Between *matematici* and *architetti d'acque*: Vincenzo Viviani, Galileo's legacy, and hydraulic engineering

Francesco Barreca
Università Statale di Milano, f.barreca@museogalileo.it

Abstract
For a long time, Vincenzo Viviani has been regarded by historians in the light of his devotion to Galileo. However, while saying that Galileo had a great influence on Viviani might seem to be an understatement, it should not be forgotten that after Galileo's death Viviani carved out a career of his own, and that he devoted almost all his life to a specific field – engineering – which often forced him to relax his allegedly strict Galilean beliefs. In particular, his apprenticeship under the guidance of Baccio del Bianco and the years he spent as an assistant engineer for the *Capitani di parte Guelfa* (before being appointed as *Primo Ingegnere*) allowed him to become a member of the narrow circle of versatile craftsmen who place themselves halfway between the *matematici* and the *architetti d'acque*. This circumstance contributed to shape both Viviani's peculiar approach to hydraulic engineering and his role in the process of institutionalisation of Galilean science.

Keywords
Vincenzo Viviani, hydraulic engineering, Galilean science, Florence, Tuscany

How to cite this article
Barreca, Francesco. "Between *matematici* and *architetti d'acque*: Vincenzo Viviani, Galileo's legacy, and hydraulic engineering". *Galilæana* XX, 1 (2023), 121-152; doi: 10.57617/gal-2.

Funding agencies
This result is part of a project that has received fundings from the European Search Council (ERC) under the European Union Horizon 2020 research and innovation programme (Grant agreement No. 818098, Tacitroots, PI: Giulia Giannini).

Article data
Date submitted: July 2022
Date accepted: January 2023

Introduction

The aim of this paper is to show that a deeper look at Viviani's experience as engineer can offer new insights into his role in the cultural and institutional changes that were taking place in the second half of the seventeenth century in the wake of Galilean science. I shall do this first by looking at the early period that Viviani spent in the service of Baccio del Bianco, and then by arguing how the need to negotiate between different cultures, expertises, practices, and cultural legacies led him to adopt a highly original and modern approach to hydraulic engineering. My claim is that we need to look at Viviani from a broader perspective – a perspective that, while including the obvious Galilean influence, will acknowledge other influences as well – in order to make sense of his role in the culture of the time.

Galileo's last disciple

Even though it lasted more than sixty years, the long time spent by Viviani as hydraulic engineer in the service first of Grand Duke Ferdinand II and then of Cosimo III is arguably the most overlooked part of his scientific activity. This is due, to a certain extent, to Viviani himself, as he not only considered engineering as something "contrary to the genius" of his studies,[1] but also reputed himself physically unfit for the job.[2] He never managed to publish or even complete a mathematical treatise on hydraulics of the kind published by other disciples of Galileo like Benedetto Castelli, Evangelista Torricelli, or Famiano Michelini;[3] and he never boasted about his role as *Primo Ingegnere*. On the contrary, over the course of his entire life he took pain to present himself as "Galileo's last disciple", a custodian of Galileo's legacy who did not miss any occasion to campaign for the rehabilitation and celebration of his master. As engineer, he served loyally and diligently, but was never happy in his office and hoped in vain to be, sooner or later, left free to follow his own inclinations. He considered himself a mathematician, and to pure mathematics he would have likely attended had the circumstances of life not plotted against his wishes.

Viviani's career in engineering started in 1644, when he was 22, shortly after Galileo's death, when he was appointed as *capomastro* for the *Capitani di parte Guelfa* on recommendation from Galileo's friend Andrea Arrighetti. That same year he was promoted to *Aiuto dell'Ingegnere* at the service of the *Primo Ingegnere*, Baccio del Bianco. After Baccio's departure for Madrid, Viviani was named *Ingegnere sostituto* (1653), and then confirmed in the position as *Primo Ingegnere* (1658) after Baccio's death in 1656. Finally, when Famiano Michelini died in 1665, Viviani was called to replace him as *Idrometra* and *Matemati-*

1 Vincenzo Viviani to Baccio del Bianco, January 13, 1656. BNCF, Gal. 157, f. 18v.
2 Vincenzo Viviani to Alamanno Salviati, April 5, 1697. BNCF, Gal. 155, f. 8r.
3 On this regard, see Maffioli, *Out of Galileo: The Science of Waters, 1628-1718*, part II.

co Granducale.[4] With the latter appointment he was formally relieved from his duties as *Primo Ingegnere*, but since no substitute was ever nominated in his place, he was forced to maintain that position as well.[5] In 1697, in a pledge for intercession addressed to Alamanno Salviati, Viviani expressed his wish to be freed from a time-swallowing office that, because of the bone-crushing journeys and tiresome dealings with bureaucracy it required, had prevented him from attending to mathematical and geometrical studies the way he wanted and, as *Matematico Granducale*, was also supposed to.[6] Moreover, during all those years, his tenure as *Lettore di Matematiche* at the *Accademia del Disegno*, his involvement in the *Accademia del Cimento*, his role as editor of both Galileo's and Torricelli's collected works, and his commitment to King Louis XIV of France to carry on with the *Divinazioni* had burdened him with further tasks, worries, and responsibility, so that by age 75 he had published relatively little. It is no surprise, then, that historians, following a lead that Viviani himself was nothing but happy to give them, for a long time looked at him merely as "Galileo's last disciple", a mathematician whose scientific achievements did not match his talents.[7] This view, however, is increasingly being challenged by recent research.[8] As studies on correspondence, work notes and personal papers flourish, it is more and more apparent that Viviani's career in engineering, given its continuity over time, the full commitment it required on Viviani's part, and the relatively large amount of sources at our disposal, represents a fertile field of study.

Highly praised until at least the first half of the XIXth Century, Viviani's work in engineering was thereafter virtually ignored by historians of science. A significant exception is Raffaello Caverni, who transcribed parts of Viviani's manuscripts on hydrodynamics and studied them thoroughly. In his monumental *Storia del Metodo Sperimentale in Italia,* Caverni noticed that, when it comes to hydraulics, Viviani's devotion to Galileo seems to waver, and that his theoretical treatise *Sogno Idrometrico*, if finished and published, "would have made the publication of Grandi's *Trattato del Moto delle Acque* pointless."[9] Studies on Viviani's engineering resurfaced in the late 1970s with a paper by Paolo Galluzzi published in the *Annali dell'Istituto e Museo di Storia della Scienza*. In this study, Galluzzi analyzes Viv-

4 On Viviani's life, see the entry in *Dizionario biografico degli Italiani* by Simon Dumas Primbault; and Righini Bonelli, "L'ultimo discepolo: Vincenzo Viviani", 656-688.

5 The *motu proprio* from the Grand Duke of 1666 established that Viviani was to be freed from his duties as *Primo Ingegnere*, but would be available as consultant on important matters.

6 Viviani to Salviati, BNCF, Gal. 155, ff.5r-5v.

7 Righini Bonelli, "L'ultimo discepolo: Vincenzo Viviani", 687.

8 Cf. for example, Bonechi, "Dediche tortuose: la geometria morale di Vincenzo Viviani e gli imbarazzi dell'eredità galileiana", 75-181; Dumas Primbault, "Le compass dans l'oeil: la mécanique géometrique de Viviani au chevet de la coupole de Brunelleschi", 5-52; Dumas Primbault, *Un galiléen d'encre et de papier. Une archéologie des brouillons de Vincenzo Viviani (1622-1703)* [forthcoming].

9 Caverni, *Storia del metodo sperimentale in Italia*, 184.

iani's attempt to mathematically demonstrate that encircling the dome of Santa Maria del Fiore with chains was an adequate solution to its stability problems. The proof is far from being convincing from a mathematical viewpoint, and Galluzzi shows that Viviani engaged in it mostly because those who opposed the proposal to encircle the dome with chains had argued that such a solution contradicted Galileo's principles of static. As Galluzzi points out, by that time Viviani had already given his approval to the chain solution and, apart from the risk that this may not work, it was the veiled accusation of 'betraying' Galileo that bothered him. To show that the approved solution was perfectly consistent with Galileo's science, Viviani resorted to an obscure theorem by Torricelli. By way of conclusion, Galluzzi notices that while Viviani was working on the proof, he was also drafting the letter to Salviati in which he asked to be released from his duties as engineer: his personal dissatisfaction with engineering, thus, seems to be somehow linked to his devotion to Galileo.[10]

In the following years, an ever-growing body of literature on the developments of hydraulics after Galileo, on the environmental policy of the Medici, and on Viviani's work as *Ingegnere* has consigned us a radically new image of Galileo's last disciple. Today, Viviani's approach to hydraulic engineering is recognized as surprisingly modern, innovative, and effective;[11] his half a century's service in the position of *Primo Ingegnere* is regarded as a key element in the institutionalization process of Galilean science and in the reformation of the technical bureaucracy of the Tuscan State;[12] and many of his theoretical researches on hydraulics have been reconsidered in the light of the concerns on some aspects of Castelli's theories expressed by contemporaries like Domenico Guglielmini.[13] In all these, however, the issue signaled by Caverni and Galluzzi – that is, a possible controversial Galilean legacy, when it comes to engineering – remains mostly on the background. The complex accommodation between 'practical' and 'mathematical' wisdom as it was experienced by Viviani received relatively little attention, and has been often reduced to the mere observation that Galilean mathematical science progressively replaced the old practical and empirical expertise. On the other hand, delving deeper into the issue by investigating Viviani's career as engineer, his engagement with the culture of his time, and his key role in the general restructuring of epistemological hierarchies led by the post-Galilean generation both at the intellectual and institutional level reveals a far more complex situation that

[10] Galluzzi, "Le colonne "fesse" degli Uffizi e gli screpoli della Cupola. Il contributo di Vincenzo Viviani al dibattito sulla stabilità della Cupola del Brunelleschi (1694-1697)", 90-102.

[11] Barsanti, "La scuola idraulica galileiana", 83-130; Maglioni, "Vincenzo Viviani e l'Arno. Scienza Galileiana e problemi di un fiume e del suo bacino nel XVII secolo", 151-170; Di Fido, Gandolfi, *Idraulici italiani*, 88-92.

[12] Vivoli, Toccafondi, "Cartografia e istituzioni nella Toscana del Seicento: gli ingegneri al servizio dello Scrittoio delle Possessioni e dei Capitani di Parte", 167-202.

[13] Maffioli, *Out of Galileo: The Science of Waters, 1628-1718*, 193-195; Gottardi, Bugini, Camprini, Manferrari, "Aspetti della tradizione scientifico-tecnica idraulica bolognese", 69-70.

cannot be reduced to the assumption that Galileo's science influenced the practice of the *architetti d'acque*, but must take into account the possibility that the process worked in the other direction, too – that is, that the *architetti d'acque*'s approach to hydraulic engineering had its share in the shaping of the institutionalization process of Galilean science.

Viviani was the first mathematician of the Galilean school to hold the highest technical position in the Tuscan State. He trained generations of engineers and technicians, and, as both *Primo Ingegnere* and *Matematico Granducale*, he experienced firsthand the need of negotiating knowledge, discourses, skills, and practices in a fast-changing intellectual and political environment, and so his career as engineer is a privileged standpoint for looking at how, during the second half of the XVIIth century, Galilean science became Tuscany's main truth-producing paradigm at institutional level.

An engineer in the making: Viviani's apprenticeship with Baccio del Bianco

For Viviani, entering the service of Baccio del Bianco was like entering a new world. Unlike Castelli and Torricelli, who were recruited as senior consultants right from the start, Viviani began his career in hydraulic engineering at the bottom of the ladder and went up through the ranks of the *Magistratura dei Capitani di parte Guelfa*. Established in 1267 in the aftermath of the battle of Benevento (1266) and the restoration of Guelph rule in Florence, the *Magistratura* was originally charged with prosecuting Ghibellines. Over time, however, it had evolved into an authority with a broad range of responsibilities in Public Works matters, and after the *Ordinazioni* of 1532 that abolished the *Signoria* and turned the Florentine State into a monarchy it assumed an increasingly technical role. The *Magistratura* was governed by a council of ten citizens (the *Capitani*), three of whom were randomly chosen among high-rank Florentines and seven were directly nominated by the Grand Duke. The *Capitani* served on temporary appointment, but two of the councilors nominated by the Grand Duke were hired on permanent basis to act as *Ufficiali dei fiumi*.[14]

Important as it was, in the XVII century the *Magistratura* was just one of the administrative bodies, within the confusing institutional structure of the Grand Duchy, that had some kind of jurisdiction over river management. Its functions and power often overlapped and conflicted with those of the so-called *Magistratura dei Nove*, the institution created by Cosimo I in 1560 to control local governments. Moreover, there was the peculiar organization of the Tuscan State, which consisted of a *Stato vecchio* (the Duchy of Florence) joined in personal union to a *Stato nuovo* (the Republic of Siena), with Pistoia and Pisa, included

[14] On the *Magistratura*, see Vivoli, Toccafondi, "Cartografia e istituzioni nella Toscana del Seicento: gli ingegneri al servizio dello Scrittoio delle Possessioni e dei Capitani di Parte", 167-202. More generally, on the institutions of the Medicean state, cf. Neri, "Relazione sulle magistrature della città di Firenze (1745-1763)", 569-689.

in the Duchy of Florence, enjoying some autonomy over territorial government and tax collecting. So, when it came to river management in the *Stato vecchio*, the main authorities involved were the *Magistratura dei Capitani di Parte Guelfa*, the *Magistratura dei Nove*, the *Pratica di Pistoia*, and the *Ufficio dei Fossi* of Pisa, not to mention the Grand Duke himself, who loomed over all of them and was always ready to intervene issuing a *Motu proprio* or appointing a *Sovrintendente* on suggestion from personal advisers like the *Matematico Granducale*.

The funding system further complicated the situation, as it ignited and exacerbated disputes. River maintenance was not part of the *spese universali* of the Grand Duchy, that is, it was not a regular service routinely funded by the State, but consisted mainly of emergency interventions ordered by the State and paid for by local landowners according to a complex system of fee distribution (*imposizioni*). As this usually sparkled disputes, it was often necessary, in the case of major projects, to mediate between conflicting interests by bringing together local communities, land-owners, and State agencies in the so-called *Congregazioni*. The issue, however, stood: the disarticulation between the State's centralistic approach to river management on the one side and the river maintenance funding system on the other remained a source of endless litigations and, perhaps more importantly, forced local communities into debt. By 1770 (when the *Magistratura dei Capitani di parte Guelfa* and the *Magistratura dei Nove* were united in the *Camera delle Comunità*) there was a huge debt of 201.792 ecus on the part of the *imposizioni* of Val d'Arno di Sopra alone.[15] Consequently, authorities like the *Magistratura dei Capitani di parte Guelfa* operated on a very tight budget and were unable to implement long-term global policies.[16]

When Viviani joined the *Magistratura* in 1644, the *Capitani* were responsible for engineering projects in their entirety: they had to survey the interested areas and draw maps, approve plans, contract out the works, calculate the *imposizioni*, settle controversies between the stakeholders, and inspect the construction works. To carry out these tasks, they employed a technical staff of *Ingegneri dei Fossi e dei Fiumi*, usually hired on a temporary basis and assigned to individual projects or specific areas. The *Primo Ingegnere*, instead, was hired on permanent basis and served at the same time as consultant of the Grand Duke and the *Ufficiali dei fiumi*, as *Ingegnere dei Fossi e dei Fiumi*, and as project inspector of the ongoing works. The *Primo Ingegnere*, being always on the move either for routine inspections or emergency interventions, had his personal staff of *Aiuti* and *capimastri* to help him out with the work. On the administrative side, the *Magistratura* relied on a bureaucratic staff of *Ministri*, *Segretari* and employees (*scrivani*), managed by the *Provveditore*,

[15] Cit. in Sordi, *L'amministrazione illuminata. Riforma delle comunità e progetti di costituzione nella Toscana leopoldina*, 102.

[16] On these topics, see Fasano Guarini, *Lo Stato Mediceo di Cosimo I*; Mannori, *L'amministrazione del Territorio nella Toscana Granducale. Teoria e prassi di governo fra antico regime e riforme*; Sordi, *L'amministrazione illuminata...*, 21-75.

who was appointed by the Grand Duke and served as his man of trust within the institution.[17] Viviani was hired as *capomastro* in 1644 on recommendation from Galileo's friend Andrea Arrighetti, who was subsequently nominated *Provveditore* in 1648. With Viviani's appointment, a new route was opened for the institutionalization of Galilean science, and from then on this process of institutionalization ran both ways: from the top down (with the occupation of didactic and managing positions), and from the bottom up (with the appointment of medium-level technical personnel).

We can only imagine how the 22-year-old Viviani must have felt on his first day as *capomastro* at the service of the *Primo Ingegnere*, Baccio del Bianco, since this was a job heavily charged with operative duties. It is true that Viviani was a skilled mathematician with a clear understanding of hydraulics and engineering at a theoretical level and also knew about the basics of *disegno*, having attended Baccio's school, but being on the field was a totally different business. He was to work side by side with artists and architects who had been in the trade all their life and had an eminently practical education. Members of this closely tied group of multi-skilled craftsmen revolved around the *Accademia del disegno* and the private academies that supplemented its teaching, and filled all the technical positions of the *Magistratura dei Capitani di parte Guelfa*.[18] They were often born into well-connected families, had started their career early, and had perfected their education abroad, travelling with armies or working in the service of court architects. Baccio himself was born in 1604, the son of Cosimo del Bianco, a mercer of the *Arte di Calimala*, the Merchant Guild of Florence.[19] The *Calimala* controlled foreign textile trade and thus was one of the most important Florentine guilds. Their prominent members had important connections to the court and Florentine elites. Cosimo del Bianco was especially tied to influential *Calimala* members Baccio and Domenico Comi, who were also notable members of the *Confraternita dell'Arcangelo Raffaele*, a confraternity that was renowned for their musical and theatrical productions. This put young Baccio del Bianco in contact with the artists/architects that were variously involved in the Florentine theatrical production apparatus. Afterwards he studied with artists Giovanni Bilivert and Vincenzo Boccacci (both pupils of Cigoli), met with artist and architect Giulio Parigi, and ended up, on Bilivert's recommendation, in the service of engineer Giovanni Pieroni. Under Pieroni's guidance, Baccio engaged in mathematics and geometry, about which he would later joke in his autobiography:

[17] See Vivoli, Toccafondi, "Cartografia e istituzioni nella Toscana del Seicento: gli ingegneri al servizio dello Scrittoio delle Possessioni e dei Capitani di Parte", 167-202.

[18] Cf. Guarducci, Azzari (eds.), "Mappe e potere: pubbliche istituzioni e cartografia nella Toscana moderna e contemporanea, secoli XVI-XIX", 29-33.

[19] On Baccio dal Bianco's life, see Thielman, *Baccio del Bianco at the Court of Spain: Early Modern Scenic Design in Context*.

> vistommi innanzi con le pratiche, mi ritirò alle teoriche, dichiarandomi Euclide; che se sudava, se sbavigliavo, Dio lo dica; contrario tanto alla mia natura quello studio, che, con tutto sentissi li 6 libri ben tre volte, sempre quando potevo (non conoscendo potermi servire a nulla), con pratiche mi esercitavo.[20]

In 1620, following the outbreak of the Thirty Years War, Emperor Ferdinand II asked his sister, Grand Duchess Maria Maddalena, to send him a specialist in military fortifications, so Maria Maddalena had Pieroni depart, together with Baccio, who was then 16, for the Holy Roman Empire. After a brief period spent surveying and restoring fortifications in Austria, Bohemia, and Moravia, Pieroni entered the service of Albrecht von Wallenstein and settled in Prague with his family. As Pieroni was often on the road, Baccio was left in charge of Pieroni's household and soon grew bored and unhappy. So he decided to go back to Florence and by 1625 was already in town, seeking a career on his own. His connections, as well as his experience in military engineering, helped him find free-lance works and eventually allowed him to land the position of *Primo Ingegnere* of the *Magistratura dei Capitani di Parte Guelfa* in substitution of Alessandro Bartolotti. As *Primo Ingegnere*, Baccio worked in close contact with architects and artists who, for the largest part, had had life experiences and education similar to his own. People like Ferdinando Tacca and Alfonso Parigi, who worked for the *Magistratura* as *Ingegneri* on several occasions, had all started their career in family workshops (they were sons of Pietro Tacca and Giulio Parigi, respectively) and by the age of 20 had accumulated significant experience on the field. They also shared a common view of *disegno*, and an approach to hydraulic engineering deeply rooted in the practice of the *architetti d'acque*. When Viviani became *Aiuto dell'Ingegnere* in 1644, together with the other *capomastro* Pier Francesco Silvani they joined the *Aiuto* already in service, Giovan Pietro della Bella. Silvani was three years older than Viviani and, as the son and apprentice of famed architect Gherardo Silvani, by the time he became *Aiuto* he had years of training; the same goes for Della Bella, who was the brother of artist Stefano and had been a student of sculptor Pietro Tacca.[21]

So, when Viviani started journeying around the Grand Duchy with Baccio, he needed to acquire a set of skills proper to the *architetti d'acque* that it is unlikely he could have acquired during his peaceful stay with Galileo at *il gioiello*.[22] These were practical skills that needed to be trained and practiced independently from mathematical and philosophical speculations, as they mostly depended on common sense, experience, and received wis-

[20] *Racconto della Vita di Baccio del Bianco scritta da se medesimo al suo carissimo amico sopra ogni altro Signor Biagio Marmi*, 396.

[21] On these artists, see the entries in Baldinucci, *Notizie de' professori del disegno da Cimabue in qua*.

[22] See, in this regard, Jensen, *Engineering and technology, 1650-1750*; Fiocca, Lambertini, Maffioli (eds.), *Arte e scienza delle acque nel Rinascimento*; Romby, *Architetti e ingegneri militari nel Granducato di Toscana: formazione, professione, carriera*.

dom. He had to learn how to draw and take field notes on the go, how to take topographical measures in tricky situations, how to deal with peasants, land-owners, and authorities, and how to find solutions to the big and small complications that could happen along the road. He also had to familiarize with engineering technical vocabulary and slang. His surviving notebook sheets from the 1640s are populated with notes, suggestions, and reminders, perhaps coming from Baccio himself. There are lists of technical terms like *posticciare, ringorgare, imporre, dapporre, argine, scannafosso, scoli di campi*, but also common words and phrases, sometimes with explanations:

> Stiancia è una erba che ha le foglie lunghe strette
> Melma sono quei suoli grandi di terra ricoperti di erbe che galleggiano nelle Chiane sopra le quali si pareggiano pascendovi vacche et altri animali
> Diramarsi di un fiume, cioè dividersi in più rami
> Batter la campagna, cioè far viaggi[23]

On other occasions, Viviani records measurement conversions:

> Le pertiche [di Pescia] sono di b[raccia] 4 di Firenze
>
> 4 pertiche quadre fanno una Scala
> 30 Scale un Quartiere
> 4 Quartieri una Coltra
>
> 2 Staia di seme alla fiorentina seminano una coltra
> 120 pertiche quadre sono una Coltra
> 20 pertiche quadre sono uno Staio fiorentino[24]

There are also instructions on how to measure height at night, notes about which kind of gunpowder is more explosive, lists of places and names, and weekly to-do lists. Most of these notes were very likely taken on the go, as they are hurriedly jotted down with a pencil and in some cases overwritten later in ink with minor revisions. In general, they suggest the image of a diligent, humble young man, willing to learn as much as he can. This image is consistent both with the one Viviani presented publicly,[25] and with the views he expressed in the barely started *Dialogo sulla conoscenza*, where he states that "if you ask what being erudite means, here is the answer: knowing the difference between things, be-

[23] BNCF, Gal. 215, f. 13r
[24] BNCF, Gal. 238, f. 1r.
[25] Viviani to Salviati, cit. note 2, f. 5r-6v.

ing able to demonstrate it and to give a name to each of them. […] The basis of erudition is learning the nomenclature of the things pertaining to art and nature. – Is this difficult? – Yes, it is, if you do it unwillingly, and with a prejudiced mind."[26] The use of extremely precise terminology, moreover, has been recognized as one the characteristic features of Viviani's engineering work.[27]

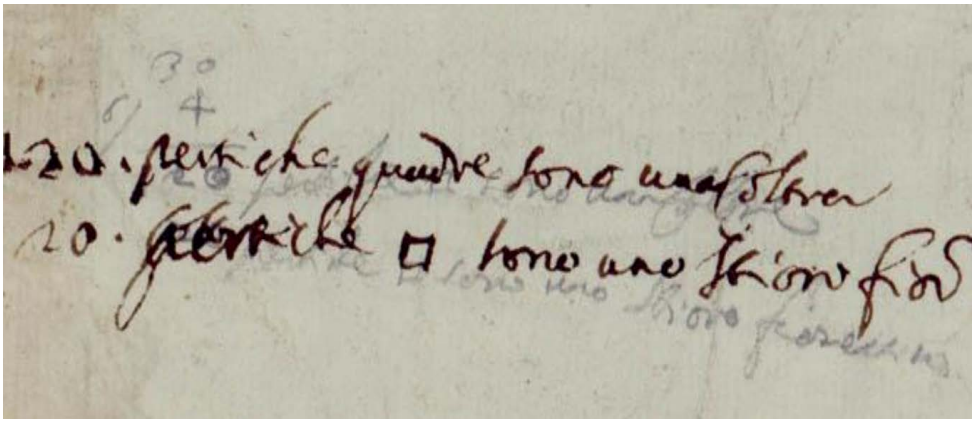

Fig. 1 – Notes jotted down with a pencil and later overwritten in ink, BNCF, Gal. 238, f.1r.

The single most important skill that Viviani needed to master proficiently as *Aiuto dell'Ingegnere* was drawing. It was not until recently that the importance of *disegno* as a crucial field of intersection between science, arts, and craftmanship has been thoroughly investigated, and in the case of Viviani his proficiency in *disegno* appears to be a promising field of study.[28] For the purposes of this paper, however, it suffices to highlight that Viviani needed to master drawing in order to become part of a community that made almost exclusive use of the graphic medium and considered it a fundamental tool for the investigation of the natural world. Members of this community filled technical positions not only of the *Magistratura dei Capitani di parte Guelfa* but of the Grand Duchy in general.

Again, what we find in the notebooks is quite interesting, as it shows us what Viviani deemed important to know about *disegno* both on the practical and theoretical side. He reminds himself, for example, to always use "red pencil or black ink" when sketching, to practice in drawing *vedute* and *paesi*, and to learn how to use colors and shadowing. On a more theoretical level, he notes that there are disciplines he needs to study more: Civil and military architecture, Practical perspective, Mechanics of Moving Machines, Gnomonics,

[26] BNCF, Gal. 156, f. 37r.

[27] Di Fido, Gandolfi, *Idraulici italiani*, 89.

[28] On *disegno*, see Bambach, *Drawing and Painting in the Italian Renaissance Workshop: Theory and Practice, 1300-1600.* On Viviani: Dumas Primbault, *Un galiléen d'encre et de papier*, Ch. 2.

and Repairing water damage (*Ripari d'acque*). To this end, he plans to write compendia of Practical geometry, Mechanics, and Fortifications, and to learn how to build scale models of machines.[29] This training program is fully consistent with Baccio's working practice and, more generally, with the conceptions and ideas of the new generation of artists and technicians revolving around the *Accademia del disegno* and the private academies, like Baccio's own school, that supplemented the practical training programs offered by the *Accademia* with theoretical ones influenced by Galilean science.[30] It is telling, in this regard, that Viviani mentions works by Galileo (the *Bilancetta*), Cigoli, Pieroni, and Baccio as reference-books.[31]

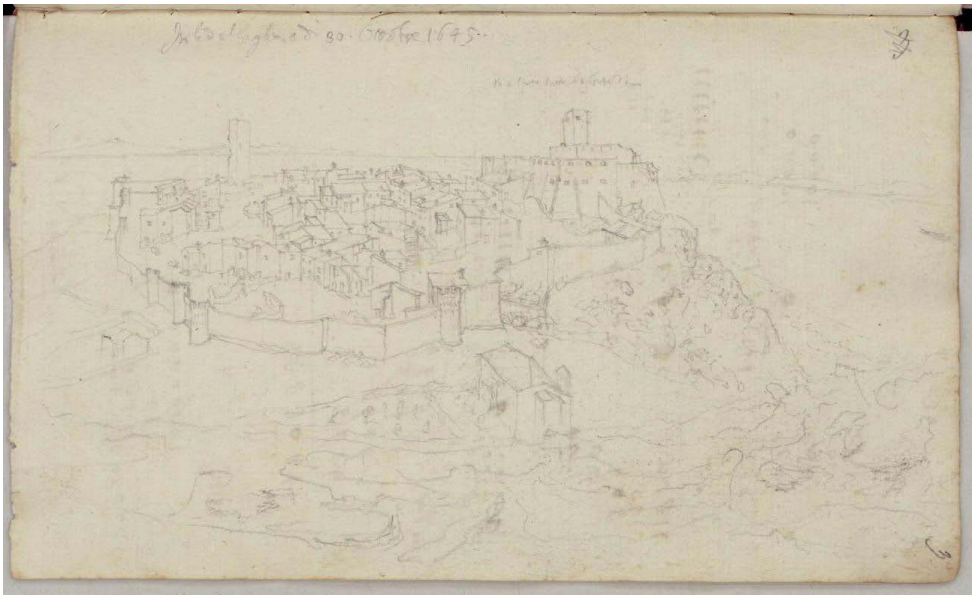

Fig. 2 – A *veduta* of Isola del Giglio, pencil on paper, October 30, 1645, BNCF, Gal. 239, f. 3r.

Mastering *disegno* would not only provide Viviani with a basic skill, but would also shape his whole attitude towards mathematics and engineering, making him a full member of a community that, while influenced by Galilean science, was nevertheless informed by ideas coming from Leonardo da Vinci, Leon Battista Alberti, Vasari, and maintained a clear distinction between the *teoriche* and the *pratiche*.[32] With his appointment as *capomastro*, Viviani was entering a world that would force him to negotiate not only between

29 BNCF, Gal. 215, ff. 17r-17v. Viviani also drafted compendia on mechanics and fortifications.
30 Magureanu, "Baccio del Bianco and the cultural politics of the Medici court", 22-24.
31 Dumas Primbault, *Un galiléen d'encre et de papier*, Ch. 2.
32 BNCF, Gal. 215, f. 17v.

epistemological perspectives and practices but also, on a more profound level, between personal desires and public duties.

This is all the more evident if we look at the initial tasks Viviani was expected to perform. As *Aiuto dell'Ingegnere,* during the 1640s he was always busy sketching drawings and maps, taking measures of the surveyed sites, doing calculations, and instructing laborers. All these tasks should be performed on the spot, and so efficiency was often more appreciated than mathematical rigor. He was also in charge of keeping track of the meetings with land-owners and representatives of the local communities, something that was of no concern to the *matematici* and would define Viviani's peculiar approach to hydraulics as compared to that of Galileo's other disciples. While both Castelli and Torricelli were routinely summoned to provide advice on engineering issues and were even sent on occasional on-site surveys, neither of them had to deal with the actual realization of engineering works on a daily basis: once a project was approved, its realization was left to technicians. Viviani, on the contrary, soon found out that this was perhaps the most awkward, demanding, and time-consuming part of the profession. Conflicting interests could undermine, or even reverse, the expected effects of an engineering project, especially if the engineers themselves were prone to surrender to external influences or were unwilling to personally oversee its implementation and execution. As Viviani would explain to Salviati in 1697, an engineer must be "a righteous, impartial, selfless, and truthful man," and above all "must personally follow the execution of the projects until they are completely finished."[33]

Rethinking engineering: Viviani and the Ombrone

By 1650, Viviani was skilled enough to work independently on sub-projects, manage map-making, and write *relazioni* and *pareri.* One the first major works he was actively involved in was the accommodation of the Ombrone Pistoiese river, a project that would end up occupying most of his professional career and contributed decisively to shape his views about hydraulic engineering. In 1644 the river had flooded its banks causing extensive damage to the lands, some of which were property of Ferdinand II. Emergency measures taken by Baccio del Bianco proved ineffective, as more floods occurred in subsequent years, and so in 1647 Ferdinand II decided that a long-term global intervention program was needed.

The matter was by no means simple. The Ombrone originates from the Tuscan-Emilian Appennine and is fed by tributaries that significantly increase its flow downhill into the Arno near Carmignano. Even though the Ombrone was neither as politically sensitive as the watershed between the Arno and Tiber in Valdichiana, which marked the boundary

[33] Viviani to Salviati (cit. note 2), f. 8v.

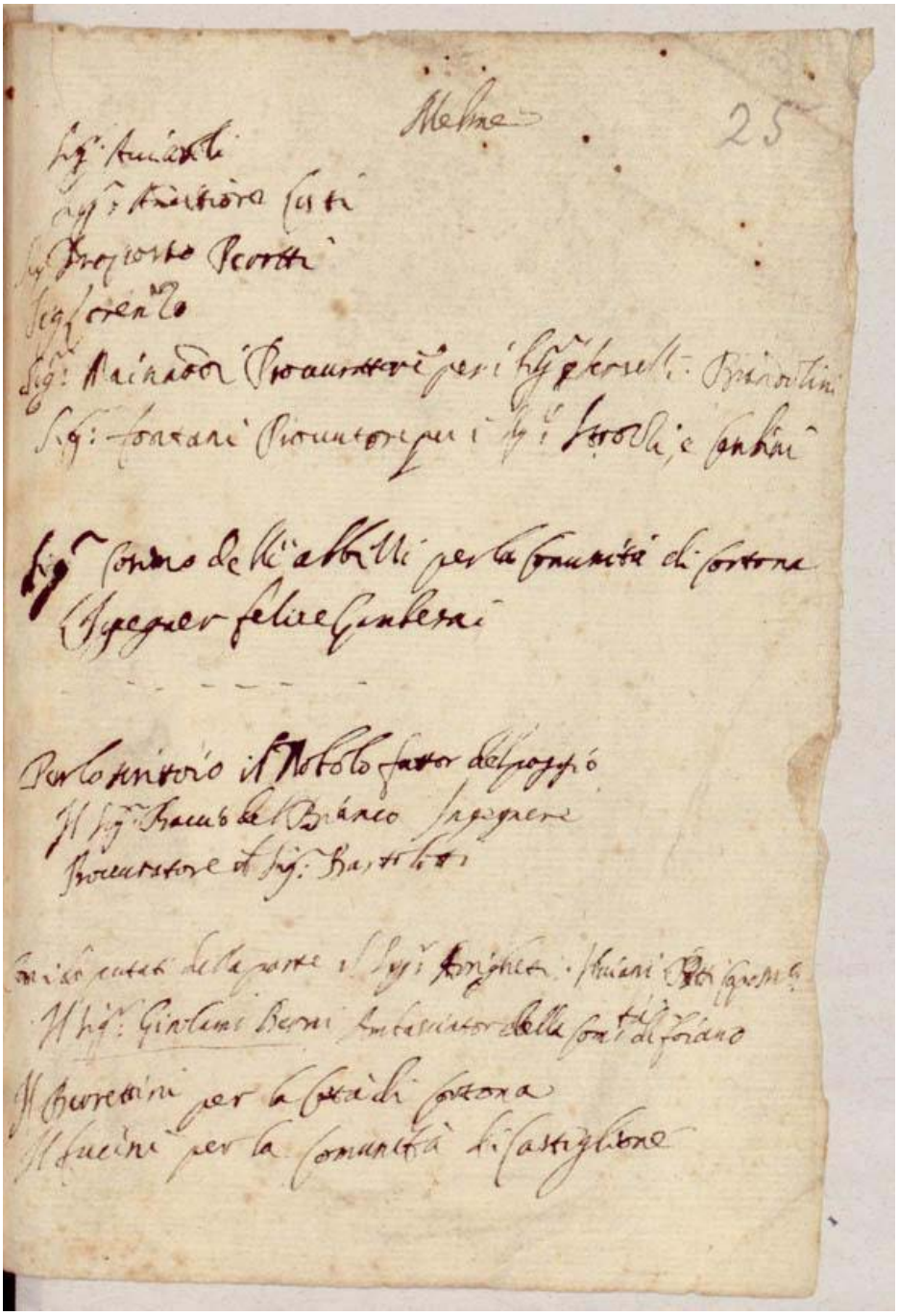

Fig. 3 – Record of a meeting with landowners, BNCF, Gal. 215, f. 24r.

between the Grand Duchy of Tuscany and the Papal States, nor as economically significant as the diversion of the river Reno, which gave rise to endless controversies between Bologna and Ferrara,[34] it presented nonetheless a number of challenges on both sides, since it traversed State-, town- and private-owned lands in the territories of Pistoia, Firenze, and Prato, and farming along its banks was intensive. So, when the engineers started working around 1650, they envisioned works that were to impact significantly the economic life of the local communities. They planned to remove weirs, demolish mills, increase bank resistance by tree planting on farmland, and so on, sparkling protests and controversies since the involved parties were required to pay for the works. Moreover, there was the issue of jurisdiction, which was addressed for the first time in 1649 with the creation of a council of three *Giudici delegati* (the secretary of the *Pratica di Pistoia*, a member of the *Magistratura dei Capitani di Parte Guelfa*, and the *Provveditore*), who worked together with the *Ufficiali dei fiumi*.

Viviani's notes from 1650 report about the situation of the Ombrone with drawings, measures, calculations, suggestions, and details about boundaries and quotas. They show how "Galileo's last disciple" had become fully acquainted with the engineer's work routine and methods,[35] and how by then he had already started to realize that the main problem of the Tuscan fluvial system was a generalized riverbed rise mostly due to poor environmental management.

This view is further developed in a *relazione* addressed to the Grand Duke Cosimo III in 1679. By then, the controversies between State officials and landowners, as well as those between the authorities involved in the Ombrone management, had reached a peak, forcing the Grand Duke to issue a *motu proprio* that granted State auditors Ferrante Capponi and Giuseppe Orceoli the authority to settle controversies and disputes. In the *relazione*, Viviani claims that the main reasons behind the unsolved issues of the Ombrone are due to both art and nature. The 'artificial' issues are "negligence, poor maintenance of the banks, transgression of the law […], and greed as well;" the 'natural' one, instead, is a generalized riverbed rise that originates in tributaries, trickles down on the Ombrone and, eventually, impact the Arno itself. While there are technical solutions for the 'natural' issues of the Ombrone, they can be effective, Viviani argues, only after having properly addressed the artificial ones. Thus, Viviani suggests, the Grand Duke should promulgate strict and clear ordinances and have them enforced tightly. It would be of no use, Viviani claims, to invest money in restoration works if the owners and tenants can destroy them for their own inter-

[34] On the watershed between Arno and Tiber in Valdichiana, a matter that at some point involved Viviani as well, see Corsini, *Ragionamento istorico sopra la Valdichiana, in cui si descrive l'antico, e presente suo stato*, 45-61. On the Reno: Maffioli, "La controversia tra Ferrara e Bologna sulle acque del Reno: l'ingresso dei matematici, 1578-1625", 239-267; Lugaresi, *Idrodinamica e idraulica. Le Raccolte sul moto delle acque. La questione del Reno*.

[35] BNCF, Gal. 238, ff. 14r-26v.

est without fearing prosecution, or if they are allowed to ignore laws preventing clearcutting and weir-building.[36]

Lack of proper legislation had always been one the main factor impacting the river management policy of the Medici, preventing them from adopting a global approach even after the entire Arno basin fell into their dominion.[37] This often would often result in conflicts of competences between engineers, state officials, and mathematicians. Viviani had just been appointed *Aiuto dell'Ingegnere* when a most-publicized and bitter dispute erupted between Famiano Michelini and Evangelista Torricelli about the reclamation of Valdichiana,[38] and was to experience himself how this kind of arguments could led to institutional and operative *impasse* in 1651, when he was instructed, together with his fellow *Aiuti* Annibale Cecchi and Pier Francesco Silvani, to provide a *parere* about the best way to reinforce the Arno banks near Rovezzano, where the river had flooded in 1647. Relying on the opinions of Baccio and Torricelli, Viviani and his partners proposed to build riverbank protection structures and dig a drainage ditch. The project was rejected by the *Ingegnere dei Fossi* responsible for the area, Stefano Marucelli, who chose a less-expensive plan drafted by Alfonso Parigi and Francesco Nave instead. However, at this point the *Ufficiali dei fiumi*, Baccio Manetti and Domenico Dazzi, weighed in, rejecting both projects and putting everything on hold. It was not until years later, when Viviani became *Sovrintendente* for the area, that he would be able to realize at least part of his original plan.[39]

The case of the Ombrone is illuminating, in this regard, as it made clear, to Viviani, the difference between being a *matematico* and being an *ingegnere*. In 1666, Viviani had been officially dismissed from his office as *Primo Ingegnere* but he was still expected to serve as "consultant on important matters" – an euphemism used in the Grand Duke's *motu proprio* to signify that Viviani was to work as usual but would be spared some journey. In 1678, then, he was sent to inspect the area between Prato and Pistoia, damaged again by a flood of the Ombrone. After the visit, Viviani wrote the *relazione* of 1679, which was approved by Cosimo III in 1681. The provisions Viviani proposed, however, were not fully implemented, first because landowners acted in court against Viviani's project and then, when the legal matter was settled by direct authority of Cosimo III, because the *Ingegnere* charged with the material execution of the works – Giuliano Ciaccheri, a disciple of Viviani – was sent elsewhere to take care of more urgent matters. To replace Ciaccheri,

36 BNCF, Gal. 235, ff. 169r-182v.

37 See Ferretti, Turrini, *Navigare in Arno. Acque, uomini e marmi tra Firenze e il mare* The *Bandi* (laws) issued between 1485 and 1737 are collected in Cascio Pratilli, Zangheri (eds.), *La legislazione medicea sull'ambiente*.

38 See *Raccolta d'autori italiani che trattano del moto dell'acque*, IV, 65-164. On the *Raccolta*, see Lugaresi, "Le raccolte italiane sul moto delle acque", 201-304.

39 See Targioni Tozzetti, *Notizie degli aggrandimenti delle scienze fisiche accaduti in Toscana nel corso di anni XL del secolo XVII*, vol. III, 284-298.

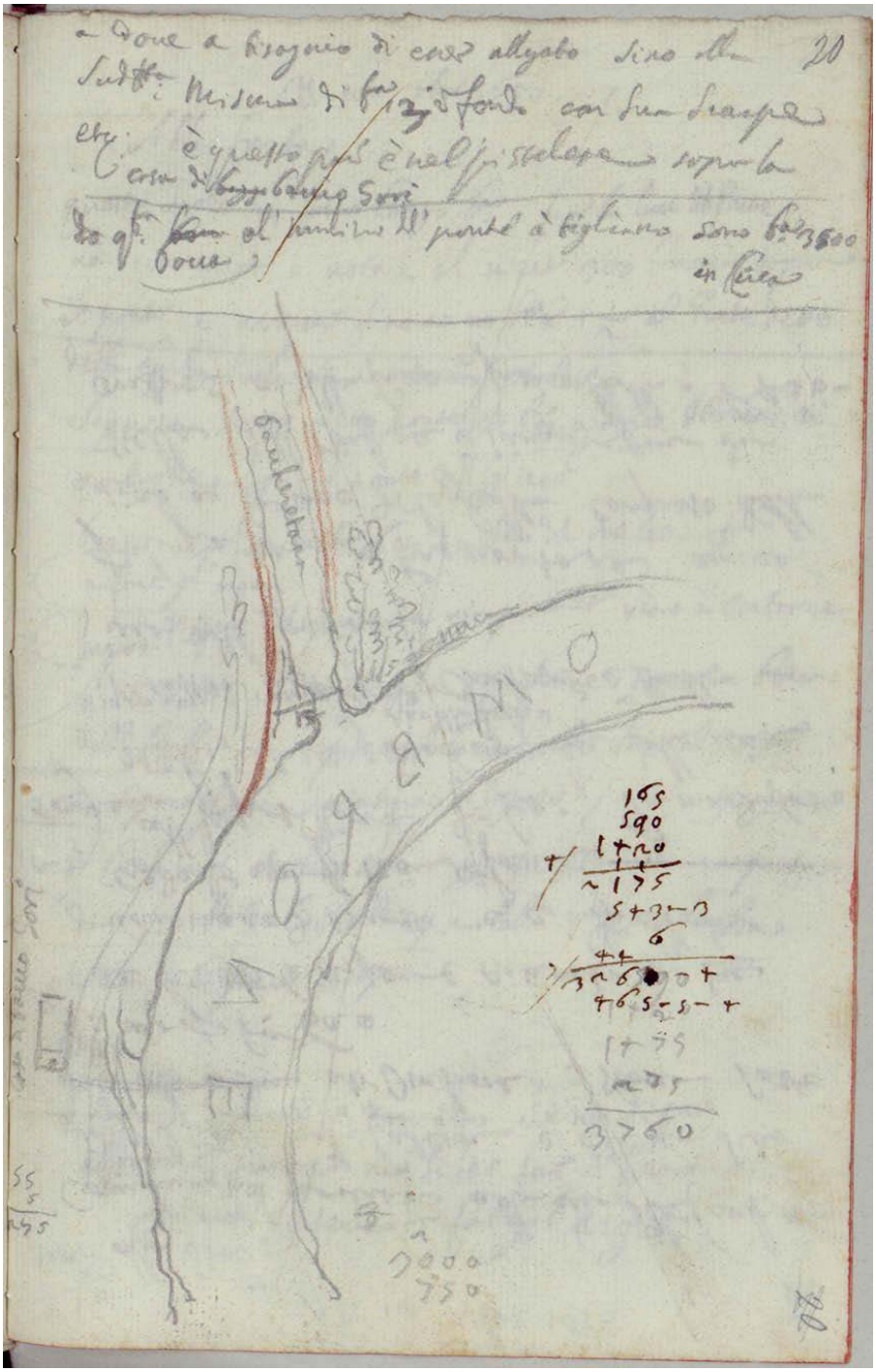

Fig. 4 – Studies on the Ombrone, 1650, Pencil and ink on paper, BNCF, Gal. 238, f. 20r.

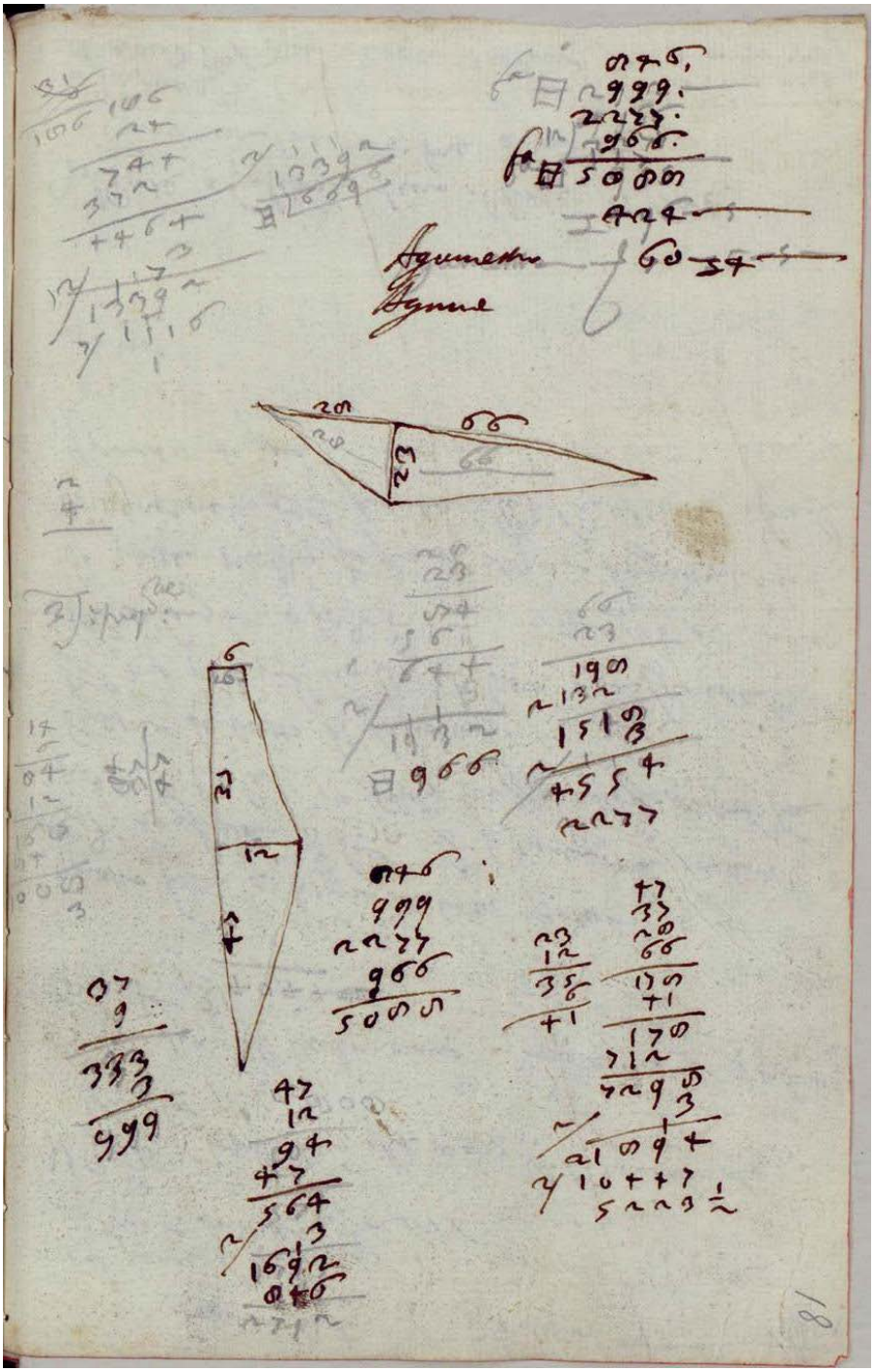

Fig. 5 – Studies on the Ombrone, 1650, Pencil and ink on paper, BNCF, Gal. 238, f. 18v.

the *Capitani* appointed Viviani's former colleague Pier Francesco Silvani, who, after several studies and with full approval from the *Sovrintendente*, decided to modify the original plan. The works planned by Silvani were finished in 1686: the main constructions were a new *Ponte di riboccatura* and a smaller bridge on the Elzana stream personally designed by Viviani, in homage to Galileo, as a single cycloidal-arched bridge.

In 1702 representatives of the town of Scarperia and other local communities filed a lawsuit against those in charge of the project – Viviani included – on the claim that the new *Ponte di riboccatura* was barely useful and that the expenses they had sustained were higher than they should have been according to the *imposizioni*, so they asked for a full reimbursement. The memoir that Viviani presented in his defense that same year 1702 can be read as a concise summary of what, according to him, was wrong with the profession. First of all, Viviani remarked, he was officially only a consultant, and thus could not be held accountable for works that are responsibility of the *Primo Ingegnere*. Secondly, in 1678 he had made clear what the cost of the works would be, and his project had been fully approved by the Grand Duke. Moreover, the plan that was actually realized was not his, but Silvani's, and the costs of the new works had been repeatedly approved by the *sovrintendente* Barberini. Finally, the local communities were contesting the work and judgment of two professionals like Ciaccheri and Silvani without providing evidences or calling expert opinions in support.[40] To Viviani, it was absurd and frustrating that, after more than fifty years, the Ombrone matter was far from being resolved, even if technical issues had been identified and addressed. He was acutely aware that engineering needed to be grounded on new institutional and legislative basis–an awareness made all the more acute by the fact that he didn't want to be an engineer. In this perspective, his insistence on tight regulations, economic planning, prevention, and good maintenance can be regarded as an attempt to free engineering from external, time-consuming duties that, in the end, prevented engineers from doing their job, that is, "putting their propositions into executions."[41]

Negotiating Galileo's legacy: Viviani and the Bisenzio

When Baccio del Bianco left for Madrid in 1653, Andrea Arrighetti, from his influential position as *Provveditore*, managed to create for Viviani the office of *Sostituto dell'Ingegnere* – an office that never existed before and would never exist anymore after Viviani – so that, at Baccio's death in 1656, the confirmation of Galileo's last disciple in the position of *Primo Ingegnere* was just a matter of bureaucracy.[42] This appointment, masterfully orchestrated by Arrighetti, marks a turning point in the institutionalization of Galilean science, all the

[40] The whole affair is reported by Viviani in his defensive memoir. BNCF, Gal. 235, ff. 208v-213r.
[41] BNCF, Gal. 235, f. 208v.
[42] Andrea Arrighetti to Ferdinand II, BNCF, Gal. 155, f. 27r.

more so because, in 1666, Viviani was also nominated *Matematico* of the Grand Duke, and so for the rest of his life he held at the same time the highest technical office in the *Magistratura* and one of the most important consultancy position at the court. Viviani crucially restructured the technical staff of the Grand Duchy, gradually putting an end to the era of the practically-trained adventuristic artist-architect, who was replaced, in the office of state engineer, by professional figures with a solid background in mathematics who operated according to standardized working routines.[43] On the other side, Viviani also contributed to reshape the role of the *Matematico Granducale*, at least for the consultancy part related to engineering. Even when written from the *Matematico*'s position, Viviani's *pareri* are always detailed to the extreme and informed with economic, geographical, geological, sociological, and historical concerns. Engineering issues are never addressed from a purely theoretical perspective – in fact, the theoretical perspective is almost nonexistent. Viviani never wrote *pareri* similar to those written by Galileo on the Bisenzio in 1630 and Castelli on the Venice lagoon in 1641[44] – that is, 'mathematical' reports written without having carefully surveyed the area to take into account its geomorphological, historical, and socioeconomic features: he wrote as *Matematico* pretty much in the same way as he wrote as *Primo Ingegnere*.[45]

All these, I think, should make us problematize the common assuption that, with Viviani, the *matematici* replaced the *architetti d'acque* as state officials in charge of engineering. From this perspective, the main question is: in which sense, by the time he became *Primo Ingegnere*, Viviani was a *matematico* of the Galilean school? The question is more complex than it may appear at first sight. If we look at Viviani's published writings on hydraulics, we notice that they are almost completely devoid of mathematics – a striking circumstance, even if we take into account that they were intended as non-technical writings. The *Discorso al Serenissimo Cosimo III Granduca di Toscana intorno al modo di difendersi da' riempimenti e dalle corrosioni de' fiumi applicato ad Arno in vicinanza della città di Firenze*, published in 1688, in fact contains just two references to mathematics, with one being an explanation of why the bridge on the Elzana stream is designed as a homage to Galileo. Viviani argues his main point – the riverbed rise of the Arno – by means of on-field observations, historical evidences, and conclusions derived from the *architetti d'acque* expertise. There is no reference to the Galilean science of motion or to Castelli's mathematical treatment of hydraulics: without knowing beforehand that the treatise is written by Galileo's last disciple, a reader might as well wonder if the author knows anything at all about Gali-

[43] See Vivoli, Toccafondi, "Cartografia e istituzioni nella Toscana del Seicento: gli ingegneri al servizio dello Scrittoio delle Possessioni e dei Capitani di Parte".

[44] On Castelli's report, see Omodeo, Trevisani, Babu, "Benedetto Castelli's *Considerations on the Lagoon of Venice*: Mathematical Expertise and Hydrogeomorphological Transformations in Seventeenth-Century Venice", 420-446.

[45] Viviani always signed his *pareri* and *relazioni* as *Matematico* from 1666 onwards.

leo's new science of motion and Castelli's hydraulics.[46]

Moreover, if we look closely at Viviani's approach to hydraulic engineering we can see how Galileo's last disciple is also the one who more often departed from the master's advice of being cautious about straightening rivers.[47] The practice of *raddrizzamenti* – diverting waters in a new bed running in a straight line – was not really popular among the followers of the Galilean school of hydraulics. Forcing a river outside its 'natural' bed, Galileo argued on mathematical grounds, was a costly operation of dubious efficacy. Castelli, for his part, remarked that it was risky, too, and could be disastrous if undertaken without a precise quantitative cognition of the river flow. The *raddrizzamenti*, however, were commonly practiced by the *architetti d'acque*, who did not share the *matematici*'s 'philosophical' concerns about the 'unnaturality' of the operation, and grounded their opinion on the common-sense observation that the absence of bends prevents the accumulation of sediment and, thus, floods.[48] Moreover, the *raddrizzamenti* could make a river navigable. During his career as engineer, Viviani realized several *raddrizzamenti*, both on the Ombrone and on the Bisenzio, the very river that, according to Galileo, did not need to be straightened. What is interesting, though, is that Viviani favored the practice because it allowed to gain cultivable lands – in other words, for him the *raddrizzamenti* were part a general environmental management policy that featured the human element as a crucial part of it.

On the other side, if we look at Viviani's unpublished theoretical writings on hydraulics, while we can have little doubts about his trust in Galileo, Torricelli, and Castelli, we can also see how Viviani was working on an alternative approaches to problem of water measurement.[49]

A convenient starting point for addressing the question is looking back at the controversy over the Bisenzio of 1630-1631, which involved Galileo and, significantly, also Andrea Arrighetti, Viviani's future patron at the Medici court and within the *Magistratura*. As is well-known, the controversy arose after a disastrous flood of the Bisenzio, when residents of the area east of the river addressed a petition to the Grand Duke asking for the intervention of a state engineer. Ferdinand II instructed the *Ufficiali dei Fiumi*, and they in turn entrusted the *Primo Ingegnere*, Alessandro Bartolotti, with the matter. After surveying the area, Bartolotti presented an ambitious and controversial plan: fixing the

[46] Cf. Viviani, *Discorso al Serenissimo Cosimo III Granduca di Toscana intorno al modo di difendersi da' riempimenti e dalle corrosioni de' fiumi applicato ad Arno in vicinanza della città di Firenze*. See also Dumas Primbault, *Un galiléen d'encre et de papier*, Ch. 4.

[47] See Barsanti, Rombai, "La politica delle acque in Toscana: un profilo storico", and Barsanti, "La scuola galileiana, sec. XVII", 1-42 and 43-68.

[48] See Menduni, "Alcune considerazioni sulla evoluzione storica recente dell'Arno fiorentino e la relativa narrazione", 31-33.

[49] Maffioli, *Out of Galileo: The Science of Waters, 1628-1718*, 193-195; Gottardi, Bugini, Camprini, Manferrari, "Aspetti della tradizione scientifico-tecnica idraulica bolognese", 69-70.

Fig. 6 – Viviani's *raddrizzamento* of the Ombrone (detail), 1700-1710, ink and watercolors on paper, Archivio di Stato di Pistoia, Deputazione sopra l'Imposizione del Fiume Ombrone, Cartoni e mappe.

Bisenzio issue once and for all by diverting the lower half of the river in a new bed that would run straight into the Arno. The plan was fiercely opposed by landowners west of the river, since while the problem was on the east bank of the Bisenzio, the new bed was to be realized in the west area of the plain, in their lands, and therefore according to the *imposizioni* it was them who were to pay the extraordinary sum of 15000 scuds estimated by Bartolotti for the realization of the work. So, they appointed an engineer, Stefano Fantoni, to argue against Bartolotti's plan. As both parties featured prominent Florentine families, the matter soon became a public affair, and then the Grand Duke decided to have his *Matematico*, Galileo Galilei, provide a *parere*. Galileo strongly opposed Bartolotti's plan, and recommended to just clean out the sediment from the bends as often as possible. As Richard S. Westfall has argued, the Bisenzio controversy is notable because it shows the ambiguous relations between "science and technology during the early stages of scientific revolution"[50]: while Bartolotti's common-sense approach and analysis makes sense, his solution was like "smashing a peanut with a sledgehammer".[51] On the other hand, Galileo's solution, though undoubtedly better "from the standpoint of modern hydraulic engineering," is derived from a misleading, abstract geometrical reasoning that "does not impress when set beside Bartolotti's conviction, born of experience, that something does happen in streams as they are forced around bends."[52]

50 Westfall, "Floods along the Bisenzio: Science and Technology in the Age of Galileo", 905.
51 *Ibid.*, 890.
52 *Ibid.*, 893.

What is interesting for the purposes of this paper, however, are not the details of the arguments brought about in the controversy, but instead the circumstance, pointed out by Cesare Maffioli, that the long theoretical discussion of the science of motion featured in Galileo's report about the Bisenzio seems to be a reply to Andrea Arrighetti rather than to Bartolotti.[53] Toward the end of 1630, after the controversy over the Bisenzio had become public, it also became a matter of discussion between the two cousins Andrea e Niccolò Arrighetti.[54] They were both friends of Galileo, knew about his new science of motion and totally agreed with it, yet on the Bisenzio they were on opposite sides: while Niccolò opposed Bartolotti's plan, Andrea favored it. They exchanged letters, and in the end, since they could not find an agreement, got in touch with Galileo.

The interesting thing in Andrea Arrighetti's position is that, as Cesare Maffioli notes, he managed to craft Bartolotti's point of view in 'galilean' fashion. More importantly, Arrighetti insisted on the fact that, as mathematically sound as they were, Galileo's and Niccolò's arguments were too far removed from reality:[55]

> Torno a dire a V.S. che non metto in dubbio nel dimostrato da S.re Galileo […] ma non voglio già concederli per questo che lo facci né l'aqqua né altro mobile se non nella maniera che suppone il S.re Galileo, cioè rimossi tutti gl'impedimenti. Però se non insegnia la maniera del rimuovere gl'infiniti impedimenti che possano impedire e trattenere lo scorrere di detti mobili o fiumi per detti canali, non mi sento strignier in maniera che sia per mutarmi d'opinione. […] Però torno a dire a V.S. che mi pare che equivochi fortemente nel supporre che nello scorrere detti fiumi e mobili per detti canali sieno rimossi tutti gl'impedimenti, perché in praticha è impossibile il fare tale cosa […].[56]

Arrighetti's view is important not only because it acknowledges the crucial role of resistance in this particular matter, but also because, from a more general perspective, hints at his conviction that the new science of motion, in order to be successfully applied to material endeavors, must take into account all the "accidents" of a situation. This is suggested also by Arrighetti's correspondence with Castelli of the mid 1630s about the construction of a channel to take waters from Monteriggi to Palazzo Pitti: while Arrighetti sought mathematical advice from Castelli, he took upon himself the task of figuring out the *accidenti* e *impedimenti* that should be taken into account in order to successfully implement the project.[57] From this perspective, for Arrighetti, the on-field, common-sense expertise of the old-fashioned *architetti d'acque* could be critically reviewed, but not totally obliterated.

[53] Maffioli, "Galileo, Guiducci and the engineer Bartolotti on the Bisenzio river", 194.
[54] On Andrea Arrighetti, see the entry by Mario Gliozzi in *Dizionario Biografico degli Italiani.*
[55] Maffioli, "Galileo, Guiducci and the engineer Bartolotti on the Bisenzio river", 190-193.
[56] Andrea Arrighetti to Niccolò Arrighetti, December 16, 1630, OG, vol. XIV, pp. 185-186.
[57] Cf. BNCF, Gal. 126, ff. 4r-14v.

Arrighetti played a fundamental role in the institutionalization process of Galilean science. He not only campaigned for Viviani's appointment as *capomastro*, but, as Viviani himself reports, also sponsored that of Torricelli as *Matematico Granducale*.[58] In the case of Viviani, the appointment appears instrumental in the creation of a technical staff of engineers who, while firmly rooted in Galilean science, were also familiar with the traditional expertise of the *architetti d'acque*. As seen from the bottom end, the institutionalization process of Galilean science appears as a matter of including the practical wisdom of traditional engineering into the new science of motion spread by the *matematici* through teaching, theoretical writings, and consultancy work. Consequently, it is my opinion that, by the time Viviani became *Primo Ingegnere*, he was no longer a *matematico* in the same sense as Castelli and Torricelli were, but his views on engineering had been profoundly shaped by his apprenticeship with Baccio and were by then aligned with Arrighetti's idea of the role of the *Ingegnere*. When he took the highest technical office, Viviani had already realized that the *Ingegnere* is a specific professional figure whose peculiar expertise is the result of a subtle negotiation between those of the *matematici* and those of the *architetti d'acque*, in the sense envisioned by Arrighetti.[59]

That this may be the case is suggested, first of all, by Viviani's recruitment policy. Viviani turned his own career path into a curriculum, and between 1654 and 1666 *de facto* transformed the technical office of the *Magistratura* in a practical school of engineering. By the late 1670s, the technical staff of the *Magistratura* consisted mostly of young professionals who, after having studied mathematics (with 'Galilean' teachers – sometime Viviani himself or his substitutes at the *Accademia del Disegno*), went on the field as *capomastri* and *Aiuti* to complete their education by dealing with the *accidenti* and *impedimenti*.[60] When they started working as *Ingegneri*, they adopted Viviani's approach, and on some occasion took it to the next level: in 1691, Giuliano Ciaccheri (one of Viviani's favorite disciples and close collaborators) presented an ambitious plan for the *raddrizzamento* of the Vingone river that Viviani himself rejected as too extreme.

Another element that points us towards the same conclusion is Viviani's understanding of the distinction between 'pure' and 'applied' mathematics – a distinction that over time would become, on a personal level, an unbearable separation. More than an ontological difference between a 'platonic' and a 'material' mathematics, for Viviani the distinction is functional, and resembles the modern distinction between research and operative work. The *matematici* engage in *speculazioni*, that is, they work with abstract principles in a fictitious, ideal world where it is assumed that the *infiniti impedimenti* and

58 OG, vol. XIX, 626.

59 The circumstance that Viviani agreed with Arrighetti, rather than with Galileo, was already noticed by Caverni. Cf. Caverni, *Storia del metodo sperimentale in Italia*, 184.

60 See Vivoli, Toccafondi, "Cartografia e istituzioni nella Toscana del Seicento: gli ingegneri al servizio dello Scrittoio delle Possessioni e dei Capitani di Parte".

accidenti can be successfully removed.[61] In this regard, Viviani's unfinished theoretical manuscript on hydrometry, the *Sogno idrometrico*, is illuminating. The rhetorical framing of the treatise is somewhat bizarre and out-of-fashion, even for Viviani's times: the treatise is an *adempimento* (solution) of the problems borne out of a dream that Viviani had during his five-months stay in Rome, on leave from his official duties and free to pursue *speculazioni*. The dream is reported in a letter of June 15, 1690, addressed to Gian Gastone de' Medici, that was likely to serve also as a dedicatory letter or preface to the treatise. In the dream, young Viviani is guided by Galileo through an allegorical fantasy place. At some point, the two reach a heptagonal building. They go inside, and see that at each angle there is a statue:

> La prima alla mia sinistra, dicevami il Galileo, che n'era pratico […] esprimeva l'Amor della Verità. L'altra incontrole a destra, il Buon Genio. La terza in seguito della prima la Arimmetica, la quarta oppostale l'Astronomia. La quinta accanto alla Arimmetica era la Musica, la sesta dall'altra parte la Meccanica e l'ultima in sesta fece arrossir quel buon Vecchio [*Galileo*], e me rallegrare, perché in luogo d'un Archimede ch'egli vi aveva veduto prima, vi era sostituito il suo proprio simulacro.[62]

Once explained the meaning of the statues, Galileo takes Viviani to the center of the building:

> Fattomi così prima riconoscere il giro interno del Tempio condussemi il Galileo verso il mezzo di quello spatiosissimo ettagono, dove era in cerchio formato un gran chiuso di una bizzarra balaustrata composta d'innumerabili figure solide geometriche d'alabastro orientale, alcune delle quali io riconobbi, ma le più mi giunsero nuovissime. Dentro di questa vedevasi in eminenza una alta vasca concentrica ma in forma triangolare equilatera, tutta anch'essa d'un pezzo e di quella pietra che noi chiamiamo Amianto, atta a resistere a ogni gran fuoco. Nel centro sopra ad un gran piedistallo cubico di diamante tersissimo, stava eretta una statua maravigliosa, la qual possanza, a giudizio mio, al par delle ginocchia di que' circostanti Colossi. Questa rappresentava la Geometria in aspetto di una fanciulla di sovrumana bellezza cavata con mirabil magistero da una sola lucidissima Agata. Ma quello ch'io non potei mai comprendere si fu che al moto che noi facevamo dalle parti di quella balaustrata, non so con qual arte, ella ridente teneva fissa la faccia sua verso di Noi. Co' pollice et indice d'ambe le mani (le quali con avvenenza e grazia mirabile sporgeva dal petto in fuori) sosteneva al di sotto un perfetto globo di vera e d'ottima Calamita, dal di cui polo inferiore pendeva aderente ad una punta un gran Tetraedro di e pulitissimo acciaio. Le cingeva la testa una superba corona tempestata di gioie a me incognite, e nella falza o

[61] See Dumas Primbault, *Un galiléen d'encre et de papier*, Ch. 7.
[62] BNCF, Gal. 224, ff. 8r-8v.

> fascia della sua splendidissima vi si leggeva a caratteri accesissimi: *Undique singulis semper eadem.* [..] La Vasca poi, a quanto riferivami il Galileo, era piena in giro d'oro fuso finissimo, indeficiente, e convien veramente che così fosse, perché da' tre angoli della Vasca, vedevasi quello traboccar in gran copia, e profondarsi, senza sapersi dove, né da qual vena o sorgente e' pervenisse.[63]

Then, on the three sides of the basin, Viviani reads, in the form of *enigmi*, the hydrometric problems addressed in the *adempimento*.[64] Encouraged by Galileo, who explain that Viviani has at his disposal everything he needs to solve the *enigmi* (namely, Galileo's *teoremi della scientia del moto*), Galileo's last disciple, on his waking up, immediately sets to work.

The problems addressed in the *Sogno idrometrico* actually derived from water measurement experiences carried out by Viviani while in Rome, but what is interesting in the *Sogno* is the choice, which Viviani himself recognizes as out-of-fashion,[65] to use such elaborate metaphors and allegories to introduce his work. Viviani penned this dantesque fantasy in his spare time. Upon his return from Rome, he had been instructed by the *Congregazione* in charge of the Bisenzio, of which he was a member as *Matematico*, to embark on a survey of the river, as the situation had further deteriorated. So, starting from June 1691, the 69-year old Viviani was on the field again, with pencil and notebooks in his hands, like when he was a 20-year old *Aiuto*.[66] In the plain near the Arno, sediment had accumulated in the bends; moving towards Prato, riverbanks were in ruin; and in Prato there was an ongoing, decades-long litigation between landowners about the works to be done on the channels. In the end, an ambitious and expensive plan featuring major *raddrizzamenti* was approved.[67] It is interesting to observe how Ciaccheri and the *Giudici* of the *Congregazione* explained the matter of *raddrizzamenti* in the *Relazione* they sent to Viviani for approval. It seems as if they were careful to not be too harsh on Galileo's last disciple:

> Portatisi alla Visita del Fiume Bisentio i Giudici di S.A. con l'assistenza degl'Ingegneri Ciaccheri, e Ramponi, e Ministro Palloni e altri, principiando dal suo sbocco nel Fiume Arno, et in andarlo scorrendo si è riconosciuto, che il medesimo si trova in stato molto ristretto e pieno di tortuosità con avere ancora le sue ripe piene di varie sorte di Posticce, consistenti in legname, grosso e minuto, quale gli cagionano ritardamento della Corrente, e acquisto di Ripa con rodere la parte avversa, e simili sconcerti. Per provvedere a questo disordine si

63 BNCF, Gal. 224, ff. 8v-9r.

64 Actually, in the dream Viviani manage to see only two *enigmi*, as he is awakened by his servant before seeing the third one.

65 BNCF, Gal. 224, f. 11r. "I moderni analitici si contentano di meno assai".

66 See BNCF, Gal. 232, ff. 4r, 33r.

67 On the works on the Bisenzio, see Lambrini, Lazzareschi, *Campi Bisenzio: documenti per la storia del territorio*, 209-263.

è fermato destinarli la sua larghezza parte parte, come la medesima si è notata su la Pianta, che cavata ora modernamente s'aveva con noi, e rimarcarla quivi con due linee, che si sono andata tirando per il Corso permanente del Fiume, con facilitar la sua dirittura, in passarla per quei gomiti, che evidentemente si riconoscono acquisti, questa terminazione poi si è ancora accennata su la propria Ripa di Fiume con alcuni paletti piantati nelle rivolte, et Angoli dell'istesse tortuosità […].

Poco giovano gli addirizzamenti in riguardo di loro solito grave dispendio, ma perché qui se ne vedono due, quelli si potriano intraprendere con forse avvantaggio del Publico, con trovarsi chi se ne vuole incaricare con solo conseguire il Letto vecchio di Fiume, e far tutto a sua propria spesa, a questo noi tutti ci concorreremmo vedendo molto bene che il Letto vecchio in riguardo della gran tortuosità è incaricato di continue spese […] che queste poi non cessano di sempre più obbligare a altre […][68]

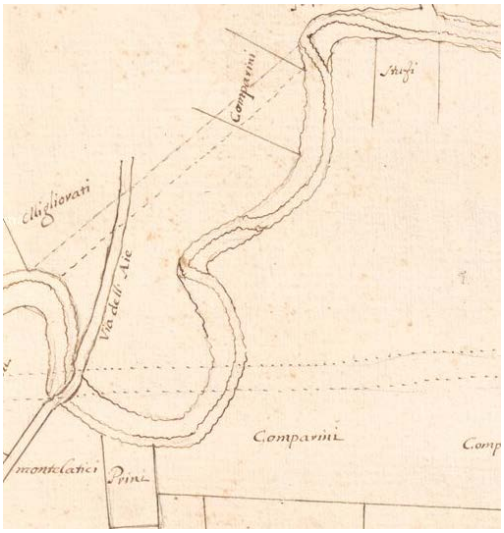

Fig. 7 – *Raddrizzamenti* on the Bisenzio (detail), 1650-1700, ink on paper, Archivio di Stato di Firenze, Piante dei Capitani di Parte Guelfa, Cartoni, Cartone XIII.

If we consider the Sogno idrometrico in this context, it is hard, for us, not to recognize the sharp contrast between the joyful walk with Galileo in fantasyland and the bone-crushing *batter la campagna* around Florence and Prato; between the otherworldliness of the enigmi posed by Geometry and the vicious disputations of landowners; between the safe haven of Galileo's theorems and the hellfire of the *accidenti* and *impedimenti*; between the

[68] BNCF, Gal. 232, ff. 52r, 56r-56v.

clear, well-defined rules of mathematics and the confusing, ever-changing laws of the State; between the freedom to engage in luxuriant allegories and the need to write sober, unimaginative *relazioni*. What we see in the Sogno is an old man trying to reconnect with his past, with a Galilean legacy that looked every day more distant; an old man who contributed remarkably to the definition of a fundamental profession – the engineer – that he did not want to do, as it seemed to require questioning at every step the legacy of his great master.

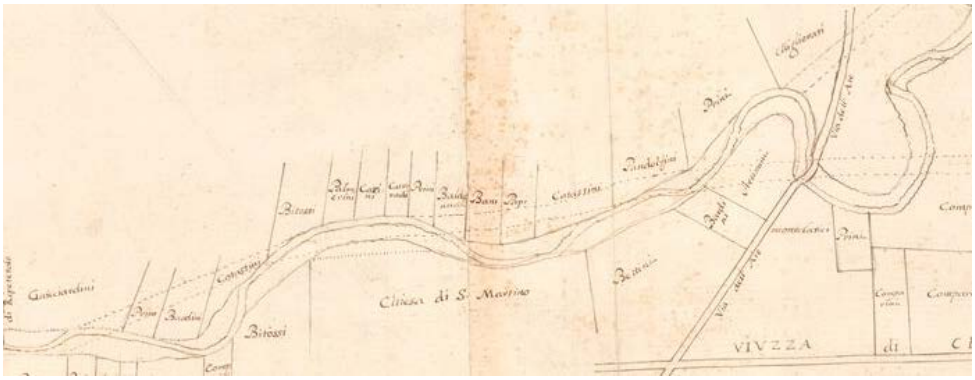

Fig. 8 – *Raddrizzamenti* on the Bisenzio (detail), 1650-1700, ink on paper, Archivio di Stato di Firenze, Piante dei Capitani di Parte Guelfa, Cartoni, Cartone XIII.

Conclusion

Today, Viviani's approach to hydraulic engineering is recognized as surprisingly innovative, modern, and effective. The *Discorso* published in 1688, where Viviani framed the problem of the Arno management within the more general context of environmental management, is seen as somewhat an anticipation of a modern tendency that would emerge only in the XIX century, and the *relazioni* are praised as examples of exactness, excellent economic planning, and careful consideration of pros and cons in engineering. Viviani's flexibility in choosing the technical solutions that best suited a particular problems is considered incredibly modern, and he is regarded as an engineer ahead of his times for the global policy he proposed. These distinctive features of Viviani's approach are often linked to his devotion to Galileo and Galilean science. It is assumed that Viviani's work in engineering is so peculiar precisely because even in engineering he was a loyal, almost sycophantic follower of Galileo. In this view, 'Galilean' influence, when is not immediately apparent – like in the *Discorso* – is implied as an attitude, a set of moral values, or a worldview that permeates everything Viviani did, almost like a religious belief.[69] While the influence of

[69] Maglioni, "Vincenzo Viviani e l'Arno. Scienza Galileiana e problemi di un fiume e del suo bacino nel XVII secolo", 169-170.

Galileo on Viviani could hardly be overestimated, delving deeper into Viviani's engineering service may help to look at the matter the other way around – that is, by investigating how his training and experience as engineer and *architetto d'acque* influenced and acted on the 'galilean orthodoxy' he always professed.[70] This is useful, I think, not only to shed light on Viviani's life and work, but also to better understand, in general, the institutionalization process of Galilean science.

Acknowledgments

I am deeply indebted to Simon Dumas Primbault who let me read in advance and make use of his forthcoming monograph on Viviani, and provided me with advice and references to material relevant for this paper.

[70] As Westfall states, "It is far from clear that the new science of motion had lessons to teach on this level of established empirical practice." Westfall, "Floods along the Bisenzio: Science and Technology in the Age of Galileo", 893.

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