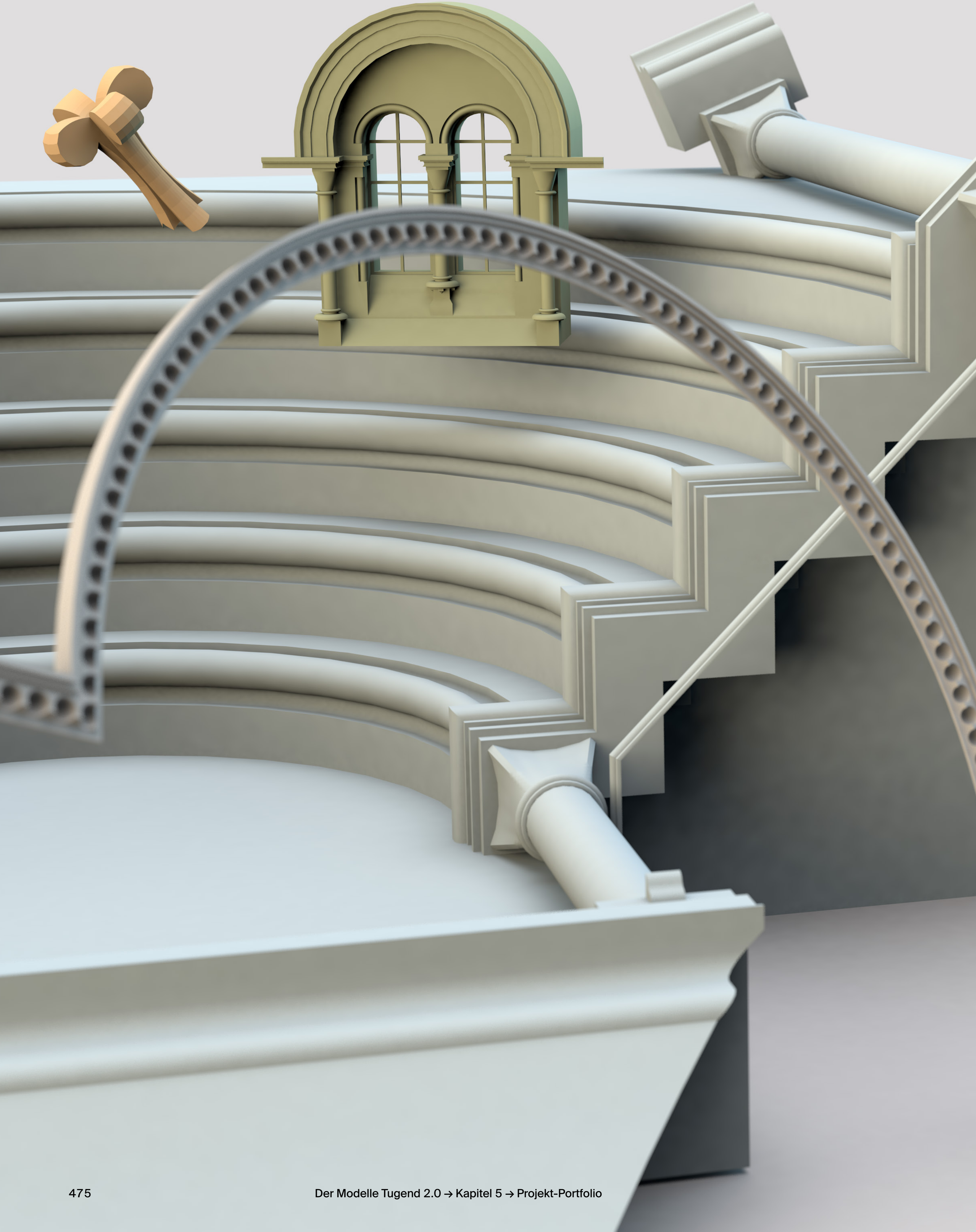


**Marco Canciani, Federica Chiappetta,
Corrado Falcolini, Manuela Michelini, Maria Pastor Altaba,
Mauro Saccone, Alice Scortecci**

III. A methodology for virtual reconstruction at different scales: Environmental, architectural and archaeological heritage.

→ 3D survey, augmented reality, heritage, virtual reconstruction

This contribution focuses on methodologies for virtual reconstruction of cultural heritage in various contexts: from urban and environmental to architectural and archaeological setting. This study is aimed to make the virtual reconstruction as objective as possible, with a minimization of the level of uncertainty related to individual elements and based on scientific contributions from various disciplines: 3D Survey, Archaeological Restoration, Mathematics, Geographic information systems. According to this deductive method, virtual reconstruction hypotheses are the result of a process starting with data collecting in a database and acquired from laser scanning and photogrammetry detection, followed by the study of ancient sources, from the analysis of most recent research, and finally return the original object in a 3D model consisting of geometric entities and mesh models, relative to the individual fragments. The aim of this research is threefold: to extend the knowledge of ancient structures, strongly transformed over time, through the integration of three-dimensional identification and modeling methodologies; to offer the tools for a better readability of monuments, through virtual and augmented reality systems; to deepen the learning of case studies through the creation of multimedia databases, which can be viewed and consulted by everyone.

III.1 Introduction

The preservation of artworks and sites belonging to the cultural heritage, more and more at risk of destruction or abandonment due to natural or manmade events 01, increasingly requires the development of a methodology for the acquisition, elaboration and interpretation of data which should be not only scientifically validated but also easily achievable and replicable in any context. Starting from the London Charter in 2009, where a clear definition of data, metadata and paradata was given, many recent studies have also focused on the traceability of the data source, the degree of uncertainty that specific data can have and the transparency of the data procedures 02. Based on these considerations, our research has been directed to the definition of a method that would link 3D models to a database that would gather all available data. Thanks to a multidisciplinary approach involving several scholars from various scientific fields, the research has been able to address many aspects of virtual reconstruction, from methodological to more specific and application issues.

■01
Canciani, Spadafora, Farroni, Flavio Mancini, Rinalduzzi &Saccone 2017, pp 75–83.

■02
Bentkowska-Kafel, Denard & Baker 2012 and Apollonio, Fallavollita & Giovannini 2015, pp. 189–194.

III.2 Related works

In these late twenty years, the interest for virtual cultural heritage has arrived to the point that a huge number of proposals of virtual reconstruction have been developed. Based on digital technology, those proposals have contributed to the enrichment of the physical experience of the real monument, archaeological site or artefact by the addition of information or objects not really tangible.

In the Italian context, these several implementations have the common purpose to obtain a user friendly virtual product, but differ in the outcome, among which: 2D reconstructions, il Museo Virtuale della via Flaminia antica 03; 3D reconstructions with fix point of observation, Villa di Livia 04, L'Ara com'era 05; 3D reconstructions, spatially navigable, Quirinale 3D VR 06, and, for the small-scale object, The David restoration project 07.

Among the initiatives undertaken at the international panorama, who use 3D models for virtual reconstruction, and develop this new dual path of research, that concerns not only the multimedia characteristics of the final product and the advanced technologies used to obtain it, but also the entire process of reconstruction, we can find several projects comparable to those made in Italy: the cases of Rome Reborne 08,

■03
Forte, Pescarin, Pietroni, & Rufa, 2006, pp. 189–196.

■04
Forte 2007.

■05
L'Ara com'era is a project promoted in 2016 about the Ara Pacis by Roma Capitale, Assessorato alla Crescita Culturale — Sovraintendenza Capitolina ai Beni Culturali.

■06
Quirinal 3D VR is a software for the virtual navigation at the Palazzo del Quirinale, realized by Digital Lighthouse in 2016.

■07
Callieri, Cignoni, Ganovelli, Impoco, Montani, Pigni, Ponchio & Scopigno 2004, pp.16–21.

■08
Dylla, Frischer, Mueller, Ulmer & Haegler 2009, pp. 62–66.

Nantes en 1757 [09] and Virtual Williamsburg [10] are focused on the creation of navigable 3D digital models, or Virtual Sarmizegetusa [11] that has also the aim to develop multimedia applications that involve the upgrade of the visitor experience, while enabling a better comprehension of the archeological remains.

In this context, our research, carried out by a series of different studies, has highlighted the need of a specific methodology as rigorous and scientific as possible based on a hierarchical classification of the reconstruction models by using a standardized vocabulary. Particularly, in architectonical and archaeological field, the reconstructions have availed themselves of the classical architectonical orders, starting with Vitruvio (Vitruvio book III, 3, 10–13 and book IV, 1, 7; 11), through the studies of XV's ancient architecture, to arrive to recent studies of codification of the terminology used in archaeological areas [12].

In this way, the 3D model of virtual reconstruction is divided in sub elements, related between them and arranged in a hierarchical tree structure, matched with a corresponding structure of database, organized in assemblies and subassemblies.

We can find a lot of research with the aim to create **a semantic description models**, as described by L. De Luca [13], and equally many researches, derived from the studies of Harris [14], which describe a wall's stratigraphy using a matrix. In this context, fits perfectly the research project of the Castel of Shawbak [15], whose stratigraphy data, that come up from the archaeological analysis and 2D and 3D models, are linked to an archaeological database, which reaches the single element, defined as **atomized** informative unit.

Some application experiences, developed in recent years, have allowed us to refine this methodology and have been a valid test sites, in particular: in an urban context, the experience of Villa Adriana in Tivoli [16] and of the Aurelian Walls [17], in the field of archaeology, the study of The Titus's Arch at Circus Maximus [18] [19], Latina Gate and Castro Pretorio at Aurelian Walls [20].

■09
Billen et al., 2012, pp.19-26.

■10
The project Virtual Williamsburg was born in 2008 from the collaboration of IAHT (Institute for Advanced Technologies in the Humanities) at the University of Virginia, and the Colonial Williamsburg Foundation (CWF).

■11
Virtual Sarmizegetusa, Romania (2013–2016). A project result of the collaboration between the National Museum of History of Transilvania (MNIT) and the Cultural Heritage and Applied Technologies Institute (ITABC) of the Italian National Research Center (CNR) that have organized several missions during the years 2013–2016, that have taken into consideration different study-cases of digitalization of antique architecture using non invasive techniques in the Sarmizegetusa Ulpia Traiana archeological site.

■12
Batley 2005.

■13
De Luca, Véron & Florenzano 2007, pp. 181–205.

■14
Harris 1989.

■15
Drap, Seinturier, Chambelland, Gaillard, Pires, Vannini, Mucciotti & Pruno 2009, pp. 320–328.

■16
Canciani, Chiappetta, Michelini, Pallottino, Saccone & Scortecci 2014, pp. 129–136.

■17
Canciani, Michelini, Saccone, Scortecci & Zampilli 2017, pp. 193–207.

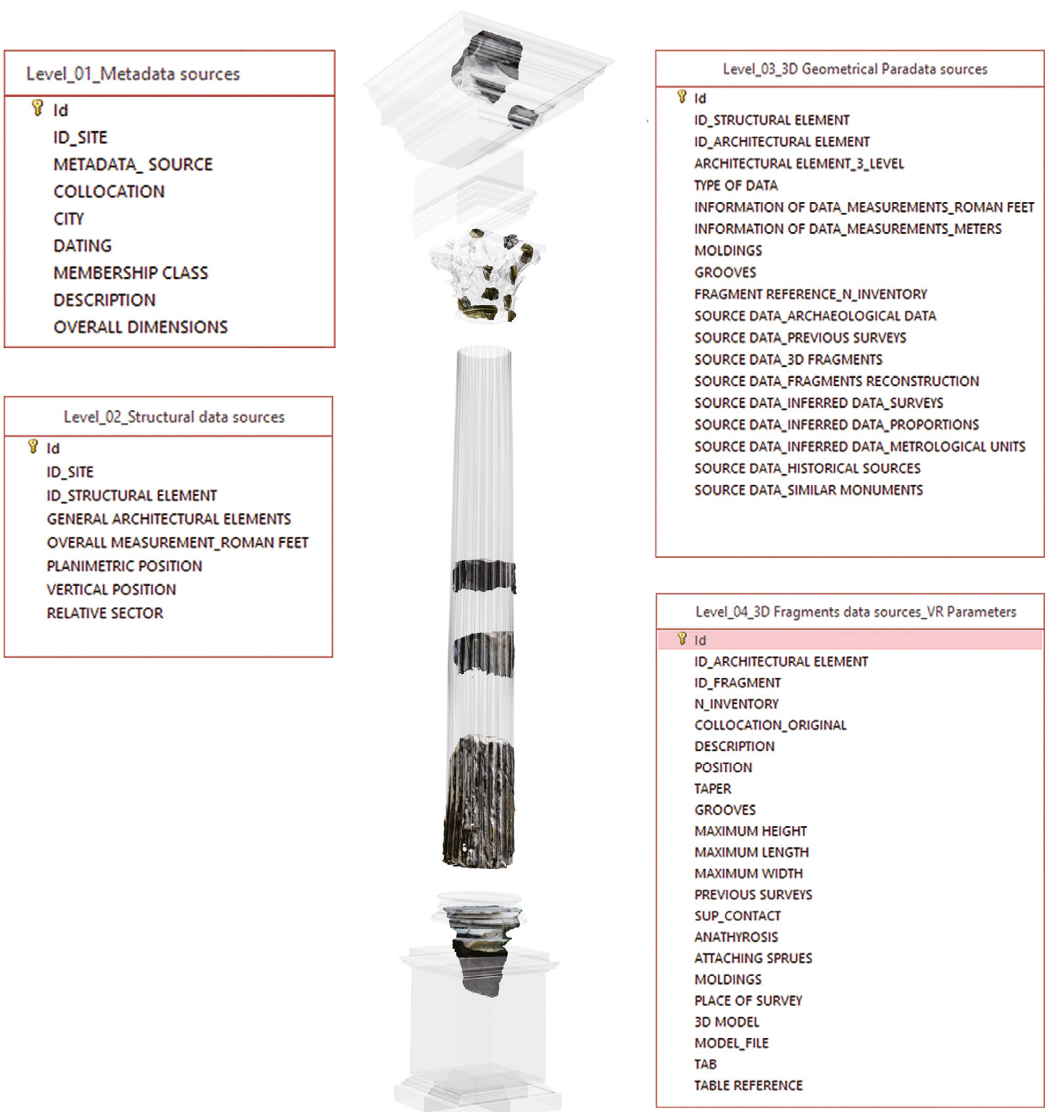
■18
Canciani, Falcolini, Buonfiglio, Pergola & Saccone 2013, pp. 61–66.

■19
Canciani, Falcolini, Buonfiglio & Pergola 2014, pp. 393–412.

■20
Canciani, Persiani, Saccone & Zampilli 2017, pp. 209–231.

III.3 A structured method for virtual reconstruction

This study aims to develop a procedure of Virtual Reconstruction (VR) in line with the latest researches, based on the gained experiences and, if possible, in a more structured form. In our method, the data are divided into two groups: the first group refers to 3D objects and their specific elements (mesh models, related to archaeological data, and geometric models, related to reconstruction data), positioned according to a unique spatial coordinates system based on a chosen reconstruction hypothesis; the second group concern a database, which collects all the data (metadata e paradata). 01



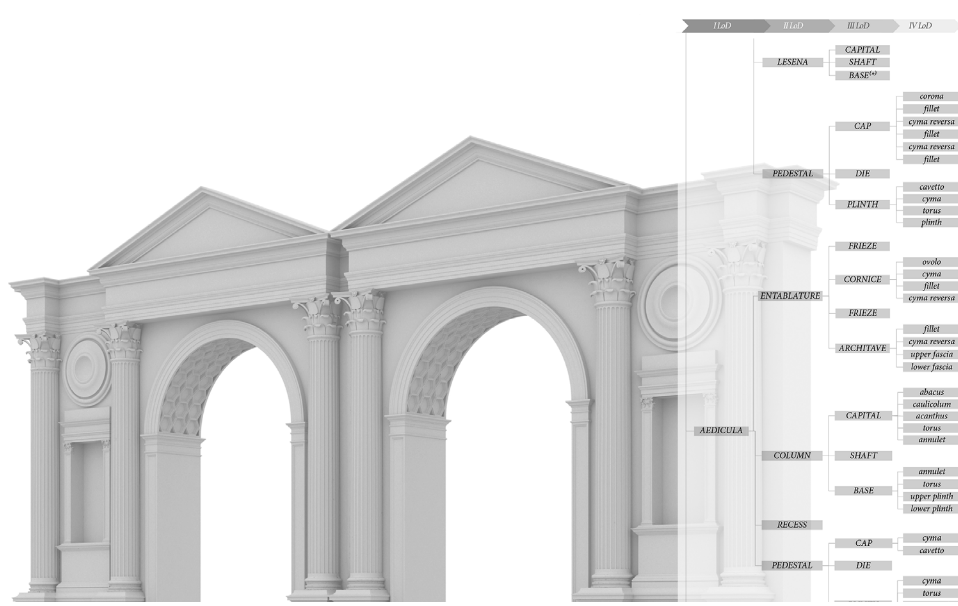
☐ 01
A 3D model of column subdivided by entablature, capital, shaft, base and plinth and the corresponding structure of database, subdivided in 4 levels of detail. (M. Canciani)

■21
De Luca, Véron & Florenzano 2007, pp. 181–205.

This structure of database, according to a similar one described in 21, is branched into four hierarchical levels:

1. In the first level the study object is filed according to general meta-data sources (titling location, typology, description, dimension etc.) and shows the main historical and documented references (such as texts, images, drawings, etc.), which can describe general features and that can become a morphological or dimensional data).
2. In the second level, the individual elements are classified according to their specific peculiarities (original position, overall size, description, belonging to groups of main elements etc.). The archeological data are acquired by an acquisition through integrated survey (with laser scanners, photogrammetric, topographic, traditional survey) concerning the whole site and the particular elements.
3. In the third level, the more specific parts of the case of study, belonging also to the previous level, are classified bringing the main paradata sources (allowable minimal and maximal dimensions, in situ and original position, proportion, metrological verification etc.) to reconstruct the 3D geometrical original model of each element by procedures and algorithms developed by the working group, as briefly described above. The results of this specific processing contribute to improve and adjust the virtual reconstruction model. These results also allow to track the source from which the data are derived and the degree of uncertainty of each element. 22 02
4. In the fourth level, every 3D element (or mesh model) of the archeological fragments is described by those features which are useful for virtual reconstruction (VR parameters). An analysis of paradata sources (geometrical, analytical, proportional, metrological, constructive etc.) is realized, comparing the individual parts and their connecting elements, carried out through the database queries.

■22
Apollonio, Fallavollita & Giovannini 2015, pp. 189–194.



☐ 02
Porta Aurea in Ravenna: a digital hypothet
reconstruction.
(E. C. Giovannini)

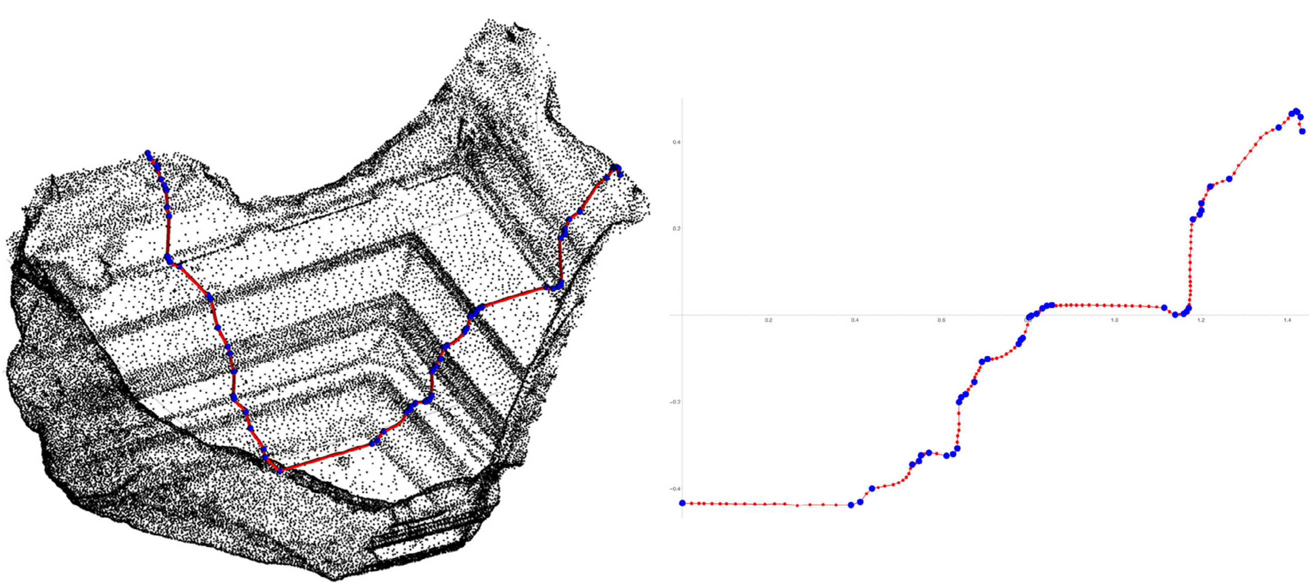
III.4 Algorithms for virtual reconstruction

Statistical and mathematical methods have been used in several steps of the procedure starting from the point clouds of the surveyed objects. We have looked for solutions of different problems such as parameterization of planar sections, best cylinder approximating a portion of a column and its high precision contour sections, segmentation based on colour or normal gradients, fracture lines extraction and their parametric representation, comparison between curves and contact surfaces for matching probability of different fragments.

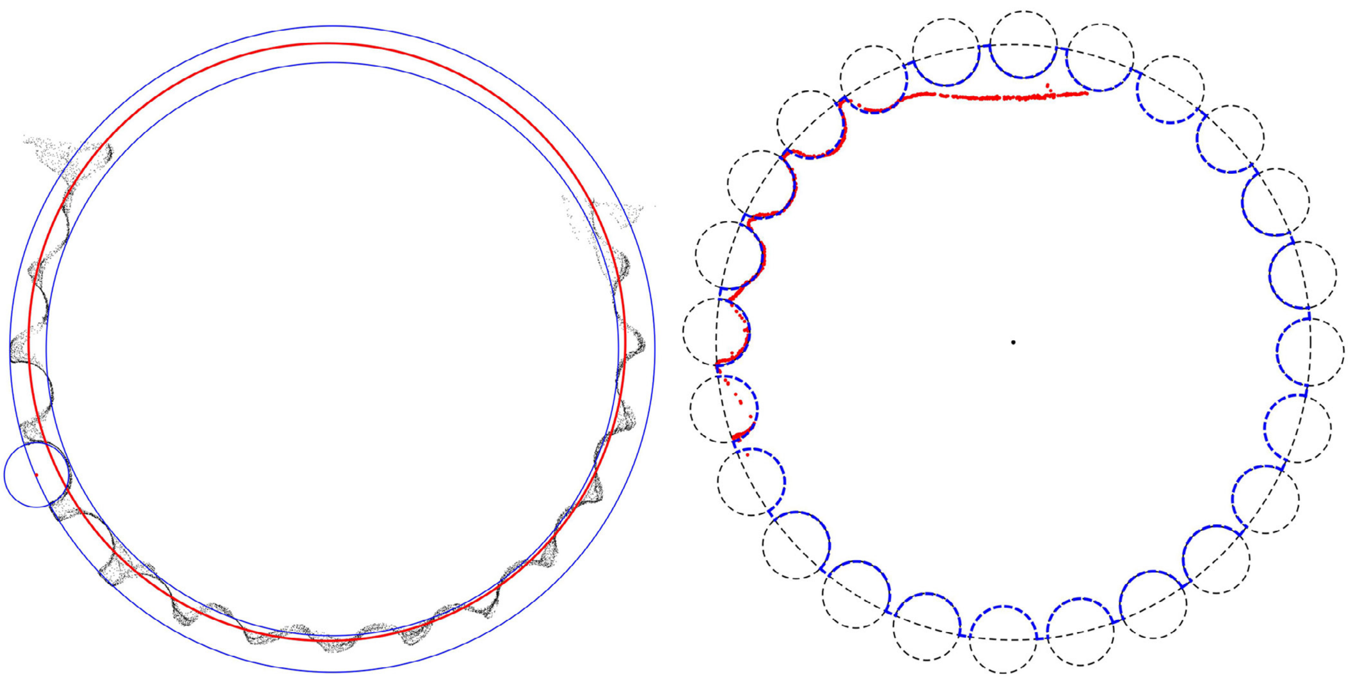
An example of the procedure to find moulding's profile of an entablature fragment 03 of the Arch of Titus: in the corresponding oriented point cloud find a relevant plane of section which optimize points selection analyzing their normal component (average normal to the closest faces of the correspon- ding triangulated surface) and look for a parametric curve fitting the points; then automatically select some nodal point on the parametric curve (i.e. point of discontinuity in the direction of normal vectors, inflection points etc.) allowing an automatic geometrical moulding construction which can be translated in feature elements of the database and used in virtual reconstruction procedures 3) and 4) of Section 2).

The requested orientation of the point cloud could be achieved analyzing statistical properties of nearby normal directions and checking precise alignments using specific properties and symmetry.

☐ 03
a moulding section of a surveyed entablature fragment and, on the right, its interpolating curve and automatic nodal points detection. (C. Falcolini)



Analogue procedure for the best section of a column fragment 04: in this case the optimal orientation is the result of a least squares problem to detect the best cylinder containing the fragment and the extraction of a piece-wise regular parametric curve of section enable a very precise estimation of column features on a proper scale. Comparing cylindrical projections of the point cloud with several section models, allows a very precise measure of column and flutings radii and then a possible drum reposition along the virtually reconstructed column taking also into account historical and architectural order information about the shape of a vertical section, entasis and tapering.



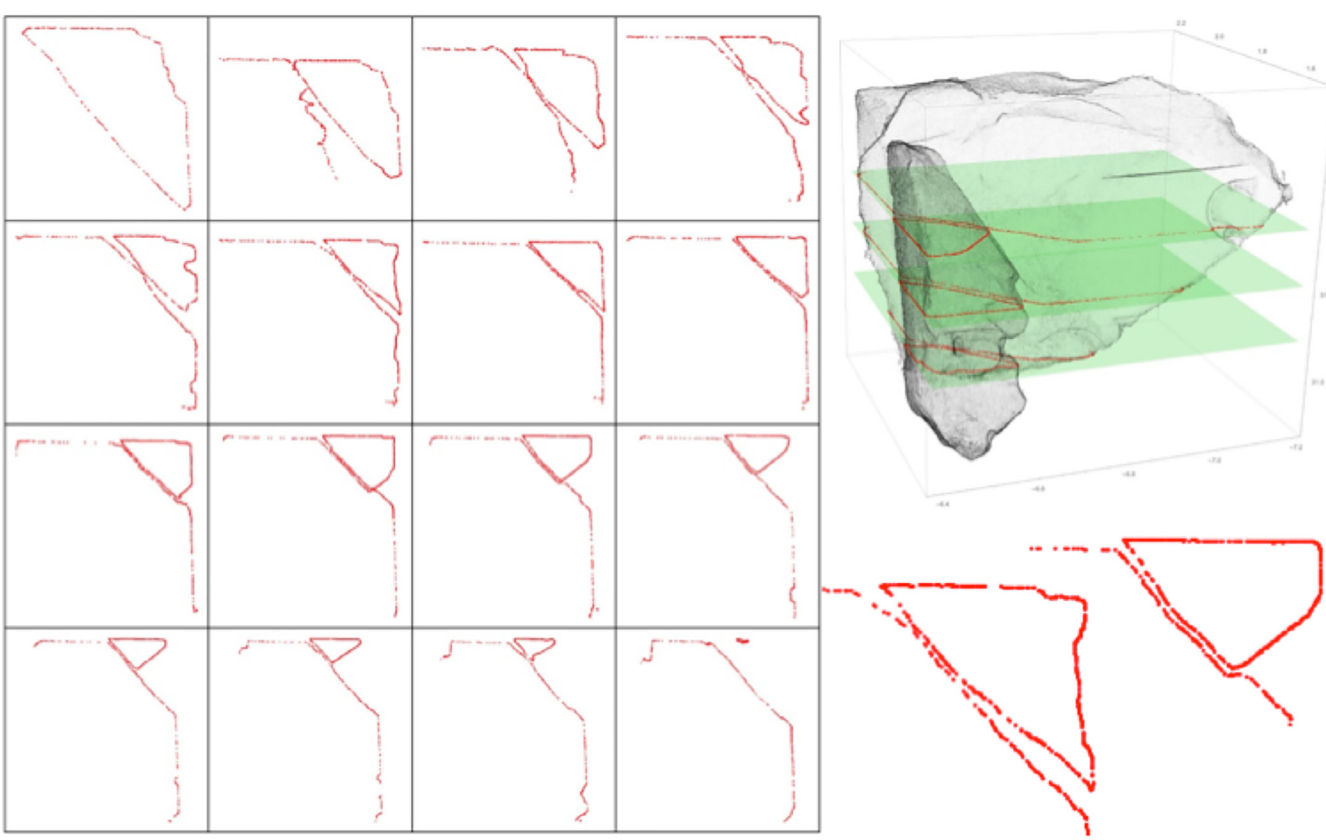
☐ 04
Construction of a column section model for two different drum fragments. The model applies, with the same column and flutings radii, to both fragments.
(C. Falcolini)

A second example is related to matching procedures for possible adjacent fragments using contact curves and surfaces: it applies to the virtual reconstruction of the Arch of Titus's epigraphy.

In the first case, we have calculated matching probability for all possible couples of fragments and since we had a given fixed plane of the epigraphy, a first rough orientation was implicit, and we selected possible adjacent pieces to test their contact surfaces.

The algorithm used parallel planar sections 05, with their parametric representation, of closer and closer position of the two fragments, carefully changing their orientation to optimize contact profiles. An exact solution was difficult to find due to the very irregular shape of the ruined fragments and to the small relative size of the final contact surface which resulted to be very irregular and not simply connected.

☐ 05
parallel planar sections of two possibly adjacent fragments of the Arch of Titus's epigraphy. On the right, two aligned pieces and their sections at minimal and maximal distance. (C. Falcolini)



III.5 The virtual reconstruction in environmental heritage: the case study of Villa Adriana

The study on Villa Adriana utilitas allowed the recovery of an important part of the value of the villa, almost unknown until some decades ago [23]. The natural consequence of the Vitruvian principle is the detection of the original routes, one of the most direct tool to restore the original villa functioning.

The extension of the archaeological site required the realization of a GIS — to map the current status in order to develop various surveys through thematic cartographies — that shows the data collected from the physical inspection and from the scientific research.

This method — that produces analysis layouts both in 2D and 3D — employs a general model of the current state based on the individual buildings and the original routes (the key elements). Through the use of GIS the whole complex was examined, with the application of cognitive data — regarding each building, the ancient roads, the current street network and the other elements of the villa — as parameters of virtual reconstruction.

The graphics processing of a general plan was the basis for the identification of the ancient routes: it is a tool with the specific aim of representing all the necessary elements for the proper interpretation of the ancient project.

The same model was also used by M. Michelini and A. Scortecci for the redaction of the last georeferred plan [24]. The new plan is outlined on a georeferred orthophoto [25] with the other graphic sources -georeferred, too. 06 07

These materials are the basis for the GIS. The virtual reconstruction required a structure divided in two series of data; the first one for the 2D and 3D objects of specific elements, rebuilt and relocated to the hypothetical position with the original orientation, in accordance with a univocal system of coordinates; the second one is organised in a semantically structured database, in reference to its relating spatial organization.

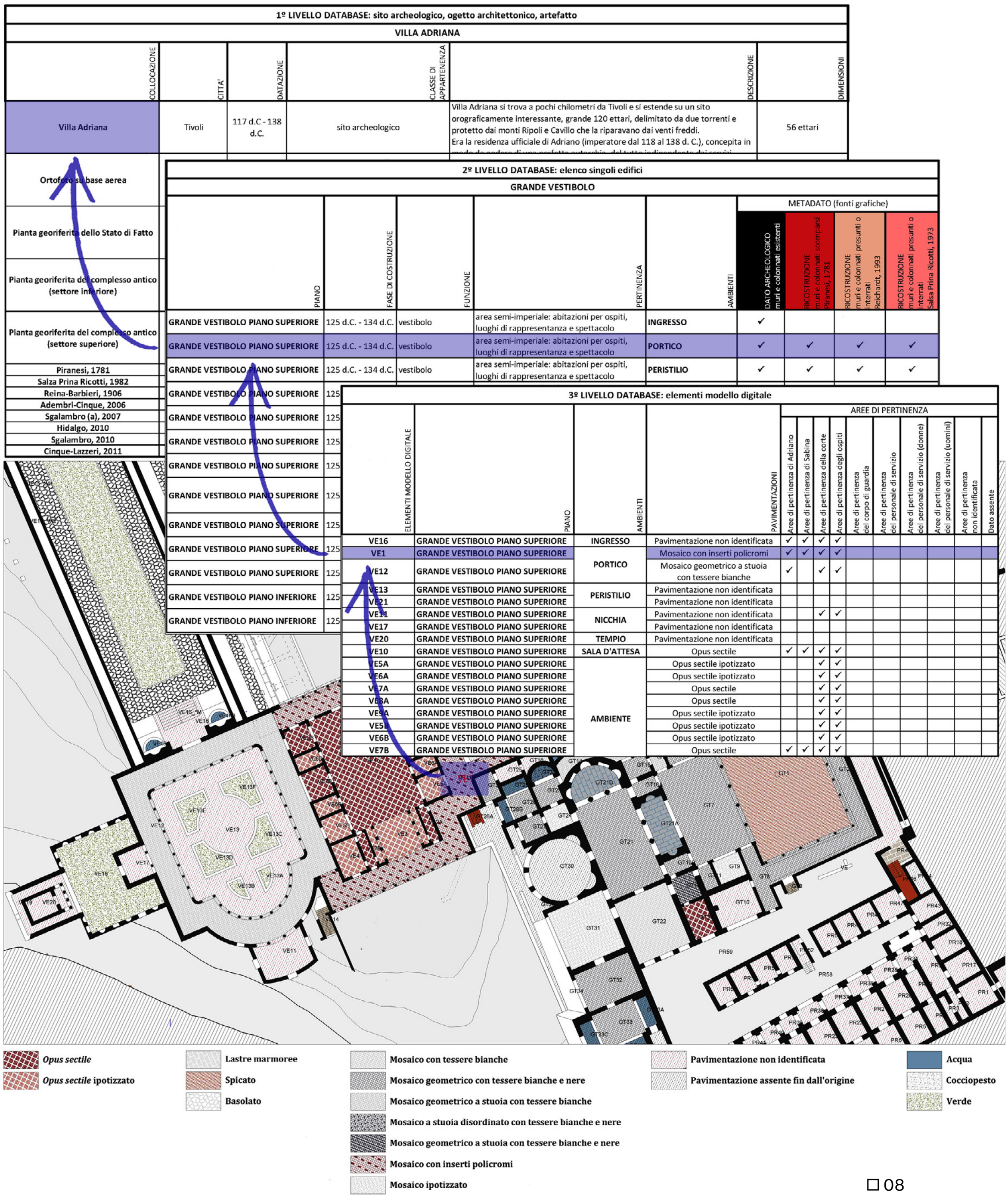
■23
Salza Prina Ricotti 1982, pp. 25–55.

■24
The survey was conducted as part of a degree thesis (University of Roma Tre — Department of Architecture, Degree thesys in Architecture — Restoration, M. Michelini, A. Scortecci, I percorsi antichi di Villa Adriana: nuovi strumenti di valorizzazione, supervisors M. Canciani, E. Pallottino, assistant supervisors F. Chiappetta, Z. Mari, M. Saccone, 2013).

■25
Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ortofoto a colori (part. Villa Adriana) 2006, http://www.pcn.minambiente.it/GN/.

☐ 06
Georeferred plan of Villa Adriana (lower and upper sectors). The vanished archaeological ruins here reported, the water and the vegetation derive from historical surveys and specific studies. (M. Michelini, A. Scortecci)

☐ 07
Georeferred plan of the current state of Villa Adriana. (M. Michelini, A. Scortecci)

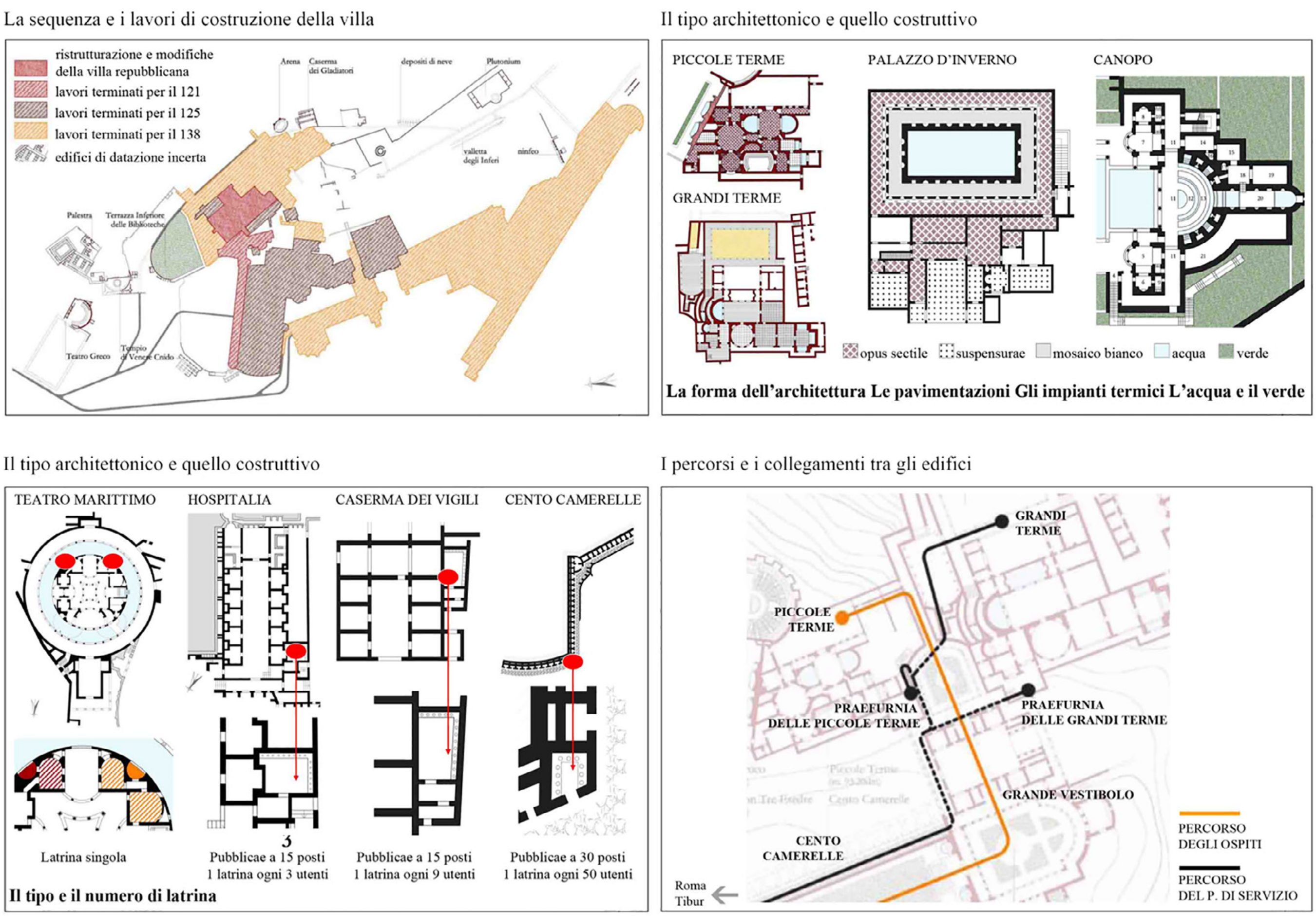


☐ 08
GIS, data structure and thematic maps.
(M. Michelini, A. Scortecci)

This structure is shaped in hierarchical levels; 1st a generic one in which the archaeological is catalogued according to the general features (titling, location, category, overall dimensions, etc.); 2nd a middle level, in which each element is described through its specific features (typology, location, description, etc.); and 3rd, in which the most important parts of the elements in the second level are classified conforming to the data useful for the virtual reconstruction (location, function, presence of helpful features for the connection of the various parts etc) 08

At the environmental scale, the individual buildings were surveyed and examined to highlight the ancient routes by the analysis of some constant VR parameters, related to functional, constructive and decorative elements, systematically compared. 26 09

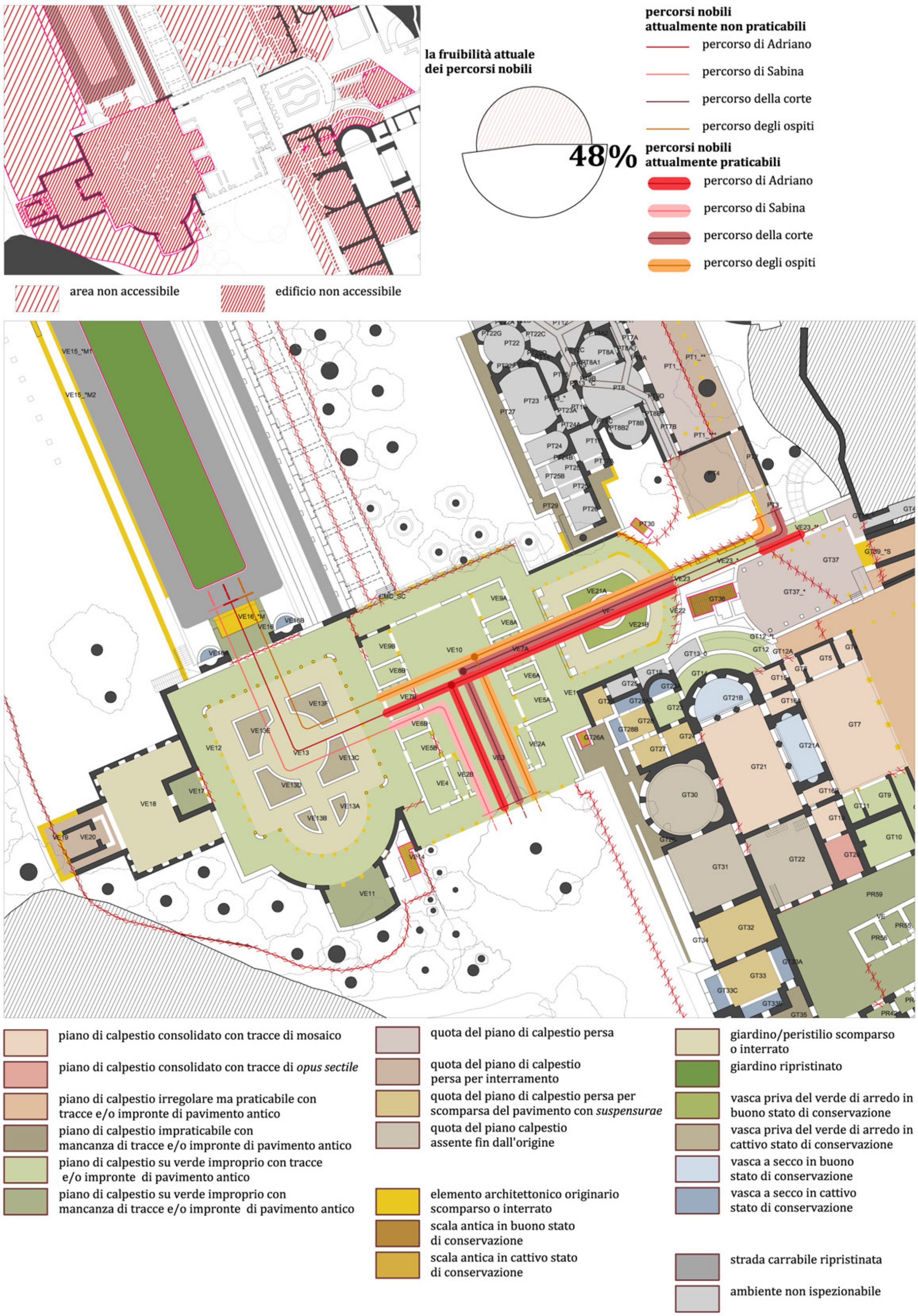
■26
Chiappetta 2008.



☐ 09
Parameters and methods employed for the identification of the ancient routes. (F. Chiappetta)

The analysis allowed the identification of the intended use of the various areas and their inhabitants: the emperor Hadrian, his wife Sabina, the court, the guests and the domestic workers.

At the architectural scale, GIS employs 2D and 3D models as bases for gathering the collected data. The detailed study concerns the Great Vestibule (Grande Vestibolo), the villa monumental entrance: multiples paths and connections unravel from this building, spread on two clear levels (the lower one, for the domestic service, and the upper one for the nobility).



☐ 10
Example of analysis made with GIS. (M. Michelini, A. Scortecci)

Nowadays, the ruins of the building lay on the most popular touristic route but the preservation condition and almost total inaccessibility diminished it to a simple passage. Therefore, GIS has been the instrument to increase the information about the site, as it has produced specific analysis regarding functions, pertinence, original pavements, preservation conditions and accessibility of the building. [10]

The last outcome from the research was the publication of a mobile application (Android and IOS) [27] in 2015. It is a simple prototype, but it includes all the potentiality of a valid tool for the proper fruition of the archaeological site. (See other bibliography) [28].

■27
Guida multimediale: i percorsi antichi di Villa Adriana, 2015. POR FESR Lazio 2007–2013. Scientific supervisor F. Chiappetta, creative designer M. Michelini, thematic specialist A. Scortecci. Production of Ohana film and music Srl.

■28
MacDonald & Pinto 1997; Mari, Reggiani & Righi 2002, pp. 16–29; Salza Prina Ricotti 2001.

III.6 The virtual reconstruction in archaeological heritage: the Arch of Titus at Circus Maximus at Rome

The project of the reconstruction of Arch of Titus at Circus Maximus takes part of the collaboration between Università Roma Tre, Dipartimento di Architettura [29] and Sovrintendenza Capitolina ai Beni Culturali [30], at the project of Requalification of the environment and enhancement of the archeological discoveries at Circus Maximus and surrounding public spaces of Via dei Cerchi and Porta Capena Square in Rome [31] [32].

The contribution of our multidisciplinary group consists on the development of a methodology that supports the virtual reconstruction; this methodology is principally based on three-dimension modelling of fragments and their connection with a multilevel database that collects different types of information.

According to the 3D survey of the different fragments, the VR parameters considered for the reconstruction are: the in-situ fragments (which are directly related to original geo-referenced coordinate system), the original orientation of the fragments, their metrological verification, the sequence of mouldings, the geometric reconstruction of their sections and the connecting elements with other fragments (anathyrosis, trace of pins, sections on the mouldings, contact surfaces). By secondary procedures and calculations, we have identified the original position of the fragments on the basis of the corresponding portion of the general 3d survey.

Then, all the specific information regarding each single fragment (general dimensions, details and specific characteristics such as mouldings, place where found, main sections, original orientation and hypothetical architectonical element of belonging) has been indexed and registered in a minor database, organized by tabs. These tabs and their contents compound the fourth specific level of the general database, which is useful to compare fragments and to find analogies between them, as well as to catalogue them in categories and relevance for the VR reconstruction. [11]

■29
The working group about Virtual Reconstruction of Roma Tre University, Department of Architecture, is formed by: M. Canciani (coordinator), C. Falcolini, M. Saccone, G. Romito, B. Mammì, M. Pastor Altaba.

■30
The working group of Sovraintendenza Capitolina ai Beni Culturali is formed by M. Buonfiglio, S. Pergola, A. Coletta.

■31
Canciani, Falcolini, Buonfiglio, Pergola & Saccone 2013, pp. 61–66.

■32
Canciani, Falcolini, Buonfiglio & Pergola 2014, pp. 393–412.

IMMAGINI	NUMERO DI INVENTARIO	FRAMMENTO	COLLOC. ORIG.	DESCRIZIONE	POSIZIONE	MODANATURE	SEQUENZA MOD.	ALTEZZA MOD.	mis.01	mis.02	mis.03	mis.04	mis.05	mis.06	mis.07	mis.08	mis.09	mis.10
77 	CM432	SET_04	-	-	non *in situ*	-	xx											
80 	CM437	SET_04	-	-	non *in situ*	NO	-	-										
86 	CM445	SET_04	-	-	non *in situ*	NO	-	-										
47 	-	F_27	BALAUSTRA / APPOGGIO	Frammento in marmo lunense	interrato	SI		xx										
99 	CM88	-	ARCHITRAVE / FREGIO		non *in situ*	SI	xx	xx										
13 	CM1190	-	ATTICO	Coronamentomarmo bianco lunese	non *in situ*	SI	LIS-GLD-LIS-GLD-LIS-CVT-CRN-PDN-SFT-LIS-OVL-LIS-DEN-TON-LIS-OVL	20	115	20	55	20	20	153	20	180	17	79
14 	CM1191	-	ATTICO	Coronamento angolare marmo bianco lunese	non *in situ*	Si	LIS-GLD-LIS-GLD-LIS-CVT-CRN-PDN-SFT-LIS-OVL-LIS-DEN-TON-LIS-OVL	20	115	20	55	20	20	153	20	180	17	79
6 	CM92	-	ATTICO	Cornice con mensola marmo bianco lunese	non *in situ*	SI	LIS-OVL-LIS-DEN-TON-LIS-OVL	17	79	17	53	30	13	56				
97 	CM86	F_24	ATTICO	Frammento in marmo lunense	non *in situ*	SI	LIS-GLD-LIS-GLD-LIS-CVT-CRN-PDN-SFT	20	115	20	55	20	20	153	20	180		
15 	CM1093	-	ATTICO/ZOCCOLO MODANATO	Frammento marmo bianco lunese	non *in situ*	SI	TON-GRR-LIS-TON-GRR-LIS-TOR-FSC	19	114	23	19	138	21	82	724			
17 	CM82	F_02	COLONNA / BASE	Base di colonna in marmo bianco lunense	*in situ*	SI	TOR-LIS-SCZ-LIS-TON-TON-LIS-SCZ-LIS-TOR-PLT	99	20	51	10	20	20	10	77	28	124	141
20 	CM1195	-	COLONNA / CAPITELLO	Frammento marmo bianco lunese	non *in situ*	NO	-	-										
21 	CM251	set-01	COLONNA / CAPITELLO	Frammento marmo bianco lunese	non *in situ*	NO	-	-										
22 	CM252	set-01	COLONNA / CAPITELLO	Frammento marmo bianco lunese	non *in situ*	NO	-	-										

☐ 11
Arch of Titus 4thLevel of database. Example of data tab of some of the analyzed fragments with the VR parameters. (M. Pastor Altaba).

As part of the initial phase of analysis, along with the 3d survey of the fragments, we have collected all the different historical sources that describe general and specific features of the monument. These documents are useful to recognize the architectonical elements of the arch and to place each fragment on its hypothetical original position.

We call all this information metadata sources, their nature is both graphic and textual (mosaics, coins, precedent surveys, images, drawings, historical texts, etc.) and they make up the first level of the database.

To complete this initial phase, we have identified the hierarchal semantic organization of the main architectonical elements of the arch and have listed them in the so called second level of the database. Then, we have connected the general architectonical elements to each single fragment registered in the initial database.

In a second phase of elaboration of the data, a third level database has been aimed to further analyze each single architectonical element of the arch. This analysis consists on the elaboration of a detailed virtual geometrical 3D model of each architectonical element, based on the information obtained by the 3D survey of the fragments and their scaled virtual mesh models.

The information specifically related to this level of the database has been linked not only with the second level of the specific fragments but also with the first one (metadata and related documents), obtaining additional information regarding the uncertainty level of the VR reconstruction, as described in 33. This information could also be organized in an independent level of database and its corresponding graphic visualization document could be directly created if we entered all the tabular information in a general Architectural Informative System. 12

■33
Apollonio, Fallavollita & Giovannini 2015, pp. 189–194.

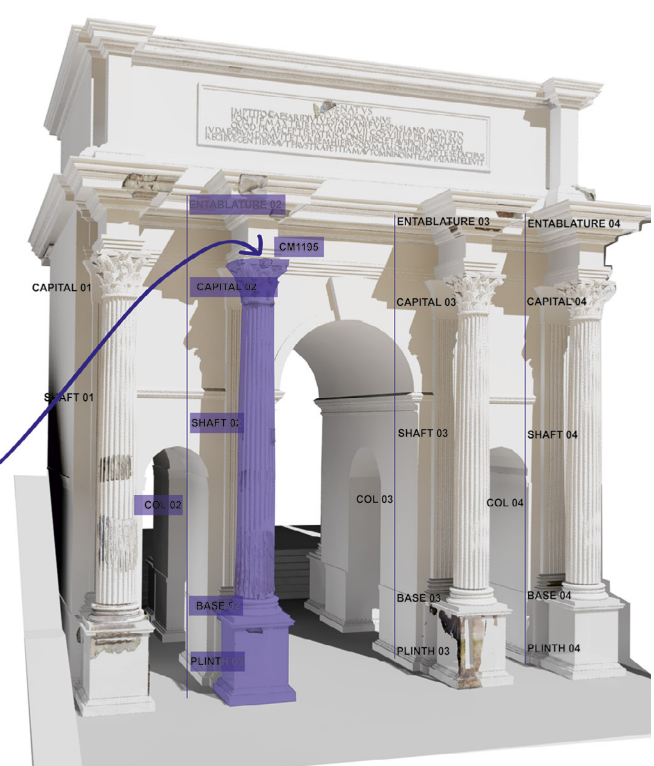
□12
Arch of Titus: database structure with table of the 3rd level, where data sources and levels of uncertainty are indicated; as well as a 4th level, where the paradata useful for reconstruction are shown for each fragment. (M. Canciani)

3rd LEVEL DATABASE: elements of virtual model

ARCHITECTURAL ELEMENT		TYPE OF DATA		INFORMATION OF DATA					SOURCE DATA								
2nd LEVEL OF REFERENCE	3rd LEVEL	GEOMETRICAL MODEL	MESH MODEL	MEASUREMENTS (roman feet)	MEASUREMENTS (meter)	MOLDINGS	GROOVES	REFERENCE FRAGMENT_ inventary number	ARCHEOLOGICAL DATA surveys	PREVIOUS SURVEYS	3D FRAGMENTS SURVEY	RECONSTRUCTION based on fragments	INFERRED DATA based on surveys	INFERRED DATA based on architectural proportons	INFERRED DATA_based on metrological units	HITORICAL SOURCES graphic and textual	SIMILAR MONUMENTS period or author
02_COLUMN	02a_CAPITAL	✓	-	4.5p.r.	1.3 m	-	-	-				✓		✓			✓
02_COLUMN	02a_CAPITAL	-	✓	*	0.21 m	-	-	CM1195			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.26 m	-	-	CM251			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.35 m	-	-	CM252			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.22 m	-	-	CM255			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.33 m	-	-	CM269			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.25 m	-	-	CM320			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.22 m	-	-	CM259			✓						
02_COLUMN	02a_CAPITAL	-	✓	*	0.13 m	-	-	CM321			✓						
02_COLUMN	02b_SHAFT	✓	-	29,5p.r.	8.6 m	-	✓	-				✓		✓			✓
02_COLUMN	02b_SHAFT	-	✓	*	0.17 m	-	✓	CM315N		✓	✓						
02_COLUMN	02b_SHAFT	-	✓	*	0.24 m	-	✓	CM454N		✓	✓						
02_COLUMN	02b_SHAFT	-	✓	*	2.17 m	-	✓	CM75/F_04	✓	✓	✓						
02_COLUMN	02b_SHAFT	-	✓	*	0.73 m	-	✓	F_14		✓	✓						
02_COLUMN	02b_SHAFT	-	✓	*	0.62 m	-	✓	CM77/F_06		✓	✓						
02_COLUMN	02c_BASE	✓	-	2p.r.	0.7 m	✓	-	-				✓		✓			✓

4º LEVEL DATABASE:survey fragments

	IMAGE	INVENTORY NUMBER	ORIGINAL COLL.	DESCRIPTION	POSITION	GROOVES	MAX HEIGHT	MAX LENGTH	MAX WIDTH	PREVIOUS SURVEYS	CONTACT SURFACE	ANATHYROSIS	ATTACHING SPRUES	MOLDINGS	PLACE OF SURVEY	3D MODEL	MODEL FILE	TAB	REFERENCE TABLE
20		CM1195	02_CAPITAL	Luni white marble fragment	noin situ	NO	0,214	0,214	0,214	-	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
21		CM251	02_CAPITAL	Luni white marble fragment	noin situ	NO	0,262	0,181	0,2	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
22		CM252	02_CAPITAL	Luni white marble fragment	noin situ	NO	0,352	0,162	0,123	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
23		CM255	02_CAPITAL	Luni white marble fragment	noin situ	NO	0,216	0,139	0,248	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
25		CM269	02_CAPITAL	Luni white marble volute	noin situ	NO	0,33	0,224	0,152	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
27		CM320	02_CAPITAL	Luni white marble fragment	noin situ	NO	0,247	0,194	0,178	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
24		CM259	02_CAPITAL	Luni white marble acanthus leave	noin situ	NO	0,219	0,287	0,211	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17
28		CM321	02_CAPITAL	Luni white marble volute	noin situ	NO	0,129	0,256	0,29	NO	NO	NO	NO	NO	laboratorio	YES	rhinoceros file	YES	TAV. 17



After all the analysis and elaboration of the information is done, in a third phase of VR data representation, we have prepared different elaborations: a first planimetric reconstruction, in which georeferenced 3D models related to the excavations are superimposed; a second altimetric reconstruction (section and elevation), in which the proportions, size of individual parts and the matching conditions with the original dimensions of reference are verified in the overall context; a third volumetric reconstruction, combining the first two ones, in which all the 3D texturized models of the fragments are relocated in a general reference geometric model in their most congruent hypothetical original position. 34

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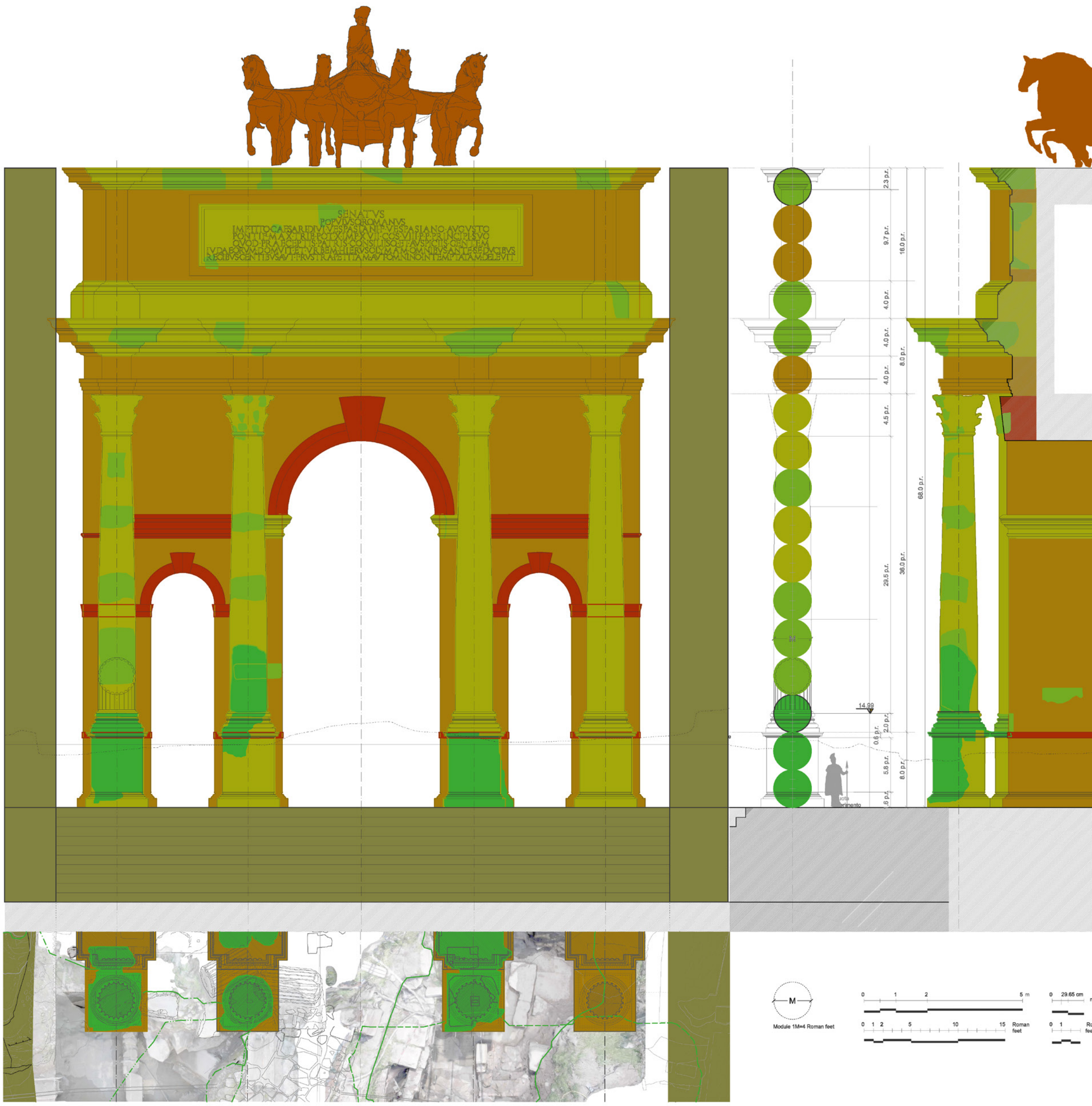
In the specific case of the capitol of the column, due to the fact that the direct source of information (i.e. the relative fragments) was scarce we have been forced to take into consideration a theoretical 3D model of a typical capitol of the same historic period as main reference. Then, studying and comparing the surface of the relative fragments and the theoretical model (using mathematical procedures, as explained in paragraph 4 of this paper) we have found the relative position of the fragments and have been able to scale the geometric 3D model.

The planimetric reconstruction, referred to the original position of the elements of the arch on their horizontal projection, has been carried out on the basis of the elements still standing and the historical documentation (3D survey and first level of database). These elements in situ, described by their textured 3D model, have fixed the main measures and helped us to complete the equivalent data for the parts where there is a lack of information (third level of database).

The first altimetric reconstruction, a front view, is based on the hypothetical reconstruction in elevation of the columns, and takes as the main reference the still standing fragments and the historical documentation of architectural orders, proportions, and sizes (Vitruvio book III, 3, 10–13 and book IV, 1, 7; 11), registered in the metadata database, as well as the metric unit of the age, the roman foot. The combination of these three parameters has fixed some minimal measures and has established the proportions of the different elements. This first altimetric reconstruction is also been used to represent the level of uncertainty (from green to brown) and the source from which the data are obtained. [13]

The second altimetric reconstruction, a section view by the centrafornix, has been prepared before reaching the third dimension. In this case, the main profile section of the fragments has been taken as the principal data. In combination with different additional horizontal sections, developed along the height of the arch, it has allowed us to determine and produce the final most probable hypothesis of reconstruction by a VR three-dimensional model.



Origin of paradata, data - Level of uncertainty

- Archaeological data; 3D model of Archaeological excavations and in situ fragments
  - Survey February 2012
  - Excavation Survey September 2012
  - Excavation Survey October 2015
  - Excavation Survey January 2016
- Reconstruction based on previous surveys and historical images of the archaeological site; Survey by Giovanni
- Archaeological data derived from 3D survey and analysis of fragments belonging to the different architectural elements
- Reconstruction based on 3D measurements of the fragments and the comparison with classic architecture.
- Circus's overall reconstruction (conducted by the Capitoline Superintendency of Rome).
- Reconstruction based on iconographic historical sources (coins / mosaic of Luni, Forma Urbis) and documentary (Anonymous by Einsideln)
- Reconstruction based on similar monuments of the same period or architect; Arch of Constantine.
- Reconstruction based on data derived from archaeological survey of fragments, analisys of classical architectural and metrological

☐ 13
Arch of Titus: Front view with plan and the section. In the drawing, the different sources and the level of uncertainty of the data (from green to brown).
(M. Pastor Altaba).

III.7 Castro Pretorio at the Aurelian Walls in Rome

The virtual reconstruction of Castra Praetoria, is a part of a bigger project made in Rome by a group of researchers from University of Roma Tre in partnership with **Sovraintendenza Capitolina ai Beni Culturali** [35]. This virtual reconstruction has two focuses, first of all we want to improve the accuracy with the archaeological evidence, and second one we want to find a way to verify our results in site, superimposed on the monument.

Castra Praetoria was the name given to the big military encampment built in Rome by the Emperor Tiberio between 21 and 23 a. D. [36]. After two thousands of years, transformations, destructions, and restorations, the ancient walls of Castra Praetoria are a very large and complex patchwork of information, stratigraphy and wall building techniques.

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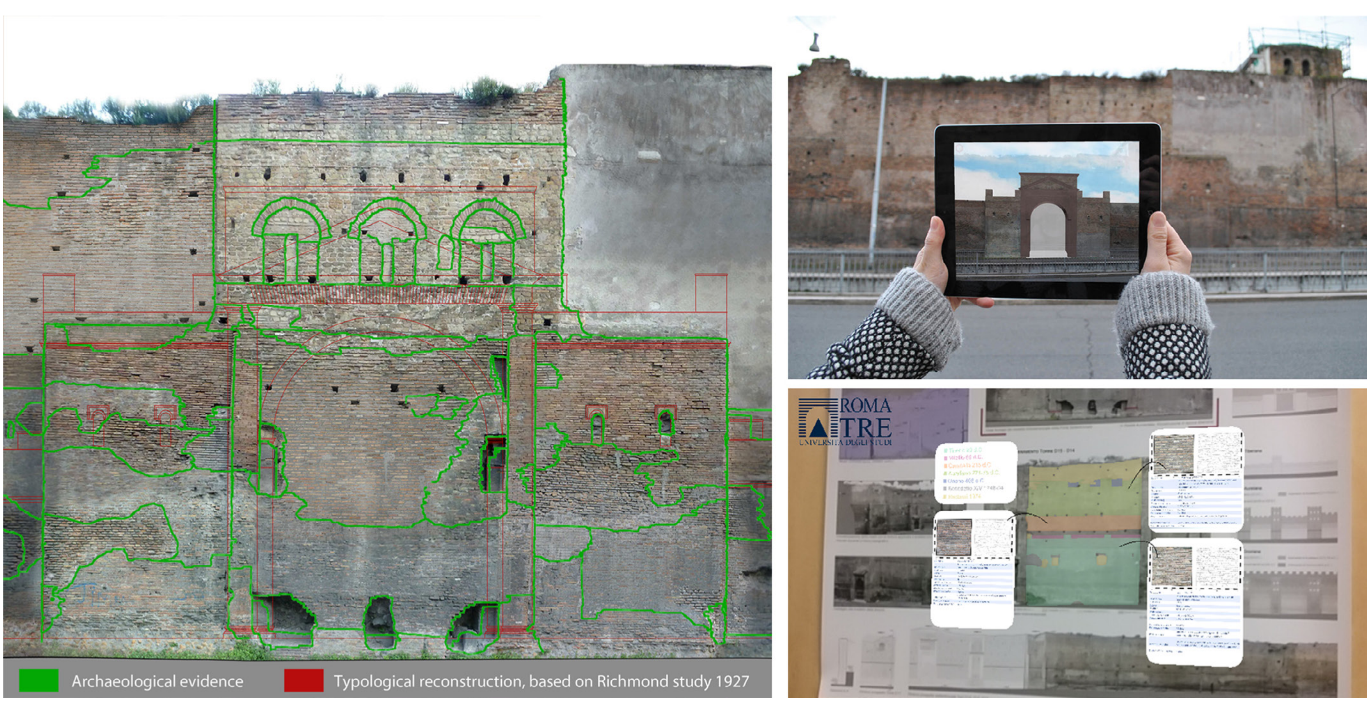
Dipartimento di Architettura dell'Università Roma Tre: Carlo Baggio, Marco Canciani, Corrado Falcolini, Andrea Filpa, Giorgio Ortolani, Simone Ombuen, Anna Laura Palazzo, Elisabetta Pallottino, Ivana Spadafora, Laura Tedeschini Lalli, Michele Zampilli. Sovrintendenza Capitolina: Francesco Giovanetti, Maria Gabriella Cimino. Dipartimento di Studi Umanistici UniRoma3: Maura Medri.

■36
Canciani, Conigliaro, Del Grasso, Papalini & Saccone 2016, pp. 931–937.



□ 14
The northern door of »Castra Praetoria«. Archaeological evidence and augmented reality. (M. Saccone)

So, the first part of this study wants to detect, organize and manage the archaeological evidence. We started with a 3D survey, to acquire 3D photogrammetric models of our monument. Using this model and orthophotos we worked in partnership with archaeologists to identify the wall's stratigraphy. To improve and manage the accuracy of our VR, according to our methodology, we create two level of hierarchical database: the first one is the study of general characteristics and the typology, based on Richmond's study [37]; the other one is based on archaeological evidence and comes from the 3D survey. The VR parameters came from both database: the first one contains 3D surface model, the second one 3D mesh model. To verify our results on site, we first create a combined 3D model with archaeological evidence and typological reconstruction. Then we use an augmented reality system, a technology that superimposes a 3D model on a user's view of the real world. So, the archaeological data, the virtual reconstruction, and all the building techniques are visible on site using a smartphone or tablet, and this help our researcher to check results and improve knowledge. [14] This first step allowed us to verify the wall stratigraphy. In the future we will improve the Augmented Reality to manage useful data for restoration and maintenance such as state of deterioration and cracks survey.

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Richmond 1927, pp. 12–22.

III.8 Conclusion

The aim of this research is twofold: first of all, to refine the proposed methodology, by applying it in other cases of study in addition to those presented; the second one, to better support the process of philological reconstruction of a site. This process, which historically has always been based on the subjective choices of archaeologists, in the context of virtual reconstruction can become a more rigorous study, always as a prerogative of the archaeologists, but validated through numerical and scientific analysis of data, as much objective as possible.