

Beginnings

Constancy. Not who begins but he who perserveres.

Leonardo da Vinci MS H³, f. 101 r, c. 1494

When I set myself to the task of writing a historical introductory chapter to my second book, *Robot Evolution*, in the early 1990s, I had learned about Leonardo's Robot Knight from Carlo Pedretti's magnificent *Leonardo Architect*.¹ I had seen the book in a book store, but it was in Italian and very expensive. Later I found a copy of it used and in English. After digesting it I leapt at the opportunity to delve into Leonardo's Robot Knight, which was described near the end of the book. Taking a leap of faith that enough material had survived to reconstruct the robot, I made my way to the University of Minnesota's Rare Books Collection on the top floor of Wilson Library. There, an elderly librarian, tasked with wheeling up from the stacks the twelve elephant folios of the Codex Atlanticus, nearly collapsed his cart beneath the volumes, which weighed several hundred pounds. From this awkward beginning I traced the faint fragments one by one, perhaps even discovering an overlapping figure that had been overlooked by Pedretti, and was able to make a road map of the design and publish the fragments. My book, *Robot Evolution*, which contained the Leonardo material, was well underway but not yet published by the winter of 1994.

While in Los Angeles in February that year, where I had gone to recover from another of my bouts of chronic bronchitis brought on by the harsh and unyielding climate of Minnesota, I found myself with little to do. On a whim, I decided to contact Pedretti himself. I called and left a message at the UCLA Arts Library on Hilgard Avenue. He returned the call to my Santa Monica budget hotel room and after a lengthy conversation, I proposed sitting in on his lecture. Suggesting that for "people like you" it would be best if I came to his house for an in-person discussion, he graciously invited me to his home in Westwood.

Driving down the endless car dealerships, restaurants, and other commercial establishments on Santa Monica Boulevard, I passed under Interstate 405 and continued on past the sprawl of Kinko's and Subway sandwich shops. As I turned off I entered a tree-lined, peaceful neighborhood whose beauty is favored by artists, educators and scholars. Walking up the sidewalk to his beautiful Spanish Colonial home with its shady, well groomed yard, the "Armed Response" security sign in front and notes to deliver packages to the neighbor across the street, I began to wonder if I would find the great man at home.

I shouldn't have worried. Carlo Pedretti opened the door and invited me to "Come on in!" I was met by a gracefully aging energetic man with inquisitive brown eyes and an Italian accent. He led me along a narrow hall lined with paintings and prints, and I realized that I had entered the world of a great scholar.

Author of a shelf of books and editor of several "Monumental Leonardo Works in Facsimile" for Giunti, Carlo Pedretti seems to embody the word "Scholar." Professor Emeritus of the UCLA Art History Department, he is better known in Europe, where he maintains a second home in Vinci, Italy, the birthplace of Leonardo.

¹ Carlo Pedretti, *Leonardo Architect*. New York, Rizzoli International Publications, 1981.

Born in Bologna in 1928, Carlo began his professional life as an artist and journalist. In nearly sixty years of research he has produced a shelf of books the backbone of modern Leonardo scholarship. His most recent and spectacular achievement was the discovery of a previously unknown terracotta angel by Leonardo at San Gennaro near Vinci. The Angel's face is a self portrait of Leonardo himself.²

His Westwood living room was filled with antique furniture, an ornate marble fireplace, and a bookcase so large that the front windows of the house had to be removed to bring it into the house! Peering through the ornate grating of that bookcase, I spied a fortune in Renaissance first editions. Pedretti ushered me to the right, into his spacious, book lined office painted in water green with plaster filigree encircling the ceiling. The overhead light was very Leonardo: a geometric sphere design. In a corner stood an ornate scale, the only piece to survive from a 1952 exhibition. On top of a book case a renaissance bronze lamp sat with implements dangling on chains to service the wick.

We discussed his rare books collection, including early editions of Vitruvius. I mentioned I had bought a copy of Vitruvius' *Architecture* and he asked what edition, to which I innocently replied "Dover"—the celebrated budget publisher. This to the man who had (in multiple copies) some of the rarest editions of Vitruvius in existence. Saying it was time to "bring me up to date," he began, with the enthusiasm of a twenty-year old and not a whiff of condescension, to educate me about the various editions of Leonardo facsimiles. He showed me the Giunti facsimiles of the Codex Hammer which he had edited (the original had been purchased by Bill Gates for 30 million dollars). One funny thing that happened was when he was showing me a very rare, early printed book he accidentally tore the page and then rubbed the two pieces together as if they would miraculously heal. Then he brought out the Codex Hammer sixteen-page facsimile notebook from a massive brown leather Solander box, exclaiming in his wonderful, flamboyant Italian way: "Look at this! Magnificent!"

The manuscript, and many like it, had been admired centuries before, while Leonardo was still alive. Antonio de Beatis, who accompanied the Cardinal Luigi of Aragon on his visit to Leonardo's retirement chateau at Cloux, France on October 10, 1517, was astounded to see an "infinity of volumes" pertaining to machinery, hydraulics, anatomy, and of other fields of study.³

Leonardo's student and eventual heir, Francesco Melzi, held the collection together and worked towards publishing his book of paintings. Unfortunately, upon Melzi's death, his son Orazio saw little value in the old papers and their dispersion around the world began. Many came into the possession of the Spanish court sculptor and pupil of Michelangelo, Pompeo Leoni. He is responsible for mutilating a great deal of material in the course of creating thematic albums now known to the world as the codices of Leonardo.

In the intervening centuries, many of the codices would be bought and sold and if lucky deposited into libraries around the world by far seeing benefactors. Often named for their owners or the country where they finally came to rest, they bear names such as Codex Atlanticus (so named for its oceanic size); Codex Forster, named for John Forster, who in 1873, donated them to the Victoria and Albert Museum in London. In 1796 Napoleon looted the Ambrosian Library while in Milan, declaring "All men of genius ... are French."⁴

The legacy currently consists of over 7 000 pages of notes, some in fairly coherent notebooks much as Leonardo left them. Most of this legacy has been published twice

² Carlo Pedretti, "Un angelo di Leonardo giovane," in the Sunday Cultural Supplement of *Il Sole 24 Ore*, April 19, 1998, no. 106, p. 21.

³ Antonio de Beatis (1905) *Die Reise des Kardinals Luigi d' Aragona durch Deutschland, die Niederlande, Frankreich und Oberitalien, 1517–1518*. In: Pastor, Ludwig (ed) *Erläuterungen und Ergänzungen zu Janssens Geschichte des deutschen Volkes*, vol. 4. Herder, Freiburg.

⁴ Kate Steinitz, *Manuscripts of Leonardo da Vinci*, Los Angeles, Ward Ritchie Press, 1948, p. 12.

in facsimile form around the turn of the last two centuries. My first impression upon learning this was to marvel at the large quantity of material. But later, after study, I mourn how much has been lost. The addition of the two Madrid manuscripts, discovered in 1965, added by twenty percent to the known material. The most beautiful of which was also the most vulnerable.

On our way to visit Carlo's magnificent white stucco library, which is housed above his custom-built garage with its red tiled roof, we climbed up some exterior side steps leading to the door. Turning about, I looked up at the ceiling corners and behind me to gauge proportions and recognized Leonardo's proportions: a perfectly square floor plan and a Renaissance style pitched ceiling. Gratified that I had understood the geometry of Leonardo in practical application, Carlo told me that he had driven the contractor mad by insisting on geometrical proportions.

I asked for his comments on the Leonardo material I was working on for *Robot Evolution* (he loved the traced fragments and exclaimed that all the drawings should be done that way). I asked him to review the manuscript and he thanked me for making reference to his work. Plying me with gifts of offprints and books, he asked me to write a paper for his journal, *Achademia Leonardi Vinci*. The subsequent paper was reported in the press and led to my first BBC appearance on their *Tomorrow's Worlds* program.⁵



What can be said when the perfect pairing of teacher and pupil meets? The pupil assimilates the teacher's life experience, not only saving an enormous amount of trial and error, but time. One does not exactly absorb all his detailed knowledge, but perhaps more importantly, his "feel" for his subject. Meeting Carlo enabled me to leapfrog past the usual need for academic training in art history and immediately begin using my knowledge of mechanical design to reinterpret Leonardo's legacy.

Likewise, building on an ancient heritage, Leonardo's training and research provided him with the skills to construct automata, the term used in the Renaissance for robots. His own teacher, Andrea del Verrocchio (1435–1488), was known in Florence as the premier armorer of the second half of the fifteenth century, and some of Leonardo's early drawings reflect this aspect of Verrocchio's workshop activity. Verrocchio also designed and built an automaton clock in the "New Market" (destroyed and now replaced by unremarkable nineteenth-century architecture) which was regarded at the time as a beautiful and whimsical thing.⁶

Illegitimate, Leonardo had little if any contact with his mother and was sent to Verrocchio's bottega, a form of arts and crafts boarding school, as a teenager. Although details of Leonardo's and Verrocchio's interaction are undocumented, it is known that Verrocchio loved geometry just as well as art. From him, Leonardo learned drawing, geometry, grinding pigments, painting, sculpture, carpentry, and metal working. Even before Verrocchio's tutelage, the young Leonardo showed early promise in his fields. Commissioned to paint a circular panel, he collected snakes and other creepy crawlies and produced a Medusa so detailed and lifelike that it scared his neighbor. Knowing a good thing, his father Ser Piero sold it in the city for a tidy sum and gave a much more mundane shield painted with a heart pierced by an arrow for his peasant tenant.⁷

⁵ BBC, "Tomorrow's World." August 12, 1998, producer: Lucy Dudman.

⁶ Cf. C. P., "Leonardo's Robot," in *Achademia Leonardi Vinci*, X, 1997, pp. 273–274, quoting Vasari, III. 375, as first noted by Simona Cremante, who suggests a relation with Leonardo's later project for a bell ringer (Windsor, RL 12716 and 12688): "È anco di mano del medesimo [Verrocchio] il putto dell' oriuolo di Mercato Nuovo, che ha le braccia schiodate in modo che, alzandole, suona l'ore con un martello che tiene in mano: il che fu tenuto in que' tempi cosa molto bella e capricciosa."

⁷ Giorgio Vasari, *Lives of Seventy of the Most Eminent Painters, Sculptors and Architects* by Giorgio Vasari. Edited and Annotated in the Light of Recent Discoveries by E. H. and E. W. Blashfield and A. A. Hopkins. Vol. II. Charles Scribner's and Sons, New York, 1986, p. 377–379.



Fig. 1.1.
The Tower of Winds from the
1521 Como edition of *De*
Architectura by Vitruvius

Other practical skills developed during and after his apprenticeship with Verrocchio would have been profitably applied. In Milan, after 1482, he also came in contact with German craftsmen with expertise in armor construction. Using the knowledge he acquired from dissecting corpses, Leonardo built mechanical models of the muscles and joints. His numerous arm-like designs for ornithopters attest to his full understanding of the mechanics of human and animal bodies.

Leonardo's initial impetus to develop robot technology probably came from his exposure to ancient Greek texts as interpreted by the humanists. One example is the well-known account of the mechanical dove made by Archita of Taranto in the fourth century B.C. According to Aulus Gellius, it was made of wood on the basis of "certain mechanical principles," so that "the dove actually flew, so delicately balanced was it with weights, and propelled by a current of air enclosed and concealed within it."⁸ Indeed, this seems to be what Leonardo himself is said to have done while in Rome about 1515: "Forming a paste of a certain kind of wax, as he walked he shaped animals very thin and full of wind, and, by blowing into them, made them fly through the air, but when the wind ceased they fell to the ground."⁹

Something that should be kept in mind is that Leonardo had access to ancient texts and perhaps to oral traditions that are undocumented and unknown to us. As Reti writes regarding Leonardo's personal library listing of *Libro di Filone De Acque*, "This is a remarkable entry. The title can refer only to the *Pneumatics* of Philon of Byzantium, who is believed to have flourished about the end of the second century. It is surprising to find such an early trace of an Arabic text which became known to Western scholars only in our twentieth century."¹⁰

A compelling use of automation for political purposes occurred in ancient Roman times following the assassination of Julius Caesar. This has come down to us from the Roman historian Appian (A.D. 95?–A.D. 165?). A Latin translation by Petrus Candidus, private secretary to Pope Nicholas V, was published the year of Leonardo's birth in 1452 and therefore would have been available to him. Appian tells us that Marc Antony was to deliver the funeral oration for Caesar, with the goal of gaining popular support for punishing the conspirators. An unendurable anguish weighed upon the maddening crowd. The tension was at a fever pitch. The potentially dangerous mob was now struck with a vision of horror:

While they were in this temper and were already near to violence, somebody raised above the bier an image of Caesar himself made of wax. The body itself, as it lay on its back on the couch, could not be seen. The image was turned around and round by a mechanical device, showing the twenty three wounds in all parts of the body and on the face, that had been dealt to him so brutally. The people could no longer bear the pitiful sight presented to them [...]¹¹

Antony's use of this robotic simulacrum of Caesar was a success in stirring the crowd to action, producing one of the greatest civil war in history.

Although unlikely, it is even conceivable that fragments of ancient prototypes could have been unearthed during Leonardo's lifetime. One wonders, for example, why the Renaissance 1521 Como edition of *De Architectura* by Vitruvius the illustration of the Tower of Winds is festooned with automata when the building has been gutted for centuries (Fig. 1.1).¹² Nero's *Domus Aurea* (golden house)—which was built between A.D. 64 and A.D. 68 on real estate reclaimed from the fire that consumed the downtown of first-century Rome and later replaced by, among other things, the Coliseum—was accidentally discovered in 1480 when a tavern owner excavating for a cellar accidentally dug through to the ancient dwelling. Artists of the day, carrying torches and sketch-

⁸ Vasari, *Lives*, IV. 46.

⁹ *Attic Nights*, X. 12, viii.

¹⁰ Leonardo da Vinci: *The Madrid Codices*, vol. 3. Commentary p. 106, McGraw Hill, New York.

¹¹ Appian, *Roman History: The Civil Wars*, Book II 147, p. 499. New York, Macmillan Co.

¹² Vitruvius, *De Architectura*. F. XXIII verso, Bronx: Blom, 1968.

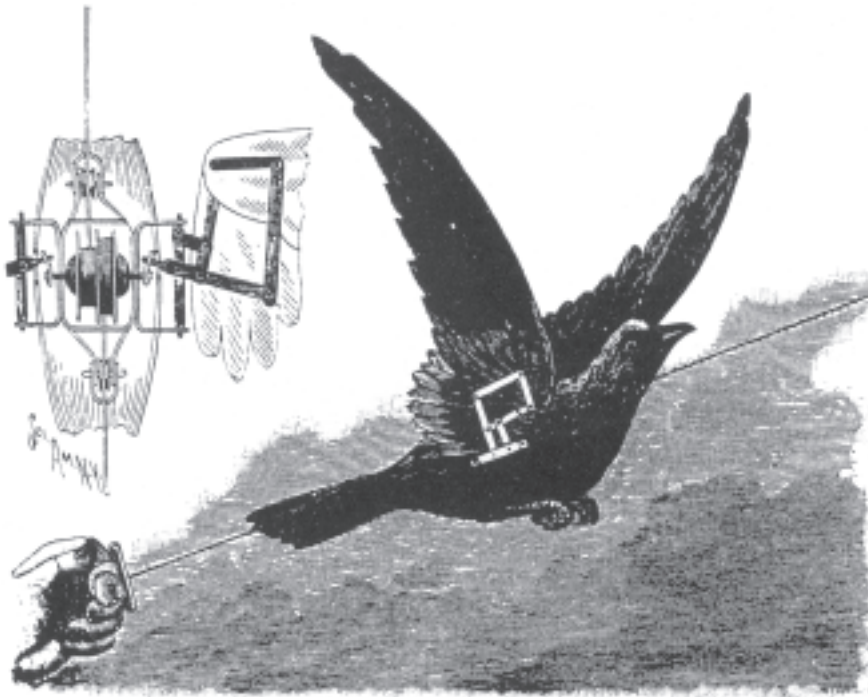


Fig. 1.2.
Leonardo's bird

books, made their way into the palace and copied the innumerable fresco paintings that covered the vaults, finding in them the source of inspiration for their decorations of palaces, chapels and villas. Raphael, master of the Vatican Stanze, was inspired by the buried frescoes and, along with Giovanni da Udine, launched a new artistic style. The *Domus*, which was buried in order to build the Baths of Titus, was built into the Oppian Hill and contained grottos and a dining room featuring a rotating ceiling that may have depicted the movements of the heavens. Leonardo was a young man at the time the *Domus* was discovered.

The Laocoön, discovered in 1506 in a grotto by the sea and identified by Michelangelo, which with its tortured, dramatic figures transformed the Renaissance conception of classical sculpture. Leonardo was working in Milan at this time.

About 1508, as he was staging a play at the residence of the French governor of Milan, Charles d' Amboise, Leonardo devised a mechanical bird that could flap its wings by means of a double crank mechanism as it descended along a cable (Figs. 1.2 and 1.3).¹³ A comparable device was sold as a toy in the late nineteenth century, and there is of course the antecedent of Villar de Honnecourt in the first half of the thirteenth century (Fig.1.3).

Another bit of evidence supporting the idea that Leonardo had not only the ambition but the knowledge needed to build automata is the Codex Huygens. Recently confirmed to be copies of several folios of lost Leonardo notes, the Codex Huygens is a late sixteenth-century manuscript based on Leonardo's lost original of about the same date (Fig. 1.4). Named for its owner, brother of the famous Christian Huygens, who was credited with the invention of the pendulum clock, the manuscript resides in the Pierpont Morgan Library in New York.¹⁴ It contains history's earliest kinesiology diagrams. As kinesiology deals with the range of motion and degrees of freedom of human joints, the knowledge of it is vital to the conception and generation of anthropomorphic robots.

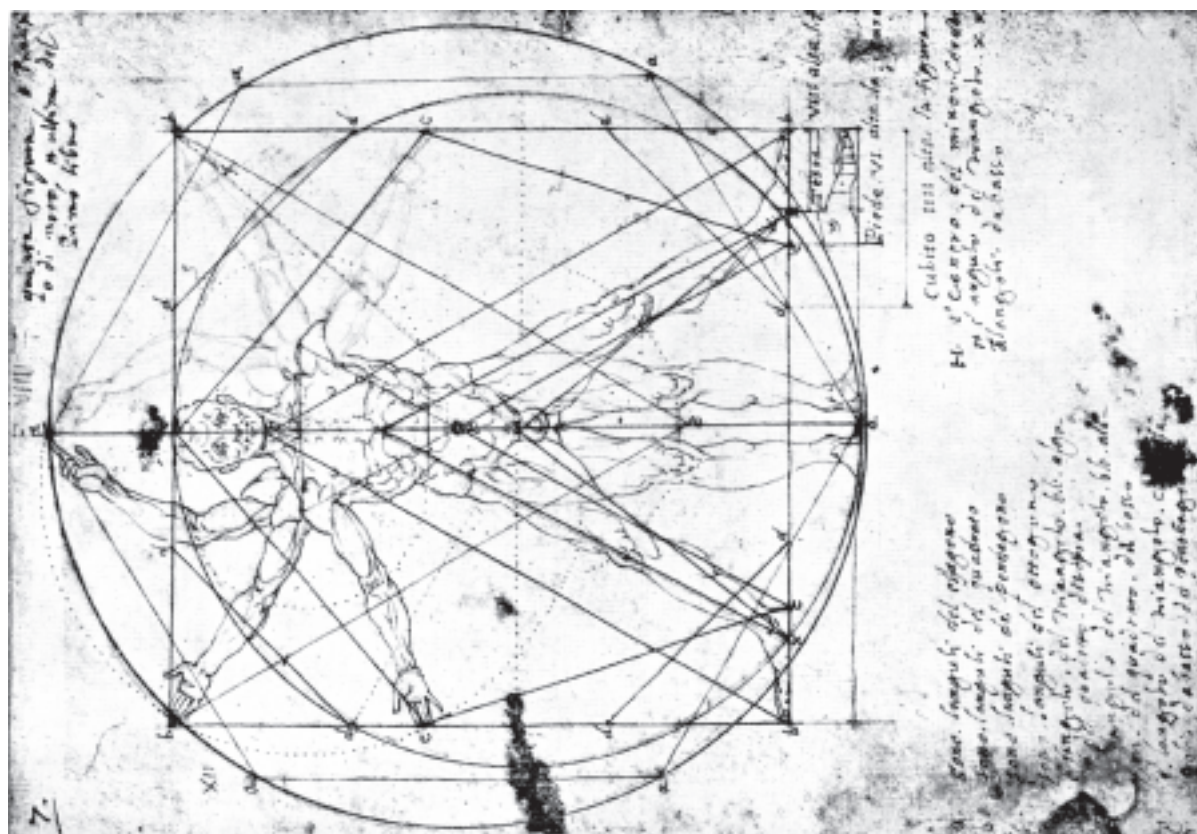


Fig. 1.3. Top: Leonardo, CA, f. 231 v-a. Bottom: Villar de Honnecourt, sketchbook, f. 58 r, Paris, National Library

¹³ CA, f. 630 v, [231 v-c], 1508, given in the Richter Commentary, note to §703 (with full bibliography).

¹⁴ Erwin Panofsky, *The Codex Huygens and Leonardo da Vinci's Art Theory*, London, The Warburg Institute, 1940.

Fig. 1.4. ▶
Codex Huygens, f. 7 and 29

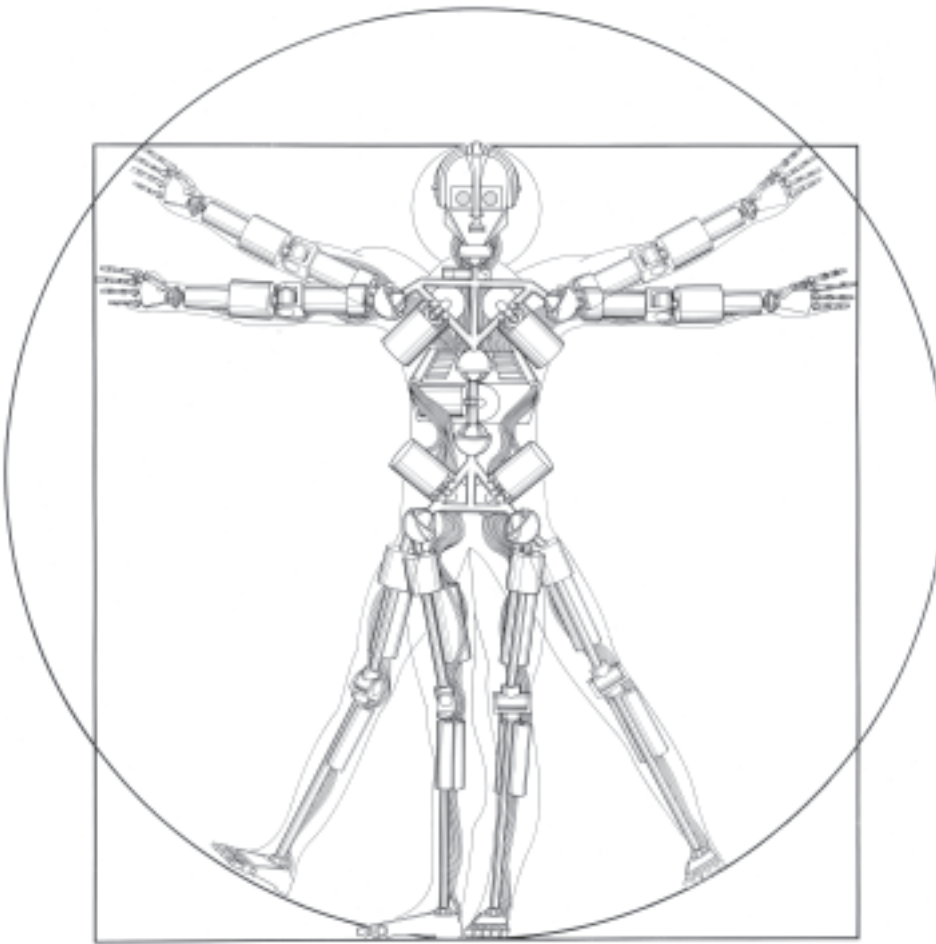


Leonardo's kinesiology diagrams not only provided him with ready reference for his art but also would have enabled him to determine at a glance the range of human limb motion. I know this from my own experience as a designer of robotic joints—much of my early work in joint technology was guided by reproductions of Leonardo's drawings in this codex. Folios 7 and 29, for example, provide a good illustration of the range of motion for legs and arms in a way that is very useful in the design of automatons.

My first design for an anthropot, which formed the cover art of my first book, *Robot Wrist Actuators*,¹⁵ was as much an exercise in art as mechanical design, was inspired by Leonardo's "Proportions of Man." This was based on the ancient Vitruvian canon of proportions (Fig. 1.5). I sought to depict the essential element of an anthropot by focusing on broad concepts of proportions and kinematics. I applied ball-and-socket joints throughout, but to my surprise, the resultant limbs did not fit the geometrical proportions of the circle and square seen in Leonardo's drawing; I had to "fudge" the limbs to make them fit. I learned two things from this. First, that Leonardo's drawings are very accurate, and may have been drawn with the aid of a *camera obscura* or other optical aid. Perhaps the model stood with his back to a white wall inscribed with a circle and square. Second, I learned that the human shoulder is far more complex than a simple ball and socket—the geometry suggested a compound joint. This would set my direction—study kinesiology to set goals for the robot's performance. And never, never, underestimate Leonardo da Vinci.

Fig. 1.5.

Proportions of Robot



¹⁵ Mark E. Rosheim, *Robot Wrist Actuators*, New York, Wiley, 1989. Dust Jacket illustration and p. 248–249.

One area, almost a subculture, which I entered through my interest in Leonardo is the world of rare books, their stores, and colorful dealers. I became so interested in it that I started taking night classes at the Minnesota Center for Book Arts in Renaissance bookbinding classes from a local master binder in order to produce my own vintage notebooks sewn on cords.

My addiction started innocently enough with the local bookstores in Minneapolis and Saint Paul, Minnesota. On the other hand, maybe it's something deeper than a simple addiction. I always find myself in the darkest recesses of antique and book stores on the most esoteric behind the scene tours. It seems I'm the last to leave or the only one in some obscure or unlikely exhibit.

Book stores were already familiar to me from years of searching for technical books in my robotics studies. As always, I began by raiding the local stores—Midway Books, Jim Lowry's, The Book House by the University of Minnesota, and later moved on to infiltrating surrounding areas. Constantly I consulted the bibliographies of my ever-growing collection to determine what the standard texts were. And I already had a long history of antique hunting and country auctions going back to my childhood in Tama, Iowa, where for a few dollars I could come home with baskets of silk-covered wire, Model T ignition coils and other wonderful turn of the century technical junk. I would also hunt with my father, who is a collector of rare Horatio Alger books.

Being a rare book addict has its own rhythm and rituals. Hunting down the book, the thrill of discovery and, in this era of the World Wide Web, the tension of ordering, making sure it is still available. Then the joy of receiving the book, with its strange foreign stamps and insurance markings from far away. Stealing off to my little office space nook. Unwrapping the parcel, unpacking the books from the padding—at last reaching the books themselves in their last layer of buff blue colored paper. All alone, delicately removing this sheath to reveal a lost fragment of the past in its impossibly impractical vellum binding. Behold, my new treasure: a piece of history intercepted by me in its travel through time. I have done this countless times, as I amassed my Leonardo manuscripts and facsimiles, down, at last, to the five volumes of the Codex Forster first edition, which nearly completes my collection.

One of my first rare books adventures took place in Berkeley, California, on Telegraph Avenue to the rare books room on the top floor of Moe's Books, then run by the legendary Moe himself. A tubercular man with long gray hair, he was beet red when I first saw him, yelling and screaming about an employee's unproductive behavior. He would be dead of a heart attack a few years later. My first set of Leonardo facsimiles was the Madrid Codices, which I had eyed in a dark hardwood cabinet with double glass doors at Moe's. I sold my Reagan era Stainless Steel Rolex Submariner watch to finance the \$300 acquisition and went home well pleased.

Another character in the world of book collecting is Jeremy Norman, the son of the major collector Haskel Norman, a New York psychiatrist who, having passed away to the big library in the sky, no doubt rolled in his grave when his collection was recently sold in three Christie's auctions. The first auction alone netted over six million dollars. Jeremy had an elegant downtown San Francisco suite of offices at 720 Market Street where stockbrokers and lawyers drop 100K on a single purchase. On my visits there I would get his employees in stitches with my impersonation of his nasal voice.

Once I met the French collector Michel Boviart at the Los Angeles book fair and purchased some of the French Leonardo facsimiles from him. When I asked what he liked the most about collecting, he said it was exploring attics of old French estates and finding rare incunabula (books printed before 1500) forgotten there by owners centuries before.

One of the palaces of rare book collecting is the vast and formidable Strand bookstore, named after the famous publishers' street in London. Located at Broadway and Twelfth Street in New York, it boasts five floors and acres of books in addition to its own side entrance rare bookstore, where I picked up a set of turn of the nineteenth-century Leonardo volumes with tipped-in reproductions of his horse drawings.

Passing through the narrow, alley-like streets of Florence, I found Gonnelli, located near the Duomo on Via de' Servi. The bay window is filled with literary treasures flaunting their engraved plates, the artists challenging the centuries. In contrast are the employees, whose perpetual frowns no amount of purchase—even a six-million dollar sale—can reverse into a smile. One employee, thinking that I would not want a broken set, mentioned in passing that they had two volumes from separate sets of Leonardo's Codex Arundel. The employee, surprised that I was interested in such sorry remnants, headed off to the warehouse to locate them. To cut costs I became a connoisseur of the broken set, having faith that someday it will be made whole once more.

One interesting phenomenon of the rare book world is that, notwithstanding the value of the objects, dealers are willing to accept checks from anyplace in the world. In the case of the Codex Arundel, my fractured credit card was not up to the job, but by dropping a few well placed names I walked out with the broken set on the strength of my promises to send a check. I guess they figured they knew how to find me. Another learning experience occurred when the State of Minnesota sent me a bill for unpaid customs duties—they too knew how to find me!

Once, in the pre-Web days of Christie's, I stayed up until four in the morning to purchase my first set of the Codex Atlanticus. I had received the notice via "Lot Finder" only a few days previously. I fell asleep by the phone and was woken up by the London auctioneer's call. As the adrenaline pumped through my sleepy head, the hammer went down at only \$1 200, and I heard the female auction house representative saying in a firm British voice, "you own it." I wasn't too upset with the price because new copies can retail for over \$40 000. Carlo commented that it was meant to be. After purchasing a "mint in box" set I later sold them on eBay to a person who thought he had an original Leonardo painting that he purchased in a flea market. I hope he's right about the painting.

As I amassed my army of facsimiles, storage became a problem. The Codex Atlanticus alone weighed several hundred pounds and took a cubic yard of space. I bought two armoires from Pier One Imports and painted them to resemble school cabinets. I subsequently painted Leonardo's Knight on the wooden panes of one and his lion on the wooden panels of the other.

One day in 1999, Jeremy Norman's rare book catalog "Classics of Science and Medicine" arrived in my mailbox. With my usual sense of anticipation I thumbed through the catalogue, looking for facsimiles of Leonardo manuscripts, and noticed a first edition of *De Motu Animalium* by Giovanni Alfonso Borelli, a seventeenth-century mathematician, a follower of the great Galileo. The catalogue showed one of his leg diagrams, which I immediately recognized as the same as one in Leonardo's Madrid Manuscript I. Not possessing \$7 500 to purchase the first edition, I located a cheap reprint in English with reproductions and commentary. As I was studying the Borelli reproduction, the staggering thought occurred to me that I was not simply looking at drawings that reflected Leonardo's interests and style: *I was looking at the missing section from Madrid MS I*. Could I have located the missing material that had eluded professional scholars for decades? Strangely, the facsimile plates were almost exactly the same size as the Madrid MS I—so you could slip them into the red leather bound facsimile as if they belonged there.



Giovanni Alfonso Borelli was an important mathematician of his time who became interested, as did Leonardo before him, in modeling the movements of animals. Born in Naples on 28 January 1608, he was the son of a Spanish infantryman and his Italian wife. In 1635, through Castelli's recommendation, Borelli obtained the public lectureship in mathematics in Messina, Sicily, then ruled by Spain. In 1658 he accepted the chair of mathematics at Pisa. Malpighi is credited with sparking Borelli's interest in the movements of living creatures. Around 1675, Borelli created *De motu animalium*

in hopes of being received and accepted into the Academie Royale de Science, which had been newly established by Louis XIV in Paris.¹⁶

The similarities between the work of Borelli and Leonardo have not gone unnoticed by modern researchers. V. P. Zubov makes the general conclusion that Borelli over simplifies.¹⁷ This may be true in some cases but in many other cases he is now viewed as being highly advanced for his time, anticipating technology that did not occur until well into the twentieth century.¹⁸ Zubov also criticizes either the absence or incorrectness of Leonardo's theories of flight. And yet, as shown by Madrid MS I, Leonardo's theories were adequate to design in 1495 a hang-glider capable of lifting a man. This has been proven through modern reconstructions.¹⁹

Only a very few of the scholars who have dealt with Leonardo's scientific and technological endeavors have called attention to Borelli's work for possible reflections of Leonardo's ideas. None has ever raised the question whether such ideas could have reached Borelli directly or through the mediation of those who had access to Leonardo's manuscripts following his death in 1519.

Those manuscripts were brought back to Italy from France by Francesco Melzi after Leonardo's death. Other books, of course, could have already circulated when Leonardo was still alive, and there is evidence that an autograph manuscript on the movements of the human body analyzed geometrically—a subject extensively treated by

¹⁶The best account of Borelli's work, in particular his innovative studies on the flight of birds, is still the one in Giuseppe Boffito, *Il Volo in Italia*, Florence, 1921, pp. 137–142 (with full bibliography). For a comparable account, see Galileo Venturini, S. J., *Da Icaro a Mongolfier*, Rome, Parte Prima, 1928, pp. 243–245, which concludes with a reference to Leonardo: “Nella pare che riguarda il volo, chi volesse fare un accurato confronto, troverebbe le stesse linee maestre, tracciate da Leonardo da Vinci: con questa differenza pero', che mentre Leonardo ci da' (ne' poteva essere altrimenti) un ingegnoso trattatello, dove non se sa se piu' ammirare la intuizione o la succosa brevità del poderoso autodidatta, il Borelli, che ha potuto far tesoro delle osservazioni sagaci di tanti predecessori, e che in quella materia se sente appieno in casa sua, ci presenta un completo trattato scientifico.”

See also the preface to Paul Maquet's English edition of Borelli's *De motu animalium* (*On the Movement of Animals*), Berlin, 1989, pp. v–ix.

Borelli was one of Galileo's most prominent followers, not only as a member of the celebrated Accademia dell Cimento in Florence and as a friend and a colleague of Evangelista Torricelli, but above all as a pupil of Benedetto Castelli, whose treatise *Della misura dell'acque correnti* (1628) was at one time believed to have been based in part on Leonardo's writings on the subject. Cf. Filippo Arredi, “Intorno al trattato ‘Della misura dell’ acque correnti’ di Benedetto Castelli”, in *Annali dei Lavori Pubblici*, 1933, fasc. 2, pp. 1–24, and *L'idraulica di Galileo e della sua scuola*, Rome, 1942, in particular p. 16. Borelli's writings on hydraulics are included in the *Raccolta d'autori italiani che trattano del moto delle acque*, Bologna, 1822, vol. III, pp. 289–336. One of his treatises, a report on the Pisa and Livorno swamps (“Stagno di Pisa”), is yet to be examined in connection with Leonardo's previous studies on the subject. Cf. Siro Taviani, *Il moto umano in Lionardo da Vinci*, Florence, 1942, pp. I–LXIV, in particular p. VI for the reference to Leonardo as having recognized before Borelli the general physiological laws of the muscular system.

¹⁷V. P. Zubov, *Leonardo da Vinci*, Cambridge, Mass., Tr. David H. Kraus, 1968, pp. 184–185. A comparable, modern assessment of Borelli's work comes from Clifford A. Truesdell, the author of a perceptive and well informed essay on “The mechanics of Leonardo da Vinci,” in his *Essays in the History of Mechanics*, New York, Springer-Verlag, 1968, pp. 324–325: “In the seventeenth century, statics was a well developed subject, and it was applied in a way then acceptable to many persons in many cases where any modern engineer would require laws of motion, then unknown. For example, we may cite Borelli's book, *On the Motion of Animals* (1685), where the parallelogram of forces seems to be the only quantitative basis for two volumes on the subject named, and where, despite the title, we look in vain for any laws of motion. I do not mean at all to ridicule the book; it is not only truly scientific but also ingenious in many places; I adduce it as an example to show the work both intelligent and extensive can be done on a wobbly foundation, and that the existence of serious literature in a domain, leading to some measure of success, does not necessarily imply that the structure is sound.”

¹⁸Paul Maquet, as cited in note 17 above.

¹⁹See Michael Pidock, “The Hang Glider,” in *Achademia Leonardi Vinci*, VI, Firenze, Giunti, 1993, pp. 222–225, with an editorial introductory note and reproductions, figures 1 and 2, of photographs of a first test flight of the reconstructed hang glider (Sussex Downs, England, 20 October 1993). A version more faithful to Leonardo's drawings has recently been built at Sigillo in Umbria by a local association of hang glider pilots. See Carlo Pedretti, *Leonardo. The Machines*, Firenze, Giunti, 1999, p. 29.



Fig. 1.6.
Borelli's table XIII, fig. 8

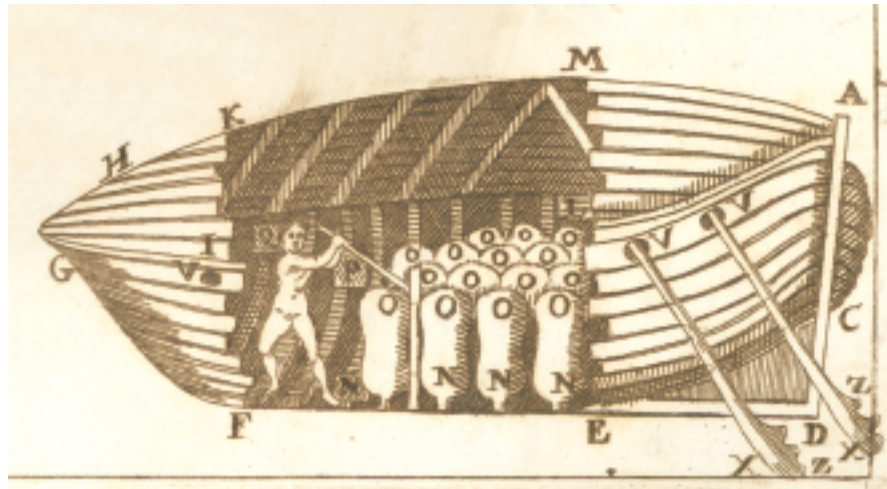
Borelli—was seen by Federico Zuccaro either in Rome or in Turin at the end of the sixteenth century.²⁰ And since a mechanical lion made for Francis I is now confirmed to have been a Medici commission on which Leonardo worked, either in Florence or in Rome about 1515, he very well may have gathered all the pertinent information in a book left to his patrons and then lost, as was the case with a book of unspecified contents given to Battista dell' Aquila, steward-in-waiting to the Pope—"cameriere segreto del Papa."²¹ Leonardo's invention of diver devices and his studies for the submarine were shown by Mario Baratta in 1903 as part of a vast historical context that includes Borelli's comparable studies.²² Indeed, the diver devices shown in fig. 8 from table XIII seem to be lifted directly from Leonardo (Fig. 1.6). Borelli might be the source of

²⁰ Federico Zuccari's account of the lost Leonardo manuscript of the Codex Huygens type of kinesiology studies is given in his *Idea*, Turin, 1607, p. 31, as fully discussed and reproduced in Leonardo da Vinci, *Libro di pittura. Edizione in facsimile del Codice Urbinatense lat. 1270 nella Biblioteca Apostolica Vaticana a cura di Carlo Pedretti. Trascrizione critica di Carlo Vecce*, Florence, Giunti, 1995, pp. 42–43.

²¹ Leonardo's memorandum in CA, f. 780 r [287 r-a], c. 1514–1515, used to be quoted, as Richter does, §7A, with the addition of the words "de vocie" (On Acoustics) taken to be the title of Leonardo's book, when they are, instead, Leonardo's "label" to an adjacent diagram. This is explained by Carlo Pedretti in his *Commentary to the Richter anthology* (Oxford, Phaidon 1977), vol. I, p. 107.

²² Mario Baratta, *Curiosità Vinciane*, Turin, 1905, pp. 179–184. See also Francesco Savorgnan di Brazzà, *Da Leonardo a Marconi. Invenzioni e scoperte italiane*, Milan, 1941, pp. 78–79, for the mention of Borelli's project of a submarine as well.

Fig. 1.7.
Borelli's table XIII, fig. 9



other lost Leonardo drawings. The summary of Madrid MS I discusses how to salvage sunken ships; pages which are now missing may have been discussed and illustrated in folios 37–42 and 55 and 56. It is interesting that Borelli's illustration 9 from table XIII (Fig. 1.7) seems to illustrate with its leather floats and boarded-up hull just that, albeit with some oars placed through openings.

Borelli's studies on the flight of birds were first mentioned by Gustavo Uzielli in 1884 in connection with Leonardo's Codex on the Flight of Birds, in particular for a note on f. 7 r (and again on f. 10 r), in which Leonardo, long before Borelli, formulated the theory that the wind acts as a wedge in lifting the bird: "il vento fa ofitio di cuneo."²³ Scholars such as Giuseppe Boffito in 1919 and Raffaele Giacomelli in 1935 systematically approached Leonardo's and Borelli's studies on the flight of birds on a comparative basis, and this is also the subject of a paper published by G. Pezzi in 1972.²⁴

It is indeed surprising that recent scholars such as Martin Kemp (1982), Kenneth Keele (1983) and Kim H. Veltman (1986), who have greatly contributed to place Leonardo's scientific studies in their historical context, make no reference to Borelli. However, in the Keele-Pedretti edition of the Corpus of Leonardo's Anatomical Studies at Windsor

²³ Gustavo Uzielli, *Ricerche intorno a Leonardo da Vinci*. Rome, Serie seconda, 1884, p. 403.

²⁴ The importance and originality of Borelli's studies on the flight of birds were first recognized by E. J. Marey, *La machine animale*, Paris, Librairie Germer Baillière, Bibliothèque Scientifique Internationale, 1873, and again, in a context that includes Leonardo's comparable studies, in roman *Le vol des oiseaux*, Paris, 1890, pp. 234–235, a classic on the subject which is not recorded in Verga's *Bibliografia vinciana* (1931). See also Modestino Del Caizo, *Studi di Giovanni Alfonso Borelli sulla pressione atmosferica*, Naples, 1886, and, by the same author, *Giovanni Alfonso Borelli e la sua opera "De motu animalium"*, Naples, 1908. Raffaello Caverni, *Storia del metodo sperimentale in Italia*, Florence, 1891–1900, 6 vols., in particular vol. III, p. 402; Giuseppe Boffito, *Il volo in Italia*, cit. (as in note 11 above), pp. 137–142 (in comparison with Leonardo); Raffaele Giacomelli, *Gli scritti di Leonardo da Vinci sul volo*, Rome, 1935, pp. 206–207, and, by the same author, "Il De volatu di Borelli," in *L'Aeronautica*, XIV, fasc. 3, 1934, pp. 1–15. For the wedge theory in both Leonardo and Borelli, cf. G. B. De Toni, *Le piante e gli animali in Leonardo da Vinci*, Bologna, 1922, p. 137. In 1900 G. B. De Toni ("Osservazioni di Leonardo intorno ai fenomeni di capillarità," in *Frammenti Vinciani*, I–IV, Padua, 1900, pp. 53–61) had already mentioned Borelli in connection with Leonardo's experiments on capillarity. G. Pezzi, "La meccanica del volo nell'opera di Leonardo da Vinci e nel *De motu animalium* di Gian Alfonso Borelli," in *Minerva medica*, LXIII, 1972, pp. 2184–2188, and *Annali di medicina navale e coloniale*, LXXVI, 1971, pp. 2750–2782. And finally: Useful information on the life and work of Borelli is still to be found in Giammaria Mazzuchelli, *Gli scrittori d'Italia*, Brescia, Giambattista Bossini, 1762, vol. II, part III, pp. 1709–1714. See also Pietro Riccardi, *Biblioteca matematica italiana*, Modena, 1970, *sub voce*, and *Le opere dei discepoli di Galileo Galilei*. Volume Primo. *L'Accademia del Cimento*. Parte Prima, ed. Pietro Pagnini, Florence, Giunti, 1942, pp. 21–22.



Fig. 1.8.
Borelli's table V, fig. 11

(1980), Keele points out²⁵ that the complex mechanism of the woodpecker's tongue, on which Leonardo intended to write,²⁶ is first explained by Ulisse Aldrovandi and again by Lorenzo Bellini and by Borelli, who gives a beautiful illustration of it in plate V, fig. 11 (Fig. 1.8).²⁷ Finally, Leonardo's extensive and innovative studies on mechanics

²⁵ Kenneth D. Keele and Carlo Pedretti, 1979/80, *Corpus of the Anatomical Studies in the Collection of Her Majesty the Queen at Windsor Castle*, London and New York, Johnson Reprint Corporation (3 vols.), vol. I, p. 362. For other aspects of Borelli's biological studies in relation Leonardo's, see F. S. Bodenheimer, "Leonard de Vinci, biologiste", in *Léonard de Vinci et l'espérance scientifique aux XVIe siècle*, Paris, Presses Universitaires de France, 1953, pp. 172–188, in particular p. 175 (flight of birds), 179 (Leonardo's studies on animal locomotion as compared with Borelli's principles of "iatophysics", i.e. the application of physics to medicine), 182 (Leonardo as precursor of Malpighi, Redi and Borelli). Cf. in the same volume the "Rapport final" by Alexandre Koyré (p. 244).

²⁶ Cfr. Windsor, RL 19070 v: "scrivi la lingua del picchio." See also Windsor, RL 19115 r: "fa il moto della lingua del picchio."

²⁷ Cfr. Guglielmo Bilancioni, "Leonardo da Vinci e la lingua del picchio," in *Rivista di storia delle scienze mediche e naturali*, XVII, 1926, pp. 1–12. Bilancioni does not mention Borelli, but for the explanation of the mechanism of the woodpecker's tongue he gives full credit to Borelli's pupil Lorenzo Bellini. The illustration in pl. V, fig. 11 (Fig. 9) is not based on that given by Ulisse Aldrovandi, *Ornithologiae* ..., Bologna, 1599, p. 838. According to Carlo Pedretti (oral communication), the way the complex mechanism of the bird's tongue is shown in an overall view of the bird's head, as seen three quarters to the right from above, is well in keeping with the type and character of Leonardo's anatomical illustrations of c. 1510 (e.g. the sheet with studies of the palate, tongue and larynx, and hyoid bone, in Windsor, RL 19002 r (A. 3)).



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