Eggs, turnips and chains: rhetoric and rhetoricians of architecture

Antonio Becchi

A strange monarchy

Another paper included in this volume appropriately calls to mind the work of Francis Bacon. I will adopt a position diametrically opposed to the thoughts expressed there in order to underline what I consider to be crucial for the historiography of architecture understood as *res aedificatoria*. I take my cue from an apocryphal letter addressed to Francis Bacon. It bears a date that takes us back almost exactly 400 years: 22 August 1603. The date is clearly not random; on 17 August 1603, just five days previously, the then 18-year-old Federico Cesi and his friends Francesco Stelluti, Anastasio de Filiis and Johannes van Heeck had founded the Accademia dei Lincei in the Via della Maschera d'Oro in Rome. This apocryphal letter, written at the beginning of the 20th century, left an indelible mark on the ensuing decades. It was published in the Berlin newspaper *Der Tag* (*moderne illustrierte Zeitung*) on 18 October 1902.

I am referring, of course, to the famous *Brief des Lord Chandos an Francis Bacon* written by Hugo von Hofmannsthal. I recall it, in spite of the fact that it has lost much of its freshness through repeated quotation, because I should like to attempt to consider it from the point of view of the correspondences with which we are concerned here: a letter published a century ago in Berlin (where the Max Planck Institute for the History of Science has its seat), addressed to Francis Bacon (the focus of our attention), and dated just a few days after the fateful meeting in the Palazzo Cesi in Rome (not far from the Bibliotheca Hertziana), exactly four hundred years ago. I will transcribe a passage from Hofmannsthal's letter without further comment, which will remain the *cantus firmus* of my considerations: "I felt at this moment with a certainty not wholly untinged with pain that I would write no English and no Latin book in the coming years nor in succeeding years, nor indeed in all the years of my life; […] because the language in which I would perhaps be able not only to write but also to think is neither Latin nor English, nor Italian nor Spanish, but a language […] in which silent things occasionally speak to me, and in which one day I shall perhaps justify myself from my grave before an unknown Judge"[1].

"Things", then, are the focus of attention, or rather (in Hofmannsthal's words) "a language in which silent things speak".

Francis Bacon himself is also linked with a scathing judgement that was formulated roughly a century ago by the author of a book which, in its own field, is unsurpassed even today. I am referring to Raffaello Caverni's *Storia del metodo sperimentale in Italia* (1891-1900), which castigates the prophecies of Baron Verulam as follows: "Francis Bacon gave the name *Instauratio Magna* to his new scientific kingdom, and he regarded himself as having been invested as its monarch for having planned the Encyclopaedia of every art and science in his book *De augmentis scientiarum*, and for having minutely fixed the rules to be followed in experimental method in his *Novum Organum*. It is easy however to persuade oneself that his monarchy was nothing but an empty name or, if you like, a kingdom that had already passed away. For if there is, in fact, no such thing as science, and never has been, as Bacon maintained, it follows that he divided up the burial niches in his Encyclopaedia without having anything to fill them with"[2].

Here, too, I shall leave Caverni's words to resonate in the background without comment. They speak for themselves. I would only add that the empty burial niches [the *loculi vuoti*] are a warning to us all in this research project, and convey one admonition in particular that is a real literary case.

My considerations will focus on a field of research that has not yet found its rightful place in the order of things and that ekes out a meagre existence on the margins of the official historiography of architecture: mechanics in an architectural context and, more generally, the history of building construction. By this, I do not mean the history of machines, nor even the history of machines for building sites (on which there is abundant literature), but the branch of knowledge that is precisely defined in German under the heading of "Geschichte der Baustatik" and which in English is called the "history of structural mechanics". It is no coincidence that I mention this field of research, of course. The project "Epistemic History of Architecture" has its origins in a collaboration between two institutes, each with its own illustrious tradition in fields of research that are apparently far removed from one another: the history of architecture and the history of science (with particular regard to the history of mechanics). The relations between mechanics and architecture will inevitably converge, therefore, in future investigations: a point of intersection in the history of thought that at present plays a modest role in architectural historiography. This is indeed an empty or abandoned burial niche, sometimes temporarily occupied by some vagabond, who comes upon it by chance, driven there by curiosity or by necessity.

One might object that the literature on this subject has grown in recent years, with new authors and new research programmes entering the limelight. Although I understand the reasons for this objection, I still think that the reality is very different – apart from the effects of a Fata Morgana that may deceive the unwary. It is true that several recent projects seem to indicate a promising development in this line of research: from the one launched by Patricia Radelet de Grave and Edoardo Benvenuto in 1992, entitled "Between Mechanics and Architecture", to that dedicated to the formation of an Archive of the Art and Science of Construction (founded in Genoa in 1999); from the First International Congress on Construction History (Madrid, January 2003), to the activities sponsored by the Construction History Society, the Sociedad Española de Historia de la Construcción and the Associazione Edoardo Benvenuto[3]; from the publications of the Instituto Juan de Herrera to the book series *Between Mechanics and Architecture* (Birkhäuser) and *Studies in the History of Civil Engineering* (Ashgate). These are encouraging signs, but they remain sporadic and isolated in nature, and it is still difficult for them to obtain the necessary institutional backing and the support that is essential for research.

Caricatures of thought

To demonstrate this without seeming too elusive, I will give two examples – two bad examples, both of which are revealing and to be avoided – which symbolically opened and closed the year 2003.

The first example dates from January 2003, when an article signed by Sigurd Fleckner was published in the authoritative journal *Bauingenieur* under the title "Gotische Kathedralen – Statische Berechnungen"[4]. The subject of the paper is stimulating, and the article is worthy of closer reading, judging at least by what is promised in the editorial note: "This specialist paper has been scientifically assessed and reviewed". The article does indeed seem to promise significant new findings, as the author stresses. In the introduction and in the text itself, one finds the following thesis: "According to the present state of research in the history of art, the erection of Gothic cathedrals was mainly based on empirical knowledge without structural calculations. This paper supports the thesis that structural calculations were also carried out in accordance with the demands of modern construction and as demonstrated by the buttressing system".

One cannot help being slightly perplexed by such formulations, torn between a sense of headiness and dismay that a person might feel who has managed to escape the rapt gaze of an eccentric dreamer. Once one has read the paper, any feeling of headiness is gone; but one is still left with a sense of dismay. In his article, our Magellan of historiography wants to convince us that at last he has understood everything. The opposite is the case: he shows that he has not even begun to think about and, what is worse, to read and look at those things that might have set him thinking. A smattering of the vocabulary of the engineer, a handful of quotations *comme il faut*, and a good dose of *amour propre* make our author believe he has found the solution that remains hidden to the rest of us. To find solutions, however, you need first to identify the problems; and that is something Fleckner has been unable to do.

Among its various useful features, the article presents an image (fig. 1) that is meant to exemplify the statics scheme to which the author refers. In its seemingly innocuous simplicity, this concept of statics would surely leave modern structural engineers perplexed; and it must make a historian's hair stand on end, conscious as one is of the slow, laborious, hazardous progress of knowledge and – in this particular case – of the first mechanical interpretations of the statics of arches. It goes without saying that Fleckner is ignorant of them; probably he does not want to know about them. This is demonstrated with great clarity by the contents of his article and the attached bibliography.

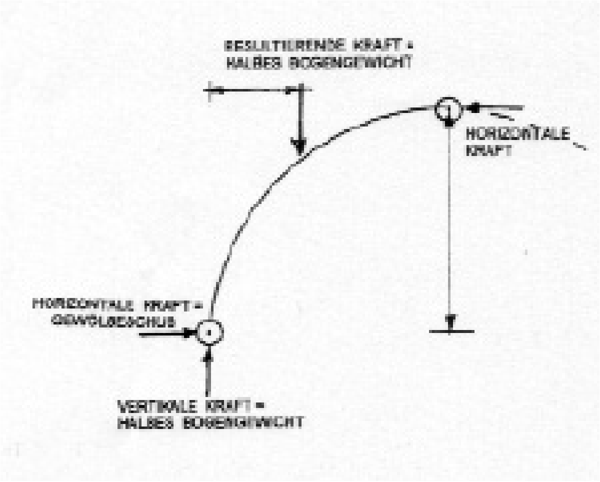
The second example is as follows. On December 2003, a seminar was held in Florence on the "Teaching of Scientific Disciplines in the Current Curriculum of the Faculties of Architecture and Engineering" to mark the 72nd birthday of Salvatore Di Pasquale. The seminar was seen as a good opportunity to review the 40-year period of research and teaching during which Di Pasquale became the main protagonist of a new way of understanding mechanics applied to architecture and its teaching within faculties of architecture and engineering (not only in Italy). Giampiero Del Piero's intervention at the seminar, however, made it clear how much still remains to be done to educate university teachers and researchers in this broader view of knowledge, where historical insights would seem predestined, by their very nature, to play a major role in research and teaching. Invited to reflect on the historical approach in teaching structural disciplines, Del Piero (professor of *Scienza delle costruzioni* at the University of Ferrara) insisted vehemently that "the science of construction is the science of construction"(!) and not its history. In his view, the historical approach represents a dangerous derivative that abandons the rigour of the classical formal approach – the only method worthy of consideration.

Del Piero's febrile words underline the typical misunderstanding of a person accustomed to tautologies and afflicted with a worrying lack of intellectual curiosity. This misunderstanding was all the more glaringly revealed at a conference mounted to pay tribute to a scholar who has dedicated a large part of his life to advancing and developing the "history of the sciences and techniques of construction" and their teaching, a scholar who has turned the *docta curiositas* into a lifestyle.

The misunderstanding, of which Del Piero became the mouthpiece, stems from the suspicion that historical analysis is a soft option, a short cut to relieve "conceptual fatigue" and to transform the hard core of the discipline into a fragile popularization of hagiographic character. There are even those who believe that the history of scientific concepts can be no more than "anecdotal". One is aware that this misunderstanding has had many advocates over the past century – some distinguished, others less so – whose hand was admittedly strengthened by some rather unedifying examples of the historiography of science. It is hard to believe, though, that this dismissal of the methods of historical analysis could be reaffirmed with such assurance as something obvious, especially by those who ought really to represent the dignity of their *spiritus rector*.

Historiography, then, is regarded as something spurious (at least by some distracted and misinformed representatives of academic culture), instead of being a wonderful opportunity to in-

1. From Fleckner 2003, fig. 10.



vestigate the genesis of the concepts and structure of the formal apparatus commonly used by the *calculatores*. Del Piero cannot yet have found time to investigate the problem with very much attention and to read the texts that could have opened up new perspectives of thought. Yet little effort would have been needed to enrich his stock of knowledge. It would be enough, for example, to consider the judgement of Gottfried Wilhelm Leibniz that Clifford Truesdell wanted to adopt as an emblem of the review *Archive for the History of Exact Sciences*: "Utilissimum est cognosci veras inventionum memorabilium origines, praesertim earum, quae non casu, sed vi meditandi innotuere. Id enim non eo tantum prodest, ut Historia literaria suum cuique tribuat et alii ad pares laudes invitentur, sed etiam ut augeatur ars inveniendi, cognita methodo illustribus exemplis". Let us hope that Del Piero is able to understand this historical idiom.

Having ascertained the intellectual fragility of certain apodictic positions, perhaps we could recommend to their devotees a reading of the recent book by Karl-Eugen Kurrer[5], in which Goethe's *Adagio* is modified but sustained with excellent arguments: namely, that "the history of structural mechanics is structural mechanics itself". We would recommend the same book to Sigurd Fleckner, who represents the natural corollary of the spuriously "rigorist" position of Giampiero Del Piero. In fact, the two authors mutually justify each other and represent the two faces of the same problem. This reciprocal justification does not denote the soundness of their positions, but the risk of falling into the trap of cultural caricatures.

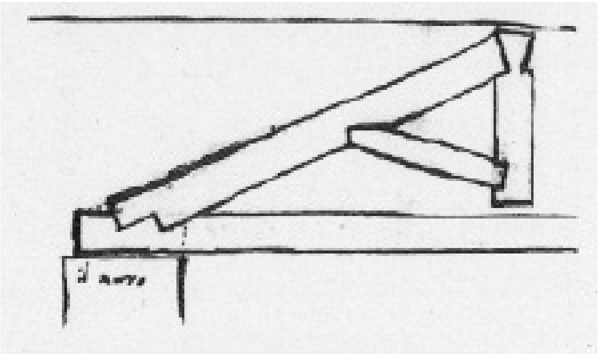
It is essential that the new project "Epistemic History of Architecture" does not fall into the same trap. It was born from the need to overcome the limitations, the pigeonholing, imposed by the traditional disciplines, which have forgotten that they are tools in the service of knowledge, and have too often been transformed into the arrogant vestals of gleaming white sepulchres.

The Haak case

To illustrate one of the many possible forms of collaboration "between mechanics and architecture", I should like to dwell briefly on what I call the "Haak case". The name of Henrik Haak is mentioned in an article I consider of great importance. It was published in the "Preprints of the Max Planck Institute for the History of Science" (Preprint 97, 1998) and, two years later, in the periodical *Science in Context*[6]. The paper reproduces a manuscript page by Guidobaldo del Monte[7], to which the authors devote a magisterial analysis. The subject is the law that describes the trajectory of projectiles and the interpretation proposed by Guidobaldo del Monte, who compares the trajectory to the line described by a chain [*catenella*] suspended between two points. The comment referred to the manuscript as follows: "At the end of one of Guidobaldo's notebooks there are two drawings which possibly depict an inclined plane used for such an experiment, together with a protocol which perfectly resembles the description of Galileo's second method mentioned in the *Discorsi* (see figures 4 and 5) [in the present publication figs. 2 and 3]. A closer inspection of Guidobaldo's drawings shows that they actually represent a roof which may well have offered a convenient setting already at hand for experimentally verifying a method similar to that described by Galileo on a scale comparable to that of ballistics, the usual context in which projectile motion was considered at that time"[8].

2. From Renn et al. 2000, fig. 4.

3. From Renn et al. 2000, fig. 5 (detail).

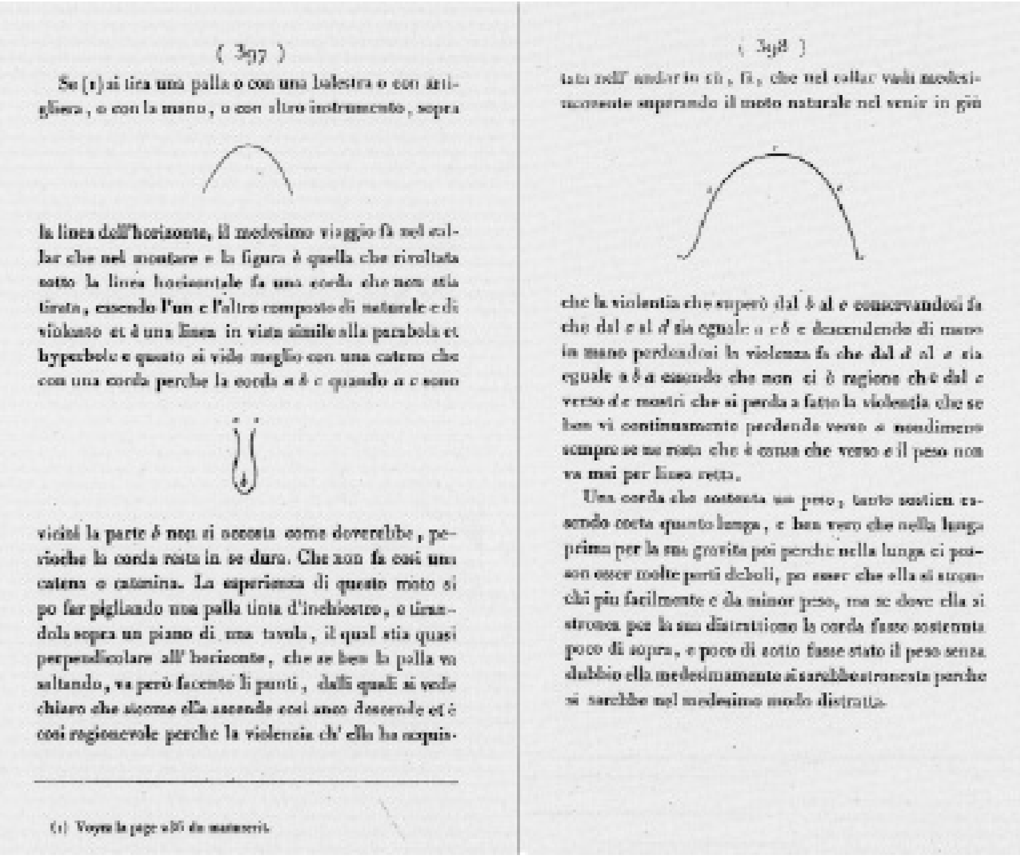


Note 11 (p. 311) explains the genesis of this interpretation: "Henrik Haak, who constructed the apparatus for our reproduction of the historical experiment, has directed our attention to the fact that the inclined planes depicted by Guidobaldo immediately before and almost immediately after the protocol represent a roof construction".

Haak is therefore the mediator between mechanical and architectural historiography, but the problem remains unresolved, rather like something of secondary importance that is worth only a marginal note. For a better understanding of what has happened, one must return to 1841, the year in which Guglielmo Libri published a partial transcription of the manuscript page in question and the respective drawings[9] (fig. 4). Neither the roof truss nor the text at the top left of the page is mentioned in the transcription. The two spheres of interest are divided by an invisible line that nevertheless seems quite concrete and apparently unbridgeable, brutally cutting the manuscript in two. Over the years, other scholars have commented on this passage, and more recently it has been subjected to a new and original interpretation[10], in which the roof becomes a "metaphor" for an inclined plane. Here, the conjunction of mechanics and architecture occurs between the lines, in an unspoken form.

Let us now try to imagine the same manuscript falling into the hands of an architect or an architectural historian (a rather fanciful hypothesis, I admit, but I shall let it stand if only for its absurdity). The architect would immediately recognize the roof truss, of course, and would perhaps more or less understand the text relating to the cable [*fune*]. Furthermore, he or she would be extremely interested in those parts of the manuscript (fig. 5) that were ignored in the

comments quoted above. In this way, the architect would discover that Guidobaldo is here dealing with the gradient of a channel designed to bring water to a mill and, by analogy, with the gradient of roofs: in other words, the question of roof slopes, which was to be a recurrent theme in architectural treatises of the period.
If the architect in question were a little more curious, he or she would go even further and note that the structure designed by Guidobaldo is far from schematic. Indeed, it is a precise description of the structural details of a roof truss. This is immediately recognizable if one compares it with those structures reproduced in the manuscripts of Taccola, Oreste Vannocci Biringuccio, Pellegrino Pellegrini and, to stick to Guidobaldo's lifetime, Giorgio Vasari.
Guidobaldo designs not just an inclined plane, not even a generic roof truss with its component parts (rafters, king post, tie beam, struts). He goes into detail. For example, he notes the bisection in the joint between rafter and strut and accurately marks the absence of junction between the tie beam and the king post, which presupposes a precise mechanical interpretation of the structural behaviour of the roof truss itself. Guidobaldo draws with a "blacksmith's eye", so to speak, in what is perhaps an improvised but not insignificant way that recalls the "constructional" clarity of Giovanni Battista da Sangallo in the marginal drawings he inserted in the *editio princeps* of the treatise of Vitruvius[11].


(397)

Se (1) si tira una palla o con una balestra o con artiglieria, o con la mano, o con altro instrumento, sopra

la linea dell'horizonte, il medesimo viaggio fà nel calar che nel montare e la figura è quella che rivoltata sotto la linea horizontale fa una corda che non stia tirata, essendo l'un e l'altro composto di naturale e di violento et è una linea in vista simile alla parabola et hyperbole e questo si vide meglio con una catena che con una corda perche la corda *a b c* quando *a c* sono

vicini la parte *b* non si accosta come doverebbe, perioche la corda resta in se dura. Che non fa così una catena o catenina. La esperienza di questo moto si po far pigliando una palla tinta d'inchiostro, e tirandola sopra un piano di una tavola, il qual stia quasi perpendicolare all' horizonte, che se ben la palla va saltando, va però facendo li punti, dalli quali si vede chiaro che sicome ella ascende così anco descende et è così ragionevole perche la violenzia ch' ella ha acquis-

(1) Voyez la page 116 du manuscrit.

(398)

tata nell' andar in sù, fà, che nel callar vadi medesimamente superando il moto naturale nel venir in giù

che la violentia che superò dal *b* al *c* conservandosi fa che dal *c* al *d* sia eguale a *cb* e descendendo di mano in mano perdendosi la violenza fa che dal *d* al *e* sia eguale a *b a* essendo che non ci è ragione che dal *c* verso *d e* mostri che si perda a fatto la violentia che se ben vi continuamente perdendo verso *e* nondimeno sempre se ne resta che è causa che verso *e* il peso non va mai per linea retta.

Una corda che sostenta un peso, tanto sostien essendo corta quanto lunga, e ben vero che nella lunga prima per la sua gravita poi perche nella lunga ci possono esser molte parti deboli, po esser che ella si stronchi piu facilmente e da minor peso, ma se dove ella si stronca per la sua distrattione la corda fusse sostenuta poco di sopra, e poco di sotto fusse stato il peso senza dubbio ella medesimamente si sarebbe troncata perche si sarebbe nel medesimo modo distratta.

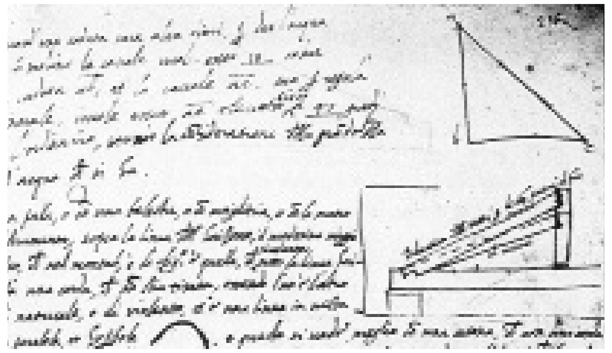
4. Guglielmo Libri, Histoire des Sciences Mathématiques en Italie [...], *vol. 4, Paris 1841, pp. 397-398.*

This is a small example through which one can follow the history of the "discovery of scientific discovery". It extends from the publication of the treatise of Guglielmo Libri, who reads Guidobaldo's text and recognizes its importance for his own purposes (the history of mathematics), through the appreciation of innumerable other scholars, down to modern scholars who broaden their investigation to include the roof truss and interpret it more generally as an inclined plane. The question we must now ask is whether it is not time to read this manuscript, too, as a detail – perhaps significant, perhaps not – in the history of construction. Should we not also read it as source material for the history of mechanics and for the history of construction – all the more so, since it is not an isolated case, but one of many examples?
To give some idea of how this simple suggestion might be fruitful in opening up new research perspectives, I should add that Bernardino Baldi da Urbino was a pupil and friend of Guidobaldo del Monte. In his commentary on the *Mechanical Problems* of Aristotelian tradition (the umpteenth Renaissance comment on these problems that architects ought to read with due attention), Baldi would take the roof truss as a pretext to illustrate the mechanical implications for architecture, as an elegant but playful reference to the treatment offered by

Leon Battista Alberti in his *De re aedificatoria*[12]. Once again, then, mechanics; and once again, architecture; once again, a text that historians of mechanics have read, hitherto ignoring the part that concerned architecture, and which architectural historians have simply not read at all, because it concerned structural mechanics.
The Haak case is a particularly eloquent example of how the separation of canons and, in many respects, the separation of codes, forces the history of construction and (in a quite special way) the history of architectural mechanics, into a *terrain vague* of knowledge, into an inhospitable and desolate swamp. There the building site (of whatever kind) is located, a laboratory of ideas between theory and practice, a space for the verification of mechanics rather hastily defined as "rational".
This no-man's-land, this free zone, which is, in principle, exempt from disciplinary idiosyncrasies, remains *terra incognita*. Neither mechanical nor architectural historians have ventured into it: the former because they do not find it "mechanical" enough; the latter because they do not find it "architectural" enough. The fact remains that the separation between them is academic and exists only on paper, not in fact.

The jugglers' chains

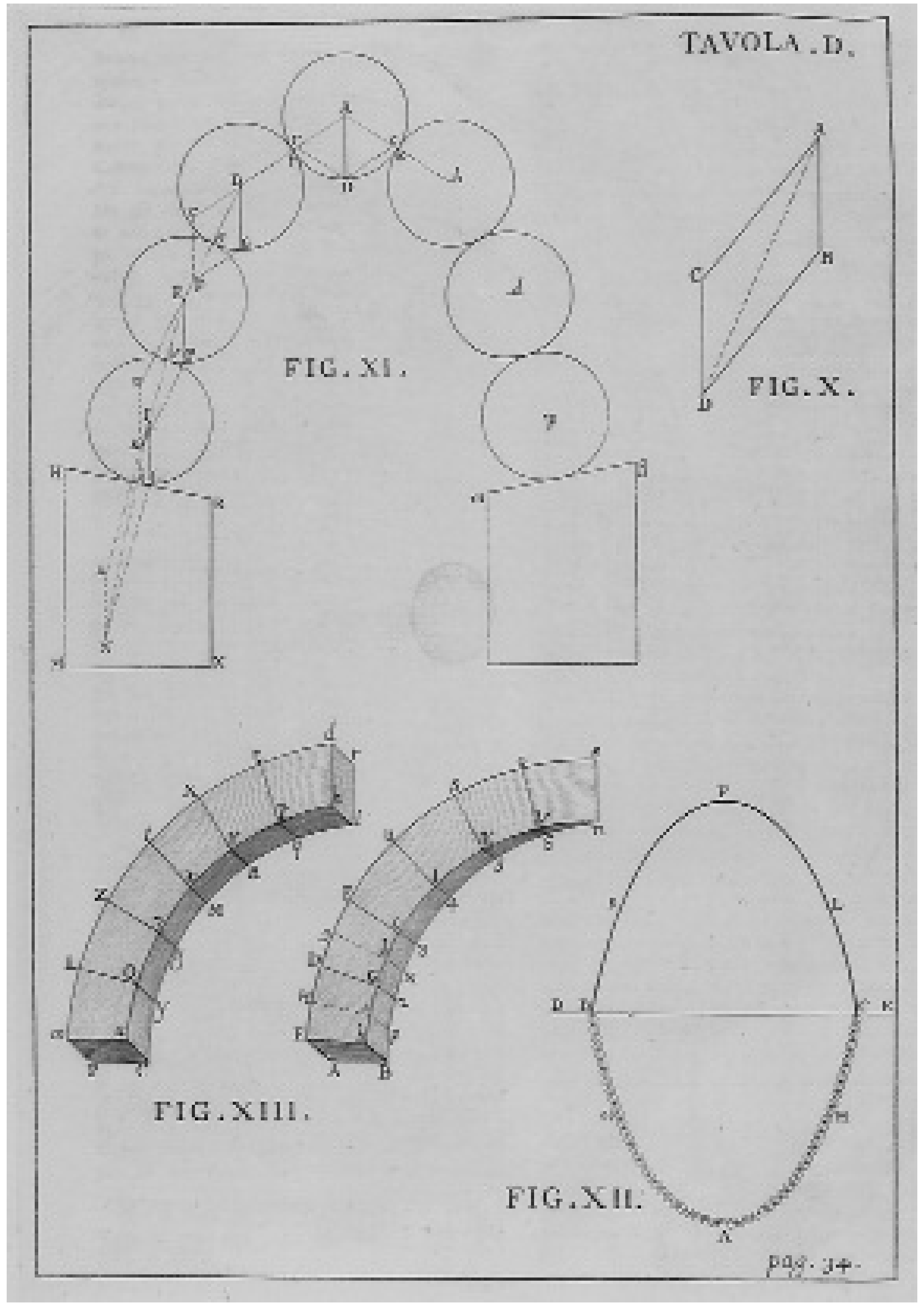
I will now move on to the second part of my reflections, the part that more directly concerns the eggs, turnips and chains of my title. Here, too, I should have liked to preface my arguments with some remarks about the remote past, with certain premises that affect the present. But since the space at my disposal is limited, I shall make only very cursory mention of this latter aspect.
It is interesting to note that the question of the chain has also become a rhetorical *topos* in the historiography of the 20th century. Architects and archaeologists alike have amused themselves by seeing hanging chains in all sorts of places, whether rightly or wrongly. From the



5. From Renn et al. *2000, fig. 4 (detail).*

heuristic tools of our ancestors, eggs, turnips and chains have been transformed by expert tightrope walkers into toys, into the components of a sophisticated game.
The great fascination exerted by Giovanni Poleni's famous *Memorie istoriche della gran cupola del Tempio Vaticano*[13], in which the author describes the analogy between an arch and a catenary curve (fig. 6), has had some surprising effects, both overt and covert, in which it is difficult to distinguish bavardage from scientific hypothesis. In the context of some vaulted structures in the Traianeum in Pergamon, for example, Klaus Nohlen asks whether the Romans were not already using the catenary to define the curvature of vaulting[14], while Hansgeorg Bankel conjectures that the catenary curve was used as a guide in defining the *scamilli inpares*[15]. The fascination of the catenary leads him to write that "one could also imagine a sagging chain directly on a vertical drawing surface, a method which to my knowledge has not yet been considered. With two nails, a piece of fine chain, and a base divided into equal sections, a curve can be quickly designed"[16].
In the late 1940s, Oscar Broneer[17] also spoke of the chain, boldly linking it with the definition of the entasis of columns (a thesis revived more recently by other authors). At the same time, Riccardo Gizdulich believed he could see a catenary revolved by 90° in the profile of the Ponte Santa Trinita in Florence. Broneer's prophetic emphasis recalls that of Bankel: "The much de-

6. Giovanni POLENI, Memorie istoriche della gran cupola del Tempio Vaticano e de' danni di essa, e de' ristoramenti loro, divise in libri cinque, *Padova 1748, Tab. D.*

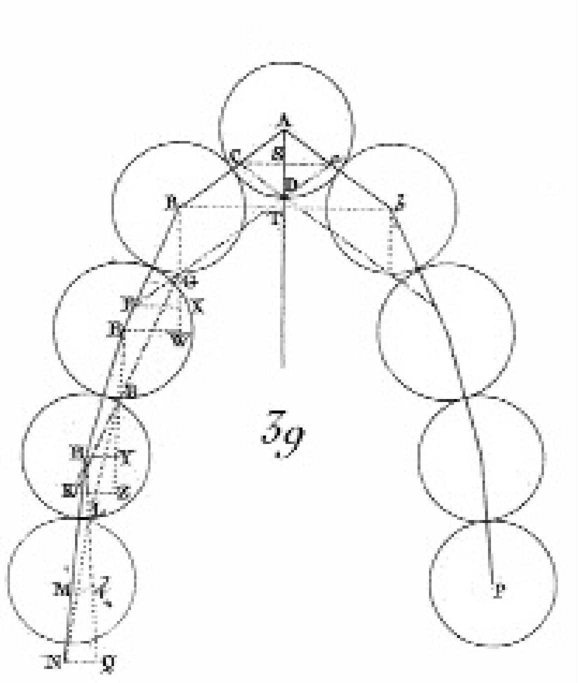


bated question whether the curvature in ancient buildings is to be regarded as an arc of a circle or a parabola has thus found a new solution. It is neither. It is in essence a catenary, which in a curve as slight as this would be indistinguishable from a parabola"[18]. Our discussion of this problem could, of course, continue at some length, recalling the important and more convincing works of Dieter Mertens[19] or Lothar Haselberger[20].

I cannot dwell on the question, but it should be borne in mind that fashions condition our interpretations and even lead us to draw bizarre and exhilarating conclusions. With regard to Broneer's hypothesis, for example, one should ask whether sufficient account has been taken of what Pietro Cataneo wrote in *I quattro primi libri di architettura* (1567), where he explained that the entasis of the column could be obtained with a long, thin and very flexible wooden batten[21]. This solution may have its roots in remotest antiquity; and it is so much simpler and more convincing (even if less brilliant and symbolic) than the catenary that it was revived by Andrea Palladio[22], who claimed to have invented it himself, maintaining that he had illustrated it years before Cataneo. No trace of this solution is to be found in Haselberger's study *Old Issues, New Research, Latest Discoveries: Curvature and Other Classical Refinements*[23], though the author does consider some Renaissance texts. Gorham P. Stevens[24], on the other hand, confirmed its widespread diffusion many years earlier, though he remained trapped in the fascination of "mathematical" constructions: "*The method employed in Italy today*: the Italian architects of today take a long wooden straight edge, bend it to the desired entasis, and then draw the curve. The method cannot be used for large columns, for the inequality of a long strip of wood causes irregularities of curvature. At best, it is but a rough method and will not, therefore, be further considered in this paper"[25].

Let us now leave aside the archaeologists'

7. James STIRLING, Isaaci Newtoni Enumeratio Linearum Tertii Ordinis; sequitur Illustratio Ejusdem Tractatus Auctore Jacobo Stirling, *Paris 1797, Tab. C, fig. 39.*



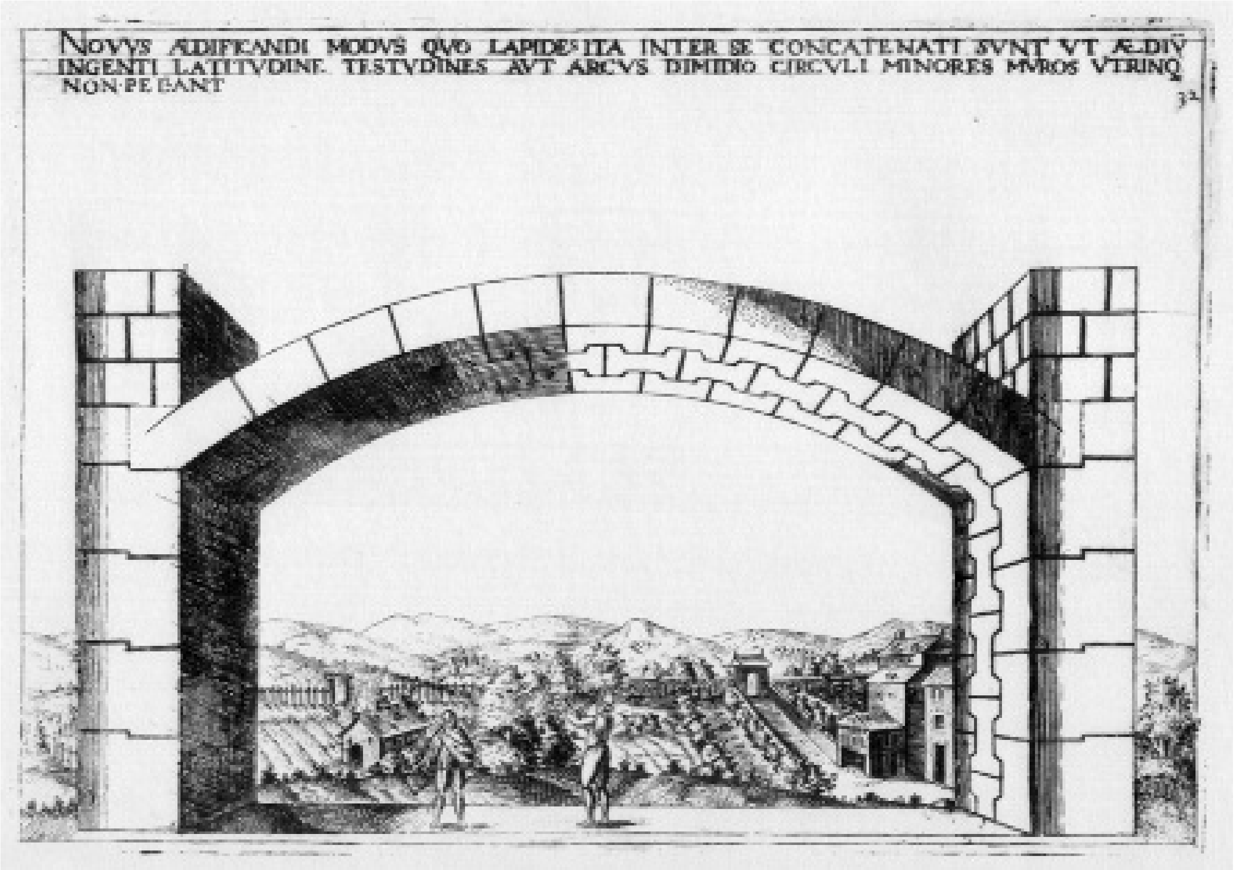
chains and return to those of the exponents of mechanics, in the hope that one day a detailed historical and critical survey of the various systems of catenary construction will be attempted. Poleni reconstructs the transition from the intuition of Robert Hooke and David Gregory to the formulation of James Stirling, right down to the pages of the *Memorie istoriche*. This transition is far from self-evident, however, if we study the details closely. Let us consider the image reproduced by Poleni and the original one provided by Stirling[26] on which the former is based (figs. 6 and 7). First of all, one observes that the focus of attention is a series of spheres in equilibrium. The *Gedankenmodell* is very clear, even though inevitably far removed from the reality of construction, with its bricks, stones, mortar and friction. What is tension in the chain (a better model than the cable, as Guidobaldo del Monte stresses) is here compression between the tangent spheres. Is that all? Is it, therefore, right for historians to recycle this image repeatedly – substituting the name of Poleni for that of Stirling – given that the image of the former is easy to find, whereas the second is a good deal harder (as well as being included in a text that is hard to come by and difficult to read)? No, Poleni tells us something more: while Stirling is interested only in the *Gedankenmodell*, which sums up what we have just been saying, Poleni is interested in the model as *trait-d'union* with the mechanical interpretation of construction, an interpretation that takes the problems of the building site into account.

Hence the motif of the apparently insignificant addition: the spheres are not suspended in the air, but rest on two bases, which could be the heads of columns, for example. These heads are not horizontal but necessarily inclined. That means that the reverse catenary arrangement of the spheres presupposes an impetus towards the outside (in other words, it could be affirmed that the tangents of the catenary at the points of suspension are obviously not vertical). This is a seemingly banal observation, but it impinges on one of the great problems of the theory of vaulting: the possibility of defining a building that does not cause impetus loading on the supports. The round arch, for instance, long enjoyed a privileged existence and was extolled in architectural treatises because it was "firmissimus": "Ergo rectis arcubus, qui sese facile tueantur, cordam non exigimus"[27]. This, as we know, is mistaken, but it is very seductive. In the case of the catenary curve, ingenuously adopted as a panacea for all ills connected with the theory of vaulting, this property is excluded in principle. In order to guarantee the constructional equilibrium of an arch designed according to the catenary principle, one has to ensure the absorption of lateral loading on the imposts[28].

If one goes further back in time to Galileo, in the *Seconda Giornata* of the *Discorsi e Dimostrazioni Matematiche*[29], one finds a celebrated passage relating to solids of equal resistance and the "problem of the beam", in which Galileo explains how to design a parabo-

la. This well-known passage reads as follows: “I use an exquisitely round bronze ball, no larger than a nut; this is rolled [*tirata*] on a metal mirror held not vertically but somewhat tilted, so that the ball in motion runs over it and presses it lightly. In moving, it leaves a parabolic line, very thin, and smoothly traced. This [parabola] will be wider or narrower, according to whether the ball is rolled higher or lower. From this, we have a clear and sensible experience that the motion of projectiles is made along parabolic lines, an effect first observed by our friend, who also gives a demonstration of it. We shall all see this in his book on motion at the first meeting. To describe parabolas in this way, the ball must be somewhat warmed and moistened by manipulating it in the hand, so that the traces it will leave shall be more apparent on the mirror. The other way to draw on the prism the line we seek is to fix two nails in a wall in a horizontal line, separated by double the width of the rectangle in which we wish to draw the semi-parabola. From these two nails hangs a fine chain, of such length that its curve [*sacca*] will extend over the length of the prism. This chain curves in a parabolic shape, so that if we mark points on the wall along the path of the chain, we shall have drawn a full parabola. By means of a perpendicular hung from the centre between the two nails, this will be divided into equal parts”[30].
In these few lines, the seduction of the *Gedankenmodell* of the catenary reaches its climax and creates a close link between mechanics and architecture. The passage could be interpreted as a significant shift in the definition of the falling trajectory of projectiles, as was brilliantly proposed in the above-mentioned study[31]. But one can also perceive a formidable connection between two problems that were to be related only much later and in rather a rash way in the case of Gizdulich and the Ponte Santa Trinita in Florence.
Galileo states that the “best shape” (in terms of solids of equal resistance) of a cantilever loaded on its free end is a parabola (this is the source of the quotation above), with an axis parallel to the longitudinal axis of the beam. This is a correct if only partial indication. Galileo adds that a homogeneous suspended chain subject to its own weight assumes a parabolic form. In this, however, he is mistaken; the form it assumes is not that of a parabola, but of a hyperbolic cosine. The application of the catenary to structural optimization, however, could not be more valid. Galileo does not proceed beyond this point, but he does come close to the solution of another problem related to structural optimization: namely, the transition from the catenary to the “best form” – not of the beam, but of the arch.
Precisely this distinction between the two types of structural behaviour – that of a beam and that of an arch – leads to the last example I wish to describe. If one goes back a little in time, to the year 1584 to be more precise, one is faced by yet another variation on the problem of the use of chains in architecture. I refer to an *invenzione* contained in Errard’s *Premier livre des instruments mathematiques mechaniques*[32], an extraordinary book that places the “architectural machine” in the classic repertoires of machinery that were widespread in the Renaissance. Here, Errard raises the question of the distinction I have just drawn: between the beam and the arch. A beam may resemble an arch if it has a curved profile; but it does not *ipso facto* become an arch in the true sense of the term. At most, it is a beam in the form of an arch. This fine distinction consists not in the form, which remains identical, but in the mechanical behaviour. Resting horizontally on two columns, a rigid beam forms part of a trilithic system that does not create lateral impetus. Moreover, like the arch, the beam may consist of a number of small elements combined together, just as an arch is composed of *voussoirs*. To form a beam, however, these elements have to be firmly wedged together, otherwise the whole structure could collapse. Errard’s in-

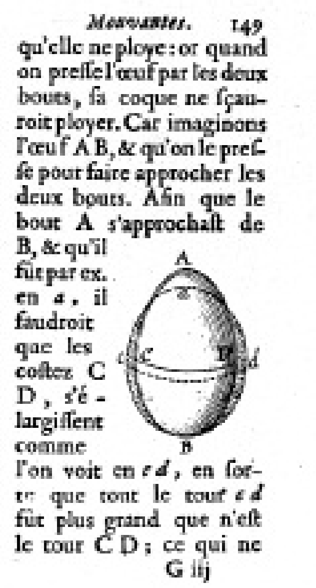
8. Jean Errard de Bar-le-Duc,
Le premier livre des instruments mathematiques mechaniques,
Nancy 1584, Tab. 32.



vention was a solution to this problem[33] (fig. 8): an arch made monolithic. In other words, it is an architectural oxymoron, which assumes the most intuitive connotation of the chain; that is to say, the sum of individual elements firmly linked together. An arch of this kind will not exert any outward impetus, because the “lapides inter se concatenati sunt”. This is a metaphoric shift in the *Gedankenmodell* of the catenary, of which wonderful prefigurations can be found in Leonardo da Vinci’s *Taccuini*.

Skulls, eggs and turnips

In the case of the egg, too, Poleni’s work *Memorie istoriche* (1748) can be taken as an indirect reference. Special mention should be made of a passage unjustly ignored by scholars (though more original and interesting that the well-known one I have already quoted), in which the dome is compared to a skull, which is not an egg and yet recalls an egg in its “structural” characteristics: “Although (in truth) no mechanical cognitions are yet evident of certain strange effects, in spite of the fact that it is beyond doubt that a random act of violence in one part may produce a disturbance in another different part: so it sometimes happens that the skull, when struck on the right side, remains fractured not in the same part, but on the left side, and vice versa, when struck in that part, is fractured in the other: the which case, called by Hippocrates an *accident* (as we would translate it), is referred to as a *counter-fracture* by many surgeons: and this happens all the more easily in those of advanced age, who having almost no sutures left in their skull, come to have this almost in one piece. Is it not to be suspected, therefore, that some strange accident (in some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qu'elle ne ploye : or quand on presse l'œuf par les deux bouts, sa coque ne sçauroit ployer. Car imaginons l'œuf A B, & qu'on le presse pour faire approcher les deux bouts. Afin que le bout A s'approchast de B, & qu'il fût par ex. en *a*, il faudroit que les costez C D, s'élargissent comme l'on voit en *c d*, en sorte que tout le tour *c d* fût plus grand que n'est le tour C D ; ce qui ne
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9. Ignace Gaston P*ARDIES*,
La statique ou la science des forces mouvantes, *Paris 1673, p. 149*.

sense of similar kind) may happen in buildings?"[34]

Poleni no doubt arrived at the analogy of the skull through intensive discussions with his friend Giovanni Battista Morgagni, a famous anatomist and pathologist with whom he had conducted experiments on the cardiac muscle. The anatomical analogy forms part of an illustrious tradition, to which Alberti had given a decisive impetus. In this case, though, it acquired a novel technical emphasis.

The skull is *per se* a good model for a dome, i.e. for a structure that should, if possible, be "thin" (the example of the Pantheon was much admired, but would not be reproposed in the same technical and structural terms), but that is also resistant, thanks to its form. The problem is always the same, namely to deduce from the nature of things (whether one is talking about a chain, subject to the natural law of gravity, or a skull as a resistant structure) guidelines for their artificial reconstruction; i.e. for construction *contro natura* (stones suspended over a void tend to fall), and *secondo natura* (a particular arrangement of the constituent elements guarantees the stability of the whole). The strategy is simple and effective: to comply with nature by governing it; and to govern nature by complying with it.

Thin-walled and yet resistant by virtue of its form, the cranium is undoubtedly a good example to follow. Another example taken from the natural world could also be adopted as a model in architecture: the bark of trees, as Vincenzo Viviani suggested in the late 17th century[35], incurring the criticism of the irascible Bartolomeo Vanni (1662-1732): "The same author [Vincenzo Viviani] informs us that this form of vault [barrel vault] is the most ancient, *as if they* [*the ancients*] *had learnt it from nature itself by observing that, since it enjoys a circular form, even the thin bark that surrounds the trunk of a tree, if sawn in half and laid on the ground with the concave part below, is able to support very large weights placed on the convex, or back, of this bark*. The bark, as Signor Viviani says, like all the bark of trees, is everywhere of the same thickness; so how does it, according to him, withstand such large weights placed on the convex and maintain its constancy? As we follow his comments, he adds that a half-barrel vault *is built twice as thick at the base (up to a height of approximately two thirds), so that the middle part of the arch, which pushes on the imposts, will find there greater resistance, and counterpressure*. What will the architects learn? What will masons do when they have to deal with a half-barrel vault? Is the shell able to support very great weights, and is it not thicker up to two thirds? Conducting careful surveys and tests to this end round Brunelleschi's cupola is not difficult; it is not science similar to that required by speaking of a half-barrel vault […]"[36].

Despite the incontrovertible appeal of skulls and bark, the analogy *par excellence* remains the egg. Its incredible resistance to longitudinal compression had been the subject of scientific enquiry since antiquity. This is attested by a passage from Pliny the Elder, taken from a long investigation devoted to the egg[37]: "Firmitas putaminum tanta est, ut recta, nec vi, nec pondere ullo frangantur, nec nisi paululum inflexa rotunditate".

At some point – it is difficult to say precisely when – the egg also became a recurrent image in relation to architectural construction. For example, one recalls the anecdote in which, strangely enough, both Filippo Brunelleschi and Christopher Columbus share a role. In Brunelleschi's case, the egg is cited by Vasari with regard to the famous dispute about how to raise the cupola of Santa Maria del Fiore in Florence: "They would have liked Filippo to speak his mind in detail, and to show his model, as they had shown theirs; but this he refused to do, proposing instead to those masters, both the foreign and the native, that whosoever could make an egg stand upright on a flat piece of marble should build the cupola, since thus each man's intellect would be discerned. Taking an egg, therefore, all those masters sought to make it stand upright, but not one of them could find the way. Whereupon Filippo, being told to make it stand, took it graciously, and giving one end of it a blow on the flat piece of marble, made it stand upright. The craftsmen protested that they could have done the same; but Filippo answered, laughing, that they could also have raised the cupola, if they had seen the model or the design"[38].


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Ainsi l'on peut faire des colonnes de planches de bois, qui seront tres-fortes ; car si on les joint ensemble comme les doiles des barriques, en leur donnant une petite courbure, & les environnant de quelques cercles de fer, ces colonnes ainsi creuses seront capables de supporter de tres-pesants fardeaux. Il y a apparence que les anciens Architectes ont eû égard à ceci dans la construction des
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10. Ignace Gaston P*ARDIES*,
La statique ou la science des forces mouvantes, *Paris 1673, p. 151*.

The choice of the egg says a good deal more than is expressed in these lines: in the case of Columbus, it is a reference to the rotundity of the earth; in the case of Brunelleschi, to the rotundity of the dome. Was it not the same Brunelleschi who used clay, wax, wood and even winter turnips to explain to his workmen the constructional idea he had in mind? As Antonio Manetti narrates with regard to the cupola of Santa Maria del Fiore: "There are many stones and concealed [stones] in the angles which are not evident to anyone, while others can be seen. Those that can partially be seen are long *macigno* beams. When he [Brunelleschi] discussed these with the stonemasons, they could not understand him at all. [He made some models for them] in soft clay and then in wax and wood. Actually those large turnips, called "*calicioni*" (large goblets), which come on the market in winter, were useful for making the small models and for explaining things to them"[39].

Among other edible analogies, one recalls Leonardo's "oranges", in other words, domes that, in collapsing or cracking, behave like squashed oranges; or the "pomegranates" of the three mathematicians Jacquier, Le Seur and Boscovich, who use the analogy of this fruit in their analysis of the dome of the Vatican Basilica. Boscovich was to return to the same image in the *Scrittura* dedicated to the *tiburio* of Milan Cathedral.

It was Vincenzo Scamozzi, however, who took the decisive leap in the direction of mechanical analysis. His *Idea dell'architettura universale*[40] contains the following description after a reference to the dome of S. Maria del Fiore: "This strength and equality of the vault in the form of a dome we can ascertain from the experience of natural things, and especially from the egg; which by its nature having so thin a skin, and being so weak, nonetheless cannot be broken by human strength, as also Pliny says; for by pressing [it] at both ends [it cannot be broken], as is demonstrated by the vaults of domes that have the form of a semi-circle or are steeper in profile, and the flat parts [along the sides of the egg], or segments that form less than half a circle; as may also be deduced from Alexander Aphrodisias. And we have proved that three eggs placed upright on a table, with a little wax on both ends, have supported the weight of a metal mortar weighing over 150 pounds"[41].

At that time, Galileo was also considering the resistance of the egg[42]. Gaston Pardies, too, dwells on the same theme in his *La statique ou la science des forces mouvantes*[43], going into a wealth of detail. Pardies investigates the strength of the egg, offering explanations and then making a huge and surprising leap to the world of architecture. Here is the first part of the passage in question (fig. 9): "However, it is as well to remark that no body ever breaks unless its parts are overdrawn [subjected to too much tension]; and if a glass that resists tension breaks when one wants to bend it, it is by means of this inflexion: namely, more effort is needed to exert pressure on the convex parts than would be needed by pulling the glass straight at the two ends, as we will be able to see in the continuation of this discourse. It is for this reason that we find so prodigious a resistance in an egg that we would like to crush by pressing it from end to end between our two hands: something that would seem all the more surprising to those who don't know the reason for it"[44].

Viviani, too, had read and annotated these pages[45], and from this (together with his reading of Scamozzi's treatise) he derives the idea of comparing the dome of Santa Maria del Fiore to an egg. Pardies goes beyond this, however. His remarks on the "prodigieuse résistance de l'œuf" give rise to a curious mechanical interpretation of architecture (fig. 10): "In this way columns can be made of wooden planks, which will be very strong; because if they are joined together like the staves of barrels, by giving them a slight curve, and surrounding them with some iron rings, these hollow columns would be capable of supporting very heavy loads. Ancient architects apparently took this into account in their construction of columns, which they made round and slightly bulging [at the centre]"[46].

Once again, then, the question of *entasis* is addressed; once again a text on mechanics deals with problems of architecture. In analysing these issues, one would have to reread the correspondence between Evangelista Torricelli and Michelangelo Ricci on the problem of "cracked" columns[47], already considered by Truesdell in his essay *The Rational Mechanics of Flexible or Elastic Bodies, 1638-1788*[48] and analysed by Paolo Galluzzi in a paper that still has a lot to teach us[49].

If we consider that a few years later Leonhard Euler was to clarify the "buckling problem" (buckling of a compressed beam) by analysing the *force des colonnes*, and that soon afterwards, the great mathematician Louis Lagrange was to tackle the question of *entasis* mathematically, citing architectural literature on the subject (Vitruvius, Vignola, Palladio, François Blondel), one might come to the conclusion that this fabric of mechanics and architecture should finally find patient weavers: among theoreticians of mechanics, among architects, architectural historians and historians of science, in the context of a rigorous, systematic and far-sighted "Epistemic History of Architecture".

To achieve this, however, one would need to overcome, once and for all and in a resolute and incisive manner, the growing pains that have left their mark on our research and on that of others into the *ars aedificandi*. This research, as I have suggested, suffers from three main ills. Firstly, it is threatened by those who deny or ignore the value of history for the development of scientific knowledge. Secondly, it is impaired by a toothless historiography that is incapable of coming to grips with the problems and that is accustomed to cooking an insipid epistemic broth in which documentary substances of uncertain origin float. Thirdly, it is rendered sterile by a sort of ping-pong between academic disciplines and by a perverse pigeonholing of studies in which so-called experts divide the exploration of a network of themes among themselves: to you the holes, to me the cords.

By carving up disciplines in this way, one plays with the mesh and the openings in the net, but the essential elements are allowed to fall through the gaps and slip away as if they were something irrelevant. As a result, architecture is divorced from its history in the shortsighted view of those who don't understand the premises of *ars inveniendi.*

[1] "Ich fühlte in diesem Augenblick mit einer Bestimmtheit, die nicht ganz ohne ein schmerzliches Beigefühl war, daß ich auch im kommenden und im folgenden und in allen Jahren dieses meines Lebens kein englisches und kein lateinisches Buch schreiben werde: [...] nämlich weil die Sprache, in welcher nicht nur zu schreiben, sondern auch zu denken mir vielleicht gegeben wäre, weder die lateinische noch die englische, noch die italienische oder spanische ist, sondern eine Sprache […], in welcher die stummen Dinge zuweilen zu mir sprechen, und in welcher ich vielleicht einst im Grabe vor einem unbekannten Richter mich verantworten werde." Hugo von HOFMANNSTHAL, "Brief des Lord Chandos an Francis Bacon (A.D. 1603, diesen 22ten August)", in *Der Tag, moderne illustrierte Zeitung*, 18 October 1902 (English translation by Peter Spring, 2005).

[2] "Francesco Bacone dette al suo nuovo Regno scientifico il nome d'*Instauratio Magna,* e si credè di dover esserne investito Monarca, per avere architettata l'Enciclopedia d'ogni scienza e arte nel libro *De augmentis scientiarum,* e per aver nel *Novum Organum* minutamente divisate le regole da seguirsi nel metodo sperimentale. È facile però persuadersi che quella sua Monarchia non era altro che di un nome vuoto, o se si vuole, di un regno già trapassato. Se, infatti, scienza veramente non ci è, e non ci è stata mai, come vuole Bacone, egli divisa dunque nella sua Enciclopedia i loculi senza avere di che riempirli." Raffaello CAVERNI, *Storia del metodo sperimentale in Italia*, vol. 1, Firenze 1891, p. 118 (English translation by Peter Spring, 2005).

[3] See Antonio BECCHI, Massimo CORRADI, Federico FOCE and Orietta PEDEMONTE, eds., *Construction History. Research Perspectives in Europe*, Firenze 2004.

[4] Sigurd FLECKNER, "Gotische Kathedralen – Statische Berechnungen", *Bauingenieur* (January 2003), pp. 13-23.

[5] Karl-Eugen KURRER, *Geschichte der Baustatik*, Berlin 2002.

[6] Jürgen RENN, Peter DAMEROW and Simone RIEGER, "Hunting the White Elephant: When and How Did Galileo Discover the Law of Fall?" (with an appendix by Domenico Giulini), *Science in Context* 13, nos. 3-4 (2000), pp. 299-419.

[7] Guidobaldo del Monte, *Meditatiunculae Guidi Ubaldi* [...], Bibliothèque Nationale de France, Paris, MS Lat. 10246, 1587-1592.

[8] RENN ET AL. 2000, p. 311.

[9] Guglielmo LIBRI, *Histoire des Sciences Mathématiques en Italie* [...], vol. 4, Paris 1841, pp. 397 et seq.

[10] RENN ET AL. 2000.

[11] See MS Corsini 50.F.1, Biblioteca Corsiniana (Rome). Facsimile in Ingrid D. ROWLAND, ed., *Vitruvius. Ten Books on Architecture. The Corsini Incunabulum. With the annotations and autograph drawings of Giovanni Battista da Sangallo*, Roma 2003.

[12] Bernardino BALDI, *In mechanica Aristotelis problemata exercitationes. Adiecta succinta narratione de autoris vita et scriptis*, Mainz 1621, pp. 101-104. See Antonio BECCHI, *Q. XVI. Leonardo, Galileo e il caso Baldi: Magonza, 26 Marzo 1621*, Venezia 2004.

[13] Giovanni POLENI, *Memorie istoriche della gran cupola del Tempio Vaticano e de' danni di essa, e de' ristoramenti loro, divise in libri cinque*, Padova 1748.

[14] Klaus NOHLEN, "Concameratio: eine leichte Wölbschale in Pergamon. War den Römern die Kettenlinie für die Formgebung von Wölbungen bekannt?", in *Bautechnik der Antike*, Conference proceedings, A. Hoffman, E.-L. Schwandner, W. Hoepfner and G. Brands, eds., Mainz 1991, pp. 166-171.

[15] Hansgeorg BANKEL, "*Scamilli inpares* at an Early Hellenistic Ionic Propylon at Knidos – New Evidence for the Construction of a Curvature", in *Appearance and Essence. Refinements of Classical Architecture: Curvature*, Conference proceedings, L. Haselberger, ed., Philadelphia 1999, pp. 127-138.

[16] BANKEL 1999, p. 135 and fig. 6.13.

[17] Oscar BRONEER, "Measurements and Refinements of the South Stoa at Corinth", *American Journal of Archaeology* 53, no. 2 (April-June 1949), pp. 146 et seq.

[18] BRONEER 1949, p. 147.

[19] Dieter MERTENS, "Zur Entstehung der Entasis griechischer Säulen", in *Bathron. Beiträge zur Architektur und verwandten Künsten. Festschrift für H. Drerup*, H. Büsing and F. Hiller, eds., Saarbrücken 1988, pp. 307-318.

[20] Lothar HASELBERGER and Hans SEYBOLD, "Seilkurve oder Ellipse? Zur Herstellung antiker Kurvaturen nach dem Zeugnis der Didymischen Kurvenkonstruktion", *Archäologischer Anzeiger* (1991), pp. 165-188.

[21] Pietro CATANEO, *L'architettura*, Venezia 1567 (1st edition: 1554), book 5, chapter 11.

[22] Andrea PALLADIO, *I quattro libri dell'architettura di Andrea Palladio*, Venezia 1570, book 1, chapter 13.

[23] Lothar HASELBERGER, "Old Issues, New Research, Latest Discoveries: Curvature and Other Classical Refinements", in *Appearance and Essence. Refinements of Classical Architecture: Curvature*, Conference proceedings, L. Haselberger, ed., Philadelphia 1999, pp. 1-68.

[24] Gorham P. STEVENS, "Entasis of Roman columns", *Memoirs of the American Academy in Rome* 4 (1924), pp. 121-152.

[25] STEVENS 1924, p. 126.

[26] James STIRLING, "Methodus disponendi quotcunque Sphaeras in Fornicem. Et inde Demonstratur Proprietas praecipua Curvae Catenariae", in *idem*, *Lineae Tertii Ordinis Neutonianae, sive Illustratio Tractatus D. Neutoni De Enumeratione Linearum Tertii Ordinis.* [...], Oxford 1717, pp. [11]-[14]; Stirling's essay was studied in its original edition (1717), but the picture shown here was copied – for conservation reasons – from an edition published in 1797. See James STIRLING, *Isaaci Newtoni Enumeratio Linearum Tertii Ordinis; sequitur Illustratio Ejusdem Tractatus Auctore Jacobo Stirling*, Paris 1797, table C, fig. 39.

[27] Leon Battista ALBERTI, *Leonis Baptistae Alberti Florentini viri clarissimi de Re aedificatoria opus elegantissimum, et quam maxime utile*, Firenze 1485, book 3.

[28] The problem had already been pointed out by David Gregory, "Catenaria. Ad Reverendum Virum D. Henricum Aldrich S.T.P. Decanum Aedis Christi *Oxoniae*", *Philosophical Transactions* 19 (1695-1697), pp. 637-652, p. 641: "Ex praecedente Corol. 5. colligitur quali vi arcus, muros quibus insistit extra propellit; nempe haec eadem est cum parte vis Catenam sustinentis, quae secundum directionem Horizontalem trahit. Quae enim in Catena introrsum trahit vis, in arcu Catenae aequali, extrorsum propellit."

[29] Galileo GALILEI, *Discorsi e dimostrazioni matematiche, intorno a due nuoue scienze attenenti alla mecanica & i mouimenti locali*, Leiden 1638.

[30] "Io ho una palla di bronzo esquisitamente rotonda, non più grande di una noce; questa, tirata sopra uno specchio di metallo, tenuto non eretto all'orizonte, ma alquanto inclinato, sì che la palla nel moto vi possa camminar sopra, calcandolo leggiermente nel muoversi, lascia una linea parabolica sottilissimamente e pulitissimamente descritta, e più larga e più stretta secondo che la proiezzione si sarà più o meno elevata. Dove anco abbiamo chiara e sensata esperienza, il moto de i proietti farsi per linee paraboliche: effetto non osservato prima che dal nostro amico, il quale ne arreca anco la dimostrazione nel suo libro del moto, che vedremo insieme nel primo congresso. La palla poi, per descrivere al modo detto le parabole, bisogna, con maneggiarla alquanto con la mano, scaldarla ed alquanto inumidirla, ché così lascerà più apparenti sopra lo specchio i suoi vestigii. L'altro modo, per disegnar la linea, che cerchiamo, sopra il prisma, procede così. Ferminsi ad alto due chiodi in un parete, equidistanti all'orizonte e tra loro distanti il doppio della larghezza del rettangolo su 'l quale vogliamo notare la semiparabola, e da questi due chiodi penda una catenella sottile, e tanto lunga che la sua sacca si stenda quanta è la lunghezza del prisma: que-sta catenella si piega in figura parabolica, sì che andando punteggiando sopra 'l muro la strada che vi fa essa catenella, haremo descritta un'intera parabola, la quale con un perpendicolo, che penda dal mezo di quei due chiodi, si dividerà in parti eguali." GALILEI 1638, *Seconda Giornata*. English translation from Galileo GALILEI, *Two New Sciences, Including Center of Gravity & Force of Percussion*, transl., with introduction and notes, by S. Drake, Madison, Wisc./London 1974, pp. 142 et seq.

[31] RENN ET AL. 2000.

[32] Jean ERRARD DE BAR-LE-DUC, *Le premier livre des instruments mathematiques mechaniques*, Nancy 1584.

[33] See Antonio BECCHI, "*Chambre H.* Per una storia del costruire", in *Degli archi e delle volte. Arte del costruire tra meccanica e stereotomia*, A. Becchi and F. Foce, eds., Venezia 2002, pp. 17-127, pp. 41-48.

[34] "Benchè (a parlar con tutta la verità) di certi strani effetti di scissure non si abbiano ancora evidenti meccaniche cognizioni, non ostante egli è fuor di dubbio, che una disordinata violenza in una parte può produrre lo sconcerto in un'altra diversa parte: siccome accade tal volta, che il cranio percosso nella parte destra, non nella parte medesima resti fesso, ma nella sinistra, e vicende-

volmente che percosso in questa, si fenda in quella: il qual caso, chiamato da Ippocrate (tradurremo così) *sfortuna*, da molti Cerusici viene detto *Contrafissura*: e ciò molto più facilmente avviene in coloro, che per l'età avanzata non avendo quasi più suture nel cranio, vengono ad aver questo quasi tutto d'un pezzo. Non è dunque da sospettarsi, che nelle Fabbriche ancora alcun strano accidente (in qualche maniera di simil genere) accader possa?" POLENI 1748, col. 115 (English translation by Peter Spring, 2005).

[35] Vincenzo VIVIANI, *Formazione, e misura di tutti i cieli* [...], Firenze 1692, p. 18.

[36] "L'Autore [Vincenzo Viviani] medesimo ci informa, che questa volta [quella a botte] sia la più antica*, come che dalla natura medesima l'imparassero nell'osservare, che godendo essa della forma circolare, fin la sottile scorza, che circonda il fusto d'un albero segato nel mezzo, e messo a diacere col concavo per di sotto e valendole a sostenere grandissimi pesi posati sul convesso, o schiena di tale scorza*. La scorza che dice il Sig.re Viviani, come sono tutte le scorze degli alberi, è da per tutto della medesima grossezza; e come ella per il suo detto, resiste a così gran pesi posti sul convesso e manterrà la sua costanza? Mentre noi seguitiamo la sua lettura, soggiunge, si lavora la volta a mezza botte, *e giù basso ne fianchi, sino a due terzi in circa dell'altezza, la fanno fare il doppio più grossa, affinchè il rimanente dell'arco di mezzo, che gravando spinge alle bande, trovi quivi maggior resistenza, e contrasto*. Che cosa impareranno gl'Architetti? Che faranno i Muratori avendo fra mano le volte a mezza botte? La scorza è valevole a sostenere grandissimi pesi, e non è sino a due terzi più grossa? Il fare le attenti ricognizioni, e le sessioni di proposito intorno alla gran Cupola del Brunellesco, non è fatica, non è scienza simile a quella, che richiede il parlare d'una volta a mezza botte [...]." Bartolomeo Vanni, *Discorso Sopra i difetti, e Vizi delle fabbriche* (...), Archivio di Stato di Firenze, MS f.212. See Luigi ZANGHERI, ed., *Avvertimenti e discorsi di Bartolomeo Vanni, Ingegnere Mediceo (1662-1732),* Firenze 1977, p. 62. The same remarks are also to be found in Bartolomeo Vanni, *Pareri di Bartolommeo Vanni intorno alle fabbriche degli archi, de' voltami, e delle cupole*, Biblioteca Riccardiana (Florence), MS 2141 (English translation by Peter Spring, 2005).

[37] Caius PLINIUS SECUNDUS, *Historia naturalis*. See Caius Plinius Secundus, *Historia naturalis ex recensione I. Harduini et recentiorum adnotationibus*, vol. VIII, I, Torino 1832, book 29.

[38] "Egli arebbono voluto che Filippo avesse detto l'animo suo minutamente e mostro il suo modello, come avevano mostri essi modelli e disegni loro; il che non volse fare, ma propose questo a' maestri e forestieri e terrazzani, che chi fermasse in sur un marmo piano un uovo ritto, quello facesse la cupola, ché quivi si vedrebbe lo ingegno loro. Fu tolto uno uovo, e da tutti que' maestri provato a farlo star ritto, nessuno sapeva il modo. Fu loro detto a Filippo ch'e' lo fermasse, et egli con grazia lo prese, e datoli un colpo del culo in sul piano del marmo lo fece star ritto. Romoreggiando gl'artefici che similmente arebbono fatto, rispose loro Filippo ridendo che egli averebbono ancora saputo voltare la cupola, vedendo il modello o il disegno." Giorgio Vasari, *Vita di Filippo Brunelleschi*, in Giorgio VASARI, *Le vite de' più eccellenti architetti, pittori, et scultori italiani* [...], Firenze 1550 (English translation by Peter Spring, 2005).

[39] "E sonvi molte pietre, e delle nascoste negli angoli, che none apariscono a nessuna evidenza, e di quelle che appariscono, e di quelle che appariscono in parte, di macigni lunghi; che quand'è ne parlava agli scarpellini, a nessuno modo lo potevano intendere. E quando con terra molle e quando con ciera, quando con legnami, e in vero lo serviva molto quelle rape grandi, che vengono la vernata in mercato, che si chiamano calicioni, a fare e modegli piccoli ed a mostrare loro." Cf. Antonio MANETTI, *Vita di Filippo Brunelleschi, preceduta da La novella del grasso*, critical text edition by Domenico De Robertis with introduction and notes by Giuliano Tanturli, Milano 1976, pp. 97 et seq. English translation of Antonio MANETTI, *The Life of Brunelleschi*, introd., notes and critical text edition by Howard Saalman. English translation of the Italian text by Catherine Enggass, University Park/London 1970, pp. 92 et seq.

[40] Vincenzo SCAMOZZI, *L'idea della architettura universale*, Venezia 1615.

[41] "Questa forza, & egualità della Volta à Cupola la potiamo conoscere anco con l'esperienza delle cose naturali, e specialmente dal vuovo; il quale per sua natura havendo un scorzo cosi sottile, e debole, niente di meno non è forza humana, che lo possi rompere, come disse anco Plinio; perche strignendolo per il capo, e punta, che dimostrano i Volti di mezo cerchio, ò apuntati, & i suoi lati quelli scemi, ò manco, che di mezo cerchio; come si può trarre anco da Alessandro Affrodiseo: e noi habbiamo fatto prova, che tre vuova fernate in piedi sù una tavola, conun poco di cera da ambi i capi, hanno sostenuto il peso d'un mortaio di metallo di più di 150. libre di peso." SCAMOZZI 1615, part 2, book 8, p. 320 (English translation by Peter Spring, 2005).

[42] Galileo GALILEI, *Le opere*, Firenze 1968, vol. VIII, pp. 604 et seq.

[43] Ignace Gaston PARDIES, *La statique ou la science des forces mouvantes*, Paris 1673.

[44] "Cependant il est bon de remarquer que nul corps absolument ne se romp jamais, que quand ses parties sont trop tirées; & si un verre qui résiste à la traction se casse quand on le veut faire ployer, c'est que par le moyen de cette inflexion, on tire les parties convexes avec plus d'effort qu'on ne sauroit faire en tirant droit le verre par les deux bouts, comme l'on pourra voir dans la suite de ce discours. C'est pour cela qu'on trouve une si prodigieuse résistance dans un œuf qu'on voudroit écraser en le pressant de bout en bout entre les deux mains: ce qui paroist bien surprenant à ceux qui n'en savent pas la raison." PARDIES 1673, p. 148 (English translation by Peter Spring, 2005).

[45] See Isabella TRUCI and Marta ZANGHERI, eds., *La collezione galileiana della Biblioteca Nazionale di Firenze*, vol. 3, 2, Roma 1994, p. 301.

[46] "Ainsi l'on peut faire des colonnes de planches de bois, qui seront tres-fortes; car si on les joint ensemble comme les doiles des barriques, en leur donnant une petite courbure, & les environnant de quelques cercles de fer, ces colonnes ainsi creuses seront capables de supporter de tres-pesants fardeaux. Il y a apparence que les anciens Architectes ont eû égard à ceci dans la construction des colonnes qu'ils ont fait rondes & un peu renflées." PARDIES 1673, pp. 151 et seq. (English translation by Peter Spring, 2005).

[47] See Gino LORIA and Giuseppe VASSURA, eds., *Opere di Evangelista Torricelli*, vol. 3, Faenza 1919, pp. 91 et seq.

[48] Clifford A. TRUESDELL, "The rational mechanics of flexible or elastic bodies, 1638-1788", in *Leonhardi Euleri Opera Omnia*, vol. X-XI, ser. secunda, Zürich 1960, p. 53, note 1.

[49] Paolo GALLUZZI, "Le colonne fesse degli Uffizi e gli screpoli della cupola: il contributo di Vincenzo Viviani al dibattito sulla stabilità della cupola del Brunelleschi", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze,* A. 2, fasc. 1 (1977), pp. 71-111.