca
foro da ponte	21,33	20,47	0	al centro	176,58	con tracce simili disposte non regolarmente	0	0
foro da ponte	18,91	15,78	0	lungo il limite superiore	245,14	con tracce simili disposte non regolarmente	0	0

CONSTRUCTION DETAILS

Tipo	Distanza orizzontale reciproca	Distanza verticale reciproca	Posizionamento	Altezza da terra	Relazione
archi di scarico in elevato	0	0	al centro	0	traccia singola
ricorsi di bipedali	0	0	lungo il limite inferiore	0	allineato verticalmente con tracce simili

BRICK PARTS

Consistenza	Colore	Finitura dei letti	Posa
dura	rosso-arancio	lisciatura	a piani orizzontali

Specifiche posa	Larg.giunti	Spess.letti	Modulo 5 x 5	WALL SAMPLE
con ricorsi di laterizi	1	2	23,54	Sì

BRICKS FEATURES

Num. Campione	Tipo	Riuso	Materia	Forma	Lavorazione	Finitura	Bollo	Lunghezza	Spessore	Larghezza	Area	Num. Costituente
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	9,92	1,04	0	10,32	1
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	12,38	1,32	0	16,34	2
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	15,65	1,02	0	15,96	3
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	15,19	1,26	0	19,14	4
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	9,81	1,31	0	12,85	5
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	8,15	3,42	0	27,87	6
1	bessali	No	ceramica	triangolari	a martellina	lisciatura	nessuno	21,64	2,72	0	58,86	7

Campione	Num.Costituenti	Area Costituenti
1	115	0,605

Figure 9. DBMS file-card for structural and construction data.

detail level between 0.2-0.4 mm / pixel, for the stratigraphic reading and for samples quantifications: in the selection of these samples, we proceeded analytically, choosing 1sqm wall-vestment areas with an adequate level of conservation and free of discontinuity elements [32].

Vertical high-resolution ortho-photomaps were extrapolated from the textured meshes and, acting a careful verification of the measurements, subjected to a vector design process.

The new documentation included also a DBMS recording updating the usual formats for ancient structural features following the guidelines suggested by the *archeology of construction*

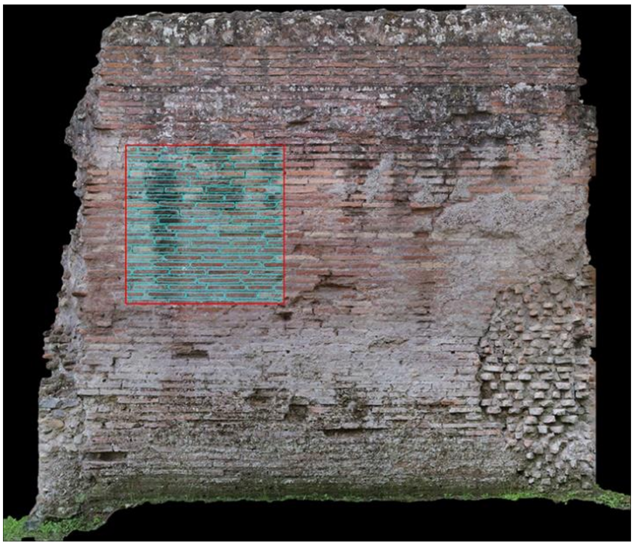


Figure 10. Vectorization of ancient walls samples.

and by *the archaeology of architecture* [33]-[39].

We have planned a new file-card format dedicated to register information about the logistic of the ancient construction yards and the related dynamics on material production and ancient building organization, in addition to data relating to their measures, composition and nature (Figure 9). In this way the chrono-typological analysis, which traditionally focuses on the recognition of the single construction features by material aspect, has been expanded with the collection of information related to building methods such as, for example, structural expedients for static stability, specific materials selection in relation to particular needs or quantification of the work in terms of time and number of the workers.

Defining trends, measures and treatments of specific building materials can help us to identify diachronically the processes and resources of the ancient construction yards, while the stratigraphic analysis of the walls, with its identification of constructive temporal sequences, is crucial to understand the formative dynamics of the ancient architectures and must be done through observation of details on the basis of a precise and clearly legible survey. Obviously, in order to normalize the data entry and editing, we have encoded standard glossaries while the detailed morphometric information, derived from autoptic analysis of samples taken from wall facades (normally their size is 1 square meter), is managed by sub-cards where each “constituent" (i.e. brick, block, etc.) is organized by type, use/reuse, material, manufacture, finishing, and measures.

Starting from these assumptions, the analysis of ancient architecture was carried out with a workflow that, as usual, started from the autopsy analysis and survey of each wall. Elaborations from photogrammetry have been vectorized in GIS environment.

For this purpose, next to the module dedicated to the analytical database of the ancient walls, a new apparatus has been created for the collection of all the data relevant to the documentary base. Here, photographs, 3D models acquired from scratch, sections and elevations, drawings and all the graphic documentation produced during the excavations, have found their place. In this way, through a simple query, it is possible to trace the whole corollary of raw and elaborated data that constitute the starting point for the analysis of each context.

For the quantifications of information coming from wall-facades-samples we have performed differentiated GIS analysis procedures, comparing the DBMS data taken directly on the field (counting bricks and measures on wall facades) and those obtained automatically on spatial vector drawings made on very detailed orthophotos (Figure 10); these measures were taken on the same sampled wall-facades but in different way: despite the different tools and procedures the results of 20 samples were indeed very similar, giving us a good indicator of a correct method [40].

Through a series of expressions specifically prepared, it is also possible to calculate automatically and expeditiously the variable of the constituent / conglomerate ratio, but also the dimensions of the components of the facades with their degree of homogeneity and variability (Figure 11).

In particular, the GIS for calculating the dimensions of each brick involves the use of two expressions whose common principle is based on the construction of a regular polygon circumscribed to each geometry returning the maximum length along the x and y axes [41], [42].

In this way length is calculated as follows:

$$bound\_width\ (\$geometry); \quad (1)$$

while the thickness:

$$bound\_height\ (\$geometry). \quad (2)$$

As mentioned, the measurements made through these expressions agreed with those taken by direct autopsy producing a great advantage in terms of time.

5. SOME QUANTIFICATION DATA

Focusing on the construction process, the first value that must be verified in the analysis is represented by the percentage ratio between constituents, in this case bricks, and binder; we must then add the values of the average of the lengths, thicknesses and areas of the bricks which, being strongly influenced by anomalies, can be misleading in describing the overall character of the masonry; regard this, the standard deviation, i.e. the index according to which the measures of each constituent deviate from their average value, can be very effective [43]; from an archaeological point of view we could say that if the standard deviation index is low this may indicate a certain homogeneity of the bricks, referable to the availability of homogeneous lots of materials; on the contrary, we could imagine very inhomogeneous bricks due the availability of different lots or reused material, recovered from pre-existing buildings, and therefore more fragmented [44], [45].

Taking in consideration the peculiar characters of 60 brick-walls samples of our complex a specific feature is the extreme thinness of vertical joints: this observation indicates a high level of specialization of the workers but does not exclude the use of recycled materials. In fact, same samples show a certain lack of homogeneity in lengths and thicknesses of the bricks, highlighting a combined use of new and recycled material,

We know that there were three standard brick types, based on multiples of the ancient Roman foot (about 29.6 cm): these were produced in a square shape and then cut into a triangle whose longest side was on the facade: by measuring this side it is possible to reconstruct the used brick types, also calculating the parts lost during cutting [46]. From our analysis of about 5700 bricks, it seems that standard type used in masonry is 67% *bessales* (2/3 of Roman foot) divisible into two groups of measures (18-22 and 22-25 cm) while 25% of the material is fragmented and probably reused (Figure 12) [47], [48].

It is maybe possible that, at the beginning of the construction, it was planned the recovery of the remained material of the previous, destroyed, building.

On the other hand, the supply of newly made material is confirmed by presence of special brick types like double-feet bricks (*bipedales*) used for horizontal planes in masonry and relieving arches in the facades, following constructive and static procedures typical of Severian architecture, with a homogeneity and number that suggests a great availability of new material.

6. CONCLUSIONS

Through the methodologies and tools described above it is now possible to evaluate specific aspects of the ancient construction yards for each period, such as the extent of resources supply, the reuse index and building materials selection level and consequently refine the chronological sequence of the construction phases of the individual buildings.

Furthermore, being able to have such a complex sequence of

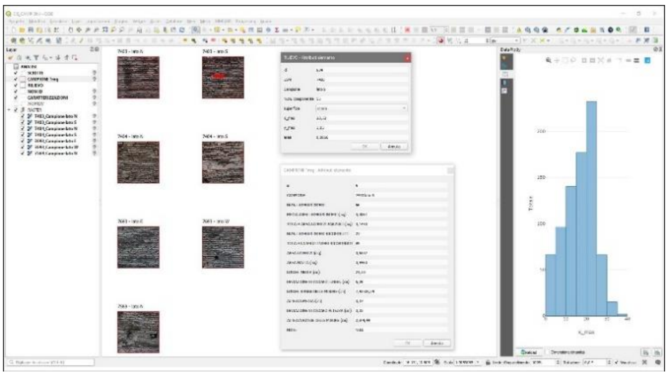


Figure 11. Vector and DBMS data analysis and verification.

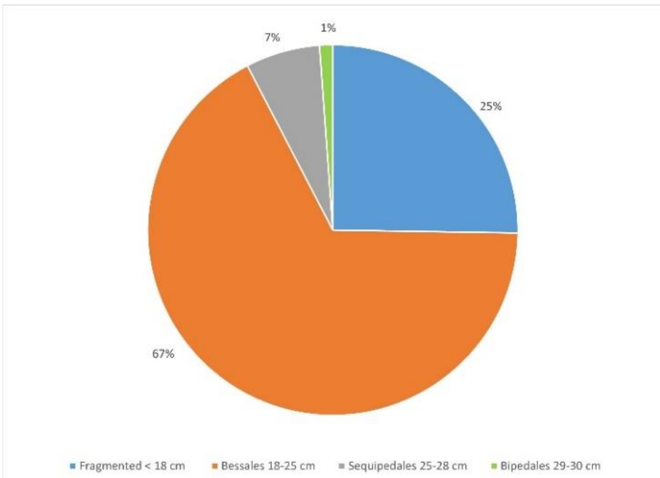


Figure 12. Quantification of bricks measures and types in masonries.

building interventions and referring them to architectures of public and private character, it is possible to plan a comparative analysis of the construction techniques adopted in relation to both chrono-typological aspects and to particular contingencies.

Finally, we have a bigger chance to clarify the structural and contextual relationships of each construction yards with the surrounding buildings, in order to formulate wide-ranging and multi-temporal reconstructive hypotheses.

Some first outcomes of our work can be briefly exposed here.

First of all, our “very-close-range” photogrammetry approach to structural archaeological evidences, using very high definition shoots of samples and supported by total station, with automatic measurement of vectorial features, has given results very encouraging if compared to measures of samples directly taken, with a tape and one by one, on the ancient walls: the dimensions of bricks and other building components of the archaeological structure are always almost the same in both cases and mismatches are very few and very little. In addiction the colours and the type of materials can be clearly distinguished.

This means that a mensio-chronological approach using our method can be correct; obviously a total analysis of building materials and their treatments (specially for mortars, concretes and conglomerates) still needs a direct autopsy, physical and material, of archaeological evidence. In particular cases, anyway, for emergency or during seasonal researches in foreigner countries, this expeditive approach can be adopted on the field, obtaining reliable results in the subsequent laboratory study.

Another result is of archaeological and architectural nature and concerns the accentuate reuse of building materials during the first Severian age which, compared to the topographical context (we are next emperor's palace in Rome) and the chronology (generally this building practice in the Capital is peculiar of late antiquity), might seem an unusual phenomenon. However, this has been already partially detected by previous study of brick stamps found *in situ* which show the reuse of Hadrian's bricks in Severian masonry in the *Terme di Elagabalo* complex [49] but also in other sectors of the rebuilt emperor’s palace on the Palatine, in particular during the first Severian phase [50]-[52]. This phenomenon, associated with a new prevalent use of *bessales* bricks, seems typical of the years of Septimius Severus, when the first emperor of the new dynasty had to reactivate the intensive production of bricks to manage the reconstruction of a large part of the destroyed city from the 192 C. E. fire [53].

We can imagine that at the initial moment, while waiting for new material stocks in large and continuous quantities, it was decided to reuse bricks from burnt walls, which must have cost about 1/5 of that of first choice, also solving part of rubble removal problem [54], [55].

This would confirm the hypothesis that the construction of our complex should be dated to the years of Septimius Severus (before 211 C. E.) rather than to the later period of Severus Alexander (222-235 C. E.) [56], [57].

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