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Feature Articles

Leonardo and the Florence Canal. Sheets 126-127 of the Codex Atlanticus

Filippo Camerota

Museo Galileo – Istituto e Museo di Storia della Scienza, Piazza dei Giudici 1, 50122 Firenze, Italy
E-mail: f.camerota@museogalileo.it

Abstract. The folios 126 r-v and 127 r-v of the *Codex Atlanticus* represent the most exhaustive account of a project developed by Leonardo over many years: the construction of a waterway between Florence and the sea. This navigable canal was supposed to restore the country from the Arno floods and encourage commercial traffic, bringing wealth to the entire region. Its length of no less than 72 km, the system of automatic locks designed to overcome the total height difference of 34 meters between Florence and Pisa, and the idea of feeding it with a water reserve located in Valdichiana would have made it one of the most imposing and technologically advanced hydraulic works of the time.

Keywords. Hydraulic engineering, river navigation, locks, siphons, cartography.

The "Florence Canal" is one of the most famous 'technological dreams' of Leonardo da Vinci. It was conceived as a navigable canal from Florence to the sea; a waterway that was supposed to restore the country from the Arno floods and encourage commercial traffic, bringing wealth to the entire region[1]. The project was developed on several occasions over many years but it never reached a final stage because, in fact, there was never an official appointment for its drafting. Leonardo worked on it with the hope of sensitizing the Floren-

[1] According to Giorgio Vasari (*Lives* 1568), Leonardo "was the first who, as a young man, talked about the Arno river to put it in a canal from Pisa to Florence" (G. Vasari, *Vite de' più eccellenti pittori scultori e architettori, 1550 e 1568*, ed. by R. Bettarini and P. Barocchi, Firenze 1966-1987, vol. 4, p. 17). On the Florence canal project, see Mario Baratta, *Leonardo da Vinci negli studi per la navigazione dell'Arno*, "Bollettino della Società Geografica Italiana", fasc. 10-12 (1905), p. 739-761; Girolamo Calvi, *I manoscritti di Leonardo da Vinci: dal punto di vista cronologico, storico e bibliografico*, Zanichelli, Bologna 1925, pp. 225-232; William Barclay Parsons, *Engineers and engineering in the Renaissance*, The MIT Press, Cambridge (Mass.) 1975, pp. 323-334; Carlo Pedretti, in Jean Paul Richter, *The Literary Works of Leonardo da Vinci / Commentary by C. Pedretti*, commentary to fol. 127r-v, Phaidon, Oxford 1977, pp. 174-175; Carlo Zammattio, *Acqua e pietre: loro meccanica*, in Carlo Zammattio, Augusto Marinoni, Anna Maria Brizio, *Leonardo scienziato*, Firenze 1980, pp. 10-67; Sara Taglialagamba, *Il Canale di Firenze. Foglio 126v*, in *Leonardo e Firenze. Fogli scelti dal Codice Atlantico*, catalogue of the exhibition, Firenze, Palazzo Vecchio (March 24th – June 24th 2019), ed. by Cristina Acidini, Giunti, Firenze 2019, pp. 52-53; Alessandro Vezzosi, *Il Canale di Firenze. Scienza, Utopia e Land Art*, in *Leonardo e Firenze,* cit., pp. 55-63.

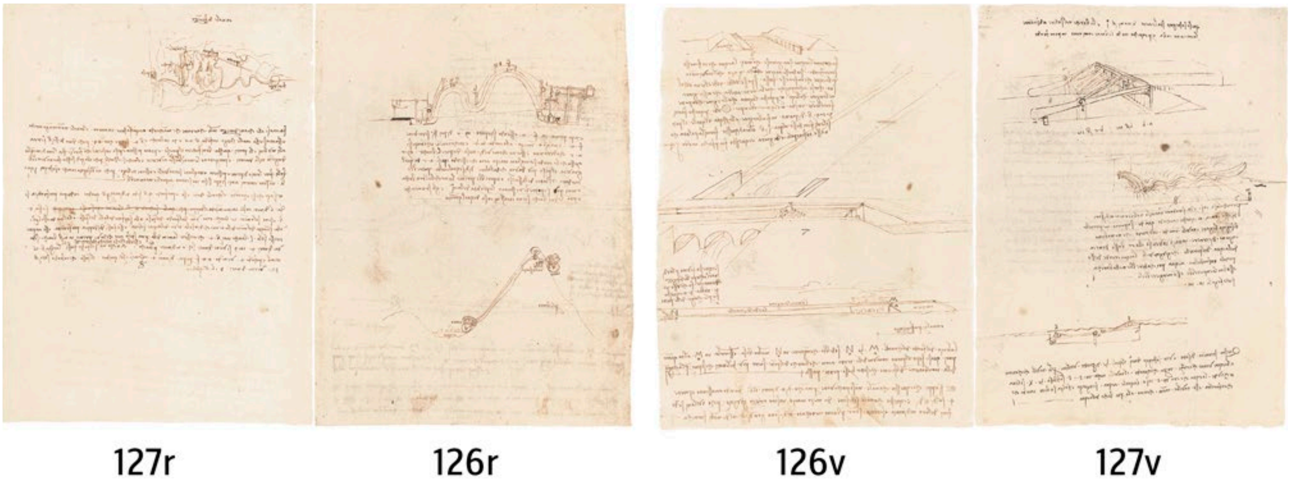

Figure 1. Recomposition of sheets 126r-v and 127r-v of the *Codex Atlanticus*.

tine Republic, especially after the assignment obtained in the summer of 1503 to divert the Arno at the gates of Pisa during the siege of the Florentine troops.

The failure of that enterprise, however, soon quenched the enthusiasm, and put a limit also to the ambitions of its main supporter, Niccolò Machiavelli, the strategist of the Pisan siege. The two men had met at the court of Cesare Borgia, when Leonardo held the office of "architect and military engineer" of the prince, and Machiavelli that of ambassador of the Florentine Republic[2].

When Leonardo was dismissed, Machiavelli called him to supervise the fortress of Verruca at the gates of Pisa, newly conquered by the Florentines, and to present a project for the deviation of the Arno towards Stagno, next to Livorno[3]. It was in the year that elapsed between the presentation of the project and its implementation that Leonardo seems to have devoted himself more assiduously to the ambitious project of the Florence Canal.

The folios 126r-v and 127r-v of the *Codex Atlanticus* represent the most exhaustive account of the project. Even in their extreme textual and graphic synthesis, the sheets contain all the elements necessary to understand the scope of the project which, for technological innovations and impact on the territory, far exceeded the expectations of the possible clients. Most likely, the sheets derive from a bifolio that Leonardo began to write from the last page, as usual for his left-handed writing. The last page (the first for Leonardo) was folio 127r, followed by 127v, then by 126v and then by 126r (fig. 1). The double sheet was presumably part of a series of "notebooks" on water engineering, mentioned by Leonardo on sheet 26r of the Codex Leicester, the treatise that he dedicated to the nature of water and its cosmological implications[4].

Sheet 127r opens with a cartographic sketch of the area affected by the construction of the canal, namely the plain of Florence and the lower Valdarno, up to the mouth of the Arno river (fig. 2). It is a very summary sketch that, however, we are able to read thanks to the much more accurate maps, now kept in the Royal Collection of Windsor Castle and in the Codex Madrid II[5]. The names of the cities of Florence, Prato and Pistoia, of the Serravalle pass, and of the Lake of Sesto (or, of Bientina), mark the route of the canal that, once deviating from the Arno at the gates of Florence, would once again have entered the river next to Vicopisano. Above the drawing, the title "Canale di Firenze" can be read, and below it there is a text that immediately indicates the essential condition for the realization of the work:

> *Facciasi alle chiane d'Arezzo tali cateratte che, mancando acqua la state in Arno, il canale non rimanga arido.*
>
> *Let's construct sluices in the Chiane of Arezzo so that, lacking water in the Arno in summer, the canal would not dry out.* (f. 127r)

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[2] Permission letter issued to Leonardo by Cesare Borgia on August 18 1502, Melzi d'Eril Archives, Belgioso (Pavia): Vaprio d'Adda 1993.

[3] See Emanuela Ferretti, *Fra Leonardo, Machiavelli e Soderini. Ercole I d'Este e Biagio Rossetti nell'impresa "del volgere l'Arno" da Pisa*, "Archivio Storico Italiano", 2019, 2, a. 177, n. 660, pp. 235-272.

[4] The hypothesis is supported by G. Calvi, *op. cit.*, pp. 224, 229. For the Codex Leicester, see *Leonardo da Vinci's Codex Leicester: A New Edition*, ed. by Domenico Laurenza and Martin Kemp, Oxford University Press, Oxford 2019; Paolo Galluzzi, ed., *L'acqua microscopio della natura : il Codice Leicester di Leonardo da Vinci*, catalogue of the exhibition (Florence, Uffizi Gallery, October 30th 2018 – January 20th 2019), Giunti, Firenze 2018.

[5] The topographical drawings of the Lower Valdarno are kept at the Royal Library of Windsor, inv. 12279 and 12685, and in the Codex Madrid II, cc. 22v-23r.

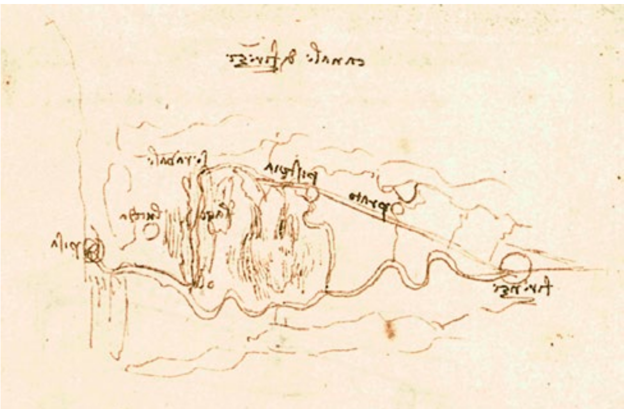

Figure 2. C.A., fol. 127r: detail of the topographic map with the plain of Florence and the lower Valdarno.

Figure 3. *Map of Valdichiana*, Windsor, Royal Library, 12278r

In order to make the canal navigable throughout the year it was necessary to guarantee a water reserve sufficient to ensure navigability even when the Arno had a limited water flow, that is, in the summer months. The water reserve was located in Valdichiana where the large swamp existing at that time could be transformed into a huge reservoir suitable for the purpose. Leonardo does not specify how, but the Valdichiana map drawn up between 1502 and 1503, and the Map of Tuscany, presumably of the same period, allow us to identify some elements of this project[6]. The swamp of the "chiane d'Arezzo" was formed in the Middle Ages perhaps due to a phenomenon of bradyseism that had caused the raising of the ground in the middle of the valley, breaking in two branches the Chiane master canal, once a commercial waterway between the Arno and the Tiber[7]. One of the two branches underwent a reversal of flow, beginning to flow towards the Arno; the other continued to flow towards the Tiber. The lack of maintenance of the water courses, due to the interruption of commercial activities in the period of the barbarian invasions, contributed to provoking the swamping of the valley that already at the time of Dante was known for its unhealthy air[8].

In Leonardo's drawing, one of the most refined cartographic products of the time, the two branches of the Chiane's master canal are traced with a darker blue inside the large swampy expanse that crosses the valley from north to south (fig. 3).

The map was drawn up for military purposes in the aftermath of the Arezzo uprising but it is likely that it was also conceived for a reclamation project necessary to restore the region that Cesare Borgia had just annexed to his conquests in central Italy[9]. To betray the possibility of a hydrographic project in the mind of Leonardo is the presence of a dry ditch not indicated in the other maps of the region, and insignificant for military purposes. The ditch is also reported in the general map of Tuscany accompanied by a significant note: "Braccio da Montona closed it, thence it has disappeared" (fig. 4).

This specific note reveals an attention to the issue of waters that goes beyond the mere cartographic recording. The dried-out canal, is called "Trasumeno" (fig. 5). It was an emissary of the Lake Trasimeno that poured the floods of the lake in the Chiane's master canal, periodically aggravating the swamping of the valley. Braccio da Montone, the lord of Perugia, closed it around 1420 in an attempt perhaps to reclaim the valley. The floods of the lake were then poured into the Tiber through the opening of a new emissary towards the south that in the map of Leonardo, as well as in other contemporary maps, is recognizable by the characteristic graphic interruption due to the tunnel path under the hills in prox-

[6] The map of the Valdichiana and the general map of Tuscany are both kept at the Royal Library of Windsor, respectively with the inventory numbers 12278 and 12277.

[7] See, Vittorio Fossombroni, *Memorie idraulico-storiche sopra la Val-di-Chiana*, Firenze 1789; A. Bigazzi, *La bonifica della Val di Chiana (secoli XVI-XX): gli aspetti tecnici*, "Atti e Memorie della Accademia Petrarca di Lettere, Arti e Scienze", nuova serie, LXIX, 2007, pp. 267-298.

[8] Dante recalls the summer miasmas of the Chiane in the 29th *canto* of *Inferno* (vv. 46-48, "Qual dolor fora, se de li spedali / di Valdichiana tra 'l luglio e 'l settembre / e di Maremma e di Sardigna i mali"), while a little later Fazio degli Uberti attributes to the unhealthy air of the region the cause of the dropsy or anasarca: *Dittamondo*, book III, chapt. X, vv. 23-24, "Quivi son volti pallidi e confusi / perché l'aire e le Chiane li nemica / sì che li fa idropichi e rinfusi".

[9] The revolt of Arezzo against the Florentine domination broke out in June 1502 and was strongly supported by Vitellozzo Vitelli, captain of fortune in the service of Cesare Borgia and friend of Leonardo to whom he lent a book of the works of Archimedes. Arezzo came back under Florentine rule already in August thanks to the intervention of the king of France who ordered Cesare Borgia to renounce the city.

Figure 4. Detail of the dried-out canal, called “Trasumeno”, from the *Map of Tuscany*, Windsor, Royal Library, 12277.

Figure 5. Detail of the “Trasumeno” from the *Map of Valdichiana*, Windsor, Royal Library, 12278r.

imity of the lake (fig. 6). At the point where the southern emissary enters the Tiber Leonardo writes “here is the outflow of the lake”. This note, together with the actual height difference between the lake and the Tiber, which is here much lower, rules out the hypothesis that Leonardo may have considered to convey Tiber´s water to the Trasimeno in order to create a compensation basin in the Chiane that fed into the Arno in the summer months[10]. It is possible instead that for that purpose he planned to reopen the northern emissary which had been closed by Braccio da Montone, a hypothesis still put forward in the sixteenth century by the savant priest

Figure 6. Detail of the southern emissary of the Lake Trasimeno from the *Map of Valdichiana*, Windsor, Royal Library, 12278r.

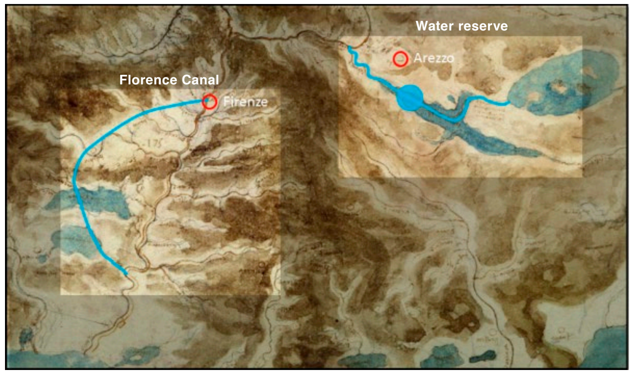

Figure 7. Scheme of Leonardo’s hydrographic project (traced on the *Map of Tuscany*, Windsor, Royal Library, 12277).

Baldassarre Nardi[11]. If Duke of Valentinois´ intent was to acquire riches from a potentially productive area, by reclaiming the whole swampland, then Leonardo seems to have conceived a more elaborate regional water system that connected the large valleys of Tuscany to one another, in order to ensure the feasibility of the great project for the “Canale di Firenze” (fig. 7).

> *E facciasi esso canale largo in fondo braccia 20 e 30 in bocca, e braccia 2 sempre [ac]qua o 4, perché dua d’esse braccia serva[n] alli mulini e li prati.*

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[10] This hypothesis is put forward by Carlo Zammattio, *Acqua e pietre: loro meccanica*, in C. Zammattio, A. Marinoni, A.M. Brizio, *Leonardo scienziato*, Firenze 1980, p. 23.

[11] The hypothesis to convey water from Lake Trasimeno into the Canale Maestro of the Chiana was resumed at the end of the 16th century by Baldassarre Nardi (*Discourse on the Reclamation of the Chiane*, ms., 17th century, Florence, Biblioteca Riccardiana, Ricc. 2575), who seems to have dreamt of the possibility to make the entire stretch a navigable canal that would have connected “Livorno to Rome through the Arno, the Chiane, the Paglia and the Tiber”; see V. Fossombroni, *op. cit.*, p. 312, note 11.

And make the canal wide at the bottom, braccia *20 and 30 in the mouth, and deep* braccia *2 always or 4, so that two* braccia *will serve the mills and the fields.* (f. 127r)

The canal would have had such a width to allow the comfortable passage of two boats in the opposite direction. Considering that the major boats used at that time had a maximum width of 7.5 *braccia* (about 4.5 meters) - so we read in sheet 1007r of the Codex Atlanticus[12] - Leonardo fixed the width of the canal at 20 *braccia* on the bottom and 30 on the surface, and established a depth of 4 *braccia* that could contain a sufficient amount of water to operate the mills, irrigate the fields and allow navigation. The minimum depth for navigation was set at 2 *braccia*, or just over one meter, sufficient to guarantee the floating of the large flat-bottomed boats of the river waterways. The canal measurements indicate a trapezoidal section that Leonardo draws in other notes of the Codex Atlanticus. In the third page of this bifolio, instead (fol. 126v) the canal has a rectangular section. The banks are formed by thick palisades with a robust plank that holds the ground to form two "3 or 4 *braccia*" docks before the gravel embankment that protects the surrounding lands from possible flooding.

Questo [canale] bonificherà il paese; e Prato, Pistoia e Pisa insieme con Firenze fia l'anno di meglio dugento mila ducati, e porgeranno le mani a spesa a esso aiutorio, e i Lucchesi il simile.

This [canal] will reclaim the country; and Prato, Pistoia and Pisa, together with Florence, will make the year better than two hundred thousand ducats, and they will help with the expenses, and the Lucchesi the like. (f. 127r)

In addition to the aforementioned functions, the canal would also have served to absorb the overflows of the Arno avoiding the periodic floods that always represented a danger for the city of Florence and the surrounding countryside. Instructions "for the canalisation of the Arno" along the urban stretch were issued from 1458 to 1477, while, before 1469, Luca Fancelli had elaborated a project for Piero de' Medici for making the river navigable from Mulino di Ognissanti to Signa. The difficulties arisen in that plan, which Fancelli still discussed in a letter to Lorenzo the Magnificent in 1487, were due to the torrential nature of this river[13]. For slowing the flow of the Arno down, it was necessary to block its course by a series of kiddles, which, however, turned out to be a barrier during floods; but it was not possible without kiddles, since in the canalised stretch the stream would have been even more impetuous, therefore it would have brought about the erosion of the riverbed and the consequent breakage of the river banks.

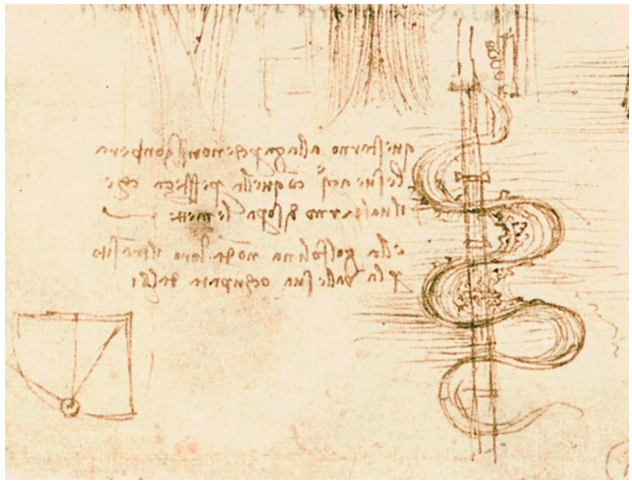

Figure 8. C.A., fol. 785ii r: detail of a study for the Arno canal.

In order to find a solution to this problem Leonardo thought to build a canal alternative to the natural course of the Arno which, by its nature, was not suitable for this plan: "This Arno floods – Leonardo explains – because it does not let its water run off with the same promptness as waters flow into it from the upper Arno Valley. And the Golfolina obstructs the passage of them through its valley filled with trees" (fig. 8)[14]. The alternative way was a navigable canal with a very slight slope, then without kiddles, which would have reached Prato and Pistoia from Mulino di Ognissanti and would have passed through the marshes of Fucecchio for flowing into the Arno near Cascina.

Prato, Pistoia and Pisa are indicated as the main cities that, together with Florence, would have benefited from the construction of the canal and should therefore have contributed financially to its construction. But Leonardo also indicates Lucca that having small commercial landings on Lake of Bientina, could have benefited equally from that important infrastructure, if the canal had been in communication with that lake.

Perché il lago di Sesto sia navigabile, falli fare la via di Prato e Pistoia e tagliare Serravalle e uscire nel lago.

[12] Codex Atlanticus, fol. 1107r: «Le maggiori barche che si faccino, sono larghe 7 braccia e 1/2 [4,5 m] e lunghe 42 braccia [24 m] e alte di sponde uno braccio e ½ [0,9 m]» (The major boats that are built are 7 *braccia* and 1/2 wide[4.5 m] and 42 *braccia* long [24 m] and one *braccio* and ½ high at the sides[0.9 m]).

[13] Luca Fancelli to Lorenzo de' Medici, Milan, August 12 1487; in Corinna Vasić Vatovec, ed. by, *Luca Fancelli architetto. Epistolario gonzaghesco*, Firenze 1979, pp. 60-62.

[14] Codex Atlanticus, fol. 785ii r.

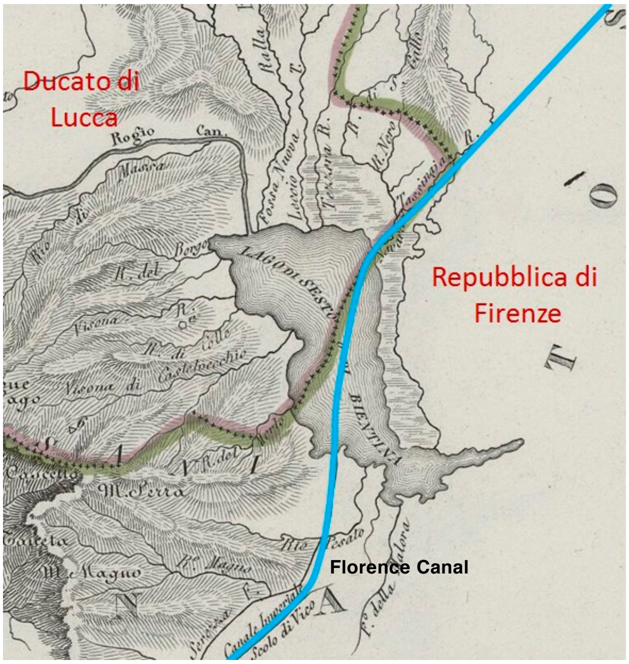

Figure 9. Lake of Sesto, or "of Bientina", *Carta orografica e idrografica del Ducato di Lucca*, in A. Zuccagni Orlandini, *Atlante Geografico degli Stati Italiani*, Firenze 1844, II.

Figure 10. *Map of the Lower Valdarno*, Windsor, Royal Library, 12685.

Figure 11. *Map of the Lower Valdarno*, Codex Madrid II, cc. 22v-23r.

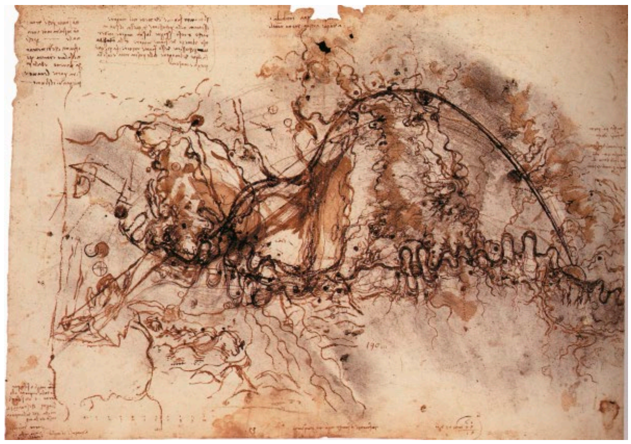

Figure 12. *Map of the Lower Valdarno*, Windsor, Royal Library, 12279.

> *For Lake of Sesto to be navigable, let it [the canal] pass through Prato and Pistoia and cut Serravalle and exit into the lake.* (f. 127r)

The "lake of Sesto" or Lake of Bientina was partly marshy (fig. 9); it dried up during the dry season but only in the outlying areas. A large central area always remained navigable and had an emissary, the ditch of Serezza, which conveyed the excess waters into the Arno near Vicopisano. The lake was half in the Lucca territory and half in the Florentine dominion. Two of the maps drawn by Leonardo to trace its route - Windsor 12685 and Madrid II (figg. 10-11) – show the canal that grazes the southern shore of Lake of Bientina, crossing a slightly hilly area that would have required a work of excavation certainly excessive. Only the Windsor map 12279 (fig. 12) shows a sinuous path that seems to bring the canal slightly further north, where it would have crossed a totally flat area to enter the lake at Altopascio. Keeping the slopes minimal was a necessary condition to avoid the construction of locks whose maintenance would have represented an important burden.

> *perché non bisogni di conche o sostegni, i quali non sono etterni, anzi sempre si sta in esercizio a operarli e mantenerli*

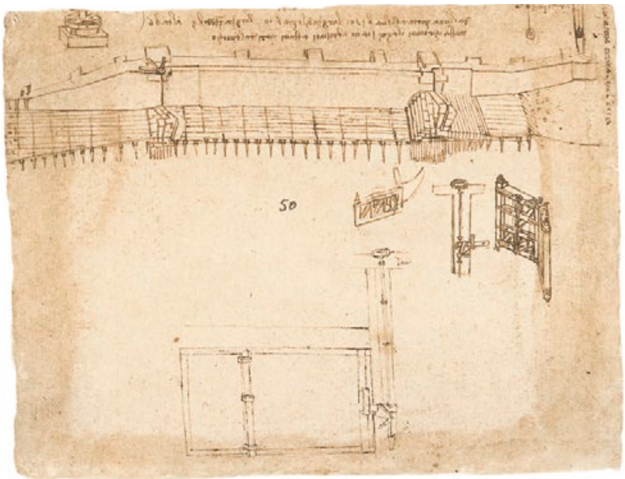

Figure 13. C.A., fol. 935r: Chamber, or navigation basin, with the kind of locks called "porte vinciane".

So that it does not need chambers or locks, which are not eternal, rather it is always necessary to operate and maintain them. (f. 127r)

The technology of 'chambers', 'bulkheads' or 'locks' was known to Leonardo for having experimented and perhaps perfected it during the Milanese years. The gates system fully illustrated by him in the Codex Atlanticus, for example in sheet 935r, is known today as "Porte Vinciane" or 'Da Vinci Gates' (fig. 13). Two large doors close the canal forming an angle of about 120° in upstream direction so as to resist the thrust of the water better than any transverse plane barrier. The doors remained tight thanks to the push of the water, and they were secured to the ground by a stone step that served as a 'doorstop'. Two gates of this type delimited the chamber where the boat was let in to reach the upper or lower level of the canal. In Lombardy canals, locks of this type allowed to overcome up to four meters in altitude. When a boat entered the chamber and the gates from which it had passed were closed, two small shutters hinged to the doors of the second gates were opened to let water enter the chamber itself, or to let it out in the event of a passage to the lowest level. The operation was risky, especially uphill, since the introduction of water into the chamber caused vortices that could push the boat too close to the inlet with consequent danger of sinking, as Leonardo explains in the verse of sheet 127 (fig. 14):

Pericolosa cosa è da fondare i navili nella conca e di fori d'essa conca; e questo accade quando s'aprano le portelle. Bisogna legare i navili in modo indirieto che non abbiano cagione di correre innanzi in verso il loco basso, dove cade l'acqua del portello, che giugnendo lì l'acqua, che cade d'esso portello infra l'altra acqua, poi caderebbe nella barca e subito la empierebbe, e sommergerebbela. Sicché legala in m.

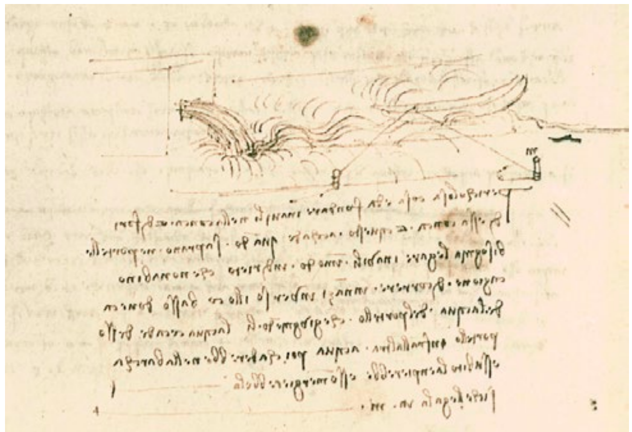

Figure 14. C.A., fol. 127v, detail: filling of the navigation basin through the door of the lock.

Dangerous thing is the risk of sinking the boats in the chamber and outside, and this happens when the doors open. We have to tie the boats behind, so that they have no way of running forward towards the low place, where the water falls from the doors, because arriving there, the water that falls from the doors into the other water, then it would fall into the boat and immediately would fill it and submerge it. Then tie it in m. (f. 127v)

The water level between the two doors went up to that of the upper section of the canal and only then could the second door be opened to let the boat pass. This system made it possible to overcome considerable differences in height but required high construction costs and, according to Leonardo's concerns, even more significant maintenance costs. Leonardo does not say it but we should consider that having to periodically absorb the floods of the Arno, the sluices would have represented a problem to the gradual outflow of the waters.

However, even without the flood problem, the Florence canal could not have been built without water supports. Even if his path could have had a constant slope, we would still have an inclination that would generate too much stream for a comfortable navigation. In its total extension of approximately 72 km between Florence and Vicopisano, the canal would have had to overcome a drop of 34 m, developing a slope of about one meter every 2 km. In the Lombardy canals, the average slope is about one meter every 3 km, a limit beyond which it was not advisable to proceed[15]. But the ques-

[15] On water engineering in the Lombardy area see, Cesare S. Maffioli, *I contributi di Leonardo da Vinci e degli ingegneri milanesi : misura delle*

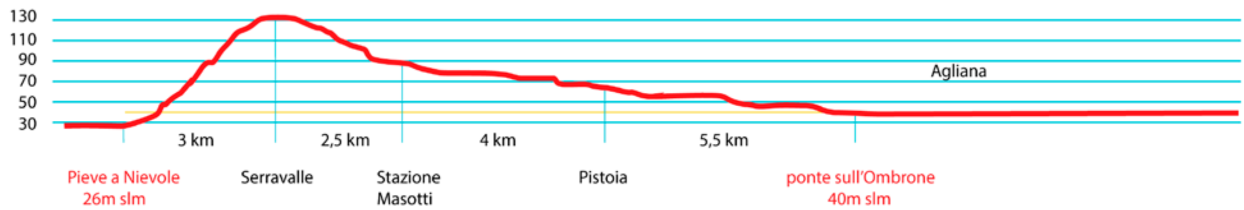

Figure 15. Topographic section between the Ombrone river and the Val di Nievole.

Figure 16. Satellite view of the plain between Florence and Pistoia with the route of the canal and the crossing of the tributaries of the Arno.

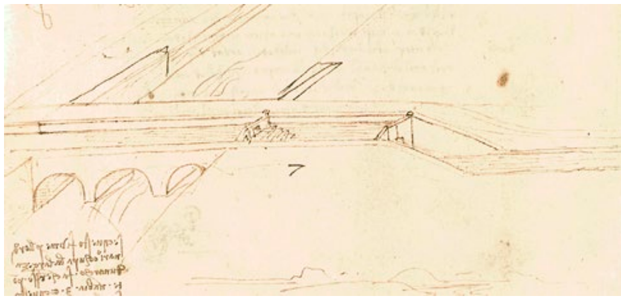

Figure 17. C.A., fol. 126v, detail: perspective view of the canal bridge.

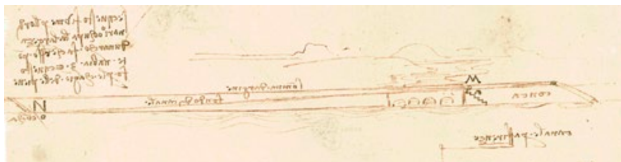

Figure 18. C.A., fol. 126v, detail: cross section of the canal bridge.

tion did not arise even in these terms because at least as far as Pistoia the canal should have had a minimum slope, finding itself having to overcome a difference in height of 14 m in the short stretch that separates Pistoia from the Val di Nievole, beyond the relief of Serravalle (fig. 15). The stretch in question measures about 14 km, impossible to navigate without water supports.

Between Florence and Pistoia the ground has a minimal slope and in that stretch the canal would have had to exceed four tributaries of the Arno, two of which, the Bisenzio and the Ombrone, particularly dangerous during the autumn floods (fig. 16). Leonardo intended to use the water of the tributaries to feed the canal through special aqueducts with controlled access, but the torrents themselves could not enter the canal; they had to be crossed with a bridge of the type illustrated in the third page of the bifolio (126v) (fig. 17). The bridge is on three arches, the central one corresponding to the usual width of the watercourse, the other two necessary to cover the riverbed to absorb the floods: "*if this river usually occupies the width of an arch, let it the bridge having 3 arches, and this is for the causes of floods* ". Above the bridge runs the navigable canal whose depth here is reduced to the bare minimum. And beyond the bridge we can see a navigation basin with corner gates.

In the cross section drawing it is clear that the canal proceeds from a higher level than that of the river that is crossed (fig. 18). In this case the filling of the navigation basin occurred by fall, as in the case of the Ivrea canal that Leonardo mentions on the sheet 563r of the Codex Atlanticus. In the section between Florence and Pistoia, on the other hand, the canal runs at the same altitude as the rivers it must pass. The bridge therefore required a navigation basin that was necessarily higher than both sections of the canal that it connected and its filling took place from below. The only technology that Leonardo could have entrusted with this artifice was that of the siphon, or "cicognola" as it was called at that time; a tube of adequate dimensions which, by exploiting the

acque e navigazione dell'Adda tra fine XV e XVI secolo, "Archivio storico lombardo", anno 142 (2016), pp. 97-127.

Figure 19. C.A., fol. 126r, detail: double siphon.

phenomenon of communicating vessels, would have put the two canal sections separated from the bridge into communication, ensuring the continuous feeding of the canal itself and, when necessary, filling the navigation basin to allow the boats to pass from side to side. This problem probably refers to the singular siphon drawn in the last page of the bifolio (126r) (fig. 19).

The siphon technology applied to the aqueduct bridges is illustrated by Mariano di Jacopo, known as "il Taccola", and by Francesco di Giorgio Martini (fig. 20)[16]. In their writings the solution contemplated by Leonardo is clearly prefigured, namely a siphon bridge that crosses a river bringing the water of a canal from one bank to the other. Leonardo certainly considered this technological solution, taking into account, however, the possibility of adapting it to the navigability of the canal. The greater length of the exit pipe that characterizes the siphon technology, here seems to be obtained with the help of a double curve with a gooseneck joint whose function was to increase the flow velocity. Once the siphon was filled from the mouths placed at the top of the two curves - keeping both mouths closed at the bottom of the canal - and the filling of the upstream channel was ensured, the mouthpieces could be opened to let the water flow into the section of canal downstream. The continuous flow of the canal would keep the siphon in constant operation. To guarantee the simultaneous opening of the mouthpieces, Leonardo studied a mechanical system with balance and counterweights that is activated by cutting a rope stretched between the two ends of the siphon.

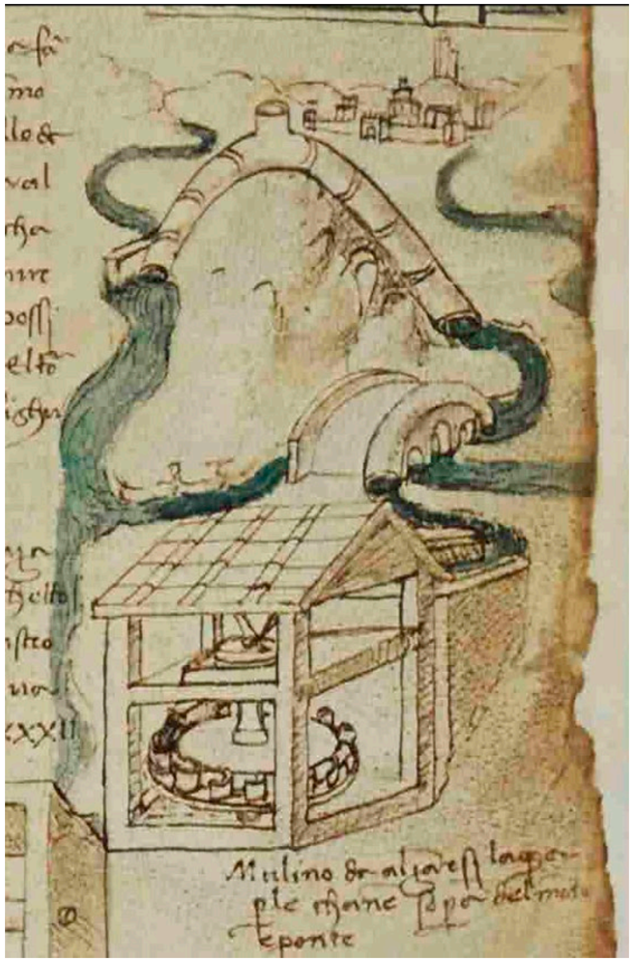

Figure 20. Francesco di Giorgio Martini, *Trattati di architettura, ingegneria e arte militare*, Firenze, Biblioteca Medicea Laurenziana, Cod. Ashb. 361, c. 38r, detail: bridge with siphon to carry the water of a canal from one bank to the other of a river.

The drawing does not explain how the navigation basin was to be filled, but if this was to be the second function of the siphon - necessary to guarantee the navigability of the canal - we should imagine an opening at the top of one of the two curves; an opening of such dimensions as to allow the introduction of water into the basin without interrupting the flow in the siphon. This solution is indicated by Leonardo in sheet 301r of the Codex Atlanticus, where it is applied to an extremely ambitious case, that of bringing the boats to the top of the hills (fig. 21): "*ogni grosso fiume si conducerà in su l'altissime montagne per la ragion de la cicognola* (every big river will lead up the very high mountains for the reason of the siphon)". The siphon

[16] See Mariano di Jacopo, called il Taccola, *De ingeneis*, ed. by Gustina Scaglia, Frank Prager, Ulrich Montag, Dr. Ludwig Reichert Verlag, Wiesbaden 1984, fols. 73v, 83r, 94v, 105r, 115r, 134r; and Francesco di Giorgio Martini, *Trattati di architettura, ingegneria e arte militare*, ed. by Corrado Maltese and Livia Maltese Degrassi, Il Polifilo, Milano 1967, fols. 40r, 42v, 45r.

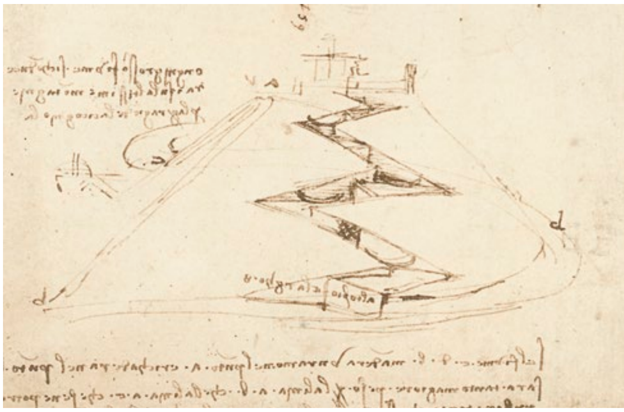

Figure 21. C.A., fol. 301 r, detail: big siphon to feed the highest navigation basin of a system of locks to bring boats up to the mountains.

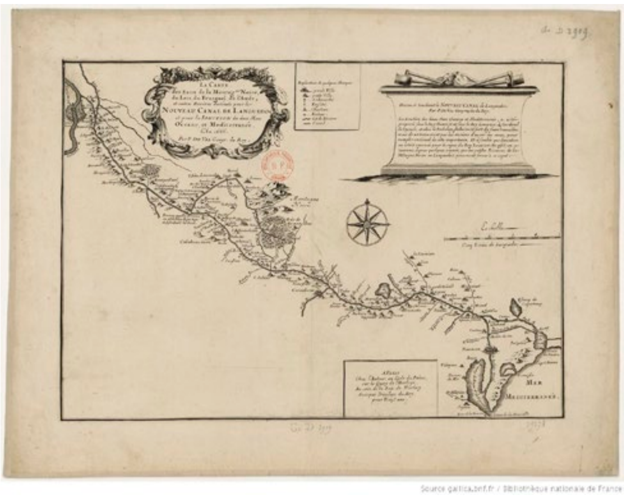

Figure 22. Map of the *Nouveau Canal de Languedoc*, Paris 1677.

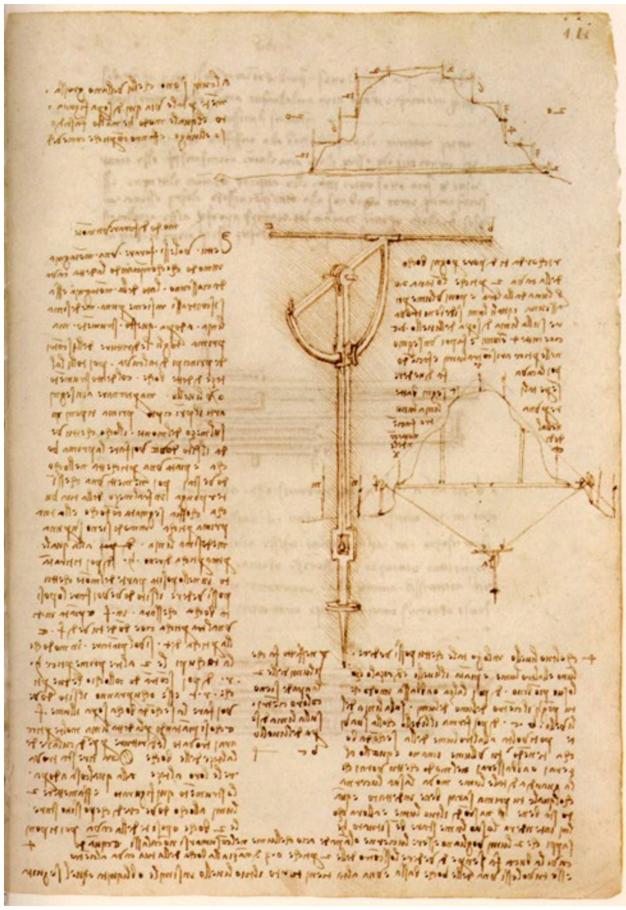

Figure 23. Codex Madrid I, c. 111r: level used to guide the excavation of a tunnel.

is used to feed the highest of a system of navigation basins which, proceeding in a zig-zag fashion, would have allowed for "*condurre delle navi in sulle montagne* (carrying ships on the mountains)". The idea would have found application in France in the seventeenth century with the construction of the Canal du Midi which connects the Mediterranean See with the Atlantic Ocean, overcoming an intermediate relief of 190 m (fig. 22). In this case, however, the supply of the highest basin occurs through a water reserve located further upstream.

If the canal had not also served as a spillway, and if it had been possible to guarantee a water supply in the Pistoia mountains, this solution would have been applicable also to the Serravalle problem. But the conditions were different.

The mountainous relief that separates the plain of Florence-Pistoia from the Val di Nievole is today crossed in a tunnel by a stretch of motorway and by the railway line, and it has been repeatedly suggested by scholars that this could be one of the solutions meditated by Leonardo. To support the hypothesis is usually the 111r sheet of the Codex Madrid I where Leonardo illustrates a new "way to drill a mountain" (fig. 23). The excavation of tunnels for canals and aqueducts is illustrated in the works of Taccola (fig. 24) and a real case well-known to Leonardo was the tunnel of the southern emissary of the Trasimeno. However, unlike the approximately 900 meters covered in tunnel by the Trasimeno emissary, overcoming the relief of Serravalle required a dig of several kilometers. If the excavation had been done horizontally, as Leonardo shows and before him Taccola, the exit of the tunnel towards Pieve a Nievole would have been found 14 meters higher than the valley that it was supposed to reach. In conclusion of his description, Leonardo states that by tilting the level the excavation

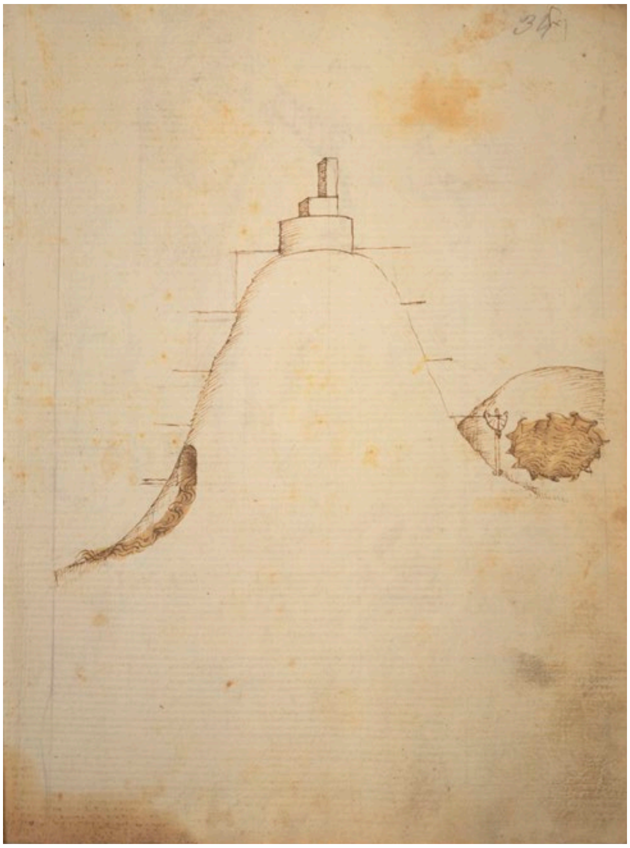

Figure 24. Mariano di Iacopo, called il Taccola, *De ingeneis*, Biblioteca Nazionale Centrale di Firenze, Ms. Palat. 762, c. 34r: method for digging a tunnel for the passage of canals and aqueducts.

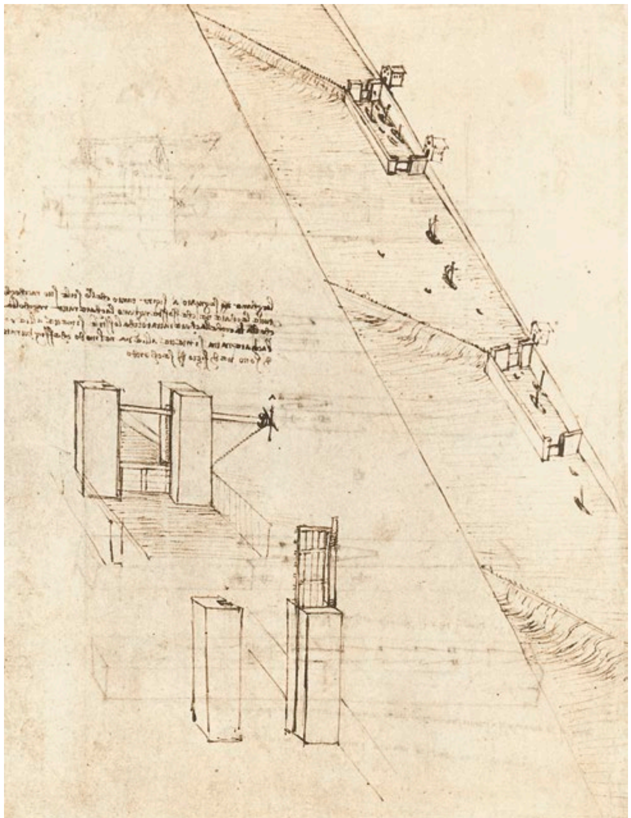

Figure 25. C.A., fol. 90v: canal with kiddles and locks.

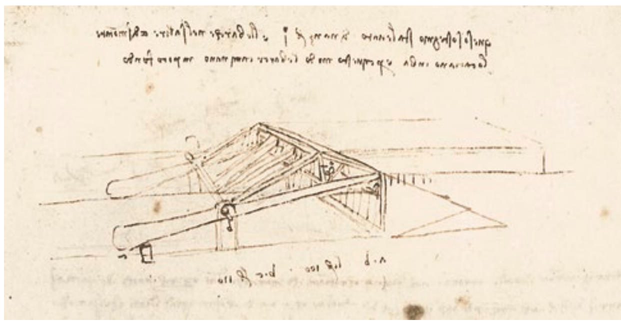

Figure 26. C.A., fol. 127v, detail: counterweight water support.

could follow an inclined plane, but there is no evidence that this excavation technique was related to the passage of the canal to Serravalle.

In the first page of the bifolio, Leonardo clearly writes "cut Serravalle" and it seems clear that his solution foresaw a passage in trench, or the cutting of an artificial gorge that would have allowed to proceed gradually downwards with a series of "steps" interrupted by weirs of the type illustrated in sheet 90v of the Codex Atlanticus (fig. 25). This drawing shows navigation basins with a system of locks simpler than the one with corner gates. These are sluice gates raised like a drawbridge that certainly required lower construction and maintenance costs. For this part of the Florence canal, and for the following stretch as far as Lake Bientina, Leonardo seems to have thought of even simpler water supports that we see illustrated in the second page of the bifolio (127v). These are counterweight systems designed to support just one *braccio* of water, the minimum allowed for river navigation, which could be operated by the boats themselves (fig. 26).

> *Ques[t]o sostegno sta levato dinanz[i] braccia uno, e le barche nel salire e dismontare lo cacciano in ba[sso], e per questo modo le barche camminano in poco fondo.*
>
> *This support rises on the front one* braccio, *and as the boats go up and down they drive it down, and in this way the boats walk in little depth.* (f. 127v)

Two similar supports had to be located at the two ends of the navigation basin (fig. 27). Arriving from

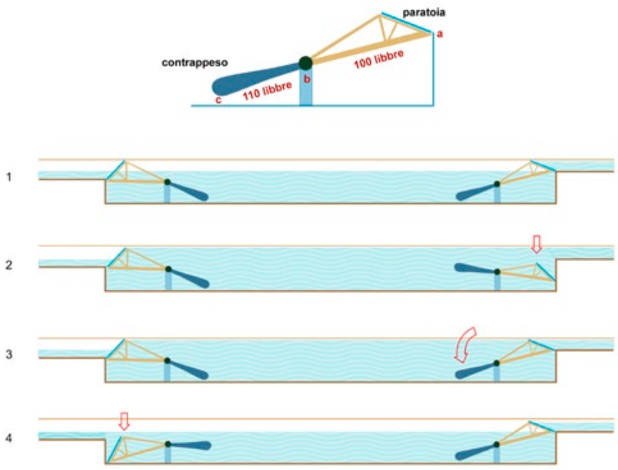

Figure 27. Operation of the counterweight system designed to support one *braccio* of water.

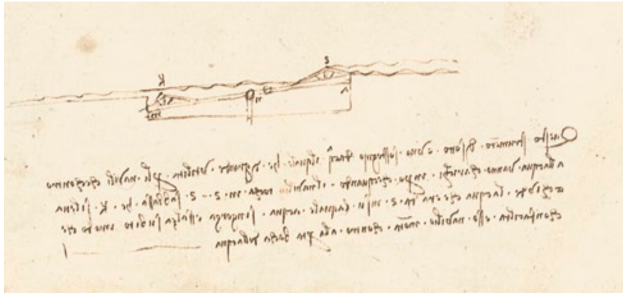

Figure 28. C.A., fol. 127v, detail: rocker water support.

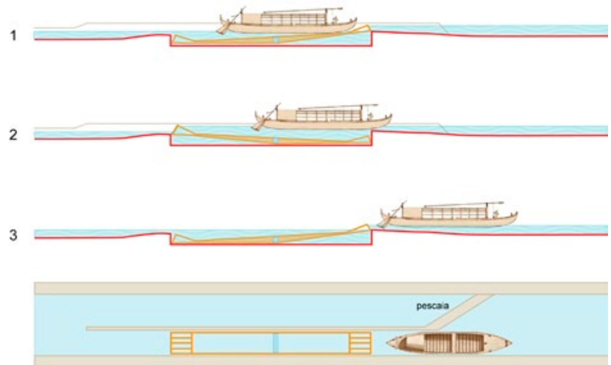

Figure 29. Operation of the rocker arm system designed to support one *braccio* of water.

the top of the canal (right, in the drawing), and tapping lightly on the sloping sluice of the support, the boat would have caused the lowering of the sluice itself which the water, pouring inside the basin, would have helped to push even more down. The opposite gate would have blocked the passage of water allowing the basin to fill up to the upper level of the canal. At that point the boat could enter the basin and proceed until it touched the second support which, by lowering, would allow the basin to empty itself until it reached the lower level of the canal. The emptying took place after the first support, brought back in position by the counterweight, had blocked the access of the water from the upper part of the canal. Alternatively, the two supports could be connected like a rocker arm, as in the drawing at the bottom of the sheet (fig. 28).

> *Questo strumento di sotto è un sostegno d'acqua, il quale è di grande utilità per li navili che contro all'acqua vanno carichi; imperò che, quando il navilio tocca in S, S s'abbassa, e K si leva e chiude l'acqua che era da S in su. La quale acqua s'ingorga, e s'alza subito in modo che con facil[i]tà esso navilio monta contro all'aperta bocca dell'acqua.*
>
> *This instrument below is a water support, which is very useful for loaded ships sailing upstream; so that when the ship touches in S, S is lowered, and K rises and closes the water that was from S upwards. Which water is engorged, and immediately rises so that with ease the boat gets in the open mouth of the water.* (f. 127v)

Here Leonardo imagines a boat that sails upstream (fig. 29). The navigation basin has the same level of the lower part of the channel; the boat enters the basin and knocks against the sluice gate which blocks water access to the upper level. This is lowered causing at the same time the raising of the downstream sluice gate which closes the access to the water in the meantime poured into the basin from the highest part of the canal. The water level in the basin then rises up to that of the upstream channel, and at this point the boat proceeds in its navigation. Here it is not clear if the system should remain in this position until the passage of another boat or if the difference in weight between the two parts of the rocker arm would have gradually brought the basin back to the initial condition. It is clear, however, that in both cases the height difference exceeded by the boats had to be minimal, no more than one *braccio*, and although numerous, these water supports would have been less expensive than the traditional locks. To overcome the 14-meter difference in height between Pistoia and the Val di Nievole, the section of the canal in Serravalle would have required about 23 water supports of this type located at a distance of about 600 meters from each other.

The next stretch, up to Lake of Bientina, would have required as many supports. Then the canal would have continued with a minimal slope until it re-entered the Arno at a point where the river itself, having no more tributaries, would have become navigable up to the mouth.

The final part of the text we are examining contains an estimate of the costs for the excavation of the canal, a decisive and unavoidable aspect that Leonardo methodically tackles in other sheets of the Codex Atlanticus.

E sappi che se cavando il canale dove esso è profondo 4 braccia, si dà 4 dinari per braccio quadro, in doppia profondità si dà 6 dinari.

And know that if you dig the canal where it is 4 braccia *deep, you give 4* dinari *per square* braccio*, in double depth you give 6* dinari*. (f. 127r)*

Leonardo carries out the calculation of costs in Milanese *dinari* probably because that was the unit value of reference most familiar to him for hydraulic works of such a scale. It was an estimate of the costs which he maintains in this form because the annotations on these sheets are still entirely personal. If the project had been translated into an official document, the costs would certainly have been converted into Florentine currency.

Se fai 4 braccia, e' sono solamente 2 banchi, cioè uno dal fondo del fosso alla superfizie de' labri del fosso, e l'altro da essi labri alla sommità del monte della terra che d'in sulla riva dell'argine si leva.

If you make 4 arms, they are only 2 banks, that is, one from the bottom of the ditch to the surface of the laps of the ditch, and the other from them to the top of the pile of earth that rises on the shore. (f. 127r)

Leonardo divides the ground into layers, or "banks," of four arms in height and considers that the ground excavated for the depth of the canal would have been used for the construction of the embankments.

E se fussi di doppia profondità esso argine cres[c]e solo uno banco, cioè braccia 4, che cresce la metà della prima spesa; cioè che dove prima in due banchi si dava dinari 4, in 3 si viene dinari 6, a 2 dinari per banco, essendo il fosso in fondo braccia 16.
Ancora se 'l fosso fussi largo braccia 16 e profondo 4, venendo a 4 soldi per opera[io], dinari 4 milanesi il braccio quadro, il fosso che in fondo sarà braccia 32, verrà dinari 8 il braccio quadro. (f. 127r)

And if it were of double depth, it would only grow of one bank, that is 4 braccia*, which grows half of the first expenditure; that is, where 4* dinari *were given first for two banks, for 3 banks is 6* dinari*, 2* dinari *per bank, the ditch being at the bottom 16* braccia.

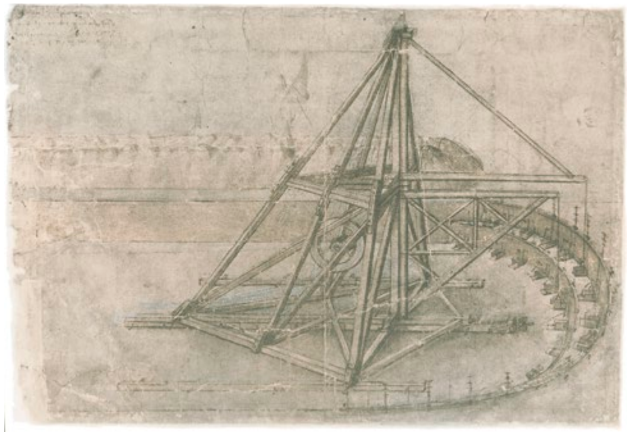

Figure 30. C.A., fol. 4r: Earthmoving machine.

Still if the ditch was 16 braccia *wide and 4* braccia *deep, costing 4 soldi per worker, 4 Milanese* dinari *per square* braccio*, the ditch that at the bottom will be 32* braccia*, will coast 8* dinari *per square* braccio*. (f. 127r)*

Sheet 126r replicates the cost per worker and suggests the best period for carrying out the work between March and June, when farmers cost less because they are free from work in the fields, the days are longer, and the heat is not excessive.

E sappi che questo canale non si po cavare per manco di 4 dinari il braccio [quadro], dando a ciascun operatore 4 soldi il dì, e questo canale si de' fare da mezzo marzo insino a mezzo giugno, perché i villani, sendo fori del loro ordinario esercizio, s'hanno per buono mercato, e dì sono grandi e 'l caldo nolli stanca.

And know that this canal cannot be excavated for less than 4 dinari *per square* braccio*, giving each worker 4* soldi *per day, and this canal must be made from mid-March until mid-June, because the villains, being free from their ordinary exercise, they are cheap, and the days are long and the heat does not tire them.*

To reduce labor costs and accelerate excavation times, Leonardo devised specific excavation and earth moving machines (fig. 30). The design commitment that transpires also from the conception of these machines betrays a deep involvement and perhaps the real conviction of being one step away from the official assignment which, however, does not appear to have ever been conferred.

The 126 and 127 sheets of the Codex Atlanticus are usually referred to the Milanese period. Calvi dates them to 1490 while Pedretti proposes a date around

Figure 31. Codex Madrid II, c. 52v-53r: map of the surroundings of Pisa. The place where the deviation of the Arno was carried out is marked as “rotta d’Arno”.

1495[17]. Only Heydernreich is pronounced for a later date, referring to the second Florentine period, around 1503[18]. The first two datings are based on critical considerations relating to the style and *ductus* of the writing, and could find support in the cost estimation that Leonardo carries out in Milanese currency. However, as anticipated, Leonardo’s estimate could simply refer to a unit value familiar to him, and would not necessarily indicate the place where he made those calculations. To raise doubts about the dating of the Milanese period is the fact that there is no strong motivation to justify the drafting of a project so detailed in economic as well as technological terms. The eventual creative stimulus produced by the frequentation of Luca Fancelli when he was in Milan to deal with the *tiburio* of the cathedral, is not sufficient to explain the level of application found in these sheets. The estimate betrays a feasibility study that implies the presence of a client, or at least the occurrence of circumstances that would have favored a specific interest. There were no such circumstances except after Leonardo’s involvement in the Arno deviation project of 1503, a period in which it seems reasonable to trace the resumption of the navigable canal project (fig. 31).

However, the project was not followed. The failure of the deviation of the Arno was presumably the most immediate cause but, perhaps, we should also consider the fact that, in view of the important economic commitment required by the grandeur of the work, lacked the political stability necessary to ensure that such an infrastructure could actually work. Pisa was still out of control and the recent revolt in Arezzo did not play in favor of such an important investment in Valdichiana. For such a project a unitary state was needed that would guarantee political stability and total control over the territory. It is no coincidence that the project was resumed in the middle of the century by Cosimo I de ‘Medici, when Tuscany was almost entirely under the rule of the Medici[19]. But even in that case the idea remained only an ambitious desire, a technological dream evidently still too far from the possibility of being realized.

[17] For Calvi and Pedretti see the bibliographical references at note 1.
[18] Ludwig H. Heydernreich, *Leonardo da Vinci*, New York 1954, pl. 218.

[19] The project is described in a letter of Bartolomeo Concini to Vincenzo Borghini, March 26 1572, in L. Cantini, *Vita di Cosimo de’ Medici primo Gran Duca di Toscana*, Firenze 1805, pp. 228, 477-478, 668-669.