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Leonardo and water: a brief historiography

Leonardo y el agua: una breve historiografía

Abstract | The aim of the paper is to draw an outline of historiography referred to Leonardo's studies on hydraulics. The philological approach has given way to a specific reconstruction of the sources (manuscripts and codices) and subjects studied and developed from the 17th century onwards which, however, is by no means exhaustive. In particular, the works of scholars such as Giambattista Venturi, Jean Paul Richter, Gerolamo Calvi, Pierre Duhem have been analysed, focusing on elements and topics they examined thoroughly, taking into consideration the different sources adopted as starting points.

The Treatise studied by Carusi and Favaro in 1923 and the Exhibition dedicated to Leonardo in Milano in 1939 are present as well as the many essays realized in the Thirties by Filippo Arconati and Carlo Zammattio which provided a basis for the studies in the Fifties. It was in this period that art historians started to understand the relationship between the scientific researches and the works of art made by Leonardo, paving the way for the interesting essays by Kenneth Clark, Ludwig Heydenreich and, above all, those written by Ernst Gombrich.

In the last decades there have been innumerable publications dedicated to Leonardo da Vinci, but very few referred to the specific and technical field of hydraulics, as the new critical edition of *Del moto et misura dell'acqua*.

Keywords | Leonardo da Vinci, Hydraulics, Historiography.

Resumen | El objetivo del artículo es dibujar un resumen de la historiografía referida a los estudios de Leonardo sobre hidráulica. El enfoque filológico ha dado paso a una reconstrucción específica de las fuentes (manuscritos y códices) y temas estudiados y desarrollados a partir del siglo XVII que, sin embargo, de ninguna manera es exhaustiva. En particular, se han analizado los trabajos de académicos como Giambattista Venturi, Jean Paul Richter, Gerolamo Calvi, Pierre Duhem, centrándose en elementos y temas que examinaron a fondo, teniendo en cuenta las diferentes fuentes adoptadas como puntos de partida. El Tratado estudiado por Carusi y Favaro en 1923 y la Exposición dedicada a Leonardo en Milán en 1939 están presentes, así como los numerosos ensayos realizados en los años

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treinta por Filippo Arconati y Carlo Zammattio que proporcionaron una base para los estudios en los años cincuenta. Fue en este periodo que los historiadores del arte comenzaron a comprender la relación entre las investigaciones científicas y las obras de arte realizadas por Leonardo, allanando el camino para los interesantes ensayos de Kenneth Clark, Ludwig Heydenreich y, sobre todo, los escritos por Ernst Gombrich. En las últimas décadas ha habido innumerables publicaciones dedicadas a Leonardo da Vinci, pero muy pocas se refirieron al campo específico y técnico de la hidráulica, como la nueva edición crítica de *Del moto et misura dell'acqua*.

Palabras clave | Leonardo da Vinci, Hydraulics, Historiography.

Introducción

ABOVE ALL ELSE, Leonardo declared himself an expert in the science of water, a science that, at a theoretical level, began with the work of Sextus Julius Frontinus in his book *De Aquaeductibus Urbis Romae*.

In Leonardo's well-known presentation of himself to Ludovico il Moro in around 1482, he tells us: "satisfying very well, in comparison with all others... conducting the waters from one place to another /satisfare benissimo, a paragone de omni altro.... in conducere aque da uno loco ad un altro" (C.A. f. 1082 r, ex 391 r-a).

Indeed, in October 1517, Leonardo gave a presentation to the Cardinal of Aragon and his secretary De Beatis "De la natura de l'acque, de diverse machine et altre cose....quali si vengono in luce saranno profigui et molto delectevolj" [*Itinerario di Mons. R.mo il Card. de Aragona mio S.or Incominciato da la Cita di Ferrara nel anno del Salvador MDXVII del mese di Maggio et descritto per me Do no Antonio de Beatis Clerico Melfitano con ogni possibile diligentia et Fede*, Biblioteca Nazionale di Napoli, Ms. X.F.28, f. 76 v.].¹

Both Vasari and Anonimo Gaddiano testify to Leonardo's expertise on these topics. Most of all, from 1635 Don G. Ambrogio Mazzenta says:

How much Leonardo meditated on that heroic deed, one may obtain from his books full of wondrous remarks, with drawings expressing on the nature, weight, motion and speed of water, and about various machines to regulate it, and useful also for many other faculties and arts / Quanto meditasse Leonardo in quell'eroica fattione, si può cavar da libri suoi pieni di bellissime consideratione, con disegni espressi circa la natura, peso, moto e giri dell'acqua, e circa varie macchine per regolarle, ed utili anche per molt'altre facultà ed arti".²

¹ This phrase has been quoted by Uzielli in 1884 (460-461), by Müller-Walde in 1898 (262) and by Von Pastor who reproduced completely the manuscript in 1905 (IV:79-80, 143).

² *Le memorie su Leonardo da Vinci*. 1919: 31.

Maps and drawings on the theme of hydraulics collected by Count Galeazzo Arconati were organized by his son Fra Luigi Maria Arconati, who selected what he considered the most important, in the treatise he entitled *Del moto et misura dell'acqua*. Arconati organized his papers into nine books.

What manuscripts were used?

Certainly those owned by Arconati,³ which would be transferred to the Biblioteca Ambrosiana in 1637, then taken by the French in 1796, of which only the Codex Atlanticus has been returned.

Arconati did not examine either the Codex Leicester or the Codex Arundel, but he certainly saw other texts that have since been dispersed.

Arconati's definitive work is in two codices: The Codex Vatican Barberinaiano Latino 4332 (*Del Moto et misura dell'acqua di Leonardo da Vinci da diversi suoi manoscritti. Nove libri raccolti e ordinati da F. Luigi Maria Arconati*, 1643), and a copy of the first edition at the National Library of Naples (XII.D.80 -2); other copies were also made for Cardinal Barberini.

The manuscript was almost forgotten, until Giambattista Venturi studied Leonardo's Parisian manuscripts on waterworks and reviewed the text Arconati had ordered.

In fact, in addition to studying theology, Don G. Venturi also studied logic, mathematics and physics. He began lecturing at the University of Modena first in logic, then in experimental physics, before being involved in water works construction for his city between 1783 and 1788. In October 1796, he was sent to Paris as Embassy Secretary for diplomatic relations with the Executive Directorate.⁴

At that time, Napoleon ordered the Biblioteca Ambrosiana's manuscripts to be brought to Paris (25 November, 1796), and there Venturi studied the manuscripts from A to N, until October 1797, and then, at the end of 1797, he published his *Essai sur les ouvrages physico-matématique de Leonard de Vinci*, in French for presentation to the Institut de France.

For the first time, a number of excerpts from Leonardo codices were presented, in a work that was defined as "the first engine of Vincian studies". The focus was on two hydraulics issues: water issuing from a channel and water turnstiles. Ms. F shows ways in which a quantity of water flows out of a defined-

3 Professor Di Teodoro states that 11 manuscripts owned by Galeazzo Arconati between 1615 and 1632 were used by his son to compose *Del Moto et Misura dell'Acqua*: Codex Atlanticus, Ms. B, Ms. A, the Codex Trivulzianus and Ms. E, F, G, H, I, L and M. Di Teodoro, F.P. 2009. «Per una nuova edizione dell'apografo vinciano *Del moto et misura dell'acqua*» In *Saggi di Letteratura Architettonica da Vitruvio a Winckelmann*. Firenze: L. Olschki, vol. I: 177-189.

4 Bernardi, W., Manzini, P., Marcuccio R. (eds.) 2005. *Giambattista Venturi. Scienziato, ingegnere, intellettuale fra età dei Lumi e classicismo*. Firenze: Olschki.

opening channel. The fourteen reasons Leonardo adduced were a highly original contribution to water management.

However, the essay became so rare that in 1924 G. Battista de Toni reproduced it, adding a section on Leonardo's life and works.

Returning to the Arconati manuscript, this reappeared in Italy in 1826, when Francesco Cardinali produced his Collection of Italian authors on the motion of waters (*Raccolta di autori italiani che trattano il moto delle acque*), adding this text in to Volume X. However, the copy used makes no reference either to Leonardo's manuscripts or to Arconati's original, and is therefore considered an incorrect version. The Barberini manuscript reappeared in correct form, with the usual quotations in the Ms. in E. Carusi and A. Favaro's 1923 text.

The so-called Codex Leicester is a second invaluable source for studying Leonardo's hydraulics. This codex, consisting of 36 folios, or rather 18x4-page sheets, is not part of the group of manuscripts left to Francesco Melzi, either because it was lent (to M. A. della Torre) or for other reasons (Vasari).

Cristoforo Solari, known as il Gobbo, a contemporary of Leonardo's who worked with him as a consultant on a number of Sforza castles, came into possession of it. He left it to his pupil Gio Tomaso (or Jacopo) della Porta. From him it went to his nephew Guglielmo della Porta, a sculptor in the service of Paul III, who lived in Rome between 1537 and 1577. It was found among his belongings by painter Giuseppe Ghezzi in 1690, who titled it *Della natura peso e moto delle acque*, which he sold to Thomas Coke, Lord Leicester, during one of his stays in Rome between 1713 and 1717.

The codex was first studied by Richter and published in its entirety by Girolamo Calvi in 1909, the year of Lord Leicester's death.

As ms 699, in 1952 it was exhibited at the Royal Academy in London. Purchased in December 1980 by oil magnate Armand Hammer, it went on show in many cities, accompanied by an English-Italian critical edition published by Pedretti in 1987.

Bill Gates purchased the manuscript in November 1994.

Other relevant sources for studies on hydraulics are ms. A, E, F at the Library of the Institut de France,⁵ published by Charles Ravaisson Mollien since 1881, the Codex Arundel 263 at the British Museum, and of course the Codex Atlanticus.

⁵ In particular, in the manuscript E Leonardo refers to the idea to create a Treatise on water since 1490-1492; in the Ms. F, we find many studies of vortices, backslidings, waves and in general superficial and deep movements of water: Ravaisson Mollien 1881-1891.

In chronological order, the first treatment to be examined is that of Jean Paul Richter (1847-1937). After studying predominantly theology in Germany, he arrived in Italy and took an interest in early Christian art and archaeology. Meeting art historian Giovanni Morelli changed the direction of his career. Richter's first publication was about the mosaics in Ravenna (1878). In 1877, he moved from Leipzig to London in 1880, he published the *Dulwich College Gallery's catalogue of paintings*.

His greatest work came out in 1883: *The Literary Works of Leonardo* was a scientific analysis of Leonardo's texts, which prior to Richter had been practically unknown. He insisted on multilingual publication, with Italian and English versions, and then brought it out in German. In 1904, he published *The Golden Age of Classic Christian Art*. Later, with his daughter Irma, he edited a second edition of Leonardo's writings, which appeared posthumously.

He may not have been a scholar specialized in Leonardo's works, but his text is without doubt key to Leonardo studies.

Richter did not set a special section aside for hydraulics. In consequence, we must winnow these topics out from two sections of the second volume, Physical Geography and Topographical Notes, as well as the Introduction.

He does make some important clarifications in the Introduction:

- on both Leonardo's theoretical and practical approach;
- he says that some evaluations of the movement of water were collected in a manuscript by a "copyist", albeit without any knowledge of Leonardo's sources. The copy, in the Barberini Library in Rome, was published under the title *Del moto et misura dell'acqua* in Francesco Cardinali's Collection in 1828. Richter also proposes organization into 9 books like Arconati (without ever citing him).⁶

Richter explains to us that he was referring to general principles, and to those texts in which geographical names were present, excluding more the specific portions covered in the Codex Atlanticus (for example, the regulation of rivers).

From his Introduction⁷ we learn of the Treatise on Water from the Codex Leicester (15v), in which the treatise was divided into 15 books, a note at the top of the sheet, with a summary of the planned treatise in final form.

He also confirms the idea of the treatise present in ms F (an initial description of the motion of water, the seabed, and figures of water from waves large to

⁶ Richter 1883, 2, 173 (XVI Physical Geography).

⁷ Richter 1883, 2, 175-179.

small); after that, it goes on to analyze the themes found in the British Museum ms (Arundel 263):

- Br M 35 a /practical applications and relationships with places (a book on combatting the onrush of rivers so that cities are not affected)
- Br M 35 b /treatment of rivers
- Br M 122 a /rivers (straightening, division into branches, embankments)
- Br M 45 a /navigation (boats, shoals, waterfalls, obstacles to watercourses).

So, in the Introduction, Richter presents:

- some declarations of intent for the Treatise
- thematic or definitive lists (Leicester)
- sections on more detailed topics, without delving into the content.

In his first chapter, *The nature of water, delle acque in se*,⁸ he moves on to content with definitions of a general and theoretical nature, using phrases from ms A, C, E, F, and Leicester, starting with the well-known definitions of what water is and of the “pelago”. It analyzes earth-to-sea transformations, for example the height of water in relation to bare earth.

In chapter two: *On the Ocean*,⁹ the ms G (why water is salty, why the ocean does not penetrate the earth), the Leicester (flow and reflux) and the Codex Atlanticus (the Mediterranean made out of rivers flowing in, flow and reflux) are used.

In the third chapter, *Dei fiumi sotterranei (Of subterrean rivers)*,¹⁰ the Leicester, Br. M., ms G and A are used.

In the fourth chapter, *Dei fiumi (Of rivers)*,¹¹ again the Leicester and ms G. are used.

In practice, Richter follows the division of the Treatise:

Dell'acque in se /Della natura dell'acqua
Del mare /Dell'Oceano
Delle vene /Dei fiumi sotterranei
Dei fiumi /Dei fiumi

8 Richter 1883, 2, 180-187.

9 Richter 1883, 2, 188-195.

10 Richter 1883, 2, 196-199.

11 Richter 1883, 2, 200-204.

Leicester 15v	Richter
Book 1 Of water in itself	I Of the nature of water
Book 2 Of the sea	II On the Ocean
Book 3 Of subterrean rivers	III Subterrean water courses
Book 4 Of Rivers	IV Of rivers
Book 5 Of the nature of the abyss	
Book 6 Of the obstacles	
Book 7 Of gravels	
Book 8 Of the surface of water	
Book 9 Of the things placed in Topographical Notes	
Book 10 Of the repairing of rivers	
Book 11 Of the conduits	
Book 12 Of canals	
Book 13 Of the machines turned by water	
Book 14 Of raising water	
Book 15 Of matters worn away by water	

Source: Author.

So, what operation does Richter perform? He identifies how the Treatise in the Codex Leicester is broken down, and organizes the text for the general parts following this outline, using in particular the English Leicester and Arundel 263 manuscripts, and those from the Parisian Institute, in particular ms E and G, with a few quotations from the Codex Atlanticus.

In fact, as he says in the introduction, Leonardo's sentences are short and complete, but scattered across pages that deal with various topics. It had thus become necessary to restore unity among the various themes.

The most specific parts refer to the *Topographical Notes*.¹²

The main source used by Richter in 1883, the Codex Leicester, was published in full form in Italy a few years later by Gerolamo Calvi, who became one of Leonardo's greatest scholars, making a highly important contribution from a philological point of view.

Gerolamo Calvi, son of Girolamo Luigi who had published books on the Sforza architects, including *Leonardo and his disciples*, in 1898 published a critical edition of ms H from l'Institut de France (*Il manoscritto H di Leonardo da Vinci, il*

¹² Richter 1883, 2, 223-256.

Fiore di virtù e l'Acerba di Cecco d'Ascoli: contributo ad uno studio sulle fonti di Leonardo da Vinci. Milano: Favero e Confalonieri), in 1907 wrote *Leonardo da Vinci e il Conte di Ligny*, and in 1909 edited a critical edition of the Codex Leicester.

Calvi has one main objective in his long, analytical Introduction to the reproduction of the manuscript: given that there are no chronological references within it, to give the Leicester manuscript a date.

Although Richter, whom Calvi cites with meticulous documentation on several occasions, believed the codex to have been written between 1500 and 1516 (1510 being a possible date), Calvi would eventually believe that the Cod. Leicester was produced between 1503 and 1508, and most likely between 1505 and 1506.

But the chronological attribution becomes almost a pretext to go through the various phases of Leonardo's life, his manuscripts and the literature already specialized in his works.

First of all, he shifts the date after 1499, especially as a result of the reference to the inspection of problems at the Church of S. Francesco al Monte (1499) in Florence, realized after leaving Lombardy [The Po Valley, Lombard lakes and rivers, the Martesana Canal and Milan canals, are named without details, while transformation of the Arno Valley is described in greater detail, with accurate indications of place].

Leonardo's annotations on Romagna shift the beginning of the Leicester to at least 1503 but not beyond 1508, when in *De Anatomia* Leonardo completely altered his view of the relationship between water in the world and animal blood. [In practice, in the Codex Leicester he maintained a parallelism between the circulation of water in the world and blood in animals; in his *Anatomy*, on the other hand, he maintains that the sea receives all the rivers in itself, but the sea of blood is the cause of all veins].

Therefore, between 1503 and 1508, he twice stayed in Florence, and Calvi is inclined to plump for the period 1505-6.

With regard to this period, Calvi proposes a very interesting comparison between various lists of topics in the Trattato delle acque, calling into play the Codex Atlanticus not mentioned by Richter (C.A. f. 201, 201v e 214 b, ex f. 74 r-a, 74 v-b, 79 r-a): Calvi considers this of the CA to be preparatory or at most in parallel to the Leicester and previous to the Br. M. (Arundel 263, 35 r/v, 45 r, 122 r: Richter 1883, 2, 176-178), begun in 1507 at Pietro and Braccio Martelli's house. He quoted also another list: that of the Ms. F 23v-24 r/v.

Calvi therefore introduces a very important piece of information about the early drafting stages of the Treatise, referring to the C.A. and ms F, which Richter did not mention.

In his introduction, then, for purely philological reasons Calvi also dwells on the sources of Leonardo's Treatise: Ptolemy's *Cosmography* of 1482, and also the "*Metaura* of Aristotle, Pliny, Albert the Great and Albert of Saxony".

This chronological approach, evaluated here for the purpose of coming up with a chronological definition of the Codex Leicester, was to become a distinctive feature of Calvi's studies of Leonardo da Vinci. In 1925, he published the seminal *I manoscritti di Leonardo da Vinci dal punto di vista cronologico, storico e biografico*, clearly departing from the thematic approach Richter used.

Around this same time, between 1906 and 1913, scientist and historian Pierre Duhem (1861-1916), a Professor in Bordeaux, investigated the historical sources of Leonardo's scientific thought in a three-volume work entitled *Études sur Leonardo da Vinci*, with particular reference to Albert of Saxony, Bernardino Baldi, and Nicola Cusano, all the way up to Duns Scotus. These are above all references to geological dynamics and situations, but Duhem's is nonetheless an important study, as it is scientific rather than generically historical. So much so that as early as 1917, an essay appeared by Henry Lemonnier, *Les Études de Pierre Duhem sur Leonardo da Vinci*.¹³

Also in the first decade of the twentieth century, Luca Beltrami produced his first report on Leonardo studies: *Bibliografia vinciana 1885-1919* (Roma 1919), which included his two texts directly related to hydraulics, both written in 1902: *Leonardo da Vinci negli studi per rendere navigabile l'Adda e Leonardo da Vinci e il porto di Cesenatico*.

We come now to 1923, when Carusi and Favaro¹⁴ published the Ms Arconati organized into nine books, entitled: *Del Moto et misura dell'acqua*.

Libro I	Definizioni – Del moto naturale – Del flusso e reflusso
Libro II	Moto dell'acqua
Libro III	Onde, pressione verso oggetti
Libro IV	Retroso
Libro V	Acqua cadente
Libro VI	Acqua dirompente
Libro VII	Fiumi
Libro VIII	Peso dell'acqua
Libro IX	Dei mulini

So that, we can now compare the Treatise organization proposed in the Leicester with that originated by the Ms Arconati and adopted by Carusi and Favaro.

13 Lemonnier, H. 1917. «Les Études de Pierre Duhem sur Leonardo da Vinci», *Journal des Savants*, XV (March 1917, 120-132).

14 Favaro had already written before about Leonardo and hydraulics: Favaro, A. 1919. «Leonardo da Vinci e la scienza delle acque», *Emporium*, vol. 49, n. 293 (may 1919), 272-279.

Leicester 15v – from Richter –	Ms Arconati (Cod. Vat. Barberiniano 4332) – from Carusi/Favaro
Book 1 Of water in itself	Book 1 About water
Book 2 Of the sea	Book 2 The motion of waters
Book 3 Of subterrean rivers	Book 3 Waves
Book 4 Of Rivers	Book 4 Strikings of waters (back flow)
Book 5 Of the nature of the abyss	Book 5 Waterfalls
Book 6 Of the obstacles	Book 6 Powerful water
Book 7 Of gravels	Book 7 About things carried away by waters
Book 8 Of the surface of water	Book 8 The weight of water
Book 9 Of the things placed in away by waters	Book 9 Water mills
Book 10 Of the repairing of rivers	
Book 11 Of the conduits	
Book 12 Of canals	
Book 13 Of the machines turned by water	
Book 14 Of raising water	
Book 15 Of matters worn away by water	

Source: Author.

In May 1939, an exhibition dedicated to Leonardo opened at the Palazzo della Triennale.¹⁵

In the volume realized in 1939 for this exhibition, Carlo Zammattio addresses hydraulics and boating.¹⁶ The theme would be taken up again in 1939 by the same author in a more general text: *Leonardo da Vinci e l'idraulica del Rinascimento*¹⁷ and subsequently in an autonomous extract, nine pages long.

Zammattio would subsequently become known for his 1981 publication *Leonardo scienziato*, with Anna Maria Brizio, which came out in a number of languages.¹⁸

How does Zammattio handle Leonardo's hydraulics?

First of all, by making general reflections as valid then as they are now: that is, what had been handed down by his predecessors on this theme, and how

15 Iacobone (2017).

16 Zammattio C., 1939. «Idraulica e Nautica» In *Leonardo da Vinci*. Novara: Istituto Geografico de Agostini: 467-482.

17 Zammattio, C. 1939a. «Leonardo da Vinci e l'idraulica del Rinascimento», *Annali dei lavori Pubblici (ex Giornale del Genio Civile)*, vol. 17, 10, 1025-1034.

18 Zammattio, C., Marinoni, A., Brizio, A.M. 1981.

much was due to Leonardo's new developments. This is a very difficult question because of the complete paucity of texts on the subject circulating in Leonardo's period, and the enthusiasm for hydraulics in northern Italy from the second half of the 15th century onwards. This renders it almost impossible to establish what foundations, theoretical and practical, Leonardo could draw upon.

This led to the erroneous assignment to him of the invention of many artifacts, information still passed on to tourists today, but these are my own thoughts.

Zammattio also dwelt on the difficulty of chronologically classifying Leonardo's various works based on examining the codices. If Leonardo's hydraulics expertise derived essentially from intuition and experimentation, Zammattio assesses Leonardo's theoretical activity in the 903 cases listed in Leicester, writing of which was attributed to 1505-6, and considers the manuscripts preserved in France as preparatory to the Codex Leicester.

Leonardo's tangible work in the field of hydraulics is inferred from the Codex Atlanticus, to which Zammattio refers and from which he draws many of the images for his essay.

According to Zammattio, Leonardo's role was responsibility for maintaining the efficiency of waterways, after examining

- the numerous drawings of basins and watercourses, including improvements to various elements
- the navigable canal between Florence and the sea (1502-1504)
- reclamation of the Pontine Marshes (Windsor)

Other topics addressed are:

- application of the laws of fluids motion to ships
- ships' defences and armour
- human activity underwater
- Pascal proto-law
- wave motion
- vortices (Arundel)

As noted, this topic that largely referred to concrete places is flanked by images from the Codex Atlanticus, plus some from the Parisian manuscripts F, L, E, and three images from the Codex Forster. No images come from the Codex Leicester.

So, the exhibition's contribution in terms of hydraulics is more associated with concrete cases in central and northern Italy.

If this is what emerges from the volume on the exhibition, I have recently found completely new material on the preparation of the exhibition itself, including some very interesting items both generally and related to hydraulics.

At a preliminary meeting on April 19, 1938, the Scientific Committee was defined, headquarters were chosen in Milan at the Palazzo della Triennale, Prof. Filippo Arredi was proposed as a specialist in hydraulics¹⁹ (In fact in 1932 he had written *Avviamento alla critica del trattato "Del moto e misura dell'acqua" di Leonardo da Vinci*),²⁰ only to subsequently be replaced by Carlo Zammattio, and mention was made of the need to assemble a reasoned catalogue.

More interesting are the *Appunti sull'organizzazione delle sezioni scientifiche*, which contain important if contradictory statements: it is stated that in mechanics, hydraulics and optics we may with sufficient certainty recognize Leonardo's precursors and realize the exact contribution Leonardo himself made, but immediately afterwards it is claimed that in reality for machines, hydraulic constructions and practical applications it is difficult to separate out what are modifications of already existing things, especially because medieval input is little known, making it is hard to assign to Leonardo or others the invention of many machines and instruments (this is what emerges also from Zammattio's text).

It is highlighted that we should underscore Leonardo's importance as a precursor of the experimental method later canonized by Galileo and that, methodologically, each discipline should express the following:

- a) the principles, demonstrations, conceptions and results that Leonardo achieves through experiments
- b) the methods used by Leonardo and the control and measuring instruments used in these experiments
- c) the results of Leonardo's experiments
- d) the applications and practical achievements of the results achieved.

All of this using the drawings, some of which are reproduced, and models. The Hydraulics section envisaged the following divisions:

- a) water measurement and motion
- b) driving and operating machines
- c) machines for hydraulic works
- d) river hydraulics

19 Iacobone 2017: 11.

20 Arredi, F. 1932.

- e) reclamations
- f) port, maritime, and naval construction.

One highly interesting aspect is the comparison between the images presented in the essay by Zammattio in the volume of 1939 and those included in the long preparatory list (of 262 items).²¹ In the essay, all of the general-theoretical portion on hydrostatics, vortices and veins is synthesized in only two images (study for liquid trickles in veins, n. 13-102), while studies on the motion of water and the solid-liquid ratio are not proposed.

Zammattio chooses images more closely linked to tangible cases, in particular basins and locks (nos. 128-129-130) and canal construction machines (122-123). We then move on to geographical areas such as the Arno and the Florence-Sea canal (225-227-233), and reclamation of the Pontine marshes (229). Another section concerns hydraulic structures and devices, such as hydraulic pumps (200), the diving suit (258), ship hulls (262), up to the augers (161) and hydraulic wheels (177-186) and ending with communicating vessels (5) and instruments (3).

The correspondence of the images in the text to specific tables in the preparatory list is evidence that the tables prepared were those that were presented in the exhibition, featuring a highly specific and detailed focus — from the general to the particular — on hydraulics-related themes.

Studies on Leonardo, including those on his hydraulics, began again in the '50s with important contributions.

Anna Maria Brizio (1902-1982), an Italian art historian, Professor in Turin and Milan, and later President of the Ente Raccolta Vinciana, whom we mentioned earlier, published the *Primo Libro delle Acque*.²² This was reissued in 1954 as *Delle Acque*.

She examined the Codex Arundel, in particular foglios:

159 r/v; 160 r/v; 204 r/v; 205 r/v; 266 r/v; 267 r/v, not considered by Richter, in which the fundamental theme is that of water. In three of these foglios (159 v, 204 v and 266 r), we find the header First Book of Water, constituting the initial parts of a Treatise with an introduction in ff. 233 and 234 r/v.

The scholar follows the chronological thread proposed by Calvi, believing water-related sections to be from 1508, dwelling on Leonardo's classic characteristic of having sketched out several Treatises but then after outlining them moving on to other things.

21 The following numbers into brackets refer to the position of that item in the preparatory list.

22 Brizio, A.M. 1951. *Primo Libro delle acque*. Torino: Gheroni.

Two themes in particular emerge from these foglios: the weight of water (266v), and the relationship between water and veins (234v).

Albeit without specific details on hydraulics, this scholar made another important contribution with her Review of Vincian Studies from 1952 to 1968.

The early '50s saw essays by Carlo Pedretti, who wrote up studies on the hydraulic machine designed for Bernardo Rucellai (Pedretti 1954) and on the Codex of Benvenuto di Lorenzo della Golpaia (Pedretti 1957).

Around this time, further research was carried out on the relationship in Leonardo between art and science, in essays by Kenneth Clark, *Leonardo da Vinci. A note on the relation between his science and his art*,²³ by Heydenreich, *Leonardo da Vinci. Art and science in his drawings* (Heydenreich 1952) and in particular by Ernst Gombrich.

In fact, in his essay *The Form of Movement in Water and Air* (Gombrich 1976) he thinks that in Leonardo's studies the subject of movement in water and air recurs with greater persistence. He starts with a comparison between the visions of the Deluge-End of the World and a scientific study of the impact of water on water (Windsor, Royal Library, 12660v) to study the relationship between seeing and knowing or better between thought and perception. Leonardo started — like every human being — from the accumulated ideas of past generations but proceeding to check and criticizing ideas in the light of *sperientia*. In particular Gombrich quoted Ms. F as particularly rich in attempts to map the full range of possibilities of waves, currents or whirlpools. He refers also to the *History of Hydraulics* by Rouse and Ince²⁴ in which to Leonardo is credited with the formulation of the basic law which is now known as the principle of continuity. Also, there's a second general law that Leonardo applied in his discussion of movement: the law of reflection or rebound which he drew upon in Ms. A of 1492, and interesting are also his studies referred to the propagation of impulses. Gombrich ends his wonderful essay with another comparison: Leonardo and Michelangelo. Leonardo considered atmospheric effects as the glory of painting, while Michelangelo in the Sistine Ceiling didn't consider them preferring the rendering of the human body.

After the discovery of the two Madrid Codices I-II (CM I Ms. 8937, CM II Ms. 8936) in the Biblioteca Nacional de España (Madrid) in 1966 and their reproduction in 1973, knowledge about hydraulic systems has increased, especially thanks to

23 Clark, K. 1952. «Leonardo da Vinci. A note on the relation between his science and his art» *History Today*, vol.2, issue 5. See also Clark (1939).

24 Rose, H., Ince, S. 1957. *History of Hydraulics*. Iowa City: Iowa Institute of Hydraulic Research.

studies and essays by Enzo. O. Macagno, in particular to *La meccanica dei fluidi nei codici di Madrid* of 1982 and *Leonardo da Vinci: Engineer and Scientist* of 1987. He started to identify, to classify and evaluating the fluid mechanical drawings by Leonardo in all the documents available, beginning with the CM I and CM II published in 1982, recognizing more than 70 entries on 20 categories of flow-fluid topics, increased subsequently to the study of the Codex Atlanticus to about 60 categories.

The idea of Macagno is that Leonardo was more original in his work on fluid-flow than in other areas, especially because Leonardo didn't start his study of flow-mechanics with a basically good level of previous knowledge, as in other fields and so he could do most original work in that science. Furthermore, Macagno started to study Leonardo's writings with an original means of understanding: the laboratory method and examples realized simultaneously.

As we can understand studying Leonardo's works in any field, Macagno states that "it's not always easy to discern in Leonardo's notebooks whether a comment or a drawing refers to existing applications of hydraulic engineering or to his own ideas and plans for hydraulic devices, machines, canals, locks, dams and other structures".²⁵

In the field of Hydrostatics, Macagno referred to the CM I (123v) in which Leonardo recorded, under the sketch of a ship floating in quiet water: "As much weight of water leaves the place where a ship floats as the weight of the boat itself", believing that Leonardo reached that conclusion by experimentation, since he investigated the force on submerged bodies by means of a balance.

But, as Macagno says, Leonardo came closer to understanding pressure distribution than hydrostatic forces. Before Leonardo, continues Macagno, there was no knowledge of what we call now the conservation equations of fluid mechanics: Leonardo understood the postulation of conservation of volume and of mass. About concrete subjects of hydraulics, Macagno refers to jets and vortices as the most representative examples of Leonardo's work (in particular the so called da Vinci's vortex). So that, at the end of this analysis, Macagno states that — even if it's difficult to estimate the influence of a work which has yet to be fully researched — Leonardo possessed modernity in several field and especially with the flow of fluid.

By our point of view, Macagno essays are interesting for another aspect: they consider many times papers of Filippo Arredi (already mentioned about the Exhibition of 1939): in particular that of 1932 (Arredi 1932a) about Leonardo's formulation of the conservation of volume and that of 1953 (Arredi 1953)

about hydraulic works in Italy during Leonardo lifetime, reassessing Arredi as one of the most important scholar in the field of hydraulics.

For the decades since then, I make just a few references: the 1983 *Leonardo e le vie d'acqua* book, a Symposium organized by engineer Costantino Fasso of the Politecnico di Milano in 1995: "Che chosa è acqua"; research by Carlo Vecce, in particular "Leonardo e il cantico delle acque" from 1997, and to conclude, studies by Paolo Cavagnero, Roberto Revelli and particularly by F.P. Di Teodoro, who has recently published a new critical edition of *Del moto et misura dell'acqua* (Di Teodoro 2018). ■

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