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The sixteenth-century find "*Treatise On Land Surveying Methods Using the Surveyor's Cross*", by Francesco Paciotti, military and civil architect to the Duchy of Urbino: the technical evolution of a surveying tool.

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Abstract **- This paper focuses on the autograph Treatise "On Land Surveying Methods Using the Surveyor's Cross" found at the Biblioteca Umanistica dell'Università degli Studi di Urbino "Carlo Bo" ("Carlo Bo" Urbino University Humanistic Library). The treatise was for many years erroneously included among the writings of the Urbino mathematician Muzio Oddi (1569-1639), author of *Dello Squadro* (*On Land Surveying Methods Using the Surveyor's Cross)* of 1625, but through careful bibliographic research has now been attributed to the civil and military architect Francesco Paciotti, (1521-1591). Paciotti's important knowledge of mathematics and geometry applied to the erection of fortifications and land measurement was essential, too, in the design of an innovative kind of surveyor's cross, which was able to provide more accurate topographic measurements and land surveys. Paciotti extolled the tool as being essential for architecture, and almost certainly used it to build the Citadel of Turin, which provided the model for the construction of all other European citadels and fortresses. Paciotti's treatise provides the restorer with a wealth of knowledge on the materials and executive technique used to manufacture the tool.**

THE HISTORICAL AND CULTURAL CONTEXT OF URBINO: PACINOTTI'S EDUCATION

The restoration and conservation of scientific tools of historic interest is strictly linked to the knowledge of the executive techniques and materials toolmakers selected for their construction, in order for said tools to perform a specific experimental function or take an exact particular measurement. In this respect, the study of the autograph Treatise "On Land Surveying Methods Using the Surveyor's Cross" by the civil and military architect Francesco Paciotti (1521-1591), discovered in the ancient manuscripts department of the Fondo Antico, (City Council Archive) at the Biblioteca Umanistica dell'Università degli Studi di Urbino "Carlo Bo", represents a primary source of information and data on the design and construction of this topographic tool, which aimed to provide specific and precise measurements when surveying land for the construction of fortifications. Furthermore, the treatise is of central importance as it bears witness to the wide and peculiar technical-scientific debate that characterised the Duchy of Urbino from the second half of the 15th century to the first half of the 17th century, making it culturally unique in Europe. The instigator of this development was Federico da Montefeltro (1422-1482), who channeled humanistic and mathematical knowledge and combined it with the modern thinking he learned under the tutelage of the pedagogist Vittorino da Feltre (1378-1446). In this small Duchy in the Italian Marches, first rate architects and military engineers excelled alongside painters, men of letters and some of the most esteemed mathematicians of the time, such as Piero della Francesca (1410-1492) and Luca Pacioli (1445-1514). These specialists, notably those specialised in new military technologies, worked at the Urbino School of Military Architecture (or Operations) at the behest of Duke Federico and included figures such as Francesco di Giorgio Martini (1439-1508), Girolamo Genga (Urbino,1476-1551), his pupils Jacopo Fusti Castriotto (Urbino, 1510-1562) and Baldassarre Lanci (Urbino, 1510-1571) and Gian Giacomo Leonardi (Pesaro,1598-1572). This environment established the relevance of theoretical and applied sciences through the practice of mechanical arts. Testimony to this are the numerous literary works on the subject, such as the *Trattato di Architettura Civile e Militare* (Treatise on Civil and Military Architecture) written by Francesco di Giorgio during his stay in Urbino between 1475-76, complete with architectural drawings and drawings of military machines. Mathematics and geometry also permeated the studies of

Girolomo Genga, who applied these disciplines to his sets in his work as a stage designer. Sixteenth-century Urbino bore witness to the renaissance of mathematical study, a veritable "Mathematical Humanism", characterised by the translation (from Greek or Arabic) into Latin and the vernacular, of Greek mathematical texts and the meeting of learned men and technical experts under the patronage of the Della Rovere Dukes following on from the Montefeltro Dukes. A central figure of this cultural movement was the Urbino mathematician Federico Commandino (Urbino, 1509-1575), who translated and annotated Euclid's *Elementi* (1575) and Apollonio's *Coniche*, along with the translation and completion of texts by Archimedes. Particularly in these latter texts, the synthesis between the theoretical and applicative qualities of the "mathematician" were represented, and for whom "theory and practice", "knowledge" and "operation" were interconnected things. Commandino founded a renowned school of mathematics centered on the study of the discipline. Notable pupils and successors included: Guidobaldo Del Monte (Pesaro 1545-1607), who started studies into mechanics and provided influence and support of Galileo Galilei and his works; Bernardino Baldi (Urbino, 1553-1617), humanist, architect and first historian of Mathematics; and Muzio Oddi (Urbino, 1569-1639), who specialised in civil and military architecture, as well as the design of sundials and scientific instruments. A mathematical instruments workshop was set up and linked to the mathematics school under the direction of the craftsman Simone Barocci (Urbino, 1525-1608), a student of Commandino's. Here, Barocci made the reduction compass (1568) commissioned by Commandino, and the proportional compass for Del Monte, as well as various water clocks (refraction), one of which is housed at the History of Science Museum in Florence.

A *The Treatise "On Land Surveying Methods Using the Surveyor's Cross" by Francesco Paciotti.*

It was in this scientific hotbed, characterised by the coming together of the study of mathematics and the making of high-quality tools, where Francesco Paciotti, or Paciotto (Urbino, 1521-1591) developed his skills as a civil and military architect. He was a member of the Rovere School of Military Architecture, founded by Francesco Maria I Della Rovere (1490-1538) and was taught technical drawing by the ducal architect Girolomo Genga, with his grounding in mathematical science being provided by Commandino. This allowed him to perfect elements taken from Urbino architecture in his works, making him unique and earning him international acclaim, so much so that,

"*... everybody celebrated him for his rarity and resoluteness, especially on all things Vetruvian, and on the whole, was considered a very good mathematician*" [1]. Amongst his great works, here we cite the revolutionary design of the Turin citadel (1564-1577), commissioned by Duke Emanuele Filiberto of Savoia (1528-1580) which "*... was said to be the first fortress in Europe to be built according to regulations"*, so much so that, *"they said this fortress opened the eyes of engineers and taught them the rules to follow for subsequent fortress building…From this fortress, the plans for many fortresses in Italy, Spain, France and Germany were derived…* [2] This innovation helped widen Paciotti's international renown, which even reached Spain, so much so that in 1566 he was made a Knight of the Supreme Order of Christ by King Sebastian of Portugal by intercession of the Duke of Savoy (1554-1578). His investiture took place at the St. John's Metropolitan Church in Turin, and it was the title of Knight that, "*the Engineer used from that day forth…and all would call him thus.*" [3] During the course of his life, Paciotti dealt with all aspects of architecture: building, gnomonics and mechanics. He also wrote important treatises, which have been long-lost and are listed as follows by Promis: *Trattato di aritmetica e geometria ad uso degli architetti ed agrimensori, Commenti sopra Vitruvio* (Treatise on Arithmetic and Geometry for Architects and Land Surveyors; Comments on Vitruvius); *Trattato di fortificazione* (Treatise on Fortifications). A product of the prolific scientific environment in Urbino, he combined his innovative studies on fortifications and architecture with the application of specially designed scientific instruments, which were available to him and fundamental in his work as an architect. Fruit of this was his treatise "On Land Surveying Methods Using the Surveyor's Cross", a topographical instrument enabling alignments to be marked out on the land and angles to be measured, which is housed at the Classics Library at the "Carlo Bo" University of Urbino, but was erroneously conserved amongst the documents belonging to Oddi, author of the *Trattato Dello squadro* (Treatise on the Surveyor's Square) of 1625 As abovementioned, Promis confirms the attribution of this work to Paciotti upon the Urbino architect's investiture as a Knight, and says: "*From now on I find him called captain or knight in his papers*"[4]. Indeed, the Treatise opens with the words, …. "By Knight Paciotto of Urbino" (Fig. 1).

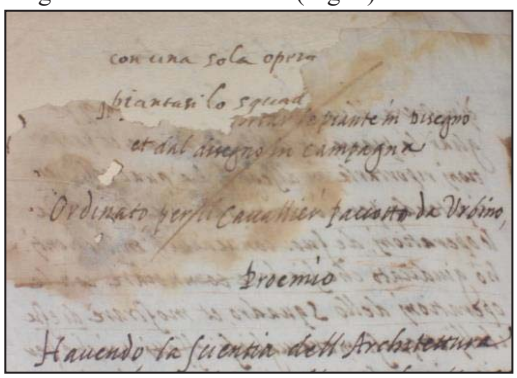
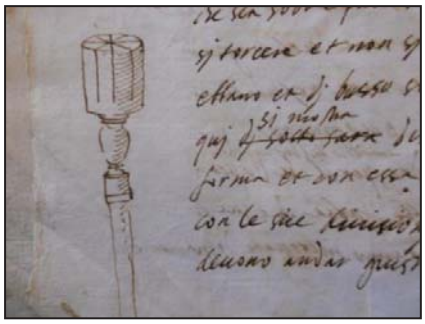


Fig.1. F. Paciotti" Treatise On Land Surveying Methods Using the Surveyor's Cross, "Preface", University of Urbino Library, City Council Archive, portfoglio118, ff. 1-31, with the words "By Knight Paciotto of Urbino" visible.

The work, which includes accompanying drawings by Paciotti, highlights the central importance of the tool for measuring the layout of fortifications and land measurement. The precision of the tool was due to the shape of the instrument, with Paciotti himself designed. The first surveyor's crosses were actually wooden circles equipped with two slits at right angles, or small holes or sights at the outer edge of the two orthogonal diameters, described by Tartaglia (1499-1557) in the third part of his Third book *Del General trattato di Numeri e Misure* (A General Treatise on Numbers and Measurements) of 1566, (Fig-2)

Fig. 2. N. Tartaglia "Third book of The General Treatise on Numbers and Measurements"1566, drawing of the surveyor's cross in circular form.

Paciotti's surveyor's cross, on the other hand, has two cylindrical and spherical forms (Fig. 3-4), equipped with eight longitudinal slits for orthogonal alignments, with 90° and 45° angles providing fixed-angle sights.



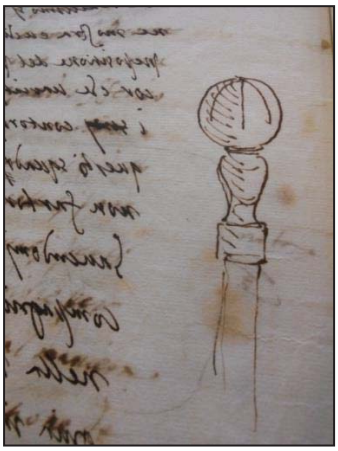


Fig.3-4. F. Paciotti "Treatise On Surveying Methods Using the Surveyor's Cross" University of Urbino Library City Council Archive, portafoglio 118, ff. 1-31, cylindrical and spherical shape of the surveyor's cross designed by Paciotti. This type of construction provided considerable advantages as it allowed angles to be sighted even in mountainous terrain and measure the distance of points in inaccessible places. The Preface of the Treatise reads:

"*Since the Science of Architecture, like all excellent sciences, has many facets, I considered that measuring plans and transferring them into drawing form, with their relevant measurements and proportions, to be one of its principle aspects, and consequently, it is extremely important to take measurements perfectly… As this cannot easily be done without the use of suitable instruments, I reckoned that it would be right to make use of the surveyor's cross and show its beautiful and almost marvelous results, because in my opinion, more precise and rapid operations can be obtained with it, as the surveyor's cross serves the same purpose in the field as the compass does on paper… The surveyor's cross can take various forms: it should be round in the form of a cylinder so as to eliminate all unnecessary angles, with its diameter being no more than the width of three fingers… Its height should be no less than a diameter, if mostly used in mountainous terrain, so as to sight uphill an downhill, in fact it will be spherical because the diameters will be the same. Otherwise, as Euclid stated in the tenth definition of the eleventh book…. the lines will be out of range, and to sight properly one would have tilt the cross or remove it from its stand or plumb line, and the measurement taking would be inexact. Its divisions will be double-crossed as shown* (Fig.5) *so as to be able to use the right angle divisions. Many functions can be more easily obtained this way than using the single-crossed division.* (Fig.6) [5]

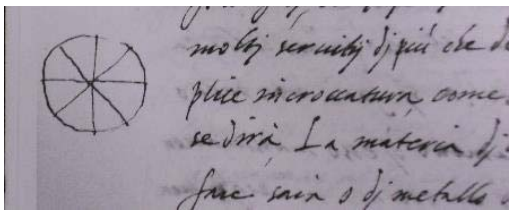


Fig. 5- F. Paciotti "Treatise On Land Surveying Methods Using the Surveyor's Cross" Trattato sui metodi di rilievo con lo squadro" Urbino University Library, City Counci Archive Biblioteca dell'Università di Urbino Fondo del Comune, portfoglio118, ff. 1-31, "Double-crossed divisions"

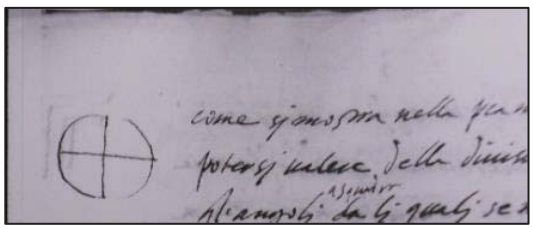


Fig.6- F. Paciotti ""Treatise On Land Surveying Methods Using the Surveyor's Cross" Urbino University Library, City Counci Archive, portafoglio 118, ff. 1-31, 2 Single-crossed divisions.

In the section of the treatise regarding *Studies on Fortifications*, Paciotti reiterates the importance of the use of the surveyor's cross and underlines the relevance of the choice of materials, both for its correct construction, as well as its preservation. On its proper construction he states:

"Having to explain, as I promised, the best way to make plans of fortresses and other fortifications, as in other places, and moreover showing how easy it is to measure and transfer these to paper, I judge it is better to start with the use of the surveyor's cross…it has been my faithful companion for thirty years, not just in our Italy, but also in Spain, France, Flanders, England, Magnia, even in Barbaria, where with its help, I have always managed to achieve my goal very easily…The material it should be made of is metal or wood. If made of metal, it should be made of silver or silver plated brass, whereas if made of wood, boxwood or pear wood should be used, or any other wood, such as ebony, provided it is hard, dry and knot-free, so as not to bend or crack during its careful manufacture." [6]

To take measurements, the surveyor's cross was planted in the ground using its spiked support in a precise observation point- Paciotti provides a sketch of this in the margin in the Treatise (Fig.7). The measurements were based on Euclid's geometric mathematical principles.

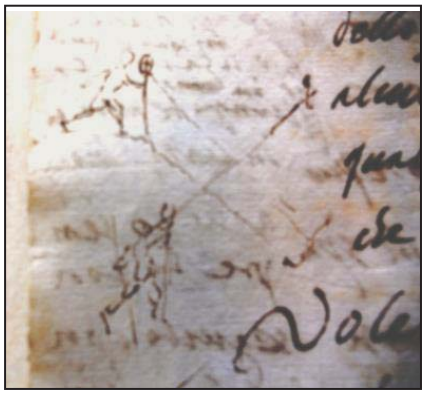


Fig.7. F. Paciotti "Treatise On Land Surveying Methods Using the Surveyor's Cross" Urbino University Library, City Council Archive portfoglio118, ff. 1-31, sketches showing how to position the surveyor's cross when surveying.

B *Conclusions*

With regards to restoration and preservation of historical scientific patrimony, the discovery and attribution to Paciotti of the "Treatise On Land Surveying Using the Surveyor's Cross" is of great importance: it has made it possible to certify that the design and construction of the surveyor's cross in cylindrical form equipped with eight slits at 90° and 45° (*double-crossed divisions*) was not the work of the Urbino mathematician Muzio Oddi, amongst whose papers Paciotti's Treatise erroneously ended up in. In Vernaccia's *Notizie Istoriche di Muzio Oddi matematico (Esoteric Knowledge of Muzio Oddi Mathematician)*, we have actual proof that Oddi was Paciotti's pupil and from whom he certainly learned important knowledge of military architecture, along with a knowledge of the instruments used. Oddi dedicated the treatise *Dello squadro* (*On the Surveyor's Cross)*, published in Milan in 1625, to this surveying tool, presenting it in its effective cylindrical form with eight slits (Fig.8), with a compass and cover attached to the top.

Fig. 8. M. Oddi, "On the Surveyor's Cross" Milan 1625, the surveying tool in cylindrical form with the eight slits visible.

Paciotti's directive on surveyor's cross construction technique, and subsequently enriched and improved by Oddi, became the widely established way to make the tool. This is evidenced by the cylindrical brass surveyor's cross with eight slits, signed Urbino 1654 housed at the Collezione del Museo Galileo, Florence. (Fig.9)

Fig. 9. Museo Galileo Firenze, Surveyor's cross signed Urbino 1654, brass, 150x60 mm

The instrument is technologically more developed. As well as the compass and cover on the top, there is an alidade equipped with sights. Even though the instrument does not have the maker's signature, it is plausible to suppose that it was made at the Urbino workshop for mathematical instruments and mechanical timepieces founded by Simone Barocci. Indeed, after his death in 1608, the workshop was run by the mathematician and maker Lorenzo Vagnarelli (1584-1675). Subsequently, the

workshop became the *Accademia degli Istrumenti Matematici* (*Mathematical Instrument Academy)* to provide both theoretical and practical training for learned craftsmen, the most highly regarded of whom were Fabio Liera and Panezio Panezi, and Pompilio Bruni (1605-1668). After these figures, the workshop remained in operation until around 1740 under Eusebio Bruni (1649-1731) and Annibale Luciani. The technique used in the making of Paciotti's surveyor's cross, moreover, highlights how the instrument was designed to be used directly in the field, with Paciotti seeking to combine portability, sturdiness, resistance to atmospheric changes and usability with high scientific efficiency.

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[3] G. Colucci, "Delle antichità picene", Tomo XXVI, Fermo 1746, p.29
[4] Promis, cit. 1863, p. 397
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[6] Ibidem
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APPENDIX

[5] Biblioteca dell'Università di Urbino (BUU), Fondo del Comune, busta 118, ff. 1-31:
"*Havendo la Scientia dell'Architettura molte parti si come di tutte le altre eccellenti facultà avviene ho giudicato che il pigliar delle piante e queste con le debite misure e proporzioni riportar in disegnio sia una delle sue parti principali et con seguentemente essere alla sua perfezione di grandissima importantia... La qual cosa non si potendo per ciò comodamente fare senza le operazioni de suoi convenevoli instromenti ho giudicato che sia bene valersi dell'operationi dello squadro et mostrare di esse i belli et quasi meravigliosi effetti poiché per mio aviso eglino sono i più giusti et i più spediti che far si possano in cotal fatto facendo lo squadro in campagna quasi il medesimo servitio che fa il compasso nella carta... La forma dello squadro ancor che variamente si possa comporre si farrà non dimeno tonda in forma di cilindro per fuggir il superfluo degl'angoli di grandezza nel diametro che non sia maggior di tre dita... La sua altezza si farà non meno di un diametro di esso massimamente si egli va operato in luoghi montuosi per doversi traguardare all'in su e all'in giù o vero si farà sferico per la uguaglianza de suoi diametri., come Euclide nella X^{a}. deffinittione dell'undicesimo libro ne mostra altramente nel traguardo dare, o che le linee restarebbero di fuori, o che bisognierebbe piegar lo squadro, levandolo dal suo perpendiculo,o piombo che dir vogliamo per il che l'operatione verrebbe falsa. Le sue divisioni si faranno incrociate doppiamente, come nella pianta si mostra (*Fig. 5) *per potersi valere della divisione de gl'angoli a squadra. Alle quali se ne cava comodamente molti servitij. Più che della simplice incrociatura "*(Fig.6)

[6] Biblioteca dell'Università di Urbino (BUU), Fondo del Comune, busta 118, ff. 1-31:
"*Dovendo io trattar come ho promesso del modo di pigliar le piante si delle fortezze et luoghi da fortificare come altri siti et inoltre mostrar con facilità il modo di misurarle et riportarle in disegnio ho giudicato che sia bene cominciar con l'operazione dello squadro... avendomi egli fatto fedelmente compagnia trent'anni non pur nella nostra Jtalia ma in Spagna in Francia in fiandra in Inghilterra in la Magnia et per fino in Barbaria dove con il suo aiuto con molta facilità ho sempre conseguito il mio intento... La materia di che si deve fare sarà o di metallo o di legnio si dj metallo o d'argento o di ottone d'argento e migliore se di legno o di busso o di pero o di quale altro legnio si voglia purchè sia sodo e pulito e atto a non si torcere et non si fendere di ebbano et di busso disegnato la sua forma... fatta sì di garbo."*