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# REVERSE DESIGNING: AN INTEGRATED METHOD FOR INTERPRETING ANCIENT ARCHITECTURE

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**Abstract**

Research on architectural archaeology conducted by archaeologists, architects, engineers – and more recently by computer scientists – is characterized by different goals and methodologies. Only sometimes does this result in profitable contributions. Instead, attitudes very often remain deeply rooted in single-discipline vision unable to communicate or interact with each other in the best interest of the subject of the research in question. In this paper, by means of a series of case studies, we intend to outline the principles of "reverse designing," that is the integrated set of methods and skills enabling the retracings of the steps taken by the ancient builder.

**Keywords**

Reverse modelling, terrestrial laser scanner, photogrammetry, treatise, ancient designing techniques, Vitruvius, Heron of Alexandria, Columella, *gromatici veteres*

## *1. Outdated and mainstream research in archaeology*

In this paper we comment on the results of numerous interdisciplinary experiences gained in the field of surveying, visualising/modelling technologies and analysis techniques in Archaeology. Over the past few decades these fields have been strongly affected by the conflict between tradition and innovation, generating a wide range of reactions: from the very enthusiastic to those more reactionary.

With a healthy dose of cautious optimism, it was finally decided to take a recent study focusing on the relationship between Cultural Heritage and Information Technologies, as our starting point to evaluate the real effectiveness of the latter in the field of Archaeology.

In fact, despite great interest shown towards this "mixing," i.e. an inter-disciplinary approach, it is often difficult to assess the actual level of integration of Information Technology (IT) into Cultural Heritage (CH).

The analysis of the findings from recent research on ancient architecture regarding performance emphasises the need for reconciliation and interpenetration among the various fields, not just those pertaining to information technology, in order to define a common operating framework.

In this sense, archaeology will be studied with a deterministic approach, through a careful reading of written sources including "outdated" studies.

Using recent case studies, we will lay the foundations of what could be defined as "reverse designing," based on surveying with active and passive sensors, the thorough examination of all theoretical aspects of ancient architecture and the changes that the building under scrutiny has undergone in time.

## *2. Archaeology from archaeologists', architects' and computer scientists' point of view*

Why do we carry out research in the field of Cultural Heritage and in particular in Archaeology?

What are the expectations and rationale in relation to such a complex, articulated and interdisciplinary range? To these ambitious questions relating to a variety of disciplines, it seems unrealistic, if not impossible, to give a single and well-structured answer in a short text.

Recent experience of the collaboration between archaeologists, philologists, surveyors, architects and computer experts, has plainly demonstrated to the authors how important it is to rethink the respective fields of research, and in some way to lay new foundations with the common purpose of providing an innovative and grounded operational structure for the study of classical architecture.

First, we must examine which are the topics, the objectives and the methodological approaches to the field of archaeology in relation to new technologies. A seemingly all-encompassing response, supported by an extensive bibliographical study, was recently published by Holly Rushmeier with her staff (Pintus, Pal, Yang, Weyrich, Gobbetti, & Rushmeier, 2014), who has been devoted to the field of computer graphics and remote sensing for years. Rushmeier has classified five categories of research in which new technologies have significantly contributed: shape perception enhancement; restoration and preservation support; monitoring over time; object interpretation and collection analysis.

This well-structured study she has developed, while taking into account the limiting factor to taxonomic research of the rapid progress in the technological field, is based on many and varied assumptions different from those typically adopted by researchers in the field of ancient architecture.

The reason for this lies in the fact that taxonomy, as described by Rushmeier, aims at organizing within a scheme of interpretation, the latest research in the three main activities – *acquisition, communication* and *analysis of buildings* – in order to determine which fields offer the possibility of carrying out innovative research. The procedure for classification introduces concepts such as the scale of the analysed objects, their numbers (that is, the number of fragments or works of art) and the relationship existing between them, and finally classifying their applications in the area of Cultural Heritage. One can include most of the studies recently developed in the Italian field of survey and representation within the categories of this taxonomy, and in particular those relating to the archaeological scope: interpretation, documentation, test for surveying methodologies and devices, virtual anastylosis.

Nevertheless, it is extremely disconcerting to discover that a detailed examination of 139 texts, all in English, entitled "Geometric Analysis in Cultural Heritage" – most papers submitted to conferences forming part of the Institute of Electrical and Electronics Engineers network "IEEE"(conferences VSMM, ICCV), of the Association for Computing Machinery "ACM" (Siggraph, Journal of Computing and Cultural Heritage), of the field of photogrammetry/metrology (ISPRS Journal of Photogrammetry and Remote Sensing, Optical Metrology), even of the Journal of Archaeological Science and of the International Conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage – almost completely omitted monographic studies on relevant UNESCO Sites (e.g. Benedetti, Gaiani, & Remondino, 2010; Bertocci, Parrinello, & Vidal, 2013; Bianchini, 2012), exhibition catalogues, PhD thesis, articles and research within a mainly archaeological editorial scope (ASMOSIA Association for the Study of Marble & Other Stones in Antiquity, DECOR-Linguaggio architettonico romano), bulletins by Superintendence containing mainly informative news, conference proceedings focusing on issues of a theoretical nature related to ancient and contemporary architecture (Nexus Network Journal NJJ), research journals in the field of drawing and representation (EGA Revista de expresión gráfica arquitectónica, Disegnare Idee Immagini). In other words, it is easier to document the *extent* to which Information Technology has extended its scope of application into the field of Cultural Heritage, rather than check the actual benefit provided with respect to the *quality* of research in Archaeology and, more generally, in Art History; the latter is a far more difficult task. However, with this articulate and well-structured study on geometric analysis in Cultural Heritage, the focus of attention has been almost exclusively limited to dissemination channels for Information Technologies.

A consideration to be made at this point is that content-driven studies, those developed to answer specific questions and requests from historians, architects and archaeologists, are not always compatible with the challenges affecting computer experts.

The mere application activity is probably less attractive to the true computer expert, as it has

become just part of routine operations that have long been implemented in software packages.[1]

In this paper it is not our intention to play down the importance of technology-driven studies, but in the interest of research and documentation of Cultural Heritage and being ourselves promoters of research topics, we cannot avoid emphasising that some applications of algorithms and new generation devices may prove illusive and of secondary importance.

In this sense, the London Charter for the computer-based visualisation of Cultural Heritage (2009)[2] together with the list of the Seville Principles (International Principles of Virtual Archaeology, 2011) on implementing regulations into the archaeological field, should constitute an important deterrent against improper or worthless use of IT (Brusaporci & Trizio, 2013).

The current state of a historic building and, more generally, of an ancient monument, is the product of a wide range of events (alterations during the building's life cycle, catastrophic natural events and subsequent restoration, decay, destruction or vandalism). Moreover, the aim of some IT research to reduce this complexity into theoretical models, based principally on shape analysis so as to catalogue and assemble architectural fragments,[3] solely because they are ruins, appears quite unrealistic if applied to concrete case studies (Vendrell-Vidal & Sánchez-Belenguer, 2014).

However, automation is precisely the objective of computer science, especially when it is intended to eliminate any personalistic or "empirical" interpretation of an object. On the one hand we have extreme complexity, whilst on the other the intent to parameterize and to automate analysis processes.

A novel and more mature approach to the interpretation of Cultural Heritage requires a "step back" attitude – for new disciplines in particular – and at the same time a "step forward" attitude namely the necessity for greater involvement regarding the cultural and historical content of the building being surveyed, modelled and geometrically analysed.

Holly Rushmeier's article (Pintus et al., 2014) is emblematic of this approach: in recent literature there only exists the so-called "sector-based approach," which barely takes into account extensive pre IT scientific literature; the latter is often assigned a passive role, a sort of starting point to the *real* research, the so-called *computer-based research*. In fact, a significant advancement of knowledge regarding a work of art is precisely due to a clash between the various disciplines.

Clearly, everyone has their own scientific point of view, a key to the interpretation of their own work and to the work of others; however it is undeniable that successful and fruitful research should focus on architecture and archaeology by developing specific and viable technological solutions, and not the other way around.

Needless to say, this is not meant to be a challenge between *quantitative* methods and *qualitative* interpretation of buildings but rather a desire to develop and pursue workable parameters for researchers to use to assist their studies on Cultural Heritage, thus avoiding the use of historic buildings as a mere pretext for the implementation of applications, algorithms, and devices.

When researching a subject to find an explanation or gain added knowledge all important is the acquisition of its geometric, chromatic, optical characteristics, as well as any other specific analysis. An example is the scale of the building (Benedetti et al., 2010; Bertocci et al., 2013). However, this rigorous data acquisition phase, which takes on the appearance of a scientific experiment (Migliari, 1999), should be followed by *interpretation* which makes use of a wide set of knowledge related to the context and site of a building, recent and previous studies, and, especially, all output from heterogeneous research fields.

Those who are neither archaeologists, historians or computer scientists, for example architects and engineers involved in surveying

[1] For an excellent example of collaboration between different research and professional fields, having a relevant role in proven 3D ranging technologies and demonstrating constant interest in art, see Paolozzi Strozzi and Zikos (2011).

[2] http://www.londoncharter.org/.

[3] Some software applications aimed at reassembling fragments (elements of architraves, fragments of objects, etc.) are emblematic. Often, as some researchers have explicitly acknowledged, tests are performed on modern pottery, worthless and of no historic significance, broken for the study in order to prove the effectiveness of new computational algorithms aimed at this complex operation. It is far more difficult but much more effective for interpretative purposes of ancient buildings, research work on anastylosis of marble fragments carried out by Canciani, Falcolini, Buonfiglio, Pergola, Saccone, Mammì, and Romito (2013) and Thuswaldner, Flöry, Kalasek, Hofer, Huang, and Thür (2009).

activities, cataloguing, drawing and digital modelling – may and even should contribute with their own specific training experience by adding an individual piece to this complex mosaic.

Remaining within the scope of archaeology, both architects and engineers should assume more strongly and clearly the role of "historians of design and construction."[4]

Actually construction, design and drawing are, especially in the ancient world, much more closely related to each other than at the present time, as many studies have highlighted. Hence the need to apply a "holistic model" as pointed out by Carlo Bianchini (2012) with respect to documentation and surveying: archaeology, in particular, belongs to the category of complex systems that cannot be examined on the basis of the traditional analytical approach, but as a whole.

The description of a complex phenomenon, when analysed from all possible viewpoints provided by the current technical-scientific framework in which we operate, may coincide with a non-finite number of variables (Bianchini, 2012). To reduce this mass of information, a selection process based on clear objectives is necessary. What are we really looking into? Which is the most important result of a particular study that is worth transmitting to posterity?

A cultural approach outlined a few years ago by Riccardo Migliari (1999) can be summarized as follows: "architectural survey is the reconstruction of the design process of the building." The understanding of the *design process* is definitely a much more ambitious task compared to mere documentation, since it assumes the ability to master architectural schooling in a particular period, to throughly understand the set of technical and scientific knowledge at their disposal. In short, it means entering the minds, customs, functions and laws governing *that* world.

But this is not such a direct and simple task: it means examining the history of a large quantity of studies, drawings and representations in general, of restorations and modifications during its existence (Apollonio, Fallavollita, & Giovannini, 2015).

In addition to the various expressions used to indicate results coming from reality-based models (virtual reconstruction, virtual anastylosis and digital reconstruction.), one could also add "reverse designing." In fact, when studying fragments and remains of architectural or archaeological ruins, once the acquisition phase is completed, the analytical process of *reverse modelling* applications is widely used due to its appropriate and efficient approach to testing 3D models from active and passive sensors. This category of applications was first designed for specific requirements in industrial design and mechanical engineering (Adembri, Di Tondo, Fantini, & Ristori, 2014).

Each building in the past was created to provide concrete solutions to specific needs and it was designed on the basis of rules, which echo still exists (even if incomplete and sometimes confused) in a limited number of treaties, ancient manuals and written sources. Although these texts have been at times the source of either confusion or misunderstanding (Vitruvio, 2002), they reflect a complex operational and theoretical context which goes beyond just dimensioning the orders.

In addition to *De Architectura* by Vitruvius, there are many other sources that should be taken into account, since they integrate this text of a hybrid nature (sometimes only theoretical but in certain cases extremely concrete and practical, depending on the circumstances). In fact, some parts of the treatise by the Roman architect just refer only briefly to various topics, as is the case in calculations necessary for designing (I, I, 4): "Arithmetic helps measuring and calculating the costs of the buildings, geometry can help solve problems related to symmetries."[5]

### 3. *Deterministic approaches to the interpretation of ancient buildings: the example of theatres*

On several occasions when studying Classical Architectural Design, the important role played by Heron of Alexandria has emerged in relation to calculation methodology adopted in the building process (Bianchini & Fantini, 2014; Svenshon, 2009; Conti & Martines, 2008; Juan-Vidal, 2013). He wrote several manuals and commentaries on mathematical formulae hence his legacy cannot only be relegated to an inventor of measuring

[4] In other countries, such as Spain, the distinction between history of architecture and history of construction is particularly evident because of the different classification of professional categories operating within the industry: *arquitecto* and *aparejador*. The latter has a scientific profile strongly focused on construction logistics, stereotomic solutions, centering and vaulted structures (including geometric technical drawings and annotations, etc.), leaving a marginal role to eminently stylistic matters.

[5] Translation and comment by Silvio Ferri, see p. 91.

devices (Docci & Maestri, 1993) or revolutionary machinery.

Similar considerations apply to other authors such as Varro, Columella, as well as to the writers of the *Corpus Agrimensorum Romanorum*: they all describe measurement units, geometrical rules and properties of specific shapes, formulae for the determination of perimeters and areas of complex geometric figures.

If we take the case of theatrical architecture, Heron's formulae complete efficiently what Vitruvius wrote in his V book on the Roman theatre: the Latin writer does not explain through the design process the way in which he determines the *perimetros imi* (Salvatore, 2007), that is the lower and smaller perimeter of the *cavea*. For Vitruvius this circle is just a starting point, whose determination is unfortunately not mentioned, information that might have provided a relevant hint on the management, calculation and solution of the problem of theatre capacity at that time[6] (Fig. 1).

**Fig. 1:** Jerash South Theatre

Once converted into drawings, all Heron's formulae for calculating *cavea*'s capacity included in *Stereometrica* and *De Mensuris* (Heiberg, 1914) make particularly clear to the reader two important concepts: one, the presence of a modular structure (formed by the orchestra's sub-modules) repeated in the orchestra and the rows of seats; and two, the simplicity of calculating the correct dimensions of the theatre (Fig. 2).

The synergy between the formulae by the Alexandrine mathematician and Vitruvian techniques for designing the theatre help us understand the relationship of cause and effect existing among the three main parts forming that typology: *cavea*'s dimensioning (Heron's formulae) leads to orchestra's circumference (*perimetros imi*), then the graphic algorithm is "run" and the set of triangles inscribed into the circle lead to the definition of the scenic building.

But there is more to be said, firstly with respect to the knowledge of other written sources, not necessarily relevant to the technical scope or in manuals.[7]

Tertullian (Cuscito, 2012) is another author, who for various reasons provides useful information on the working principles and use of the theatre and location for performances.[8]

Architecture for the performing arts, in ancient times as well as today, underwent numerous and radical changes, changes in use, adaptations and restoration. Thus, it is worth quoting the research work of Salvador Lara-Ortega (1992) on the Roman Theatre in Saguntum: he has actually proven through surveys, drawings and diagrams that a continuous transformation was crucial for this type of building. This study largely contradicts or at least raises serious questions about the reliability of the conclusions reached by other famous researchers in the field of classical theatrical architecture in an attempt to supercede the draft plan by Vitruvius (Sear, 1990; Hammond, 1964; Small, 1983).

Lara-Ortega's research is widely recognised for its excellence, because it provides a very vivid and realistic overview of the problems that the ancient architect had to face when the theatre was forced to change its admission capacity.

Basically the consequences of this are twofold: first, an increase in the audience seating area, and second, the pushing back of the *postscenium* wall. This concept of a moving theatre, in which all elements take shape on the basis of "parametric" constraints (Fig. 3) and where the reuse of former structures built following Vitruvius' graphic algorithm took place, is of date totally different to anything suggested by other researchers. Occasionally scholars tend to interpret through new graphics and more complicated drawings

[6] In this sense, it is quite surprising that one of the more recent books on Roman theatres by Frank Sear (2006) still shows hypotheses about calculations and formulae for theatre capacity from contemporary authors, such as Forni e Moretti, (Sear, 2006, pp. 25-27) and does not make reference to Heron (*vide infra*).

[7] As in the case of *Lex Roscia theatralis*, from which we learn the set of rules providing the class of *equites* with preferential allocation of 14 rows of seats in the *ima cavea*.

[8] Although his *De Spectaculis* (3th century) is principally focused on criticism of the pagan customs.

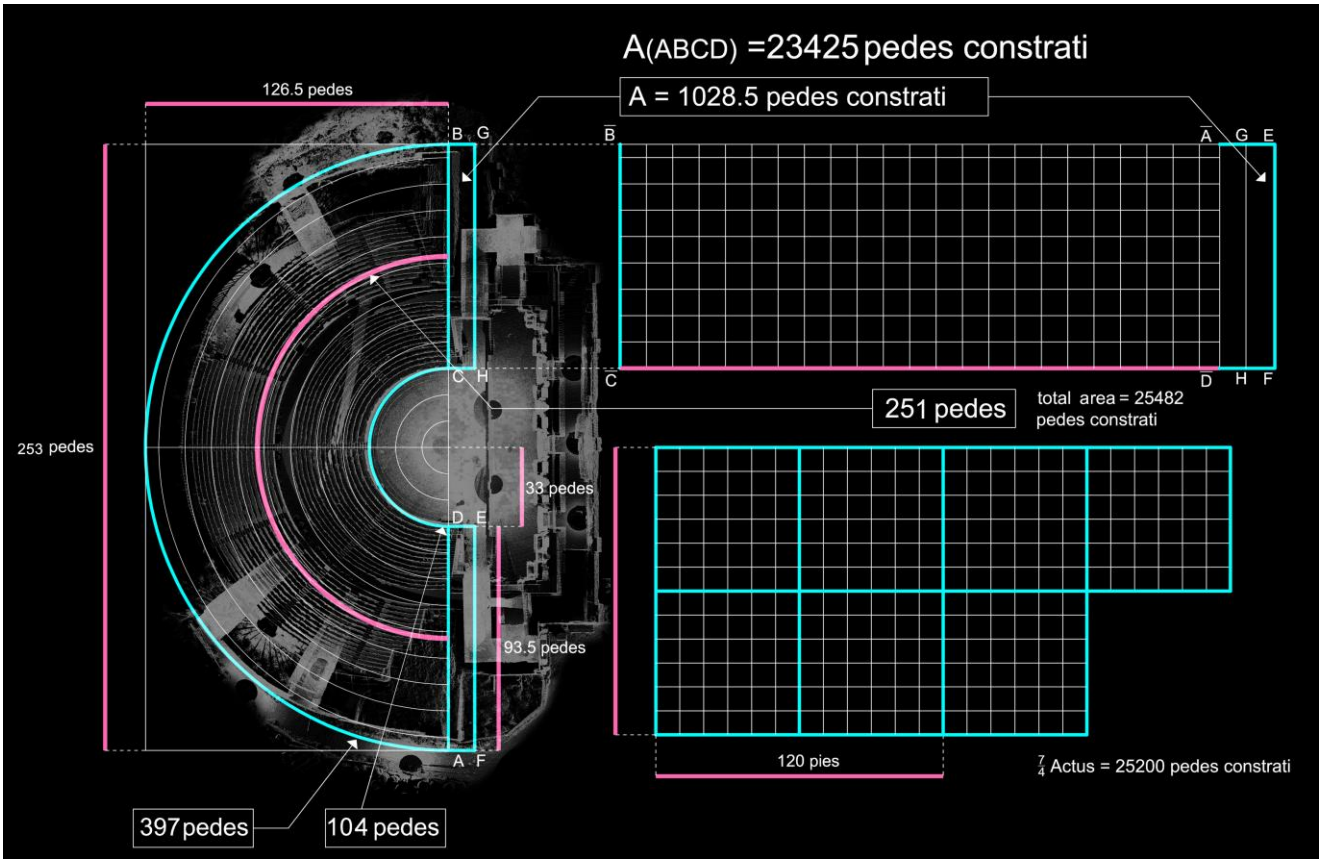


**Fig. 2:** Application of Heron formulae from *Stereometrica* and *De Mensuris* to the design analysis of Jerash South Theatre (drawing from Bianchini & Fantini, 2015)

when unable to fully understand what is actually not clear.

The ancient graphic constructions which are the starting-point for *ichnographia, orthographia* and *scaenographia*,[9] originate from professional knowledge, gradually improved over centuries and generally not complex. In fact, these rules had the advantage of being simple, easy to remember and draw with the means available to architects at the time. Moreover, they were easily understandable by unskilled workers without specialist knowledge and undoubtedly not able to read instructions written by designers, if not in a simplified graphic form.

Research today which is closely connected to specific contemporary needs, should therefore be aware of the versatility of ancient buildings – from both the point of view of construction techniques adopted and the effectiveness of geometric models on which such structures were based. This is particularly important with respect to the new 3D digital representation technologies.

A static image, as offered through a realistic 3D reconstruction of high impact in visual terms, can be misleading due to the fact that it leaves no room for interpretation; moreover it does not show up a significant point, i.e. the fact that architectural structures, constantly changed and transformed over time.

In terms of academic content, little has changed since the research work on reconstructions carried out by 18th century *pensionnaires*, albeit with other means. On the contrary, it is exactly this *deterministic attitude* based on actions and reactions, cause and effect involving architecture that is currently lacking. Perhaps this is because the "laws" by which a building changes in time are more difficult to understand and, therefore, represent.

Architecture for the performing arts (circuses, theatres, amphitheatres and stadiums),

[9] *Vide infra.*

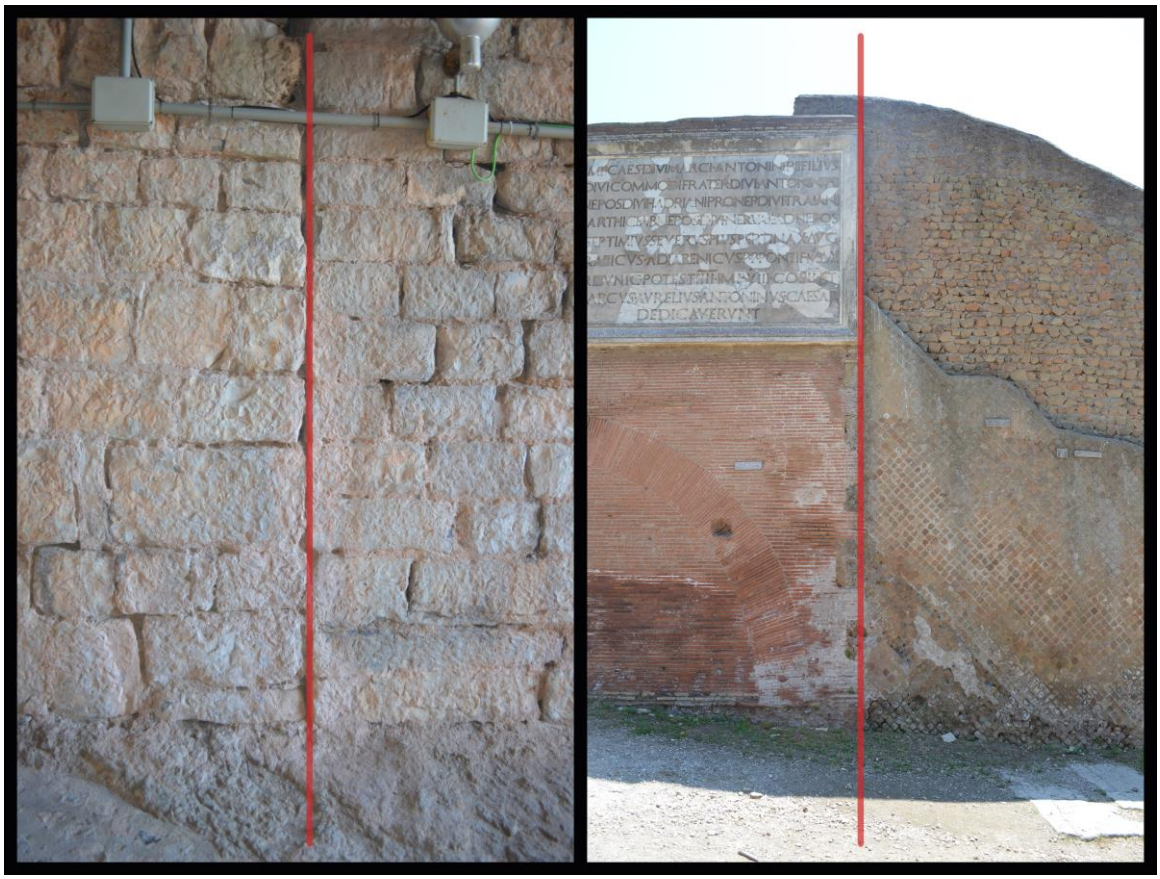

**Fig. 3:** Two images of the *analemmata* walls, from Saguntum and from Ostia respectively. The presence of a discontinuity witnesses the enlargement of the *cavea*

geometrically formed by combinations of straight lines and circular arcs, provide the clearest picture of the undeniable possibility for a project to adapt and evolve.

Through "cuts," "offset" and mirrored tiers, these buildings over many centuries have adapted to new functional requirements, to changed social, economic and religious conditions.

Some famous examples are the Circus of Caesarea Maritima (Figs. 4 and 5) built by Herod the Great next to his seaside villa and then transformed into an amphitheatre (Humphrey, 1996), or the theatre of Lixus, also converted into an amphitheatre (Akerraz, El Khayari, Essadra, Siraj, Majdoub, Hassini, Ranieri, Spanu, & Zucca, 2009). Exemplary is the stadium of Aphrodisias in Caria, where a sort of small amphitheatre dedicated to *venationes* was built in front of one of the two *sphendonai* (Welch, 1998).

Besides these three examples, the countless number of Roman theatres built in the Augustan era should be mentioned here. They were an expression of the strong political will of those times. In the centuries to follow, for example at Saguntum, the number of theatres were increased and modified for the reasons set out above (Bianchini & Fantini, 2015).

The principal lesson to be learned from the study carried out by Salvador Lara-Ortega is that everything surveyed is the product of a series of actions and reactions, of rules and of designing or construction precepts, applied and then modified to provide new answers to the changing needs in

**Fig. 4:** Southern *shendone* of the circus-amphitheatre of Caesarea Maritima

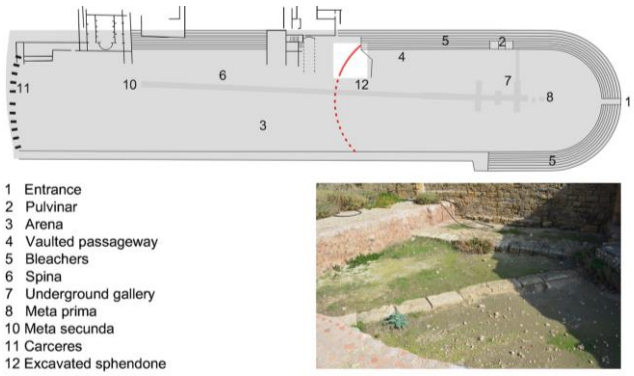


**Fig. 5:** Typological transformation of the circus into an amphitheatre at Caesarea Maritima. A new *shendone* is added (in red) in order to reduce the *dromos* and convert it into an *arena*

the use of the building:, to attend a theatrical performance, a *triclinium*, thermal spaces and other similar examples.

## 4. *Vitruvian theory: guidelines for the reverse designing process*

Once considered the essence of ancient manuals centred on geometry and architecture, as well as the correct record of the evolution process over the centuries, it is now necessary to deepen the knowledge of more theoretical issues concerning architectural design.[10]

The first book of *De Architectura* is the only ancient text dealing with the theory of architectural design: it explains how to build legitimately, following set methods and techniques which guaranteed stability, aesthetic quality, and more in general, control of the designing process (Fig. 6).

In the second chapter of this book (I, II, 1-9) Vitruvius lists six terms, all coming from the ancient Greek lexicon about architecture, forming the basis of ancient construction theory; they are: *ordinatio* (ταξις), *dispositio* (διαθεσιν), *eurythmia*, *symmetria*, *decor* and *distributio* (οιχονομια). Vitruvius then explains how *dispositio* involves three other concepts, coming once again from the Greek lexicon: *ichnographia*, *orthographia* and *scaenographia*.

The problem of their interpretation goes back to the Renaissance period in Florence, to scholars such as Leon Battista Alberti,[11] who took inspiration from the work of the Roman writer, and continues up to present day philologists.[12] This list of Latin and Greek terms is then followed by several pages which are especially difficult to interpret; the text is so unclear and succinct that a succession of semantic studies have been carried out over their meaning and, in fact, some of these patently show analogies and overlappings.

In order to really take advantage of this precious document survived to this day from the Ist century BC, a large amount of information needs to be taken into account and points of view considered – archaeologists, philologists, architects, palaeographers, – then, those concepts need to be applied to geometrical analysis based on reality-based models and more in general to surveys of ancient sites.

The reading key for these six terms is based on the studies from Robert L. Scranton (1974) who suggests a general interpretation: he considers the terms as belonging to two different categories, one formed by three terms that are tools for an architect (conceptual and theoretical), the other consisting of three qualities of a construction built in compliance with those tools.

for the meaning of *ichnographia* and *orthographia*, recent affirmations by Antonio Corso (2012) supply a clear and very useful interpretation of these two terms which have been misunderstood on several occasions, for example plan and façade have been mistaken for sections of a building. So, *ichnographia* is not the plan and *orthographia* is not the façade or section; but both are graphic algorithms for drawing plans and sections.

For the term *scaenographia,* the interpretation given by Maria Teresa Bartoli (1994-1995) is considered to be the more pertinent although quite far from the one by Ferri (Vitruvio, 2002) and other scholars, who prefer to emphasize similarities with respect to our current perspective drawings.

With the ultimate aim of finding a definition for each one of these terms, it is more convenient to

[10] In a previous study (Cipriani, Fantini, & Bertacchi, 2014) some of these terms and concepts have already been discussed. This paragraph represents a thorough examination of this subject and clarification from Scranton's point of view (Scranton, 1974).

[11] Despite disapproving of his bad habit of using too many Greek words, making the text too ambiguous and not clear.

[12] In particular the work from Silvio Ferri, who translated and commented on book I to VII of the treatise (Vitruvio, Architettura (books I-VII), (1960), BUR, Milano 2002) and more recently the edition by Pierre Gros (1997).

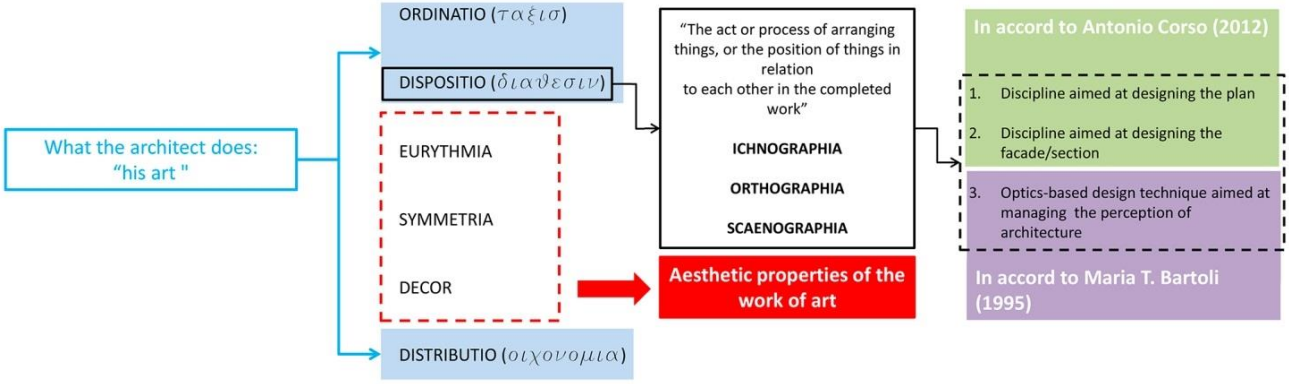


**Fig. 6:** The Vitruvian theory of design (*De Architectura*, I, II, 1-9) according to Robert L. Scranton (1974).

begin with two concepts: the first is architectural typology; the second, grid-based design (Pinho & Xavier, 2013).

For architects in antiquity – not just those in the classical period – the application of specific and tested models to new designs was common practice and an effective and natural way for giving an answer to the specific requirements of new constructions. They did not perceive it as plagiarism.

This attitude continued into the medieval period and even later. Those "models" were stored in specific drawings (plans, facades, sections, etc.) and were based on underlying modular structure. A modular structure provides several advantages to a designer: first of all it supplies him with a simple tool to make calculations easier and more intuitive (of lengths, areas and volumes) and, at the same time, it allows an easier management of drawing in reduced scale. Every typology of buildings has its specific modular grid and generally in antiquity they were made of squares, as in the case of prostyle and amphiprostyle temples (almost all the III book) and by concentric rings in case of theatres and other buildings characterized by circular shapes (V, VI, 5, and Bianchini & Fantini, 2014). In other words: once a typological scheme was chosen by the architect to design a specific construction, "included" in the scheme was a specific modular grid, typical for that specific type of building (Figs. 7 and 8).

The problem was to fit a typological scheme into the available parcel of land: the construction site with its system of physical and legal constraints. The formularies provided by manuals such as those by Heron (Heiberg, 1914), *Gromatici Veteres* (Masci 2005), etc. provided the architect with a set of easy formulae to correctly calculate the new building area.

Therefore, the architect's task was to make the typology fit the parcel of land and in order to do this, he had to establish the dimensions for the module so the building would completely and efficiently cover the ground provided.

At this point it would be worthwhile defining what might have been a graphic scheme at the time of Vitruvius since they were remarkably different in comparison to current standards and protocol. Those drawings were the product of a long developmental process and encoded accomplishments achieved by generations of architects. Different studies in recent times have deepened the complex and not so well documented field of ancient drawings and other forms of representation such as scale models and construction or assembly schemes directly carved into masonry.[13]

Graphic schemes, grids and geometrical constructions using the compass and set square may have been aspects of *ichnographia*, *orthographia* and *scaenographia*, but they had a different purpose as seen from the limited number of maps carved on marble such as the Forma Urbis or similar: they were a set of tools for managing, computing and establishing proportions for a new design (Fig. 9 and 10).

But they were not exactly the same as a plan or section. *Dispositio* was a sequence of steps or tools, linked to one another and aimed at first defining

[13] For architectural representation in the Classical Age, see: Azara (1997). For architectural models: Sardo (2004). For carvings: Inglese (2000).

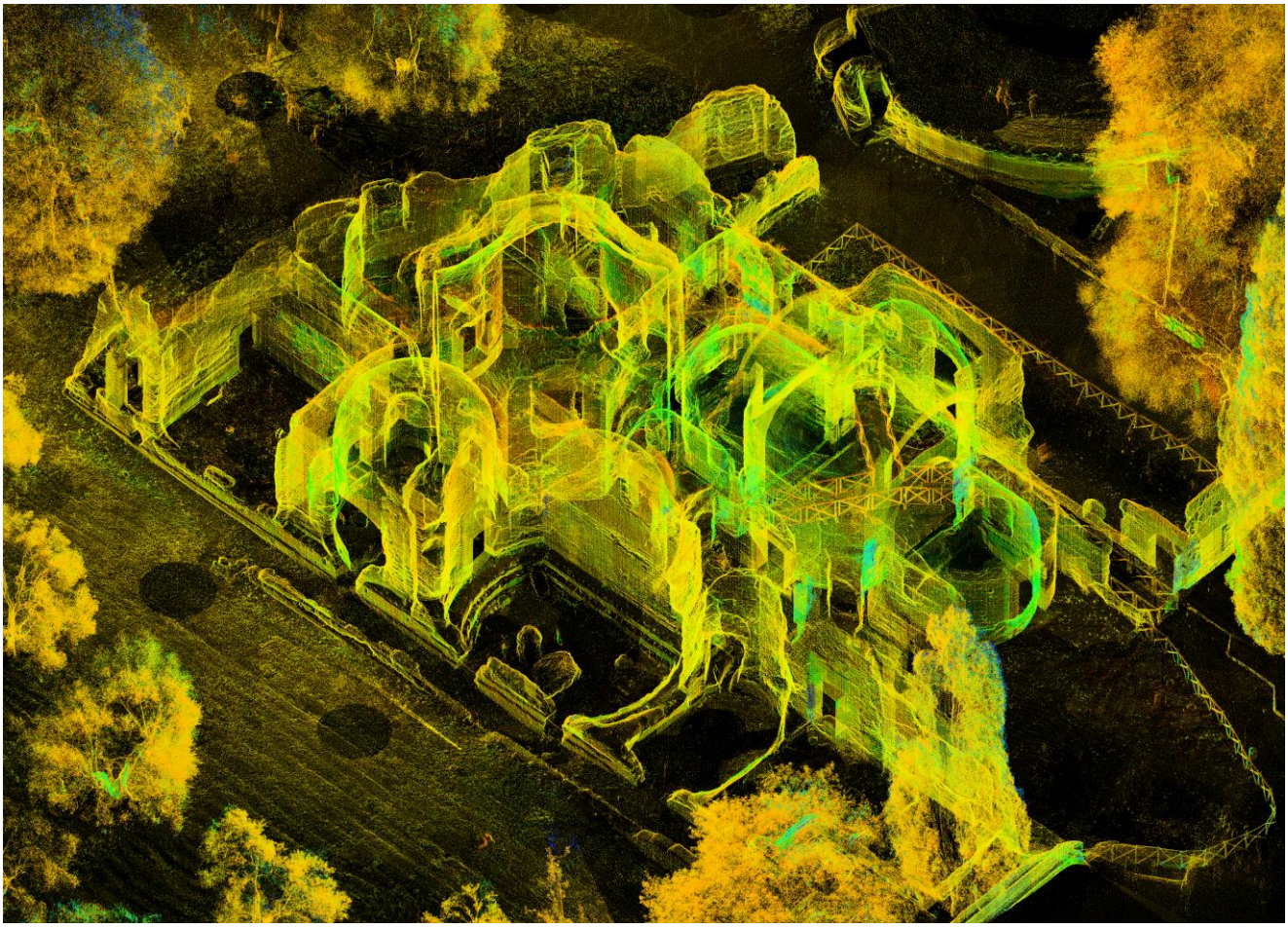

**Fig. 7:** Small Baths at Hadrian's Villa, digital survey of the complex, year 2015 (image by Gianna Bertacchi)

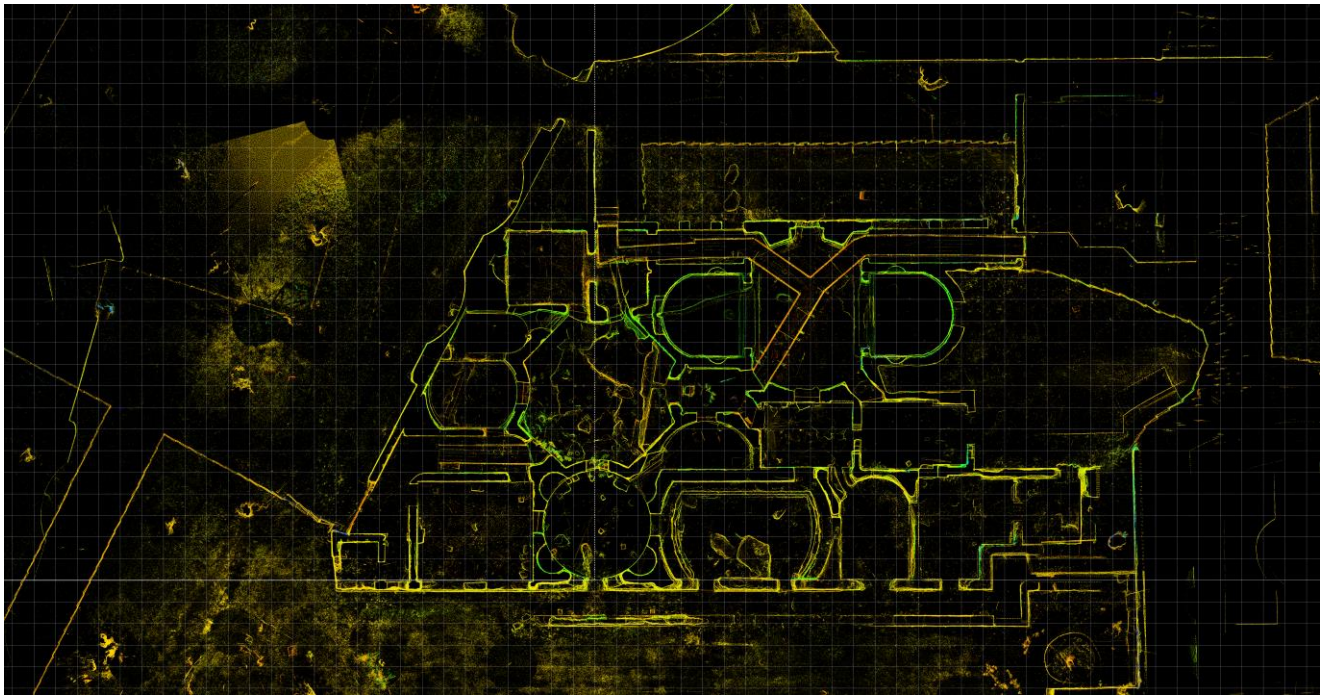

**Fig. 8:** A 5 *pedes* grid overlaid on Small Baths' plan, demonstrating a typological scheme. The presence of a common module guarantees the effectiveness of the design and the achievement of the quality called "*symmetria*" (image by Gianna Bertacchi)

**Fig. 9:** The plan of Piazza d'Oro at Hadrian's Villa, digital survey of the complex, year 2015 (image by Luca Grossi)

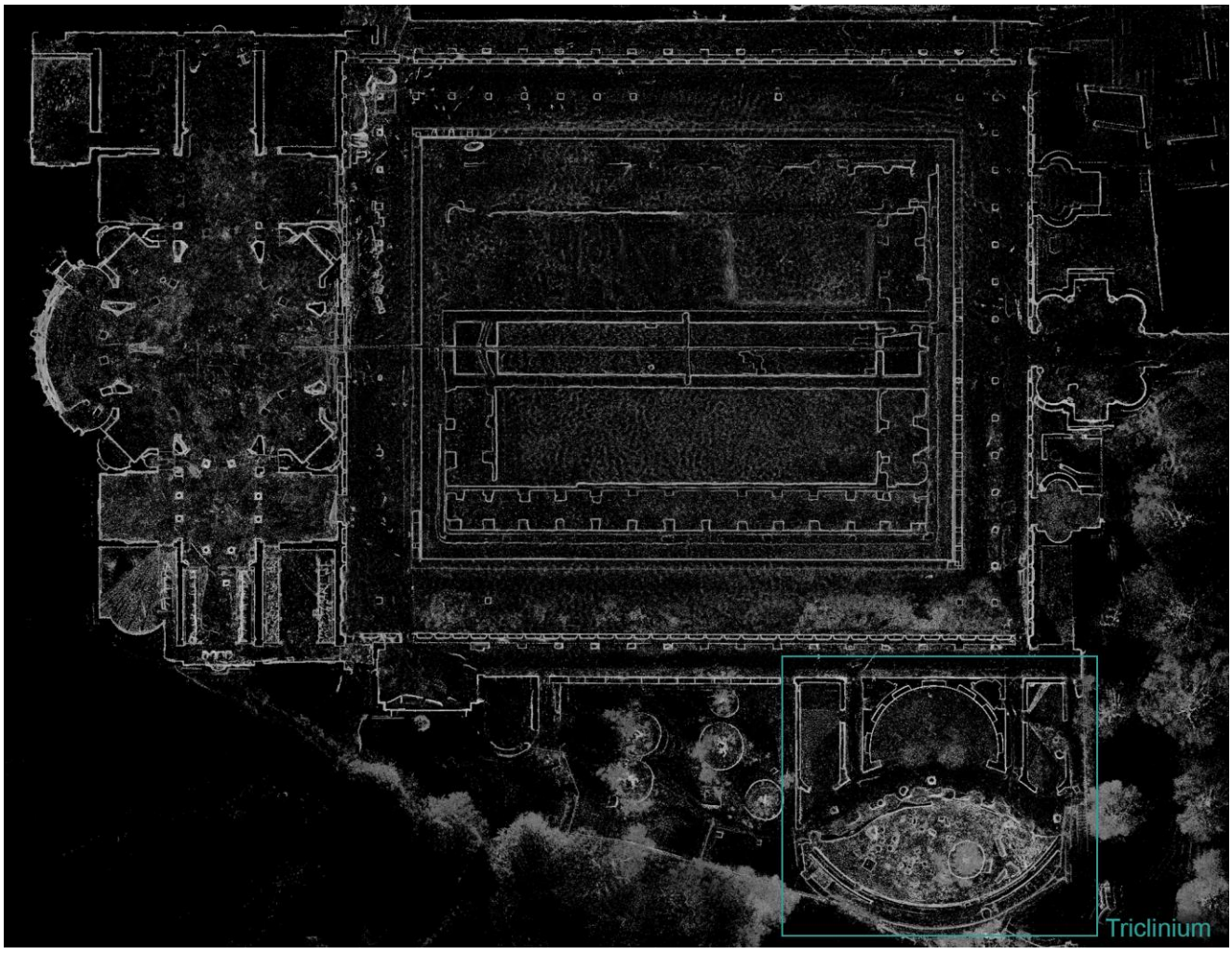


**Fig. 10:** The plan of Piazza d'Oro. In evidence the tricliniar area toward the so called Valley of Tempe (image by Luca Grossi)

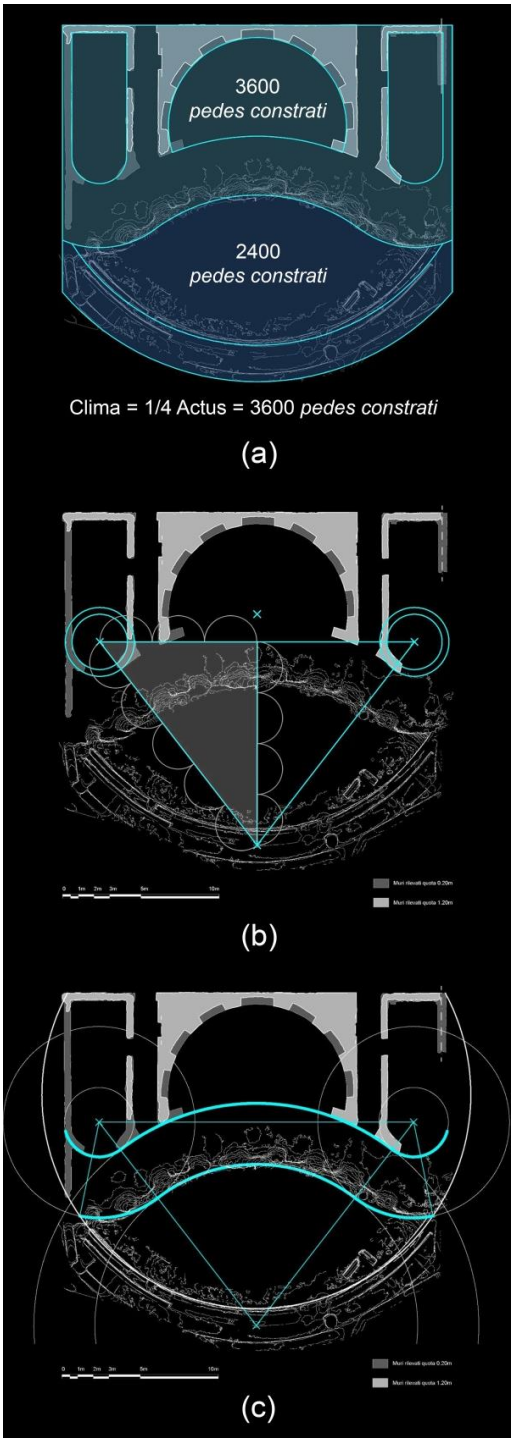


**Fig. 11:** Geometric analysis carried out on the eastern tricliniar area of the Piazza d'Oro. In (a) a vivid application of *distibutio*: the architect in antiquity designed the plan of the building taking into account common standard areas (actus, clima, etc.) with the aim of defining roofed and open-air areas with a 3/2 ratio. In (b) an example of the ichnographic technique used for amphitheatre design and applied with some customization to the plan shape of the pavilion (Pythagorean triple). (c) the construction guarantees the continuity of tangency on both lateral sides of the bended corridor (images by Milo Montalti)

the plan, followed by the façade and lastly modifying and displacing elements so as to correct them according to the law of optics.

Hence the three aspects forming *Dispositio* were actually a set of graphic constructions, complex and well-structured, rather than being the drawing of a plan, or a façade of a specific building (Fig. 11).

The first term used by Vitruvius is *ordinatio* (I, II, 1-2) and concerns the technique used by architects in order to give specific proportions to a building and its parts; this aspect of the design process is fundamental and is based on an extensive use of modular grids whose elements are called ποσότης (posótēs): a quantity or module that can be found in all the elements of a building as well as in the whole structure.

*Ordinatio* is deeply linked to the concepts already examined. In particular it manages, within a unique frame, the system of proportions, both at the global and local levels, according to the requisites of the specific typology of a building, connecting plan with façade, as well as the position of vertical elements and their distribution (Fig. 12).

The fact of drawing on a grid-based design produces architecture with a specific quality called *symmetria*. But the complex set of typological rules, practice, calculations and graphic schemes, necessary for designing a new structure, leads to the need for some additional revision: in particular when a building shows irrational quantities due to circular or bended shapes or for other reasons (mutual proportions obtained through compass as 2).

In order to facilitate construction, *symmetria* had to be preserved; hence irrational quantities of some building elements (obtained through those calculations) had to be edited and converted into finite quantities in accordance with the general modular structure.

When Vitruvius explains how to design a temple (III, II, 1-8), first of all he lists different typologies of plans (in antis, prostylos, amphiprostylos, peripteros, pseudoperipteros, dipteral, hypaethros), then he shows different possibilities for giving proportions to the façade (III, III, 1-7) through a different quantity of modules between the columns (pycnostylos, systylos, dyastilos, aerostylos, eustylos) (Fig. 13).

In other words, he first gives a name to each sub-typology of temple, then he explains through the number of columns (main façade and sides) a

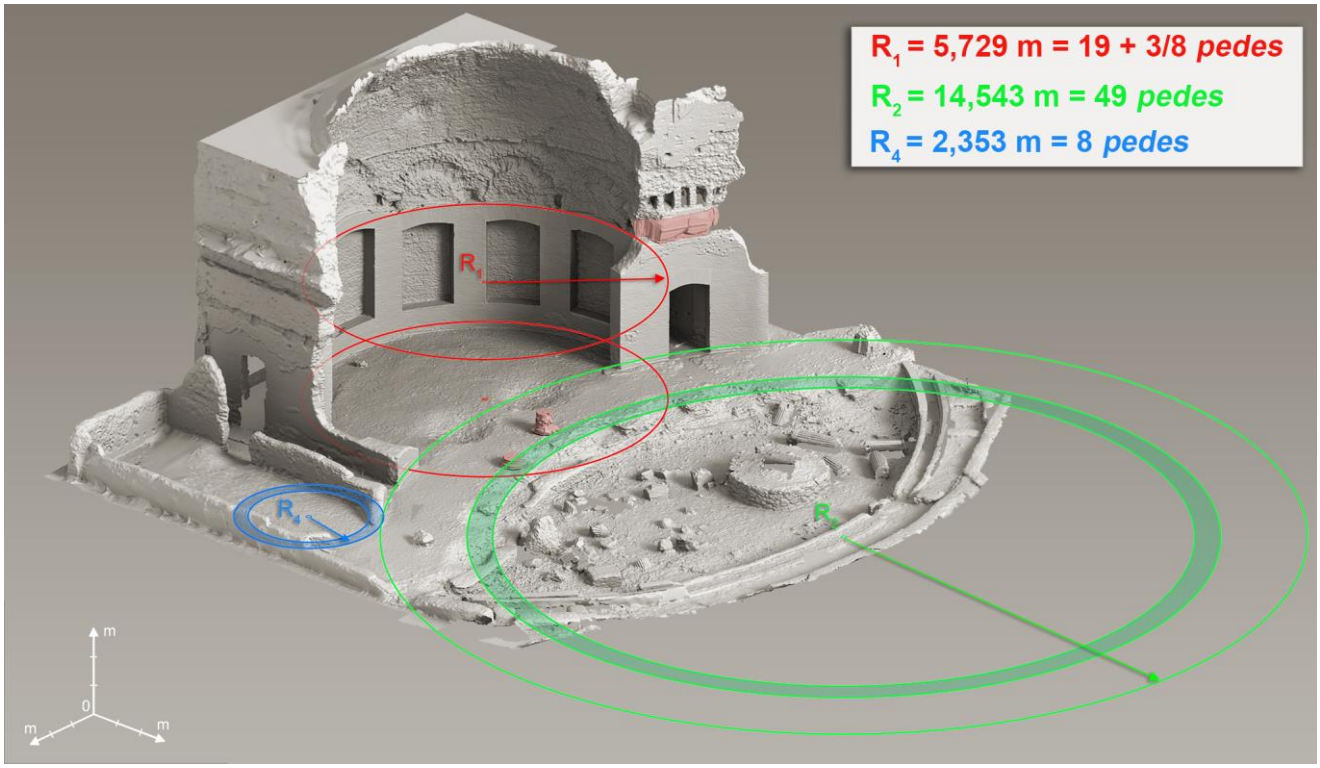


**Fig. 12:** Circles from reverse modelling application showing the system of proportions and checking ancient measuring systems

first modular grid whose aim is to draft structural elements. This is an example of ichnographic drawing. Then, he refines the exact proportions and positions of the structural elements forming the façade through specific typologies of *ordinatio*. The third book is all aimed at providing modular and geometrical rules for refining specific aspects of each order, step by step, splitting the finished quantities into smaller elements (crepidoma, column, architrave) and so on until a complete definition of the decoration. (Figs. 14 and 15)

The meaning of the architectural quality called *eurythmia* is clear: the first quality, *symmetria,* is achieved through the application of a grid, *posótēs*, but the global and local system of proportions i.e. a way of subdividing elements, is responsible for the *eurythmia*. This clear and powerful method helped the architect in the very complex task which requires both now and in antiquity,, great experience. This task involves increasing the detail between the first design step and the following ones. *Distributio* is the last of these tools used by the architect in designing structures and concerns two aspects of the design process: the first is an economic one, dealing with what is commonly called the financial estimate. The second has to do with functional and distributional aspects of a building as well as how it matches the real needs and status of the client or community.

*Decor* is the last aesthetic quality of a structure. It pertains to the concept of *function* rather than just being simply grouped with the concept of decoration.

This concept also covers architectural decoration when dealing with architectural orders concerning the requirements of specific deities.

*Conclusions*

Research on ancient architecture corresponds to the study of a long and never-ending process where a single building is the result of a vast series of modifications; a building is not the result of a single design effort.

For this reason, graphic analysis has to be carried out with a high level of awareness in order to avoid strict applications of rigid designing schemes.

In particular if a cause-effect phenomenon is not detected and clearly expressed, graphic schemes only produce blind complexity. Therefore automatic solutions for segmentation, shape recognition, anastylosis and assembling of deteriorated and altered construction elements that computer science has so far developed, seem

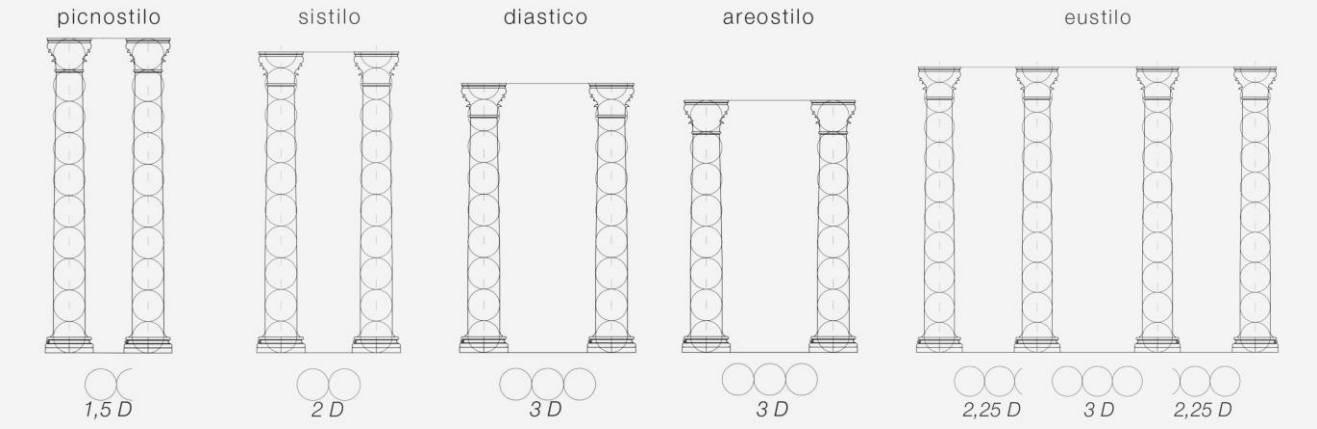


**Fig. 13:** Measurements from laser scanners and the Vitruvian treatise help the complex matter of anastylosis (image by Alex Bernardelli, Andrea Fratton, Francesco Giampiccolo, Enrico Valerio of the Accademia Adrianea di Architettura e Archeologia, August 2015)

not to give exhaustive responses. Nevertheless it should be noted that the existing difficulty in real communication between archaeologists and pure computer scientists is just one of the many critical issues that are emerging in this context.

The rapid dissemination of texts, articles, and research, together with the increased number of informed professionals in the fields of architecture and archaeology, demonstrate the extent to which knowledge regarding technical and scientific literature in antiquity has spread. Given the fact that such knowledge can be traced back to just a limited number of sources, it is a shame that current literature tends to avoid in-depth analysis

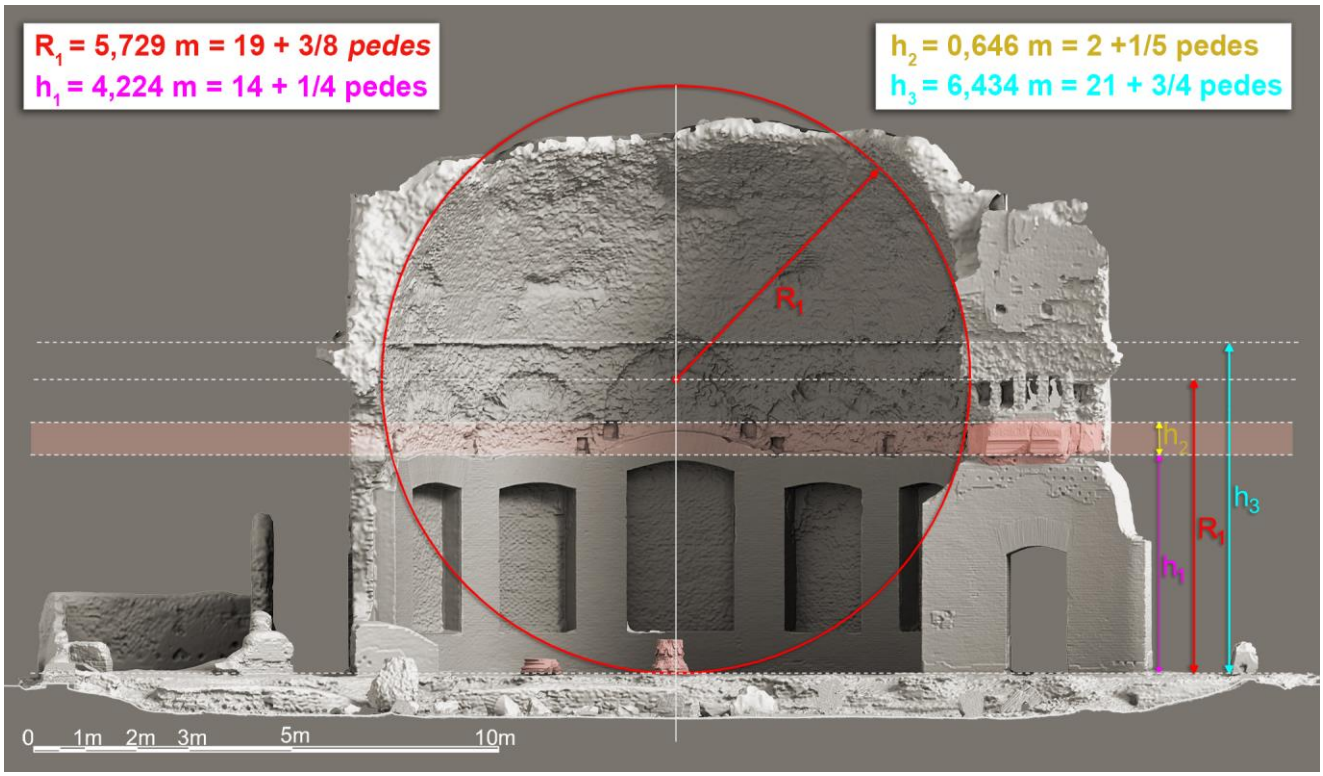


**Fig. 14:** In many situations the presence in the masonry of marble fragments of the entablature can help achieve reliable and high standards for anastylosis or reconstructions


**Fig. 15:** Fragment of a marble frieze whose bend radius (best-fitting circles) appears to be compatible with the circumference of the triclinium. Due to its incomplete shape the circles in red just give a preliminary hint but not an accurate positioning (3D model by Monica Bercigli). Such analyses may help in examining geometric rules of construction (see also Fig. 12 for best fitting circles)

of important geometrical and mathematical issues discussed in these ancient texts.

A new, updated edition of the books published by Täubner, as well as an updated edition of the body of the writings of *Gromatici Veteres*, may help the archaeologist's work of interpretation to a greater degree than, the many, and often fruitless, attempts of software development addressing Cultural Heritage.

To conclude, it could be said that the relevance of ancient technical texts and their integration into the knowledge apparatus with the aim of correctly interpreting architecture in antiquity, would lead to concrete and significant progress towards a shared and updated method of "reverse designing."

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