Preprint of Cristiano Zanetti's chapter "The Diverse Agencies of Renaissance Engineers in the Shadow of War" (pp. 173-200) in Bowd, S., Cockram, S. & Gagné, J. (eds.), *Shadow Agents of Renaissance War. Sufffering, Supporting, and Supplying Conflict in Italy and Beyond*. Amsterdam: Amsterdam University Press 2023 doi: 10.5117/9789463721356_ch06

# *The Diverse Agencies of Renaissance Engineers in the Shadow of War*

Cristiano Zanetti[1]

*Figure 1. De t[em]p[o]r[e] incipiendum bellu[m] sec[undu]m astrologia[m],* Taccola*, De re militari et machinis bellicis, f. 6v.* Bibliothèque nationale de France, n.d. MS Latin 7239.

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# Abstract

Early Modern military engineers are obvious 'shadow agents' of war: not necessarily present on the battlefield, their impact on the art of war was nevertheless considerable. The complexity of the professional profile of Renaissance military engineers during the 'military revolution' still makes their identity a historical riddle. In this chapter, I will try to address two issues concerning Renaissance military engineers from the standpoint of the history of science and technology: the cultural models behind their apparent polymathesis – here intended as a wide-ranging learning freely pursued independently from cultural models – and their agency in lesser-known military affairs such as technological propaganda, intelligence and astrology.


**Keywords:** Military Astrology, Renaissance Polymath, Renaissance Engineering, Superior Craftsman, Vitruvian Artisan

# Ennoblement of the Military Engineer

According to Mario Biagioli, it was early modern warfare (ca. 1450–ca. 1600) which gave Italian mathematicians, among them the 'traditional empirical military engineer …, the chance to ennoble themselves and their discipline by partaking in the high social status of the '*milites*', a term referring to the traditional feudal warrior aristocracy. Biagioli argued that 'the cannon-syndrome and the introduction of the bastion forced the milites … to begin to rely less on their horses and more on Euclid for their survival as a distinct social group'.[2] Biagioli identified two 'disciplinary and professional types of mathematical practitioners', who were 'socially distinct' and together generated the early modern military engineer, whose profession become so appealing for the noble. Not only were there 'upper- class'

[2] Biagioli, 44-45.

astrologer-physicians,[3] but Biagioli also listed the socially inferior groups of the bookkeepers, land surveyors, engineer-masons, and the urban teachers of arithmetic and geometry in the abacus schools. These mathematicians often interacted with the local authorities because of their expertise as 'empirical-engineers'.[4] Biagioli focused on the cultural and social processes taking place especially between the time of the math- ematician and engineer Niccolò Tartaglia (1499–1557) and Galileo Galilei (1564–1642), but he did not deal with the earlier interactions between these social classes of mathematicians. As Paolo Galluzzi lamented, the collaboration between these socially distinct groups, in the figures of the artists-engineers and the humanists, is a crucial problem that has not sufficiently been emphasized.[5]

Following Galluzzi, I here attempt to demonstrate that the encounter between these two groups on the topic of ancient engineering was perhaps of even greater consequence for the rise of practical mathematics and its practitioners than the aristocratic cultural appropriation of the compe- tences of the empirical engineers, a process that seems to have already started in earlier periods.[6] If increasing numbers of the nobility, whose expected place in society was mainly at war, found the role of military engineering attractive, then perhaps this was because the discipline had become increasingly respectable following the revival of interest in much- admired authors and engineers such as Archimedes and Vitruvius, whose aura had already elevated the reputation of practical mathematicians at war.

[3] Strangely, Biagioli does not quote the most important work on medical astrologers and practical mathematics: White, 295–308.

[4] Biagioli, 44.

[5] Galluzzi, 14–17. Galluzzi's call has produced some new inquiries into the relation between the Renaissance engineer and humanist: Long, *Openness*, chap. 4; *Artisan/Practitioners*; Maffioli, 197–228; Valleriani; Zanetti, 'Erudite'; *Janello Torriani.*

[6] See, for instance, the twelfth-century Cremonese consul Tinctus Musa de Gata, son of a count palatine, and the hidalgo Pedro Navarro (1460–1528): Caretta and Degani, 23; Sandoval, 253. However, it is still mistakenly believed that these two were ennobled engineers of lower social roots: Purton.

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# The Medieval Tradition

A first surprising thing to emerge at the time of the Italian Wars (1494–1559) is that, although there were officials denominated 'engineers' in many Italian administrative structures, there was no such thing as a 'military engineer'. There were no semantic distinctions between military and civil engineers and in practice they often moved between military and civil projects. In order to avoid this disorientating fact, scholarship tends to project the concept of the 'polymath' as if it was the naturally determined effect of the Renaissance encyclopaedic interest to explain – albeit, without explaining it – a very complex historical problem.[7]

From the late eleventh century the term *ingenierus,* with very inconsistent spelling, makes its appearance in contemporary documents.[8] Even if there was no guild or school through which one could become an engineer – the first guild appears in sixteenth-century Milan – there was a tradition in medieval northern Italian urban administrations to have a public office for such a function with that specific name, although it remained interchange- able with other designations – for instance, *master* or *leveller of the waters*, *surveyor*, *civic evaluator*, and so on.[9]

Most of the time, engineers came from the guilds associated with the arts of building (carpenters and masons) and metallurgy, as well as from arsenals, mining sites, and sometimes monasteries and cathedral schools. Engineers could be educated in drawing at scriptoria and painters' workshops. Geometry – one of the four branches of the *quadrivium* (arithmetic, geometry, astrology and music) – was a necessary mathematical skill for the design and development of mechanical structures, as well as for representing nature: a vivid example of this trend is represented by the famous thirteenth-century illustrated notebook by the northern French expert of constructions,

[7] For example, see Lenman.

[8] Settia, *De re militari*, 18–19. For a thorough investigation of the history of the engineer see: Vérin.

[9] Settia, 'L'ingegneria militare all'epoca di Federico I', 69–85; *L' ingegneria militare*, 272–89; Zanetti, *Janello Torriani*, 331–32.

Villard de Honnecourt.[10] By the fourteenth century, with the expansion of the Visconti lordship in northern Italy, we find the creation of the office of 'ingeniarii et architecti' in every city subject to their rule. In such cases, two public engineers were constantly employed with a higher salary than that of masons or carpenters.[11]

## Humanists at War

During the fourteenth century, humanism became a strong and visible feature of Latin Christian cultural elites. By humanism, we mean that non-institutionalized cultural movement that, starting from a Christian perspective, devoted its study to the classical literary tradition that came to be known under the Ciceronian term of *studia humanitatis*. The literary, historical, philological and antiquarian interests of the humanists brought to the systematic recollection and analysis of classical culture – considered the highest of all models of learning – political success and poetic elegance.[12] In 1364, writing to the *condottiere* Luchino dal Verme about a good education in the arts of war, Petrarch (1304–74), the most influential humanist poet, explained how the excellent warrior needed to exercise also in peacetime, taking lessons from history and the experiences of veterans and from a more elevated type of 'militaris disciplina'. This he could find in 'books on strategy' that the Greeks called 'stratagematici' and the Latins 'rei militaris' – 'of military matters'.[13] Petrarch's approach to education in the art of war in the form of a chiasmus (practice-theory-theory-practice) here reflected the classical literary commonplace of excellence reached through a mixed education, a central element in the rise of the Renaissance engineer.

[10] Villard de Honnecourt.
[11] Poli
[12] On humanism, see the classic essay by Mommsen and the more recent synthesizing work by Celenza.
[13] Settia, *De re militari*, 24. On humanism and Renaissance Italian military culture, see also: Verrier.

It appears that physicians – many of them from the universities of Padua or Bologna – employed in courtly settings formed the group of humanist scholars most often responsible for the analysis of the ancient texts devoted to natural philosophy, practical mathematics and 'rei militaris', which provided the most important theoretical fields underpinning the transformation of Renaissance engineering. It seems that their employment at court brought them into privileged contact with the warrior nobility, stimulating their interest in military engineering.[14] The progressive discovery of ancient Greek, Byzantine and Arabic scientific texts and their translation into Latin turned the simple traditional mathematical curriculum of the *quadrivium*, into more challenging fields of practical experimentation, such as mechanics, optics, observational astronomy, cosmography and other fields of applied mathematics that Aristotelians called 'mixed sciences', positioned between theory and practice.[15]

The mixed science of mechanics embraced the art of designing and constructing machines. This made it a particularly attractive branch of knowledge for rulers and provided curious and ambitious physicians with a means of gaining a better social position in their service. Dominion over both nature and the enemy was the ultimate cause of the princely patronage of mechanics. The classical tradition, both historical and mythological, offfered several famous examples of ingenious authors of military and civil engineering in the service of distinguished political figures with whom the modern ruler liked to identify himself: Pericles and Artemon, Attalus I and Biton, Hiero II and Archimedes, Augustus and Vitruvius, Trajan and Apollodorus of Damascus, King Minos and Daedalus, Alexander the Great and Dinocrates, not to mention those technicians of medieval legend who enabled Alexander to dive under the sea and fly into the skies.[16]

One of the earliest known medieval Latin illustrated tracts on siege warfare displaying military contrivances was written by a northern Italian physician: Guido da Vigevano (ca. 1280–ca. 1349), the author of

[14] White.
[15] Helbing, 573–92; Høyrup, 459–77.
[16] Høyrup.

the *Modus acquisicionis Terre Sancte* (*The Means of Acquiring the Holy Land*). This was contained inside his *Texaurus regis Francie*, which also dealt with medical issues and aimed at preserving the king's health during his attempt to militarily conquer the Holy Land. Most likely educated at the University of Bologna, Guido worked at the courts of the Holy Roman Emperor and the king of France. Several classical works inspired Guido's work: *De re militari by Sextus Julius Frontinus* (ca. 40–104), the *Epitoma rei militaris by Publius Vegetius Renatus* (ca. 383–450), Byzantine tracts – such as the tenth-century Parangelmata Poliorcetica by Hero of Byzantium, modelled on Apollodorus of Damascus's *Πολιορκητικά* (ca. 100) –, and the anonymous *De rebus bellicis*.[17]

The German physician Konrad Kyeser (1366–post 1405), who had studied at the University of Padua, wrote a popular illustrated book on military machines: the *Bellifortis* (ca. 1405). This work was created for a ruler: it was first dedicated to King Wenceslaus of Bohemia (1361–1419) and then to Rupert of the Palatinate (1352–1410), the *Rex Romanorum*. Kyeser also worked for Emperor Sigismund (1368–1437) and for Francesco of Carrara, Lord of Padua (1325–93).[18]

The Venetian Giovanni Fontana (ca. 1390– post 1454), who had also studied and taught at the University of Padua, wrote several illustrated works on civil and military machines (e.g. *Instrumentorum bellicorum liber*). Fontana seems to have been working far from courtly settings, although he dedicated the latter book to an anonymous influential character, perhaps a *condottiere*.[19] The German Konrad Gruter von Werden (ca. 1370–post 1424) wrote another important illustrated book, mainly focussing on hydraulic machines. Gruter studied at the University of Cologne between 1391 and 1393, before moving to Italy, where he worked at several courts including that of Pope Boniface IX (1350–1404). Gruter, who may have had connections with the University of Padua, wrote his tract in nearby Venice at the behest of

[17] Apollodorus of Damascus; Allmand; Settia, *L'ingegneria militare all'epoca di Federico II*, 84–85; 'Guido da Vigevano'.
[18] Allmand; Kyeser.
[19] Battisti and Saccaro Del Bufffa.

the Scandinavian monarch, Erik VII (1381–1459), who was, at that time, resident in the city.[20]

One of the most famous physicians of the University of Padua was Giovanni de' Dondi (ca. 1330–1388), a friend of Boccaccio and Petrarch, from whose library he had copied Vitruvius' *De Architectura* and Pliny's *De Naturalis Historia*.[21] De' Dondi was the first to build a functioning planetary automaton, the most complex machine of the day: the Astrarium.[22] This machine was made for the Visconti lords of Milan. He wrote an illustrated tract on the construction of this device, the *Tractatus Astrarii*, several copies of which are preserved.[23] As we shall see, this topic was also relevant for military problems.

Not all university-educated humanists interested in engineering were linked to university medical faculties, but it seems that all of them were connected to courts: the Sienese notary and sculptor Mariano di Jacopo, nicknamed *il Taccola* (1381–1453) wrote two influential illustrated treatises on civil and military machines, titled *De Ingegneis and De Machinis*, and he was involved with the imperial and papal courts. Roberto Valturio (1405–75), perhaps the most refined humanist involved with military engineering, if we exclude Leon Battista Alberti's (1404–72) contributions to the art of fortification, wrote the bestseller *De re militari*, which was the first printed book on machines (published in 1472).[24]

Valturio taught rhetoric and poetry at the University of Bologna before joining the courts of Sigismondo Pandolfo Malatesta (1417–68) and his son Roberto (1441–82) at Rimini and Fano – the latter being the only known place where Vitruvius had erected a building. Valturio created this book as an illustrated manuscript in around the mid-fifteenth century and several copies circulated among powerful rulers.[25]

[20] Gruter et al.
[21] Petrarch; Pesenti.
[22] In England, Abbot Richard of Wallingford (1292–1336) designed and partially built a similarly complex machine, but without finishing it: North.
[23] Dondi dell'Orologio.
[24] Settia, *De re militari*, 47–48; Bevilacqua and Williams.
[25] Settia, De re militari.

Valturio's sources were classical and they also included non- military machines, such as the Vitruvian water clock.[26]

The striking characteristic of these works is the large iconographical apparatus that is sometimes the real core of the tracts. Art historian Eugenio Battisti has noted how this tradition of technical illustration seems to relate to the milieu of the University of Padua.[27] The complexity of me- chanical contrivances could not be explained with a purely verbal language, clearly decipherable only to a scholar specialized in natural philosophy and mechanical problems. This was probably the crucial moment at which the university-trained scholar met the skilful and ambitious artisan. The craftsman could provide the scholar with technical knowhow in construction and illustration. Considering the astrological interests of the medieval and Renaissance physician, the observational mixed science of astronomy had to be a prominent 'trading zone' to attract the medical scholar and the craftsman.[28] The construction of mathematical astronomical instruments was the cross discipline that required both scholarly and practi- cal skills. Contrivances used in clocks, cranes and military machines drew upon the same mathematical knowledge: as the mathematician Luca Pacioli (1445–ca. 1517) noted, 'all military machines, artilleries and fortifications were made according to mathematics'.[29]

From the time of Campanus of Novara (ca. 1220–1295), some physicians had learned to create mathematical instruments to find the position of the celestial bodies in the zodiac: paper volvelles named 'equatoria' (i.e. plural for *equatorium*).[30] During the fourteenth century, certain medical scholars even acquired the technical skills to produce them in metals, and even to have them geared to mechanical motors.[31]

[26] Zanetti, 'Ctesibio'.
[27] Battisti and Saccaro Del Bufffa, 40.
[28] Long, *Artisan/Practitioners*, 94; Long, 'Trading Zones', 5–25.
[29] Pacioli, 23.
[30] Campano da Novara.
[31] Zanetti, *Janello Torriani*, 87–100.

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# Archimedes and Vitruvius

More often, the interaction between scholars and craftsmen caused a transfer of knowledge in the other direction: talented and ambitious craftsmen learned mathematical theoretical knowledge from humanists (and some- times also from abacus teachers, such as Niccolò Tartaglia)[32] who translated classical Latin and Greek scholarship into the vernacular. The engineer's ambition to gain a higher social status through the acquisition of a superior knowledge was also supported by classical moral philosophy (true nobility comes from virtue rather than blood) and by Hellenistic models of mixed knowledge.[33] There were many possible sites for interaction between the humanist and the craftsman, including these places of discussion, and for the realization of civil and military projects commissioned from talented artisans in charge of mathematical public offices, such as the public clock- keeper and the civic engineer.

This process of interaction is exemplified by the careers of two of the most successful Renaissance engineers concerned with the invention and construction of machines: Filippo Brunelleschi (1377–1446) and Janello Torriani (ca. 1500–1585). It appears that they had both been tutored in mathematics by medical astrologers: Brunelleschi by his younger friend Paolo dal Pozzo Toscanelli (1397–1482), who had graduated from the University of Padua. Although the first document about Torriani dates only to the year 1526 – when, following the crushing siege of Cremona,[34] he was there employed for several years to restore and maintain the public clock –, there is a later reliable account stating that, when still a child, he had been educated in astrology by Giorgio Fondulo (fl. 1470–1550), a physician graduated from the University of Pavia.[35] This humanist milieu pushed artisans not just to imitate, but even to challenge ancient models: Brunelleschi's dome of Santa Maria del Fiore in Florence overcame in size the hitherto unsurpassed models of the Pantheon in Rome and Hagia Sophia in

[32] Sgarbi.
[33] Skinner, 132–33.
[34] Zanetti, *Janello Torriani*, 327.
[35] Zanetti, 'Erudite'.

Constantinople. Works of this kind were broadly encouraged because they brought honour and prestige to the entire civic community, and to the prince and his court. Janello Torriani's planetary automata made for Emperor Charles V (1500–58) and the colossal hydraulic machine he made for King Philip II of Spain (1527–98) reflected the magnificence and power of the patrons. We should note that during the fifteenth century, as a token of the fact that machines, as much as books, were increasingly being recognized as intellectual products of individual ingenuity, the practice of granting privileges for invention spread in Europe.[36]

Within this cultural turn, the term 'engineer', etymologically connected to the concept of ingenuity to solve difficult practical problems, was now considered a divine gift.[37] Moreover, during the fourteenth century, both in medieval Latin and vernacular Italian, the semantic difference between the traditional medieval term of 'engineer' and the classical – therefore more prestigious – ones of 'architect' and 'mechanician' disappears.[38] For the learned scholar even the latter ambiguous term, traditionally used to describe all manual professions, becomes clearly connected with the mixed science of mechanics. Ancient sources never addressed Archimedes, a renowned author, as 'engineer' – a medieval term – but as *machinator* and *mechanicus* and 'inventor'.[39] For example, Tommaso Garzoni (1549–89), supported by classical authorities, among them Plato and Plutarch, wrote that 'mechanic is a most honourable word', and he united the three terms under the sign of intellectual ingenuity.

The term 'architect' was to enjoy an even greater fortune.[40] Among Garzoni's quotations we also find the Italian translation of a passage from Alberti's introduction to his *De re aedifiicatoria*, which reads 'the

[36] Molà; Zanetti, *Janello Torriani*, 238–51.
[37] Zanetti, 334. On early modern concepts of ingenuity, see: Marr et al.
[38] In Latin: ingeniarius, ingeniator, etc.; architectus, architector, etc.; and machinator, mechanicus.
[39] Livy, 6:282 (24.34.3).
[40] Long *Artisan/Practitioners*, 62–93. On the term 'architect' see: Merrill. On the complexity of the institutional situation of architects-engineers in Renaissance Milan, see: Repishti; Bossi, Langé and Repishti.

architect should be the engineer able to discuss intellectually'.[41] The Latinized Greek term 'architectus' or 'architector' means 'chief constructor'. Vitruvius' influential work titled *De Architectura* had circulated in dozens of manu- scripts during the Middle Ages. However, it was in the Renaissance that its vernacularization, illustration and dissemination through numerous printed editions made it one of the more influential technical treatises of the period. Vitruvius was *machinator* (constructor of ballistic machines) to Emperor Augustus and dedicated his book to him. *De Architectura* did not refer to the art of the edification of buildings alone (*aedificatio*), but also to the construction of sundials and clocks (*gnomonice*), and civil and military machines (*machinatio*).[42] In this work Vitruvius expressed the concept that the true architect (understood as an inventor-constructor who directed subaltern workers) ought to be well educated in both theory and practice.

The man who only mastered practical knowledge would be a mere executor of other people's projects, while the man who relied solely on theoretical knowledge would only be able to design a project and would need somebody else to turn it into reality.[43] The marvellous stories about Archimedes' military machines and Vitruvius' role as a constructor of *ballistae* for the first Roman emperor provided powerful models for the engineer involved with war, and were eagerly read by scholars and rulers interested in classical culture.

This process of identification with classical technicians contributed to the creation of the image of the Renaissance polymath. Writing about mechanics, Pappus of Alexandria (f l. 300–350), who was popular with Renaissance humanists, stated that:

> The science of mechanics … is held by philosophers to be worthy of the highest esteem …. The mechanicians of Heron's school [Heron of Alexandria (fl. first century AD) was the most famous Alexandrian author on the topic of automata making] say that mechanics can be

[41] Garzoni, 769–63.
[42] Vitruvius Pollio, bk. 1, chap. 3: 'Partes ipsius architecturae sunt tres: Aedificatio, Gnomonce, Machinatio'.
[43] Vitruvius Pollio, bk. 1.

> divided into a theoretical and a manual part; the theoretical part is composed of geometry, arithmetic, astronomy and physics, the manual of work in metals, architecture, carpentering and painting and anything involving skill with the hands. The man who had been trained from his youth in the aforesaid sciences as well as practised in the aforesaid arts, and in addition has a versatile mind, would be, they say, the best architect and inventor of mechanical devices.… Of all the [mechanical] arts the most necessary for the purposes of practical life are: (1) *that of the makers of mechanical powers,* they ... lift great weights; (2) *that of the makers of engines of war* …; (3) *in addition, that of the men who are properly called makers of engines*—for by means of instruments for drawing water which they construct, water is more easily raised from a great depth; (4) *the ancients also describe as mechanicians the wonder-workers*, of whom some work by means of pneumatics, as Heron in his Pneumatica, some by using strings and ropes, thinking to imitate the movements of living things, as Heron in his *Automata and Balancings*, some by means of floating bodies, as Archimedes in his book *On Floating Bodies*, or by using water to tell the time, as Heron in his *Hydria*…; (5) *they also describe as mechanicians the makers of spheres*, who know how to make models of the heavens, using the uniform circular motion of water. Archimedes of Syracuse is acknowledged by some to have understood the cause and reason of all these arts; for he alone applied his versatile mind and inventive genius to all the purposes of ordinary life.[44]

Because of this epistemological model, successful 'superior craftsmen' (a phrase coined by the sociologist of science Edgar Zielsel to describe these craftsmen with a double education, practical and theoretical)[45] willing to challenge all these fields of mechanics were often hailed as the new Archimedes.[46]

It is important to remember that the classical tradition, although especially strong in Latin Christendom, traversed the Mediterranean world, as we can see when considering the mechanical interests of the Byzantine scholar Bessarion (1403–1472), later to become a Catholic cardinal,[47] the professional trajectory of the most prolific early modern

[44] Pappus of Alexandria, 615–18. Author's emphases in italics (except for titles of works).
[45] Long, *Artisan/Practitioners*, chap. 1; Zanetti, *Janello Torriani*, Introduction.
[46] Zanetti, *Janello Torriani*, 190–92.
[47] Keller; Ghisetti Giavarina.

architect of the Ottoman Empire, the renegade Sinān (ca. 1490–1588), or of the Mantuan Jew Abramo Colorni. Sinān, an Armenian Christian who converted to Islam, started his career as a carpenter in the Sultan's army to become commander of the Janissary catapults, and therefore imperial architect and author. He produced autobiographical books on his constructions by dictating them to a friend. Abramo Colorni (ca. 1530–99), the famous escapologist, clockmaker and inventor of mechanical objects, served many important rulers around Europe as military engineer, inventor of new guns, alchemist, and author of books.[48]

Leonardo da Vinci's career is a paradigmatic example of the social elevation of an artisan thanks to the humanist appreciation of painting and classical mechanics. Leonardo (1452–1519) is said to have demonstrated an early predisposition towards drawing. However, his status as the il- legitimate son of a notary would have prevented him from pursuing his father's respectable career: the guild of notaries 'excluded illegitimates from their ranks'.[49] The workshop of a painter such as Andrea del Verrocchio (1435–88) was probably one of the highest respectable solutions for an illegitimate son, as Leonardo was: classical works such as Pliny the Elder's *Natural History* and Diogenes Laertius' *Lives of Eminent Philosophers*, which had a great impact on Renaissance Florence, gave painters and sculptors a high level of dignity among craftsmen.[50]

However, Leonardo pursued a career beyond painting: his successful application for a position at the court of Milan in 1482 must have represented for Leonardo a precious opportunity for further social elevation. At court, the fiscal and professional obligations of the guilds were irrelevant, and traditional epistemological boundaries could be dissolved by the will of the prince. Among the professional competences in his application were listed, first of all, engineering and architectural works for both wartime and times of peace, then sculpture, and, eventually, the only competence he actually possessed officially in

[48] Necipoğlu; Toafff.
[49] Kuehn, 80.
[50] Vecce, 112–22. See Pliny, vols. 9–10 (bks. 33–36); Diogenes Laertius, 281.

the guild system of Florence: painting.[51] Nevertheless, the professional skills he picked up at the wide-ranging workshop of Andrea del Verrocchio (Verrocchio himself had been trained in different workshops as a goldsmith, painter and sculptor) were multifarious.[52]

As in the case of Leonardo, many Renaissance engineers had been educated as painters since this craft was closely linked to the study of geometry. Especially from the time of Brunelleschi's development of linear perspective, any engineer who wanted to give a convincing appearance to his ideas needed to employ Brunelleschi's technique, which was rapidly acquired by the best painters' workshops.[53] It has been observed that even far less realistic illustrations were considered as pieces of technological intelligence: the naïve representations of war chariots by Guido da Vigevano and Valturio drew upon extant north Italian tactical machines.[54] The power of these less realistic images of machines is also confirmed by the story of a manuscript copy of Valturio's *De re militari* sent as a gift by Sigismondo Pandolfo Malatesta to the Sultan Mehmed II (1432–81). The book never reached its intended recipient: in fact, it was seized by the Venetians, who were afraid it would reveal critical technological secrets to the Turks. The Venetian government described the manuscript as 'a marvelous thing and a most valuable possession on account of the novel and important military information found in its text and drawings'.[55]

As a recent archival find by Daniele Conti confirms, even barely functional Renaissance military machines had a remarkable power to inspire: in a short manuscript dated August 1515, Francesco Guicciardini described a tank propelled by three rockets invented by Francesco Barducci Cherichini for the ruler of Florence, Lorenzo di

[51] Leonardo da Vinci, fol. 1082r. On the letter's dating, see: Lohrmann. On Leonardo at war, see: Brioist.
[52] Caglioti. On the circulation of mechanical knowledge in Renaissance Florence: Bernardoni, 143 n. 16.
[53] On the functions of early modern drawings of machines, see: Lefèvre. On Leonardo's drawings of machines: Laurenza.
[54] Settia, 'L'ingegneria militare all'epoca di Federico II', 84–85; 'Guido'; *De re militari*.
[55] Gatward Cevizli.

Piero de' Medici (1492–1519).[56] Guicciardini held the employment of engineers during war in great esteem: at the time of a possible invasion of Italy by the Turks, he wrote that, given the impossibility of bringing together all the Italian princes, the skills of an engineer (employed in hydraulic and military tasks) were the only hope for stopping them. The Republic of Venice had previously employed Leonardo for a similar task.[57]

In Milan, Leonardo was employed as 'painter and engineer of the Duke',[58] then as 'architect and general engineer'[59] to Duke Cesare Borgia (1475–1507). Finally, in France he was known as the 'noble Milanese, first painter, engineer, royal architect and state mechanician'.[60] Leonardo's employment at the Sforza court provided him with the impressive yearly salary of 500 golden *scudi*, which in France was increased to 700 golden *écus*, where the king also gave him the use of a small castle at Cloux.[61] The apotheosis of the commoner bastard craftsman was complete: Leonardo died a gentleman thanks to his reputation as a painter and engineer, a title that also allowed him to investigate natural philosophy.[62] Although Leonardo never published, he had constantly dreamed of becoming, like Archimedes or Vitruvius, an author-engineer,[63] as his friend Luca Pacioli clearly testified in 1498.[64]

Leonardo's story seems to contradict the claim recently made by Bruce Lenman in a recent collection of studies on military engineering that 'bureaucracy does not breed polymaths'.[65] On the contrary,

[56] Balducci's rocket-propelled tank was meant to break up the enemy lines: 'apta a rompere exerciti' ('fit to break armies'). One drawing of the machine was secretly shown by the author to Francesco Guicciardini and Lorenzo di Piero de' Medici, and then poorly sketched by the untrained hand of the historiographer, who, luckily enough, also described it in writing: Conti.
[57] Guicciardini, 80–81; Bernardoni, 84–85.
[58] Heydenreich.
[59] Starnazzi, 41.
[60] Houssaye, 311.
[61] Mafffei, 211; Ferri, 302.
[62] Bernardoni, chap. 4.
[63] Vecce, 65–76, 123–42.
[64] Pacioli, 33.
[65] Lenman.

Renaissance courtly bureaucracy seems to have done this, if by 'polymathesis' we mean the entire classical range of mechanical competences of the Renaissance engineer: applied geometry, the principles of statics and dynamics, and the empirical study of materials.

## Engineers in the Shadow of War

Given that, as Cicero wrote, 'the sinews of war' consist of a 'limitless supply of money',[66] it is also important to remember that Renaissance engineers were involved in supporting the economy far from the battlefield: new powerful pumping systems were developed to drain mines, water fields and supply cities. Canals were created to transport goods and to carry water to power mills and other machines used in industrial processes. Early modern administrations employed an increasing number of engineers to improve agriculture (irrigation and land-reclamation),[67] measure the land for taxation through large cadastre surveying projects,[68] and to solve conflicts through demonstrative mathematical persuasion. For example, in 1377, during a territorial controversy between Venetians and Paduans, Giovanni de' Dondi used a map to find a solution based on measured arguments in order to avoid a conflict between the pretenders, while in 1459, the ducal engineer Aristotile of Bologna (ca. 1420–ca. 1486) convinced the worried inhabitants of Soncino about the safety of a hydraulic project.[69]

The self-representation of power through engineering was also a tool of 'psychological warfare'. For example, Federico da Montefeltro (1422–1482), duke of Urbino, enjoyed being seen as a new Caesar. In an official portrait with his son (ca. 1475, attributed to Justus van Gent, now in Urbino, Galleria nazionale delle Marche), the duke is represented reading a book while wearing plate armour. The Duke of Urbino also hired one of the most talented painter-engineers of the time: the Sienese Francesco di Giorgio Martini (1439–1501), author of

[66] Cicero, 202–3 (5.2).
[67] On Renaissance hydraulic engineering and land reclamation, see: Fiocca, Lamberini, and Maffioli; Cazzola, 15–35.
[68] See the impressive organization of teams of engineers that surveyed the state of Milan at the time of Emperor Charles V: Jacopetti; Maffioli, 207–8.
[69] Pesenti; Zanetti, *Janello Torriani*, 333.

splendid manuscripts on machines that greatly inspired Leonardo.[70] In the dedicatory letter of the *Opusculum de Architectura*, another of Francesco's technical manuscripts, addressing the duke – to whom the tract was dedicated – he wrote that just as Alexander the Great did with Dinocrates of Rhodes, and Caesar Augustus with Vitruvius, Duke Federico himself had also to consider employing an architect as Giorgio, who was such an expert in machines.[71]

The duke ordered his craftsmen to create bas-relief sculptures based on a series of drawings of ancient and modern civil and military machines commissioned from Francesco, which would be placed on the facade of his ducal palace: a successful ruler, like Augustus, had to be a patron of mechanics, also called 'mathematical magic', so as to dominate both the enemy and the natural elements.[72] The message was clear and loud, and influential mathematicians such as Luca Pacioli celebrated this iconographic programme as a tribute to the promotion of practical mathematics.[73]

Emperor Maximilian (1459–1519), more entitled than any Italian petty tyrant to represent himself as a Caesar, also made use of the image of me- chanical devices as symbols of the military might of his state machine, as can be seen in a wonderful series of woodcuts by Hans Burgkmair (1473–1531) of an imperial triumphal procession where mechanical allegorical carts representing imperial victories are driven by muscular Landsknechts on board pulling on cranks and walking on treadmills.[74] In reality, it seems that triumphal processions adopted mechanical devices for propaganda purposes, such as when King Louis XII of France (1461–1515) used Leonardo's lion automaton to celebrate his military victory over Venice in 1509.[75] Magnificence was a necessary component to the representation of power, and Renaissance engineers were also involved in the creation of machine tools for the production of luxury goods or military equipment.

[70] di Giorgio Martini, 'Trattato'.
[71] di Giorgio Martini, 'Opusculum'.
[72] Grafton, 'Magic and Technology'.
[73] Pacioli, 23, 37–38.
[74] Burgkmair, Aspland, and von Burtsch.
[75] Burke.

On a macro-scale and with a view to celebrating claims to universal authority, new hoisting devices were created by engineers to erect colossal buildings, such as the royal compound of San Lorenzo El Escorial (1563–1585), the new basilica of St Peter (1506–1626), and the ancient fallen obelisks in Rome. European clockmakers can be considered engineers working on a micro-scale. As architects and engineers, clockmakers did not have specific guilds until the second third of the sixteenth century. Filippo Brunelleschi, educated as a goldsmith, made clocks: apparently, it was because of this skill that he could invent hoisting machines to elevate great buildings.[76] European clockmakers invented new mechanical devices, including timepieces and other clockworks, which were also presented as diplomatic gifts to impress competing civilizations, such as the Ottomans, Persian, Indians, Chinese, and Japanese.[77] More efficient steel springs were created and employed in different devices: they provided the common ground for the developing fields of both watches and clocks and triggering mechanisms for crossbows and firearms. John Gagné, in a pioneering study, has shown how, during the Italian Wars, specialists in mechanical constructions provided bombardiers – who often lost their hands in battle – with prosthetic mechanical iron surrogates.[78]

Renaissance engineers such as Aristotile of Bologna were highly valued during both peace and war. Aristotile's travels to several European states (namely Hungary and Russia) seem to be strictly connected to the diplomacy of the time promoted by Cardinal Bessarion, with an anti-Turkish perspective. Aristotile was able to move stone towers with his machines and oversaw the construction of large cathedrals and the new fortifications of the Kremlin, besides being in charge of the mint and commanding Ivan III's (1440–1505) artillery.[79]

These engineers were capable of transferring knowledge, and even of stealing it in their occasional capacity as spies.[80] They could also provide security against spies: a cryptographic tool or 'small volvelle

[76] Zanetti, *Janello Torriani*, 329.
[77] For example, in relation to the Turks see: Mraz.
[78] Gagné.
[79] Ghisetti Giavarina.
[80] Adams, Lamberini, and Pepper. See also Iordanou's contribution to this volume.

for enigmatic writing' was created by the Jewish Renaissance engineer Abramo Colorni, to help rulers establish a safe communications system.[81]

Engineers were also involved with military astrology, an important practice in Renaissance European warfare.[82] One manuscript copy of Taccola's *De re militari et machinis bellicis* opens with an illustration of a physician holding an astrolabe and the caption: 'On the [best] time to start a war according to astrology' [fig. 1].[83] It was believed that every physical phenomenon and human activity was under the influence of the stars, including war.[84] Although the Roman Catholic church and some Protestant theologians could not accept the most extreme consequence of judiciary astrology (i.e. predestination), the doctrine of physical influences was widely accepted, legitimizing electional and inceptional astrology: man could change the ill influences of the stars, which impelled rather than compelled.[85]

Arabic and Latin treaties offering techniques of military astrology were in wide circulation: these could be employed to prognosticate the outcome of a battle; to interrogate the stars about the qualities of an army, its soldiers and their commander; or to choose a propitious moment for military action.[86] In 1404, it was the Florentine Republic's astrologer who chose the right moment for the army to attack the castle of Vicopisano. Moreover, Renaissance Florentine military leaders were traditionally elected to office following the pronouncements of astrologers on the correct alignment of the stars. Florentines also elected in point of astrology the most propitious moment to commence the construction of their fortifications.[87] In Naples, the medical astrologer

[81] Toaff, chap. 8.
[82] For a detailed view of astrological practices at Renaissance courts: Oestmann, Rutkin, and Stuckrad; Azzolini; Hayton.
[83] Taccola, fol. 6v.
[84] For some Renaissance examples of the astrological influences of Mars on military predisposition, see: Verrier, 140.
[85] Grafton, Cardano's Cosmos. On the Roman Catholic church's censorship of astrology see: Tarrant. On Lutheran views see: Thoren, 83–84, 216–18.
[86] Burnett; Hand; Orbán, 134-35.
[87] Casanova. I thank Dr Maurizio Arfaioli (Medici Archive Project) for pointing me to Nardi, 87.

Agostino Nifo (ca. 1470–1538) claimed that he had been able to predict 'the unexpected political and military events of 1504–1505 for his master' *el Gran Capitán* Gonzalo Fernández de Córdoba (1453–1515).[88] Luca Gaurico (1475–1558), another famous astrologer, was proud to have publicly predicted King Francis I's (1494–1547) victory at Marignano (1515) and his defeat at Pavia (1525).[89]

The powerful psychological implications of astrological prognostications probably explain why Giovanni II Bentivoglio (1443–1508), lord of Bologna, after commissioning a horoscope from Gaurico, ordered him to be tortured: the poor astrologer had imprudently prognosticated the lord's future defeat, which eventually occurred, increasing Gaurico's reputation.[90] Even a sceptic like Emperor Maximilian I was aware of the power of prognostication in war and it seems that he made use of it as a diplomatic tool.[91]

However, because of a technical *caveat*, the basis of such prognostications was often perceived as weak: besides using unstable instruments for direct observations such as astrolabes, astrologers consulted astronomical tables or *ephemerides* which were, as Pacioli lamented, nine times out of ten imprecise and also diverging, therefore affecting the accuracy of the predictions.[92]

Moreover, the simultaneous consultation of these tables was not an easy task. This is why the aforementioned Campanus had developed the equatorium. Nevertheless, Gerolamo Cardano (1501–76), the celebrated medical astrologer, still refused to offer precise predictions about upcoming wars remarking that 'there is no part of astrology harder than this one'.[93]

This problem called for more accurate astronomical tables and for ex- pensive and complex mechanized planetary equatoria, which

[88] Grafton, *Cardano's Cosmos*, 52–53.
[89] Grafton, 99
[90] Ivi, 124.
[91] Hayton, 2.
[92] Pacioli, 23.
[93] Grafton, *Cardano's Cosmos*, 41.

allowed the instantaneous vision of the whole celestial configurations in real time. Only a few states could afford the expenses and find the engineering knowhow, and the cutting-edge astronomical knowledge to develop such automata, which were the most complex machines of the Renaissance. The prototype of such automata was the abovementioned Astrarium,[94] which, during the Italian Wars, became thoroughly worn out. Its reconstruction was undertaken by the engineer Janello Torriani.

He completed this task in around the year 1550, after two decades spent designing it. This complex cosmomorphic automaton, called the *Microcosm*, the *Emperor's Large Clock*, or *Caesar's Sky* (made for Emperor Charles V, after the devolution of Milan), was a technological prodigy. The emperor granted Torriani a privilege whereby he called him 'mathematician', a synonym of astrologer. Torriani, when asked by the emperor how he would like to be named on a celebratory portrait, replied 'architect of clocks', revealing the Vitruvian model of his aspirations (he owned three copies of Vitruvius).[95] After Charles' death, Torriani entered the service of his son, King Philip II. When the court historiographer Ambrosio de Morales (1523–91) asked Torriani about his planetary automata, the artisan said that he had always wanted to create 'a clock with all the movements of the sky, so that it would be more than the one made by Archimedes'.[96] These automata, together with other impressive technological achievements – e.g. the construction of the *Ingenio de Toledo*, the first giant machine of history – won him the name of 'new Archimedes'.[97]

At first sight, Torriani's brilliant career seems to exclude military practice, aside from the construction of a ballista (most probably the Roman catapult described by Vitruvius), which was more of an antiquarian than a military enterprise.[98] However, some clues point in the opposite direction: the first known document testifying to his

[94] Bedini and Maddison.
[95] Zanetti, *Janello Torriani*, 197.
[96] 'El comprehendio en la imaginacion hazer un relox con todos los movimientos del cielo, assi que fuesse mas que lo de Archimedes que escrive Plutarco, y que lo de otro Italiano destos tiempos …'. Morales, fols. 91r–94r (quotation at fol. 92v).
[97] Zanetti, Janello Torriani.
[98] Viganò.

employment in the administration of the State of Milan (1544) was related to a payment to one 'engineer', Torriani, for 'staying by His Majesty's army in Piedmont'.[99] Considering his excellence in hydraulics and planetary horology, his expertise as army engineer could have related to fortification, hydraulic engineering, or military astrology. The latter seems more probable, if we consider that, on the one hand, the first two accounts connecting Janello to hydraulic engineering (by Marco Girolamo Vida and Girolamo Cardano) both date back to a later period: 1550;[100] on the other hand, according to the doctrine of Great Conjunctions (every twenty years Saturn and Jupiter appear closer in the heavens), astrologers were expecting major historical changes for that very year of 1544,[101] and the astrologer Cardano tells us that at this date Torriani was already working on planetary automata.[102]

Shortly after, in 1547, Charles V commissioned the construction of a cosmomorphic automaton to Torriani. The imperial librarian and counsellor Willem Snouckhaert von Schauberg (1518–1565), in his biography of Emperor Charles V, wrote that the ruler was strongly against prognostication (*iudiciis illis Astrologoru[m] quam maxime adversabatur*)[103] but at the same time he believed deeply in the selection of favourable astrological moments for his actions. Snouckhaert, adopting the rhetorical model of Cicero's *De divinatione*, asked:

> Is it not true that this Caesar among all kings, emperors and monarchs was the greatest astrologer and mathematician? And that when he was in Ulm … he summoned Janello Torriani of Cremona, who arrived on the very day of Charles V's forty-seventh birthday? And immediately after listening to him, he ordered the task of building the instrument of the motion of the eighth sphere [i.e. the Microcosm]? And that instantly afterward, there was a [military] progress in Saxony almost as a prophecy of the future victory? What then does the knowledge of the stars have to do with the discussion on war, what did it have in common with it? It is the great spirit of the emperor, who

[99] Viganò, 275.
[100] Viganò, 34.
[101] Grafton, *Cardano's Cosmos*, 5, 38–55.
[102] Zanetti, *Janello Torriani*, 206.
[103] Snouckhaert von Schauberg, 148–49.

> always despises human activities, and only respects the divine and the celestial ones.[104]

According to Snouckhaert, the arrival of the engineer on the very day of the emperor's birthday was seen as a good omen, and it appears that the discussions about the mechanical commission involved some electional astrological practice that supported certain actions in the war against the Protestants. These actions brought about an immediate success in Saxony, which according to Snouckhaert was perceived as propaedeutic to the great imperial victory of Mühlberg two months later in April 1547. According to the Spanish royal librarian Jose de Sigüenza, the choice of the place for Charles V's retirement was also made by 'his engineer Janello, who was very knowledgeable in astrology'.[105]

After 1552, when the Emperor had this powerful astrological machine completed, we witness between 1554 and 1568 three of the foremost Lutheran princes investing in a similar technology: namely Elector Count Palatine Ottheinrich of the House of Wittelsbach (1502–59); Prince William the Wise of Hesse (1532–92) – who later became William IV Landgrave of Hesse-Kassel; and Elector Augustus of Saxony, of the House of Wettin (1526–86).[106] The involvement of these Lutheran princes with astrological speculation emerges from several documents.[107] Further north, King Frederick II of Denmark (1532–56) granted the noble Tycho Brahe, friend of Wilhelm IV of Hesse, large state funds to support his astrologic-astronomic-alchemic observatory and laboratory at Uraniborg.[108] The theme of alchemy recalls another

[104] 'Sed hic Caesar an non omnium Regum, & Caesarum, & Monarcharum maximus fuit Astrologus, & Mathematicus? an non cum ulmae Suevorum … anno quadragesimo septimo vitae suae, Ianellum Turrianum Cremonensem ad se accersivit? Ac is quidem die natali Caaesaris ad eum venit? ac statim illi (auditus cum esset) instrumenti de octavae spherae motu conficiendi curam mandatumque inunxit? Mox in Saxoniam profectus est futurae quasi victoriae prescius? Quid autem habet astrorum cognitio cum belli tractatione sociale, quid coniunctum habebat? Magnus igitur Caesaris animus, qui humanas actiones semper contemnens: divinas, coelestesque solas semper est admiratus'. Snouckhaert von Schauberg, 149.

[105] Zanetti, *Janello Torriani*, 168.

[106] Oestmann; Zanetti, 'The Microcosm'; *Janello Torriani*, 156–73.

[107] Moran, 218; Oestmann.

[108] Thoren; Christianson.

important techno-scientific and cultural shadow agency of war, which unfortunately cannot be discussed here.

To conclude, I believe that the confusing traditional reading of the Renaissance engineer as a polymath can be explained through the popularity of the classical epistemology of mechanics promoted by humanist culture.

The Archimedean and Vitruvian model of the intellectual military engineer is the key to understanding the evolution of this profession with no specific curriculum but with a precise range of fields of action, as clearly listed by Pappus of Alexandria. Therefore, the labours of the Renaissance military engineer were diverse and extended far beyond the broadly acknowledged construction of war machines and fortifications. In the shadows, far behind the lines, rulers recognized the importance of other forms of engineering to sustain the increasing costs of war. Renaissance engineers were also employed in perhaps the most shadowy of all military agencies: the creation of intelligence instruments for cryptography and military astrology.

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