Ingegna Romana. From Sources to Models, from Artefacts to Reconstructions

Adriana Rossi, Claudio Formicola, Sara Gonizzi Barsanti

Abstract

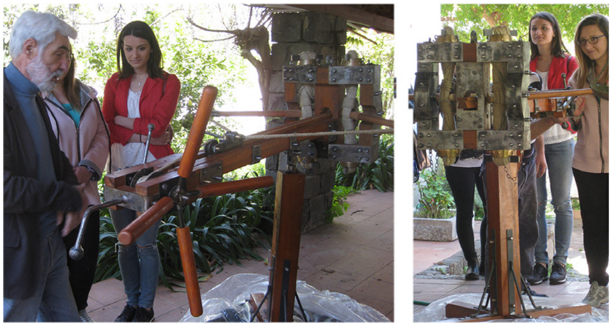
We present an aspect of the research activity shared with the students who approached the topic: Comparative Analyses and Certified Reconstructions for a correct experimental archaeology of Roman artillery. *The occasion seemed useful to reflect on the tangibility of models in which to break down, in the light of current technologies, the configurations between material and immaterial values. For this purpose, we present surveys of physical reconstructed prototypes of catapults from the imperial republican era, based on three types of sources and tested in operation. Moving from the interpretation of the photogrammetric acquisitions to the numerical control of the models based on reality, we look at the dialectical tension between opposing past and present paradigms: survey/design, analogue/digital, tangible/intangible. The transversal aspects of the phenomena related to ontologies that characterize the commensuration of components and building systems, i.e. material, cultural and thus historical, stand out as multidimensional vectors potentially capable of directing cultural policies. Advanced visualizations, based on the rewriting of ancient obsidian histories, promise in the case study to become flywheels for the redevelopment of archaeological areas even of considerable renown.*

Keywords: Roman artillery, digital culture, physical model, virtual model.

Introduction

It was in the 1980s when the School of Architecture in Venice was addressing the 'philological excavation of architecture', while the School of Milan was focusing its attention on the survey for the analysis of urban and territorial problems [Manieri Elia 1983, p. 93]. 'Operational criticism' was spreading in Italy and beyond the Alps to overcome the dichotomy between practice and theory [Tafuri 1969, p. 177]. The themes addressed, laden with the principles that characterized graphic representation in that historical period, focused on the need to appreciate the 'already made' as 'text'. Interpretation, as an intellectual lever [Dal Co 1999], has allowed a host of masters of undisputed calibre (too many to mention without omitting any) to claim an independent space for the elaboration of original and transversal thoughts guided by the acquisition of data and oriented by their graphic processing. Following in the footsteps of Luigi Vagnetti [cfr. Vagnetti 1971; 1972], they claimed, in other words, the disciplinary autonomy of survey and drawing: systematic action aimed at extracting geometric and dimensional properties, proved to be a 'picklock' for raising objectionable issues through repeatable and comparable procedures. 'Designing' (hence the term 'Drawing') went beyond the limits of being a mere tool at the service of Design, qualifying as a 'metaphor' for architecture, recognised as such even by experts in other fields [Lampugnani 1982]. An opportunity to test the criteria underlying the discipline, the adjustment imposed by years of computer revolution. The collection of articles and lectures printed by James S. Ackerman [Ackerman 1991; 2002] offers a framework for the transformations on the way the architectural project is disseminated: in those years, analogue/digital and physical/virtual recurred as recurring oppositions. In the notion of the model, a place was found where the antinomies could be diluted. The anthology of writings edited by Riccardo Migliari in 2004 [Migliari 2004] provides themes for reflection. Several of the authors whose papers are collected in that volume have continued to explore innovative paths, persevering in the challenges posed to the Science of Representation. Towards the current demarcation of concepts/meanings that, in more recent years, the contents of that volume have fuelled a fervent debate on the shift towards digital culture [Brusaporci 2019], the use of the interpretive model and in particular its visualization in the context of cultural heritage [Hodges 2020]. More modestly, the essay intends to draw attention to the multiple dimensions of the model to highlight its heuristic role, based on the ability to understand the content in order to act accordingly. A content that advanced techniques enrich. The case study is, consequently, a pretext chosen for the purpose of bringing research activity closer to teaching experience. The model, even the one that the "ancients built with their hands" [Scolari 1988, p. 137], refers, in fact, to an all-encompassing experience in which the antinomies –old (relief/project), new (real/virtual/tangible/intangible)– are diluted, showing the transversality that is established between the poles of a unitary, cyclic and interactive pathway, by virtue of which the mind perceives, looks, knows, reads and interprets.

Fig. 1. Scorpione. Prototype reconstructed by F. Russo (2014) on the basis of the modiolus found in Ampurias (Spain); Lab/TAR students (prof. A. Rossi a.y. 2016-2017) visiting the Officine di Archeotecnica.



The practice of constructing 'models' on the basis of technical drawings, which became systematic in the 15th century, had multidirectional uses from the outset: Filippo Brunelleschi used them to convince patrons enraptured by the realistic views of painters [Manetti 1976, p. 117]; Filarete regarded them as an erudite tribute for patrons [Filarete 1972, vol. I, p. 40; p. 207]; Leon Battista Alberti used them to verify the calculation of 'symmetries' [Alberti 1966, vol. I, pp. 860-862] while Michelangelo built them to provide the site with a safe guide [Millon 1988]. Giorgio Vasari, on the other hand, introduces an entirely new aspect, reporting on the precision to the nearest centimetre sought in the construction of maquettes in which the wall textures and architectural mouldings of practicable interior spaces were miniaturised [Millon 2002]. A leap that, manifesting the desire to observe the very small and the very large, demotes the possibility of zooming in on details, navigating not only in space but also in time [De Luca et al. 2023] of faithful copies that, for all their informative aspects, prove to be 'twins' of physicists [Grieves 2011].

Materials and methods

In presenting the case study, we have kept in mind the objectives outlined in the *Introduction*: on the one hand, we wish to persist in reasoning on the ontological identity of the notion of model, which, in its evolution, records the metamorphoses of culture, declining the variation of canons and epochal processes; on the other hand, we wish to give substance to the applications that computer research offers, directing them towards a shared thematic knowledge that is both flexible and inclusive as well as implementable. It is within this argumentative context that the no-contact survey of some working prototypes of Roman catapults, known as 'scorpions' in the military jargon of the 1st century B.C. and A.D. eras, is framed. The reflections that follow are restricted to the aspect shared with groups of students who, at the three university levels, have touched upon or approached the subject in a broader and recently funded research project [1].
Compared to architectural artefacts, the catapults elected as emblems of application are small in scale but for this reason emblematically suited to the understanding of the rules of composition. At the basis of the weapon's proportioning is in fact the measure of the module, based on which Vitruvius imposed the commensuration of the parts

[Vitruvius 1758, III, I, pp. 91-101] and, from the Renaissance to the present day, the exegesis of his passage incisively affected the way architectural organisms are analyzed and designed in the West. Mediating didactic aspects and the interests of students and researchers, we visited the workshops of Archaeotechnics to handle and in some cases test (fig. 1), physical (analogue), fully functional prototypes of Roman catapults reconstructed in full scale (1:1) by engineer Flavio Russo, consultant and collaborator of the Army General Staff. All reconstructions, the scholar explains [Russo 2004, p. 44], are based on:

1. the analysis of artefacts found, identified, and inventoried [2];
2. the study of the few scientific volumes and articles written on the subject [3];
3. the technical translation of fragments of classical works directly interpreted by the Russian in comparison with what is available in the literature [4];
4. the verification of functioning physical prototypes.

Supported by the scientific evidence of the paleo-reliable and transparent sources [UNESCO 2003; 2009; 2019], comforted by the omnipresent quotations of Russo's texts by anyone who has tackled the study of Roman artillery in our times and, last but not least, enthused by the all-round experience offered to the students of the Advanced Representation Techniques Laboratory (Lab/TAR) laboratory activated at the Department of Engineering, Università degli Studi della Campania *Luigi Vanvitelli* since the 2014 academic year, the work phases were arranged in order to transfer technical skills and scientific knowledge. The results were then shared by opening the doors of the laboratories with citizens and technical staff from private public bodies. Building a bridge between the Academy and the area in which the Department is located is now a constant commitment at all levels of the activities undertaken.

Operative phases

The catapults studied were manufactured using technologies and techniques congruent with the period of reference: the structure is made of wood and the armouring is of matt metal. The materials therefore prove to be compatible with the use of the chosen surveying technique. Close-range photogrammetry, Structure from Motion (SfM), made it possible to reconstruct the three-dimensionality of the machines' exterior with millimetric precision and

Fig. 2. SfM survey of the reconstructed prototype of the scorpion by F. Russo (manu balista) on the basis of the archaeological findings in Xanten (2008), (digital elaboration by the Lab/TAR students, prof. A. Rossi a.y. 2021-2022; tutor S. Gonizzi Barsanti). Phases: a. alignment and position of the images around the object during the survey; b. sizing of the bounding box and scaling; c. 3D dense point cloud; d., e. 3D mesh.

3. Blindfolds of the propulsion unit ('capitulum') found in Emporiae Spain, (courtesy of F. Russo).

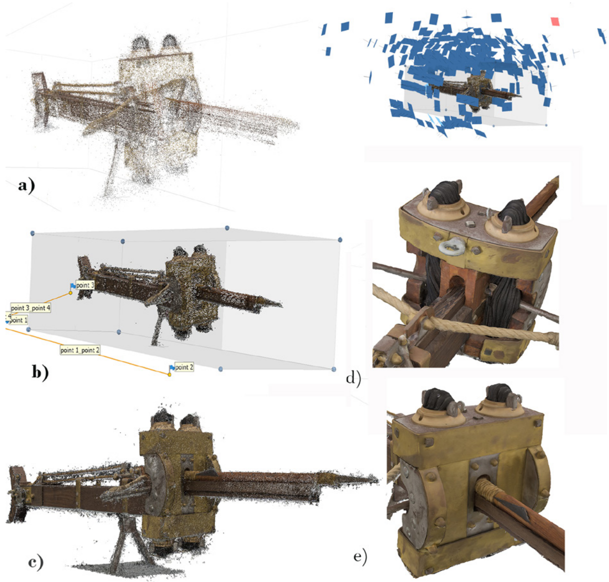
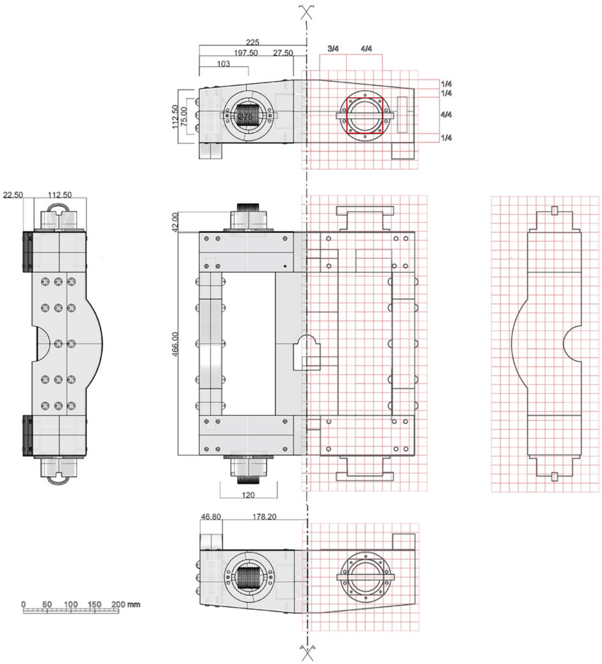


photo-realistic accuracy. For this purpose, the students' mostly SLR cameras proved functional. In dim light conditions and compatible shadows, a series of shots were taken from different angles along a 360° path around the object to cover the entire surface. Good image quality was achieved using an 18 mm lens with a diaphragm set at 9 and ISO at 500. The captured shots, subject to the necessary basic precautions, were processed with *Agisoft Metashape 2.1.1 Professional*. At the end of processing, the software generated a textured polygonal mesh of satisfactory quality (fig. 2).
The orientation process of the individual frames is fully automatic, based on the recognition of homologous points between pairs of stereoscopic photos in which exposure differences are minimal. The intersections of projective beams provided the spatial configuration of

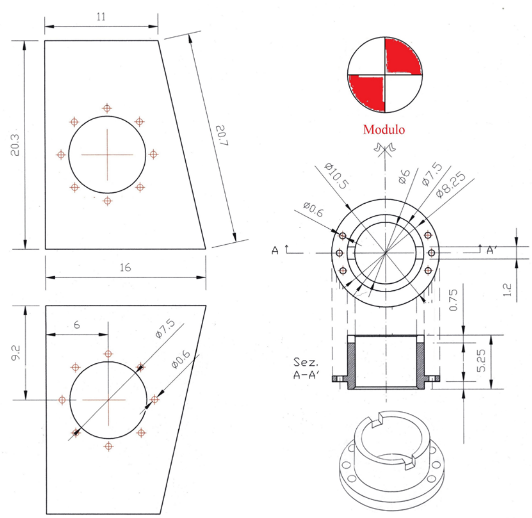
Fig. 4. 'Capitulum eutitone' commisuration [Vitruvius 1758, X, pp. 418 and foll.] on the basis of the 'modiolo' found in Ampurias (digital elaborated by S. Acerra, R. Anzalone, F. Damasco, Lab/TAR a.y. 2017-2018, reconfigured and corrected by the tutor C. Formicola).



the point cloud, an initial approach to the reality-based 3D model. The greatest difficulties encountered concerned the definition of thin parts, such as the arching strings or the cusp of the darts. The triangulated cloud, appropriately scaled, cleaned and decimated with different degrees of detail, was texturized, using the same photographs. The result, overall satisfactory, returns the three-dimensional and photorealistic shell of the 3D model, which can be measured and exported in an .obj or .stl format or other extensions compatible with vector modeling programmes. It is indeed necessary to do a semantic partition of the parts of the surface, producing the trajectories of the contours congruent with the functioning of the components.
To this end, the manageability of the physical prototypes facilitated the task, motivating researchers and students engaged in 'transducing' the characters that identify the continuity of form, from an analogue to an equivalent digital signal and thus referred to the mathematics of the discrete.
Before the construction of the models there is the reasoning on the proportioning of the parts in the meaning given by Vitruvius [Vitruvius 1758, III, I, pp. 91-101]. At the basis, therefore, is the measurement of the '*modiolo*', which in technical jargon identifies the internal diameter of the flanges on which the elastic hank rests. The term, handed down to us by the same treatise writer [Vitruvius 1758, X, 9, pp. 401-405], betrays an obvious architectural derivation. As in classical temples the diameter of the column proportioned the parts and the whole according to '*symmetria*' [Migliari 1991], so the small module (hence the diminutive '*modiolo*') provides the guiding principle for proportioning the parts that archaeological findings make objective and the missing parts that the repeatable and criticizable procedure makes methodologically grounded. The prototype reconstructed by Russo is calibrated on the remains of the artefact from Emporiae, in Spain [5] (fig. 3). All the ratios of proportions of the organs of these weapons are calculated on the basis of the length of the dart they are to shoot, the ninth part of which corresponds to the diameter of the hole in the frame of the *'capitulum'* (the propelling unit) through which the bundle of twisted fibres that support the arms passes' [Vitruvius 1758, X, 9, 1-4, pp. 401-405]. In the light of Vitruvius' passage, it should be reiterated that the unit of measurement of the weapon, i.e. its module, is equal to 1/9th of the length of the dart. Consequently, the same

length and width of the drive ('*capitulum*' for Vitruvius) must be a multiple or submultiple of this module. The axes, upper and lower of the frame, defined peritreti by Vitruvius, must have a thickness equal to one module and a width equal to one module and three quarters [in the middle] and one module and a half at the ends. This is followed in *Book X* by indications that are not always clear, but which, Erwin Schramm's, Dietwulf Baatz's, Eric William Marsden's and other authors' texts [Schramm 1918; Baatz, Feugere 1981; Marsden 1969], due to their substantial concordance, help to resolve, at least in terms of the morphological aspect [Russo 2002, pp. 232-243].
The commensuration exercise proved to be a training ground for researchers and students who, in short, were able to contribute effectively to the definition of 'constructive' designs [see Galiani, in Vitruvius 1758, p. 5]. The results (fig. 4) are in turn a prompt for the formalization of ready-to-use information, which has much in common with the current way of proceeding in standardized production [Gaiani 2006].
Point clouds imported into Rhinoceros 8.0 and placed as the origin of the workflow, guided the vector modelling of the scorpion of Ampurias, so-called because it is calibrated to the size of the *'modiolo'* found near the Spanish town. The views derived from the 3D reality-based model were compared with the executive plans drawn up for the reconstruction of the physical prototype [Russo, Russo 2008] and digitised in the same software environment (fig. 5). The geometric modeling process did not present any executive difficulties (figs. 6, 7). The process was based on the morphological synthesis of graphic primitives and in a few cases, translations or rotations of generators along lines or tracks. Indeed, the characteristics of neuroballistic machines leave no room for free-form drawing [Valenti 2022, pp. 87-102]. Even the reduction of models to parametric form has no reason to be dynamic due to the configuration derived from the tight commensuration of each part to the whole that leaves nothing to subjective arbitrariness. Instead, it is almost indispensable to be able to scale each element proportionally to be able to move swiftly from the configuration of '*maneschi*' (hand-carried) to large, fixed scorpions [6].
That techniques are never neutral with respect to outcomes is a well-known truth [De Simone 1990]. Still relevant today is the use of the 45° square for the construction of the axonometries disclosed by Abbot William Farish in 1840. Even though the procedure was already

Fig. 5. Executive plans (courtesy of Archeotecnica).



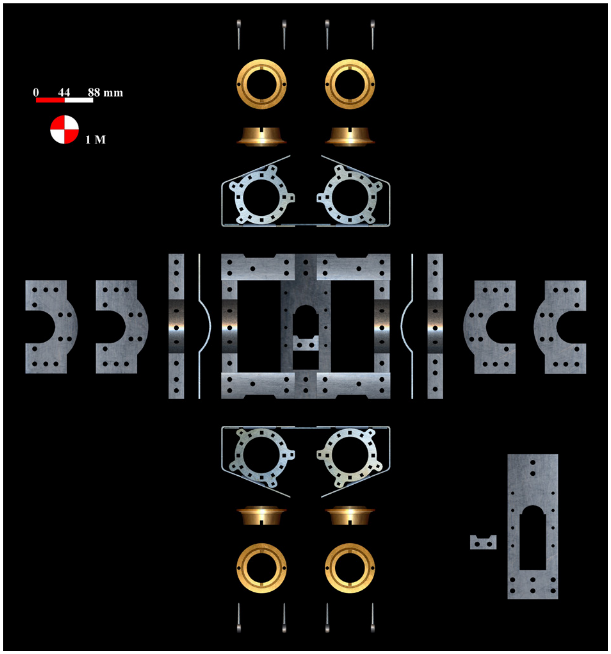
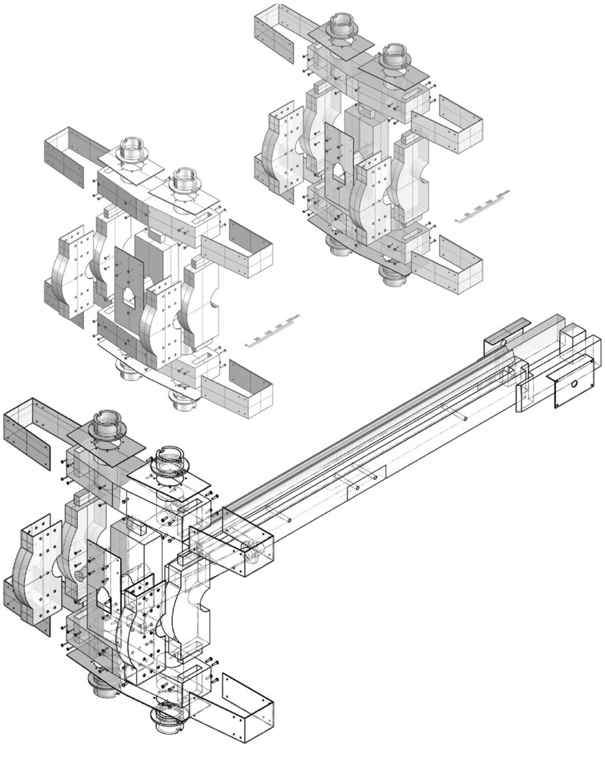


Fig. 6. 'Capitulum eutitone'. Isometric axonometric view of the model (graphic elaboration by the Lab/TAR students a.y. 2017-2018; shaded, semitransparent view reconfigured by the tutor C. Formicola).



known to Luca Pacioli, Nicolò Tartaglia and in France to Oronce Finé, the 'oblique' drawing was shown to renew the way of thinking [Scolari 2005] affecting the industrial production of the time and in the following century the research of architectural forms [Reichlin 1979; Sartoris 1983, pp. 82-93].
The speed of execution, not secondary to formal clarity and immediate measurability, has, in the present case, guided hand and mind to an initial control of the geometric configuration (fig. 8c).
Digital modeling integrates and accelerates the dialogue with one's intelligence, introducing a third element between hand and mind. Pre-set instructions condition the results based on technical ability: experienced critical skill is required to obtain views that have communicative quality. These, in addition to communicating obvious properties, must be able to express attributes; computer design makes transparent readings-interpretations: at each stage the appropriateness of the choices can be compared with the propositions taken backwards. In addition to distinguishing between analysis or project drawings to interact with the forecasting system, the operator is enabled to consult databases and archives.

Objectives achieved and in progress

The models presented, circumscribed to a case selected from the exercises conducted with the *Laboratorio di Tecniche Avanzate della Rappresentazione* (Lab/TAR; Advanced Techniques of Representation Laboratory) students (figs. 8a, 8b), document the convergence of three models: the geometric model that translates the analytical structure into an equivalent figurative system; the mathematical model that makes the problem formulation concrete; and the simulated model that verifies the algorithmic characteristics. The syncretic nature of the construct facilitates the organization of data according to strategic objectives. Although the analogue information provided by the material prototypes (fig. 9) has to date proved to be much richer than that shown by the numerical models, we look at the hardware and software solutions that integrate *Model Theory* [Hodges 2020], Visual Science and Graphic Science in the representative model. The resulting cultural product goes beyond the traditional confrontation-help provided by maquettes, to generate a conceptual space in which antinomies can be broken down and relief/design, signifier/meaning, material/immaterial dialogue can take place. The applications show that they accompany the direct observer with the 'physicality' of a digital construct. There is no deception, but integration in the image of the differently tangible perceiver [Jenkins 2007]. 'Real' and 'Virtual', far from being opposites, identify a problematic field in which the protagonists are the users [Lévy 1995] who are invited to rectify with their imagination the perception of what they have sensitively experienced [Brusaporci 2023]. In step with the times, the experience conducted looks at the advantages contained in the possibility of studying the very small and the very large on the same model that has become the collector of an overlapping and navigable information system, an implementable geography of multidimensional knowledge [Comte et al. 2024]. Valorizing the now recognized archaeological findings of Roman artillery, defining a protocol for the construction of physical and digital artillery of the period, providing

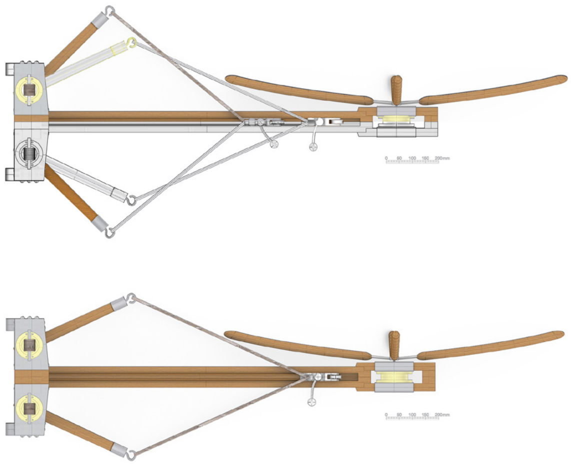


Fig. 7. Horizontal view of the model. Movement of the arms at rest and in loading (Lab/TAR students, a.y. 2017-2018; reconfigured views by the tutor C. Formicola).

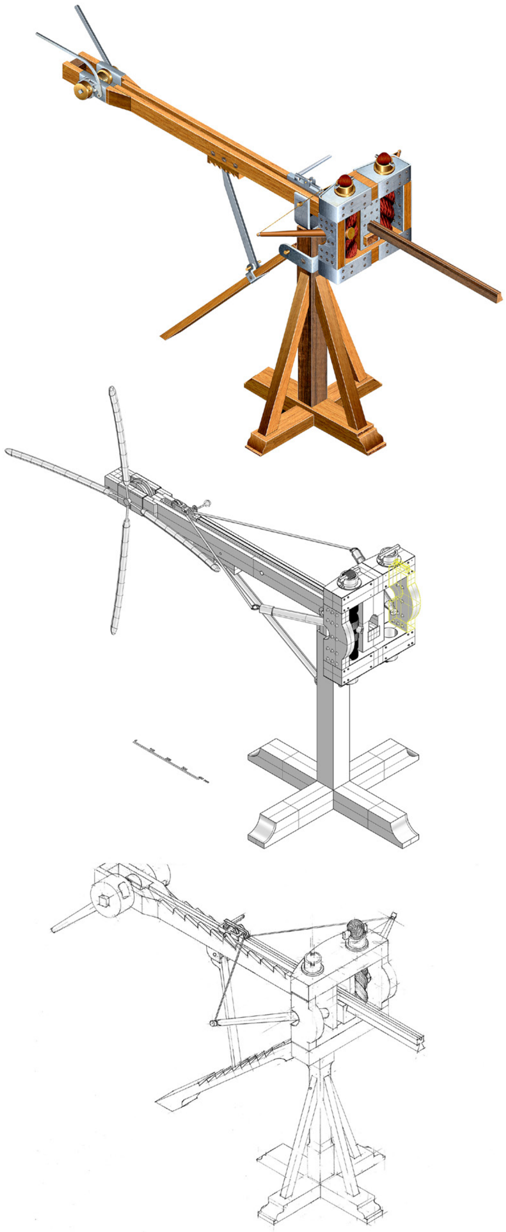
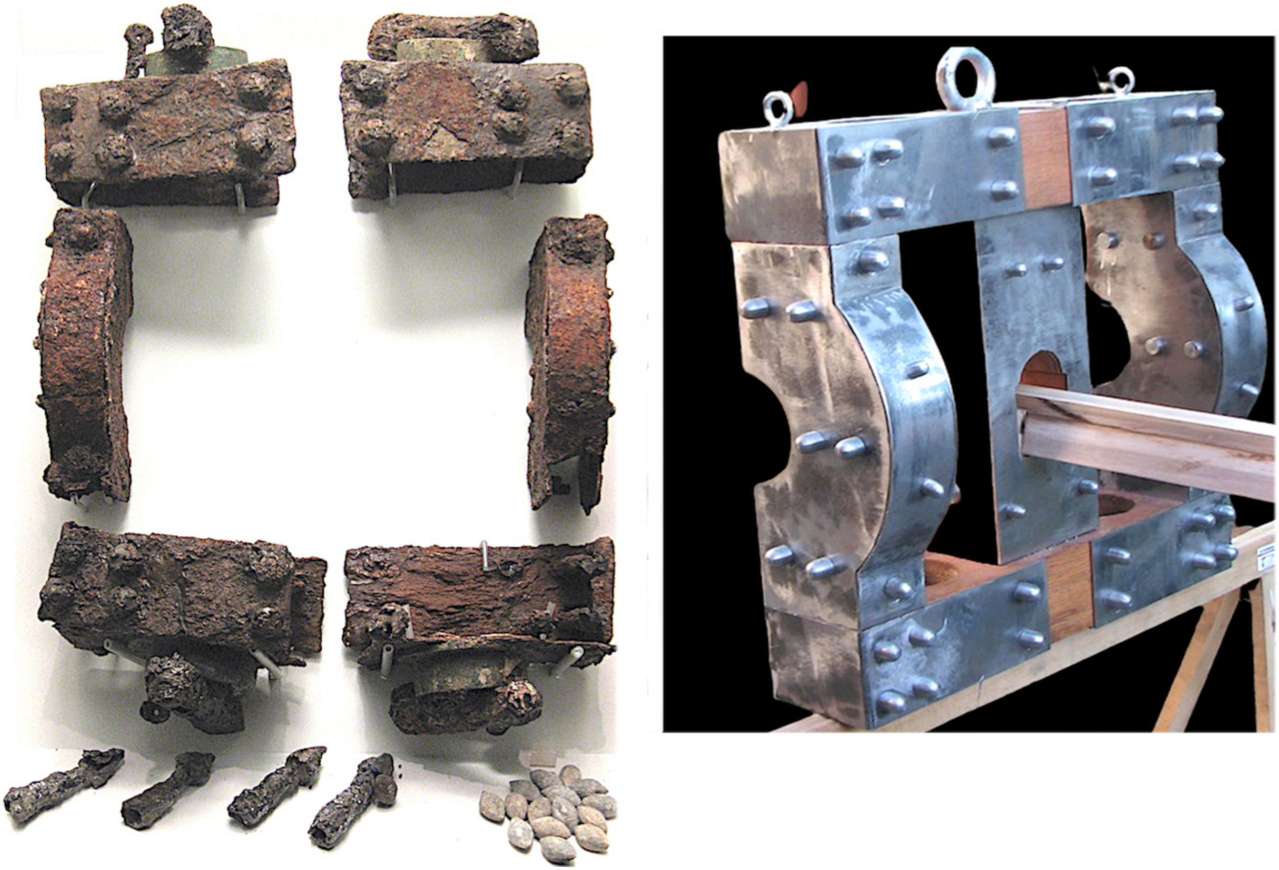


Fig. 8. Scorpion of Ampurias. Comparisons of physical models. Form top to bottom: rendered view of the model; shaded view (Lab/TAR students a.y. 2017-2018; reconfigured by tutor C. Formicola according to an optimized swing concept); study isometric view (A. Rossi for Archeotecnica).

details for a better historical understanding of the oxidional investments of archaeological areas, is the final goal approached in stages. To date, the above contents seek the convergence of teaching and research. The sharing of workshop outcomes with secondary school pupils and local administrations has shown on a small scale what is hoped for on a large scale in the field of digitization and technology transfer of the shared and interoperable theme to different user levels: from scientific research to gaming and entertainment, culture and tourism, and services.

Fig. 9. Archaeological outcomes of the 'capitulum' found at Ampurias (courtesy of Archeotecnica). Model used for digital reconstruction.



Credits

Author Contributions: Conceptualization: A. R.; methodology: A. R.; software: C. F., S. G. B.; validation: A. R.; formal analysis:A. R.; investigation: A. R., C.F.; data curation: A. R., C. F. S. G. B.; writing original draft preparation: A. R.; writing review and editing: A.R., S.G.B; supervision: A. R. All authors have read and agreed to the published version of the manuscript. F. S. G. B.; writing original draft preparation: A. R.; writing review and editing: A.R., S.G.B; supervision: A. R. All authors have read and agreed to the published version of the manuscript.

Notes

[1] Project SCORPiò-NIDI. B53D2302210 0006 PRIN 2022 D.D. n.104 /02-02-2022 Prot. 20222RJE32, ERC Area SH5 'Cultures and Cultural Production' admission to funding MIUR D.R.n.10790/2023.24 months, from 1/X/23. P.I. A. Rossi. Members for the UNICAMPANIA unit: Sara Gonizzi Barsanti, Silvia Bertacchi, Claudio Formicola. D.R. 10790/2023. P. I. Prof. Adriana Rossi, University of Campania Luigi Vanvitelli.

[2] Some thirty *modioli*, all of bronze except two; half a dozen arresting harpoons, six hank holders of various workmanship and sizes, one of which was made of bronze; a *kamarion*, several iron and bronze armour plating for catapults and ballistae, a frontal shield and some fragments of a winch.

[3] In chronological order are the texts by Escher 1867; Schramm 1918; Marsden 1971; Garlan 1974; Wilkins 1995.

[4] The indications given by Heron of Alexandria (1st century AD), the dimensioning given by Bitho (2nd century BC) and handed down by Philo (3rd century BC) in the *5th Bok of Mechanical Syntax*, as well as the proportional ratios of the components described by Vitruvius for the catapult [Vitruvius 1758] are fundamental.

[5] Preserved at the Ala Ponzone Civic Museum in Cremona, they were measured and examined by Russo in 2014 by kind permission of the Museum.

[6] '*Eutitone*' if the arms rotate outwards from the fulcrum; 'palintone' if the movement is reverse: Filone, Heron, Marsden [Russo, pp. 86 and foll].

[7] Oronce Finé went so far as to bring back to the angles of oblique figures those '*metriae*' that would give rise to the name 'axonometry', although it would take Ludwig J. Weisbach (1806-1871) and Karl Pohlke (1810-1850) for the method to be codified.

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