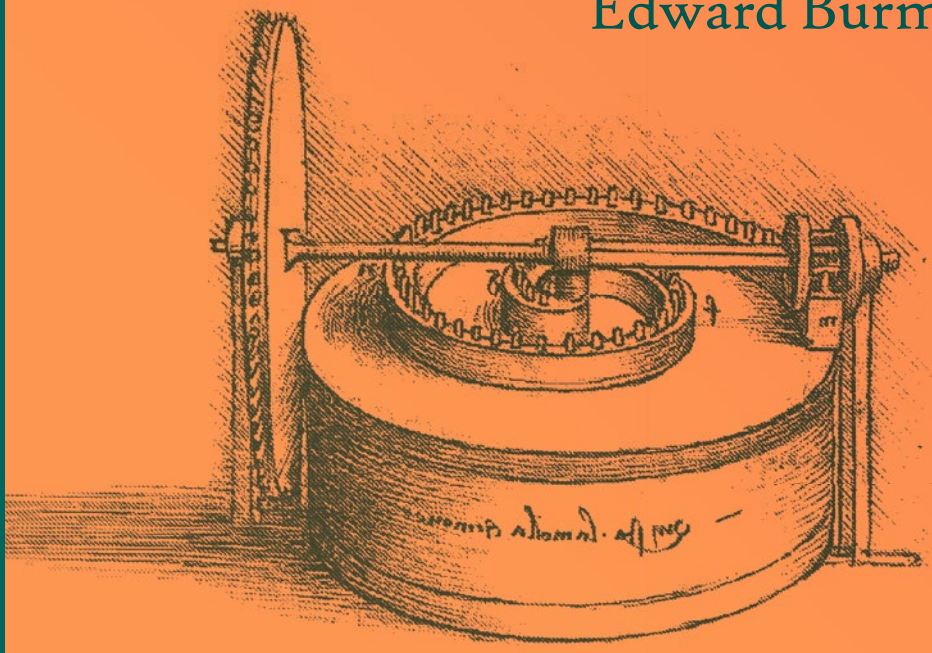
Plinio Innocenzi

THE INNOVATORS BEHIND LEONARDO

The True Story of the Scientific and Technological Renaissance

Foreword by Edward Burman



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To Ilio and Daria

Foreword

Leonardo da Vinci is like one of those authors—Dante, Proust, Joyce—whom everybody "knows," but few have actually read in their entirety. How good it is therefore to have a book about his drawings by an author who is not only a connoisseur of art in general, but also a professor of physics capable of explaining what the elaborate constructions Leonardo depicted are supposed to do. Most of us know about the parachute, the attempts at flight, the putative helicopter, and of course the Vitruvian Man, but few of us can truly understand the myriad machines which throng the six thousand pages of his surviving notebooks. That feat requires someone in possession of specialist scientific knowledge, familiarity with the arcane vocabulary of modern engineering, and a thorough understanding of the technical terms used in Renaissance Italy, both in Latin and Italian.

But perhaps the most fascinating aspect of Plinio Innocenzi's study is his convincing investigations into the origins of those magnificent machines. For Leonardo was very much a man of his time. He was not averse to recognizing a good idea in someone else's work and making it his own with superior draftsmanship and the targeted use of techniques such as unusual perspective. He was part of a community of thinkers exploring the world in new ways, pushing the boundaries of knowledge together. He could perhaps be considered *primus inter pares* as a result of his immense talent, but not a towering solitary genius who sprung from nowhere, as he is often made out to be. In fact, Plinio goes well beyond a straightforward list of Leonardo's artistic and technical achievements, instead informing the reader that he has used Leonardo "as a lens through which to understand a number of stories of technological inquiry and inspiration that originated during the Renaissance."

This leads to a book that is far broader in scope and relevance than a list of works in a museum catalog.

This method is exemplified by the opening chapter, which introduces a number of Leonardo's brilliant predecessors and contemporaries, who worked on similar problems and themes. A reader who has worked through a good biography of Leonardo knows about the key influence of one of the greatest and most original of the Florentine engineers and architects, Filippo Brunelleschi, and how a young Leonardo learned from designs for the Cupola of the cathedral of Florence. But who, to take just a single example, knows Mariano Daniello di Jacopo, known by his nickname Taccola ("Jackdaw")? I checked one of the best-known biographies of Leonardo in English, six-hundred pages long, and found no mention. Yet Taccola is one of the most fascinating minor characters in Plinio's story. This Sienese hydraulic engineer, painter, sculptor, and author of a ten-volume treatise on machines was the source of many of Leonardo's ideas. He deserves to be better known, and this book provides a good start, including drawings that were a genuine revelation for me. In fact, the choice of illustrations by those other than the main subject is exemplary throughout the book.

Taccola also appears in the chapter on the Vitruvian Man, along with his fellow Sienese engineer Francesco di Giorgio, whose translation of part of Vitruvius's *De Architectura* was used by Leonardo himself. It was in fact Taccola who attempted the first Renaissance rendering of the Roman architect's instructions on how to create a human figure simultaneously within a circle and a square. His friend Francesco di Giorgio also made an attempt. The results are both less attractive than Leonardo's famous drawing, but work well enough on a technical level. Still other versions are discussed and illustrated in this fascinating chapter, which manages to throw fresh light (for all but specialist scholars) on one of history's most famous drawings.

Another unexpected and unusual delight for me was the chapter on "Flotation, Walking on Water, and Diving Under the Sea." Leonardo's sketches of vortices of water and mill-rushes are celebrated. They were also the drawings that most impressed me in a volume that arrived as a childhood Christmas present—and when I saw some of the originals in Milan and London. But once again, Plinio takes us far beyond those famous sketches into a little-known world of life jackets with inflatable cavities, like the ones flight attendants teach us to use before take-off. He also covers snorkels for surface diving, with masks and goggles; and scuba-like systems, with tubes and other breathing apparatus for going deeper under water for longer periods. Once again there were precedents, but Leonardo's designs were often more sophisticated from a technical point of view—and certainly better drawn, an important

consideration in view of their military application, for then as now technological innovation was often driven by the needs of warfare. But Leonardo's liberal adaptation of previous ideas does not detract from his genius. As Plinio writes, "He may not always have used original ideas, but he had the extraordinary ability to go beyond the general representation of a concept to design detailed working projects that we are still able to reproduce and test today."

This book is full of such unexpected pleasures and insights, and I could go on with fascinating examples from each chapter, but it would be better for readers to plunge into this astonishing world and let themselves be guided by the author through its maze of invention. In his conclusion, Plinio comments on Leonardo's delight in the world of machines and dreams, arguing that he "was happy only when he could spend his time with mathematics, geometry, and mechanics, exploring the natural world…"

That, it seems to me, might equally apply to the author of this volume.

Beijing, China
November 2017

Edward Burman

Edward Burman is currently Executive Director for Mediapolis Engineering in China. He also serves as a Visiting Professor at Xian Jiaotong—Liverpool University at Suzhou and as a Trustee of the Xian City Wall Protection Foundation. In addition, Burman is the author of a number of popular books about history for the general public, including *Emperor to Emperor: Italy Before the Renaissance* and *Italian Dynasties: The Great Families of Italy from the Renaissance to the Present Day*, among numerous other volumes. His most recent work, *Terracotta Warriors: History, Mystery and the Latest Discoveries*, has been published in February 2018.

Preface

Another book about Leonardo? I can image your first reaction looking at the title of this volume. The scholarly and popular literature about Leonardo is seemingly endless, and every tiny detail of his extraordinary life has been analyzed and described, from his artistic work to the famous notebooks. So it might seem that there is not much remaining to discover and tell.

However, frequently, the book you end up writing is the one you would like to read, but cannot find... This has been the case for me in deciding to write *The Innovators Behind Leonardo*.

The greatest portion of publications about Leonardo is academic biographies, catalogs, and specialized articles written by art historians or experts who have dedicated significant time and effort to investigating in detail particular aspects of Leonardo's work in his various and varied fields of interest.

However, the focus has gradually extended to encompass science as well as art, and this has allowed us to gain deeper insight into a very complex personality with many interests in different fields—an approach which nowadays we like to define as multidisciplinary. This has manifested in books and studies by nonspecialists, scientists, and engineers who have brought some fresh air to the field. Particularly notable because of their original critical approach focused on Leonardo's technological legacy are Fritjof Capra's books[1,2] and a handful of articles written by mathematicians and engineers, which we will encounter in more detail in the chapters to come. A very nice illustration of Leonardo's scientific and engineering work can be found in *Leonardo Da*

[1] Capra F (2013) Learning from Leonardo. Berret-Koehler Publishers, San Francisco.

[2] Capra F (2007) The science of Leonardo. Anchor Books, New York.

Vinci: Experience, Experiment and Design by Martin Kemp[3]. Likewise, readers can find a vibrant description of Leonardo's studies in mechanics and mathematics, with a deep analysis of his work in anatomy, in Kenneth Keele's *Da Vinci's Elements of the Science of Man*[4]; this book, published in 1983, is still considered a fundamental work on the subject.

Leonardo's machines, such as his robot, flying machines, and musical instruments, have also been the subject of several detailed reconstructions, sometimes with a certain dose of fantasy—as in the case of Leonardo's purported bicycle, which most scholars believe to have been the work of a fanciful prankster. In recent years, with the aid of computer graphics, an extraordinary level of accuracy in these reproductions has been achieved. The machines' operation and operating principles can now be understood with an unprecedented level of precision, even when only fragments appear in Leonardo's notebooks[5].

Leonardo's extensive notes on mechanics, anatomy, geometry, physics, and optics (to name just a few) bear witness to his efforts to achieve a deep understanding of nature in its entirety. Examining the results of his incredible efforts without an awareness of his scientific predecessors and contemporaries, however, only provides a small part of the "true" story. Leonardo's achievements are prefaced by the appearance of a new generation of innovative thinkers, engineers, mathematicians, and architects who all contributed to creating the fertile environment that nurtured Leonardo's studies and ideas. To omit this backdrop gives only a fragmentary knowledge of a complex process. Leonardo appears as a kind of isolated genius—an attractive image, perhaps, but one which does not correspond to the historical reality. On the contrary, Leonardo was part of a much broader historical trend—the Renaissance evolution of science and technology in the Western world.

During Leonardo's lifetime, from the middle of the fifteenth century to the beginning of the sixteenth, Italy was experiencing one of the most turbulent periods of its long history. The region was divided into a mosaic of small Signorias and city-states, which engaged in a continuous struggle for power while simultaneously facing the threat of invasion by other European countries. The people of this time lived hard lives, which necessitated daily efforts for survival. Despite these difficulties, however, some individuals managed to develop significant technical and artistic skills.

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[3] Kemp M (2011) Leonardo Da Vinci. Experience, experiment and design. V&A Publications. London.

[4] Keele KD (1983) Elements of the science of man. Academic Press.

[5] Taddei M, Zanon E, Domenico Laurenza D (2005) Le macchine di Leonardo. Giunti Editore. Firenze.

Though it may seem unlikely, the Renaissance was born from precisely those turbulent times and in that small geographical region of the world. Political instability did not represent an insurmountable obstacle for the brilliant minds that flourished in a unique and vibrant combination in the same place within a limited range of time. In addition to the arts, banking and accounting systems, architecture, medicine, engineering, and technology found a fertile ground for rapid development. This avalanche of innovation was triggered by the rediscovery of the Latin and Greek classics. An enormous past knowledge, which had remained buried for centuries, thanks to the translations of dedicated scholars, suddenly became available as an invaluable source of inspiration for new discoveries in a wide range of fields.

Leonardo was born in the midst of this wonderful moment, and as a child was a direct witness to those extraordinary times. Very close to the workshop of Verrocchio in Florence, where Leonardo was apprenticed, the Brunelleschi Cupola (dome) of the cathedral was already part of the city panorama, making an enormous impression on residents. The realization of the dome, with its challenges of design and implementation, can be considered the beginning of the technological Renaissance. It was an unprecedented architectural and engineering masterpiece that continues to impress, even in the modern age. It was also a sign of new times to come, when new challenges would be tackled by men rich in talent and imagination and hungry for knowledge.

Leonardo, better than anybody else, represents the true essence of the Renaissance man. As a curious child, he observed the complexity of the world from a new point of view. At the same time, he tried to employ this knowledge to adapt nature to his needs. These attempts remained in part only fragments of a world of illusions and dreams—a world of flying machines and robots which was, however, destined to become part of our modern reality. Despite, or perhaps because of, their extraordinary farsightedness, the Renaissance men were frequently simply too advanced for the times in which they lived.

The vision of a new technologically enhanced world, where machines would be able to do most of the work, thus releasing man from daily drudgery, may have appeared at that time as a childish game for naïve dreamers. As we will see, however, Leonardo and his fellow visionaries went far beyond mere dreams, developing concrete machines and innovative technologies.

These were a special type of men, not yet the super-specialized experts that we are familiar with from the present day, but rather artist-engineers with multifaceted interests. They were able to pass from painting to mathematics to architecture, all the while assuming that this multidisciplinary capability was absolutely normal. This was a distinctive sign of the times. They had a

true thirst for knowledge which acted as the driver for interest in just about everything, combined with a confidence that, given sufficient scholarship and effort, they could conquer nature.

During Leonardo's lifetime, and even much before it, there developed an extraordinary cultural environment for innovators. All of them shared with Leonardo this unique capability of being at the same time artists, engineers, and inventors. As we shall see over the course of the pages to come, Leonardo is enormously indebted to this intellectual community. They not only showed him how to design machines and devices but, even more importantly, they also introduced him to the possibility of imagining a new world.

It is a history not well known outside of specialist circles and not fully explored until now. Without being aware of this unique story, however, it is almost impossible to understand the genesis of Leonardo's ideas, particularly his work on mechanics and machines. From a scholarly perspective, this context has been well described by Bertrand Gille in the *Engineers of the Renaissance*[6] and in Paolo Galluzzi's *Renaissance Engineers: From Brunelleschi to Leonardo da Vinci*, and dedicated readers are encouraged to see out those texts.[7] We will see that the link between many of Leonardo's most famous ideas and those of these precursors is very direct; indeed, many of them simply look like direct copies or rearrangements of his predecessors' work. Ironically, while today the impulse toward seeing Leonardo as an isolated genius has led to a kind of collective self-censorship where the original sources of his work are concerned, for centuries the scientific and technological work of Leonardo itself went almost unnoticed, before suddenly becoming part of a popular cult which styles him as an iconic and mystical figure in movies and bestsellers.

To put Leonardo in the right perspective does not minimize his achievements. On the contrary, it makes even more evident his difference from his contemporaries, which can essentially be summed up in a single concept: the scientific method. As we will see in more detail throughout this book, Leonardo's studies marked a change, since they were based for the first time on *sperienza* (experience), and this represented a real turning point in the history of science and technology. The experimental method itself would come later, with Galileo Galilei, and with it the foundation of modern science, but it was already clear to Leonardo that only direct knowledge through experiments could catalyze true advancement of human comprehension of nature.

[6] Gille G (1996) Engineers of the Renaissance. MIT press, Cambridge, Massachusetts.

[7] Galluzzi P (1996) Renaissance engineers. From Brunelleschi to Leonardo da Vinci. Giunti Editore. Firenze. It is a well-illustrated catalog of the exhibition *The Art of Invention: Leonardo and Renaissance Engineers* and contains several images and descriptions of Renaissance machines and their computer reconstructions. http://brunelleschi.imss.fi.it/ingrin/index.html.

Many of Leonardo's works are a kind of "thought experiment" or "proof of concept" in our modern terminology. They contain the seed of real scientific and engineering innovation largely in advance of their time. Leonardo's machines appear as true exercises of design. His unique capability of complex spatial representation allowed him to visualize projects with a detailed precision that, in many cases, would only be possible to reproduce with the help of computers.

Leonardo also had another important skill, one which has been significantly underestimated: he drew and elaborated upon previous knowledge. In this, too, Leonardo used the same method that every scientific researcher uses today. He consulted libraries, taking note of everything that he considered important; he made field trips to see in person what could be of interest to know; and he exchanged ideas with some of the most brilliant minds of the time. He had a thirst for knowledge and was lucky to live in one of the most incredible periods of human history during an explosion of creativity, which has left behind some of the most precious human legacies.

Putting Leonardo in the context of his scientific predecessors and contemporaries makes him feel more human and much closer to us; the thin rope that links the world before to Leonardo's own life is also directly connected to our present. The road to reach our technologically advanced age would be, however, an uneven one. History is never an easy, linear development of events. Failures are part of the learning process, creating problems that require long collective effort to solve, sometimes over the course of centuries. Several routes would turn out to be simply dead ends—such as the obsessive search for perpetual motion, or squaring the circle. Other dreams such as flight, which for a long time appeared impossible, would become reality only some centuries later.

In his notebooks (about 6000 pages of which are available today), Leonardo noted and sketched everything that looked interesting to his curious mind with the intention of making these notes the basis for his studies. The contents of these pages are not limited to drawings and concepts, but also include exercises in Latin and arithmetic, shopping lists, and lists of books to collect. They contain observations on mechanics, paintings, flight, physics, anatomy, and mathematics, but also jokes and personal memos. Also to be found are several machines and ideas taken from outside sources—from manuscripts in Leonardo's possession or from notes taken during visits to the rich libraries of Italian cities such as Florence and Pavia, which he visited quite often.

Leonardo's notes are, however, not easy to read. As is well known, he wrote from right to left; in addition, the calligraphy and his Italian are difficult to interpret. The incredible efforts of several generations of scholars have been

necessary to decipher his enormous volume of notes. We are sincerely indebted to them for the access we now have to the extensive patrimony of knowledge that is Leonardo's legacy. A beautiful account of this patient and systematic work can be found in the book *Leonardo & io,* written by one of the most famous Leonardo scholars, Carlo Pedretti.[8] Thanks to this sustained collective enterprise, all surviving pages have been digitalized, and a diplomatic (i.e., a transcription of the text that reports the characters as they appear, with minimal or no editorial intervention or interpretation) and critical transcription is now available online.[9]

The digitization of the technical knowledge of the Renaissance, most of it contained in delicate manuscripts with very few copies, is not limited to Leonardo's work. Today, online versions of Leonardo's main sources of inspiration, such as the treatises of the Siena engineers, Francesco di Giorgio[10] and Taccola,[11] are also available. This has allowed for much easier consultation, and critical comparison of the different original sources, which only a few years ago would have required years of patient exploration in European libraries.

Starting from these manuscripts it is possible to take a long journey back into the past, which will carry us into a world full of contradictions that is quite difficult to understand. In this strange world, the same person who sketches odd war machines capable of mutilating people in horrible ways is also able to represent on the same page a picturesque scene with a peaceful fisherman sitting on the shore of a river. Such unexpected juxtapositions are not unique to Leonardo—they were in the nature of what were, from our perspective, difficult and contradictory times.

In this book, I have used Leonardo da Vinci as a lens through which to understand a number of stories of technological inquiry and inspiration that originated during the Renaissance. Following the traces of these stories makes it easier for us to understand Leonardo and his time. Every chapter is dedicated to a different story, though they always relate to scientific and technological subjects. The first chapter introduces some of the "others"—Leonardo's scientific predecessors and contemporaries. Foremost among them, the Siena Engineers will figure prominently in the specific stories that follow. The

[8] Pedretti C (2008) Leonardo & iO. (in Italian) Mondadori, Milano.

[9] The *Biblioteca Comunale Leonardiana di Vinci* has realized a digital archive, which contains the diplomatic transcription of all the written work of Leonardo da Vinci. www.leonardodigitale.com.

[10] Four codices of Francesco di Giorgio (Codex Ashburnham 361, Ms. Regg. A 46/1/9 bis, Vat. Urb. Lat. 1757, Ms. 197.b.21) are available online also at www.leonardodigitale.com.

[11] A copy of Taccola's De Ingeneis can be downloaded at the Cornell Library web site: http://ebooks.library.cornell.edu/k/kmoddl/pdf/037_001.pdf.

remaining chapters chart the origin and genesis of a range of ideas, from flying machines to diving apparatus, that captured the imaginations of Leonardo and the other great minds of his time, and whose pursuit continues into the present day. Because each chapter charts a different area of inquiry, they need not be read strictly in the order in which they appear. As Leonardo himself was used to do, readers should feel free to jump from one topic to another as the interest strikes them. The subjects have been selected to capture the most interesting ideas, and those with the deepest connections between Leonardo's world and our present reality.

Rather than providing simply an illustrated catalog of Leonardo's machines, it is hoped that this topical approach will give readers a taste of the scientific excitement of Leonardo's time, making it possible to experience the dreams of the "hungry and foolish"[12] (to borrow Steve Jobs's turn of phrase) that allowed Leonardo, his predecessors, contemporaries, and successors to imagine and shape the future.

Alghero, Italy Plinio Innocenzi

[12] "Stay hungry, stay foolish". Steve Jobs's speech at Stanford, on 12 June 2005.

Note to the Readers

The completion of this manuscript in its current form would not have been possible without the digitalization of the invaluable cultural heritage represented by Renaissance and Medieval manuscripts related to science and technology. Only a few years ago, consulting these materials, dispersed as they are among libraries across Europe and the USA, would have been a task that required enormous amounts of time and financial support. Thanks to digitalization efforts, it has been possible for me to consult the original versions of many of the manuscripts mentioned in this book. In particular, all of Leonardo's written work is now easy to view from the comfort of one's own home. When available, I have noted the sources I consulted in the body of the text. I have likewise cited the sources of all the images I present in the figure captions. I have preferred to use such images in edited form to allow readers not accustomed to the peculiarities of original manuscripts to appreciate the technical aspects of these drawings in detail. I have also included the original (untranslated) version of all quotations in the footnotes. It would be quite difficult for most non-Italian readers (or, for that matter, most Italian readers) to understand the language used at the time. It is, however, fascinating to have a look at the original words used by Leonardo; and any reader can have the pleasure of seeing the explanations in Leonardo's own words while imagining the sound of his voice.

Acknowledgements

I am so much in debt with Sara Kate Heukerott and Sanaa Ali-Virani from Springer for their incredible support. Without them I could not have realized this book. Grazie! I am also in debt with prof. Attilio Mastino for the translations from Latin and with Edward Burman for his support in reading the manuscript. A very special acknowledgment to my family, my wife Tongjit and my sons Jacopo and Lavinia, because they are my main source of inspiration.

Contents

About the Author

Plinio Innocenzi is a full professor of Materials Science and Materials Technology at the University of Sassari and has a special interest in science popularization at different levels. He has a doctorate in physics but attended a Classic Lyceum dedicated to Humanities, Art, Latin, and Greek, which is why he has always maintained a multidisciplinary vision and developed a special passion for the connections between science and art. He has dedicated particular attention in recent years to Leonardo's scientific work and has participated in numerous conferences and festivals on the topic. This book is the result of Prof. Innocenzi's desire to make general readers more aware of the multifaceted origins of scientific and technological knowledge.

Abbreviations

BAM	Biblioteca Ambrosiana, Milan (Italy)
BAV	Biblioteca Apostolica Vaticana, Rome (Italy)
BIF	Bibliothèque de l'Institut de France, Paris (France)
BL	The British Library of London (UK)
BML	British Museum, London, (UK)
BMLF	Biblioteca Medicea Laurenziana, Florence (Italy)
BNCF	Biblioteca Nazionale Centrale di Firenze, Florence (Italy)
BNE	Biblioteca Nacional de España, Madrid (Spain)
BNF	Bibliothèque Nationale de France, Paris (France)
BRT	Biblioteca Reale, Turin (Italy)
BSBM	Bayerische Staatsbibliothek, München (Germany)
GDSU	Gabinetto dei Disegni e delle Stampe degli Uffizi, Florence (Italy)
ULJCS	University Library, Johann Christian Senckenberg, Frankfurt Am Main (Germany)
VAM	Library of Victoria and Albert Museum, London (UK)

1

Leonardo and the "Others": Engineers and Inventors of the Early Italian Renaissance

The general perception of Leonardo da Vinci as a self-educated genius who suddenly appeared in Florence during the Renaissance is highly fascinating and romantic, but unfortunately quite far from the reality. This popular image does not take into account the extraordinarily fertile environment of the time, when versatile artists and architects were able to innovate in many different fields, contributing to that unique season of human history. Leonardo is very much in debt to these "others": a significant portion of his work on mechanics and machines is largely a derivation or development of the studies of his predecessors, who had already planted the seeds for a scientific and technological Renaissance.

From the very beginning of his apprenticeship in Andrea del Verrocchio's workshop, Leonardo came into contact with the wonderful world of machines, which exerted on him a fascination which lasted all his life. Some scholars observe that he loved his studies on mechanics more than his artistic work as painter, which gave him fame and success when he was alive. As we can see in his notebooks, Leonardo carefully drafted and studied the machines created by Filippo Brunelleschi (1377–1446) to build the Cupola of the Duomo of Florence (Cathedral of Saint Mary of the Flowers). At the same time, he used the patrimony of knowledge accumulated by a small group of talented engineers, mostly from the Republic of Siena, to develop visionary projects of unprecedented ambition.

Leonardo's body of work on mechanics is not diminished if we put it in this context. We simply begin to appreciate it, not as the work of an isolated genius but as the synthesis of a lengthy process that started in the mid-fourteenth century in Italy with Brunelleschi and in greater Europe with the

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German school. It is during this period that we see dramatic strides in scientific and technological knowledge. The contributions to this season of innovation came from a variety of different sources and places. It was also a collective process, furthered in part by anonymous artisans, such as those who participated in actualizing Brunelleschi's machines, whose work has never been fully credited.

In this chapter, the protagonists of this creative season will be introduced. They are the "others:" figures largely unknown to nonspecialists, who developed the foundation for Leonardo's own work and ideas.

While this chapter focuses only on the main group of Italian artist-engineers, largely from Tuscany (and Siena in particular), since they stand out as a group for their strong influence on Leonardo, Roman and medieval knowledge also played a significant role, as will be discussed in future chapters where we delve into the development of individual ideas and devices.

The "Sienese Archimedes": Mariano di Jacopo–Called Taccola

As we will see, two individuals play an outsized and fundamental role in the history of the technological Renaissance: Mariano Daniello di Jacopo called Taccola ("jackdaw")[1,2] (1381–c. 1458[3]) and Francesco di Giorgio Martini (1439–1501), both from Siena. Not very well known outside of scholarly circles, their work and its impact on the history of technology has been studied in depth only recently.[4] They are some of the main sources of inspiration for the machines, mechanics, and military technology that have been attributed to Leonardo. Often, in museums and exhibitions, some of their inventions that were only reproduced or slightly modified by Leonardo are wrongly attributed to him. Taccola and Francesco di Giorgio were not simply

[1] The nickname Taccola (Jackdaw) came from his father; his certificate of baptism reads, "Mariano Danniello of Jacomo detto Tàcchola." For some time it was thought that the nickname was due to his very pronounced aquiline nose.

[2] Doti G (2008) Entry on Mariano di Iacopo, In: Treccani. Dizionario Biografico degli Italiani. Volume 70.

[3] The date of death is not known with accuracy but was sometime between 1453 and 1458.

[4] The manuscripts of Taccola were rediscovered in the second half of the eighteenth century, but were then forgotten again in the libraries of München in Germany and Florence in Italy. It was only in the 1960s that a critical edition of his work was published. The rediscovery and publication in facsimile is due to the work of Gustina Scaglia and Frank Prager.

Frank D. Prager, Gustina Scaglia. Mariano Taccola and his book "De ingeneis." Cambridge (Mass.), MIT Press, 1972. Mariano di Iacopo detto il Taccola, Liber primus leonis, liber secondus draconis,… and addenda, edited by Gustina Scaglia, Frank D. Prager, Ulrich Montag, Wiesbaden, L. Reichert, 1984, 2 v. (I text, II facsmile).

precursors, they were much more—innovators, engineers, and artists with multifaceted personalities—true Renaissance men who represent a fundamental stepping stone between the knowledge of the Middle Ages, the German school of machines, and the new age of the Renaissance.

Taccola and Francesco di Giorgio were singular individuals, not only because they played a fundamental role in the history of engineering but also for their innovative way of diffusing knowledge beyond the closed environment of the workshops of the Middle Ages and early Renaissance. Their treatises represent the first systematic attempt to elaborate and reproduce technical knowledge through explanatory illustrations. On the other hand, identifying Taccola and Francesco di Giorgio only as engineers (*ingeniarii*) is actually quite reductive: they had interests which spanned a variety of fields, from arts such as painting and sculpture to engineering and architecture. They represent the cultural element in the progression between Brunelleschi and Leonardo in a kind of ideal handover between different generations of artist-engineers.

Taccola survived Brunelleschi by 12 years. He completed his treatise *De Ingeneis* just as the Florentine architect finished his Cupola and died (Leonardo was also born around this time). Francesco di Giorgio had the opportunity to read and study Taccola's books, and Leonardo, in turn, would read and annotate Francesco di Giorgio's own manuscripts. This direct line of intellectual descent among the different protagonists of Renaissance is notable; it represents an ideal passage of knowledge that marks the transition from the Middle Ages and the new age to come. If we look at the years in which each lived—Brunelleschi (1377–1446), Taccola (1381–1458), Francesco di Giorgio (1439–1501), and Leonardo da Vinci (1452–1519)—we immediately notice that their lives overlap such a way as to allow a direct connection between each successive generation. Records show that there was a direct transfer of knowledge from Brunelleschi to Taccola: the Sienese engineer described in his manuscripts his encounter with the Florentine architect and the discussions they shared on different subjects.[5] They shared a common passion for engineering and machines, which was likely the basis of their friendship. A detailed account of this event can be found in *De Ingeneis*, where Taccola writes about Brunelleschi with great respect. The discussion between the two engineers included the problem of plagiarism and intellectual property. Ironically, many of the machines invented by Brunelleschi for the construction of the Cupola, such as a special boat for shipping marble, are reported in Taccola's notebooks,

[5] Prager FD (1968) A Manuscript of Taccola, Quoting Brunelleschi, on Problems of Inventors and Builders. Proceedings of the American Philosophical Society, 112:131–149.

only to be later wrongly attributed to Leonardo. Leonardo would have been well aware of these innovations, thanks to the efforts of Taccola and Francesco di Giorgio; their "catalogues" of technologies remained a benchmark for several generations.

The Sienese engineers shared with Leonardo not only a common basis of technological knowledge but also a working method: all three used as an essential instrument of work a notebook, in which they annotated and traced ideas and projects. These notes made it possible to extract and re-elaborate a second time what they needed in order to fully realize a given project (see, e.g., Taccola's machines and techniques for sieges in Fig. 1.1). Another

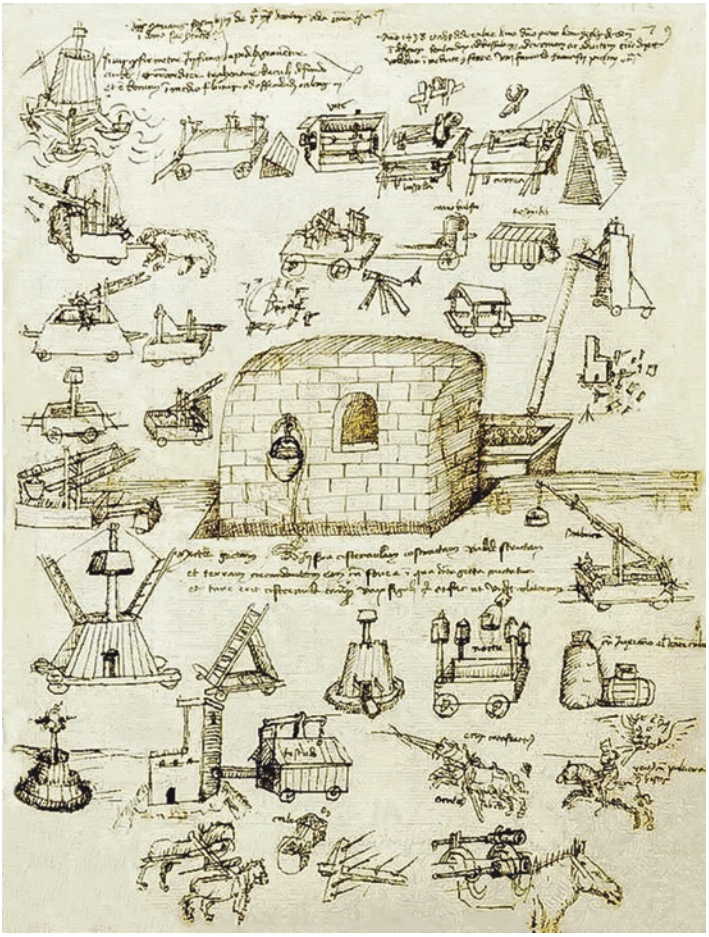

Fig. 1.1 Machines and techniques for sieges. Mariano di Jacopo (Taccola). (De Ingeneis, Cod. Lat. Monacensis 197 II, folio 82r. (BSBM))

common element is the wide use of graphical representations and notes to illustrate ideas and practical projects. Their drawings are, in most cases, clear and easy to understand, even if they sometimes exhibit a naive simplicity. They also share with Leonardo's notebooks the will to elucidate rather than hide knowledge. It is an unexpected "open access" approach, which was quite surprising for a time in which technical know-how generally remained carefully confined within the boundaries of the workshop.

Another distinctive element is the illustrative and didactic use of drawings that reached, especially in the case of Francesco di Giorgio, an unprecedented level of technical quality. The sketches were used to explain projects in detail, allowing them to be reproduced. The drawings in their manuscripts are clear and elegant, a significant advancement with respect to the simple and sometimes naive sketches that appeared during the Middle Ages or in the texts of the German school. These drawings mark a definitively new approach to engineering based on significant attention to graphical representation of projects and the requisite technical explanation to realize them. There is also another remarkable difference, which is the explosion of creativity and the remarkable ability to innovate that can be found in the manuscripts of the Italian engineers with respect to the past. These figures exhibit an awareness that they were not alone. They were living and working with some of the most creative artists in history, competing and cross-fertilizing to develop new ideas and new visions of the future.

Taccola wrote two treatises. The first, *De Ingeneis*[6] ("Concerning engineering"), was a four-volume work written over a long period, between 1419 and 1450, and was dedicated to projects of civil and military engineering, with special attention to hydraulics.

His second, more ambitious collection is *De Machinis* ("Concerning machines"), a ten-volume work written between 1430 and 1449. This treatise is mainly composed of descriptions of military technology—machines for sieges and fortifications. Taccola, the son of a winemaker who nonetheless received a good literary education, wrote in Latin. In contrast, Leonardo, an illegitimate son of a wealthy Florentine notary, had only a basic education and

[6] The autograph copies of books I and II of *De Ingeneis* are conserved in the National Library of München, Codex Latinus 197; book I is composed of folii 1–21, 30–75, while folii 22–29 are bound in a separate file. Book II includes folii 76–96 which continue in the books I–IV, folii 97–137. Books III and IV are conserved in the National Library of Florence, Codex Palatinus 766, book III folii 27–57, and IV folii 58–76.

A copy of *De Machinis* is conserved in the Bayerische Staatsbibliothek as Codex Latinus 28,800.

At least other three copies of *De Machinis* survive: one at the New York Public Library as Codex Spencer 136, another at the Biblioteca Marciana of Venice as Codex Latinus 2941, and the final copy, illustrated by Paolo Santini, is conserved at the Bibliothèque Nationale de France as Codex Latinus 7239.

developed his knowledge only thanks to his autodidactic efforts. Leonardo did not know Latin, and, because of this, he modestly termed himself *omo sanza lettere*: a man without education. In time, Leonardo was able to achieve a reasonable mastery of Latin which, during the Renaissance, was still considered the language of the educated. He studied Latin with dedication, and several pages of his manuscripts are filled with sentences and lists of words with their translation in Italian, which he compiled for practice.

Taccola, on the other hand, was much more self-confident about his erudition and his capability as an inventor and man of genius (*ingeniarius*). In *De Machinis*, he dared to term himself the Archimedes of the magnificent and powerful city of Siena: *Ser Mariano Taccole alias archimedes vocatus de magnifica ac potente civitate Senarum*.

Taccola was a tranquil person with no special ambition for advancement (though, as we have just seen, he was quite proud of his skills as an inventor and engineer), who spent most of his life in Siena in a relatively peaceful setting, at least considering the turbulent times. He had a successful career in the administrative ranks of the small republic, became administrator of the Domus Sapienta (one of the main cultural institutions of the city), and was later employed as a hydraulic and military engineer by the Republic of Siena. His true interests lay outside of administration and law, and he developed a particular passion for art and engineering. We have evidence of some artistic works in wood that were commissioned from him. One of these works was requested in 1437 by the famous *Maestro* of Siena, Jacopo della Quercia, indicating that in Tuscany Taccola was appreciated for his artistic as well as engineering talents.

Taccola lived in very dangerous times, and the small Republic of Siena had to work hard to survive, bouncing between military confrontation and strategic political alliances with other states in order to maintain its independence and democratic government. From the year 1386, just 5 years after Taccola's birth, until 1487, Siena was ruled by the elected council of Priori, with the exception of a brief period between 1399 and 1404 when Gian Galeazzo Visconti,[7] the Duke of Milan, was nominated to be Signore of the city.[8,9]

[7] Gian Galeazzo Visconti (1351–1402), was the son of Galeazzo Visconti II and Bianca of Savoy and became in 1395 the first Duke of Milan.

[8] During the Middle Ages, the Italian cities gradually transformed into city states, mostly oligarchic republics. Over time, some of the oligarchs tried to seize power as individuals, and transformed the cities into "Signorie." This is, for instance, what happened to Florence when the Medici family obtained the control of the city. In the case of the Republic of Siena, the people were afraid that the city was too weak to face an attack from Florence, so they spontaneously nominated Gian Galeazzo Visconti as Signore of the city state.

[9] The Priori were generally selected or elected from within the noble families and the city corporations. Between 1386 and 1399, several different "priorati" ruled Siena, 10 "priori" (1386–1387), 11 "priori" (1388–1398), and 12 "priori" (1398–1399). Between the years 1404 and1487, the governing body of Siena had 10 priori.

From 1487 to 1525, Siena was ruled by the Petrucci family, who took power from the Priori (Signoria dei Petrucci). Throughout both periods, Siena had a very powerful neighbor, the city of Florence, and conflicts for supremacy were almost unavoidable.

These confrontations were ongoing, culminating in Siena's capitulation in 1555 following a long siege. This loss marked not only the end of the small Republic of Siena but also the start of a trend whereby foreign powers would, little by little, take control of the mosaic of small Italian states, ending the region's period of democracy and government of free people.

Sigismund of Luxemburg (1368–1437), Emperor of the Holy Roman Empire, supported Siena against Florence, so it is easy to understand Taccola's devotion to him. In 1432, Taccola put himself under Sigismund's protection, offering his services as a hydraulic engineer. In exchange for his devotion, Sigismund personally granted Taccola the important title of Count Palatine. In spite of the high rewards and important positions he reached within the city administration, at the death of his wife, Taccola became a friar and refused any other appointment until his death, sometime between 1453 and 1458.

The search for a powerful patron was a common and fundamental need not only for artists but also for architects and engineers throughout the Renaissance. Many of Leonardo's choices were dictated by the necessity of seeking financial support and protection. This explains his frequent moves from one Italian city to another as the political situation changed. Notably, Leonardo offered his services to the Duke of Milan on the basis of his ability as military engineer rather than for his artistic skill, though it was for the latter that he was already famous. In a time of continuous war, this type of knowledge was highly prized by the Italian city states, which valued not only military engineering but also the ability to design fortresses and castles, siege machines, and new weapons.

As mentioned above, Taccola became famous in Siena as a hydraulic engineer. Traces of this interest survive in his treatises, where several projects for pumps, water mills, and dams are described. Taccola's engineering work was well known in the sixteenth century, and numerous copies of his manuscripts were made. Notwithstanding the popularity of Taccola's treatises during the Renaissance, at least within the circle of people interested in civil and military engineering, his work quickly felt into oblivion. The copies of *De Ingeneis* and *De Machinis* remained dispersed and forgotten in European libraries, a fate similar to that experienced by Leonardo's notes. Their recent rediscovery has finally allowed for a more complete understanding of the influence of Taccola's work on figures like Leonardo and, more broadly, on the history of technology.[10]

[10] Fane L (2003) The Invented World of Mariano Taccola: Revisiting a Once-Famous Artist-Engineer of fifteenth Century Italy. Leonardo 36:135–143.