MYTH AND MANAGEMENT IN THE CONSTRUCTION OF BRUNELLESCHI'S CUPOLA

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The cupola of Santa Maria del Fiore, erected under the direction of Filippo Brunelleschi from 1420 to 1436, shares with other extraordinary architectural monuments a tendency to generate myths about its realization. A noble earlier example of this phenomenon is the great Justinianic basilica of Hagia Sophia in Constantinople (532-537), which inspired its own legends elaborated over centuries, despite repeated collapses of the dome, the first occurring only twenty years after its construction.[1] Brunelleschi's dome, still standing proud over Florence, possesses all the myth-attracting ingredients: mammoth size, striking form, assertive color, axial position in the city that spawned the Renaissance of the visual arts (Fig. 1). Above all, however, the structure's mystique derives from the fact that its double-shelled octagonal cloister vault was erected according to the architect's revolutionary invention, without the supporting armature employed to sustain soaring Gothic vaults (including those of the nave and crossing arms of the Florentine cathedral itself) until their keystones were in place. The cupola was an astonishing technical accomplishment, one that still inspires awe in those who visit it.

But myth goes a step beyond the appreciation of brilliant engineering. In the case of the Florentine dome a compelling story was spun around the figure of the structure's inventor and the circumstances of its realization, constructing a heroic epic in which the stature of the protagonist is necessarily commensurate with the monument created. The vault of the dome had scarcely been closed around its central

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[1] Already in the time of Justinian the court historian Procopius glorified the emperor's contributions to its complex structural solutions, and legends that sedimented in the ninth- or tenth-century *Diegesis* continued to weave fantastic tales around the astounding structure. See especially MANGO 1992, 41-56, as well as MANGO 1986, 72-78, 96-102, and OUSTERHOUT 1999, 40-41, 50.

oculus in 1436 when Leon Battista Alberti, hailing the outstanding artists he found in Florence, where he had come in the entourage of Pope Eugenius IV, alluded to both mythic components in the introduction to his treatise *On Painting*: "Who could ever be hard or envious enough to fail to praise Pippo the architect on seeing here such a large structure, rising above the skies, ample to cover with its shadow all the Tuscan people, and constructed without the aid of centering or great quantity of wood?"[2] This passage seems to insinuate by disclaimer that the ingenious structure of the massive cupola embodies the triumph of its inventor in the face of invidious episodes. The architect's heroism is amplified by antagonism.

Such would be the approach to the story of Brunelleschi's life as written decades later by Antonio di Tuccio Manetti, who claimed to have put down information gleaned from the protagonist himself before his death in 1446.[3] It is a partisan account of the architect's career which, with all its exaggerations and omissions, was the principal source for Giorgio Vasari's incomparably influential pages on the construction of the cupola in his *Lives of the Artists*.[4] What is particularly interesting in the present context is the fact that Manetti had recourse to the archives of the cathedral's board of works, the Opera of Santa Maria del Fiore, in order to substantiate his statements. That is, administrative documents were adduced to lend credence to versions of events that the author had heard from Brunelleschi or other period witnesses. A famous example, long unmasked by modern scholars, is the citation of the text of two payments made in 1419 to Brunelleschi and to his proverbial rival, Lorenzo Ghiberti, for competition models for the cupola. Lorenzo receives nearly six times as much as Filippo for expenses incurred that were, in Manetti's words, "thrown away" because useless.[5] But a closer look at the documentation reveals that the pay-

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[2] English translation from HYMAN 1974, 26. On the date and precedence of the Italian redaction of Alberti's treatise, see BERTOLINI 2000, 181-210.

[3] Giuliano Tanturli discusses the nature of Manetti's account and its sources and proposes a dating of 1475-80 in his commentary to the standard edition of Domenico De Robertis: MANETTI 1976, xxiv-xxxv.

[4] VASARI 1971, 3:148-180. For Vasari's "pirating" of Manetti's *Life*, see RUBIN 1995, 169, 173-74. It should be noted that, although Vasari fully exploits Ghiberti's *Commentari* in other matters, in the case of the cupola the self-aggrandizing affirmations of that source are brushed aside in favor of Manetti's account with its heroizing of Filippo.

[5] Manetti transcribed complete entries from the now lost account book of the treasurer, Migliore di Tommaso, whose text cited the relative allocations of funds made by the *operai* in

ment to Brunelleschi regards only the finishing wood components of his last, large-scale model and is excerpted from a two-year-long campaign of competition projects, during which the Opera's investments for models were substantially greater and more diversified. The documentary texts were snatched from their archival context and brandished by a biographer who counted upon the Florentine readers' penchant for historical records and respect for the institutions that produced them.[6]

Selective documentation, if on an expanding scale, has continued to characterize the historiography of the Florentine cathedral. The archival sources on the cupola have been the subject of two very dissimilar editions: the corpus assembled by the archivist Cesare Guasti in 1857 with the purpose of providing an objective basis for renewed studies of the cathedral, and the documentary appendix provided by the architectural historian, Howard Saalman, as a support tool for his 1980 monograph on Brunelleschi's cupola. The former has remained almost the sole locus of consultation in the last 150 years, perhaps because the latter presents philological defects and is arbitrarily organized in fragmented categories.[7] Guasti's work conforms to the practices of nineteenth-century erudition, with its emphasis on personal histories, models, and prestigious, institutional documents, and although it does not ignore matters of worksite practices and supplies, the choice of examples constitutes the tip of the iceberg of the actual archival records. Meanwhile, in scholarly works and popular literature alike, the time-honored stories of the heroic cupola effort continue to be woven into the web of known documentation, with little attempt to distinguish the relative authority of the sources.[8] Saalman himself, misreading a payment to

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August 1419, recorded in two extant codices of the Archivio dell'Opera di Santa Maria del Fiore (henceforth AOSMF), Stanziamenti II-4-8, cc. 51vc and 51vd, and Deliberazioni II-1-76, cc. 47vf and 48a, both published in GUASTI 1857, docs. 20 and 30. See MANETTI 1976, 91.

[6] Another actively documented account of the building of the cupola of Santa Maria del Fiore is Baldinucci's *Life* of Brunelleschi: BALDINUCCI 1812, 153-288, esp. 187-232. The account leans heavily on the *Life*, subsequently recognized as the work of Antonio Manetti, that is published in the same volume; at the same time it presents numerous new transcriptions of sources from the Opera archive. This work was left unfinished by Filippo Baldinucci at the time if his death in 1697 and was completed by his son Francesco Saverio, as stated in the preamble: see also Bruno Santi's commentary in the edition in *Zibaldone baldinucciano* 1980, 2:525-527.

[7] GUASTI 1857; SAALMAN 1980. An exception to the neglect of Saalman's monograph in studies by Italian scholars is represented by the contributions of Luca Giorgi; see, for example, GIORGI and MATRACCHI 2006, 277-324.

[8] See, for example, the interchangeable use of Manetti's account and archival sources in

a kilnman for bricks, provides a telling example of the "discovery" of a document to prove Manetti's unlikely story that Brunelleschi had a kitchen installed in the dome's lofty worksite to dissuade workers from descending for lunch.[9]

The textual database, *The Years of the Cupola*, reaches beyond the scope of these previous documentary editions, with its aim to embrace the complete administrative documentation extant in the archive of the cathedral board of works, the Opera di Santa Maria del Fiore, for the two decades (1417-1436) that saw the planning and construction of the great dome. Begun in 1994 as a pilot project commissioned by the cathedral Opera, it has developed into a powerful online edition comprising over 21,000 official acts that are freely accessible to a new generation of scholars. The documentary texts, only about 7 percent of which had been previously published or cited, are fully transcribed and annotated, provided with summaries, indices, analysis for guided access, links to related acts. They deal with every aspect of the Opera's activities, from the cupola to the church's magnificent furnishings, from the cathedral's financing to its administrative personnel, from the papal apartments in the nearby Dominican convent of Santa Maria Novella to the fortifications in the countryside assigned to its workforces by the beleaguered Commune.[10]

Di Pasquale 2002; and most recently Jones, Sereni and Ricci 2010, 38-61. The efficacious story-telling of the Renaissance authors continues to resonate in modern popularizing literature, such as King 2000 and Walker 2002.

[9] Saalman 1980, doc. 270-71. Cf. Manetti 1976, 98, emphasized by Vasari 1971, 176. There is no record of workday food service on the dome or elsewhere in the Opera worksite. The only regularly documented refreshments offered to workers were barrels of wine on certain holidays or to celebrate moments of achievement in the building history, and the simplest of bread and wine repasts in the context of special, after-hours service. The only recorded exception is the meal offered on the occasion of the benediction of the completed dome (see note 50).

[10] The web edition of this source is cited in the present essay as *Cupola*. See Bibliography for the full citation and internet addresses. An undertaking of this scope would have been impossible without the enlightened support of the modern Opera di Santa Maria del Fiore and the special interest of its past president, Anna Mitrano. The project is indebted to Eugenio Picchi and the DBT team at the Center of Computational Linguistics of the National Research Council in Pisa (CNR-Pisa) for providing the textual database program, customized to accommodate the complexity of the data and revised and updated over the years. The long-standing partnership with the Max Planck Institute for the History of Science in Berlin, thanks to the vision of its director, Jürgen Renn, has endowed the project with the scientific collaboration and tools to enable realization of its fullest potential as an internet edition, prepared by Jochen Büttner. For the photographic documentation and virtual restoration of flood-damaged manuscripts, the project has benefited from the generous collaboration of the Conservation Institute

The documentation contained in *The Years of the Cupola* edition constitutes a sort of self-portrait of the cathedral's administrative structures and provides the material for an "authorized biography" of the cupola construction, set in the context of the full range of the Opera's activities. Although it includes several extensive written programs for the dome project, there is very little theory in these businesslike records, and any graphic material they once contained has long been lost or discarded. One finds instead the proceedings of the meetings of the Opera wardens (called *operai*), agreements and contracts with collaborators and suppliers, payments and accounts of all kinds recording the day-to-day running of the vast worksite. In the digital edition the most "prestigious" documents, in many cases previously published, are contextualized amongst more commonplace, no-longer-neglected aspects of the construction effort, such as administrative personnel and skills, logistics, and the workforce. Its completeness opens new research perspectives by allowing comparison over time and quantitative analysis. The following reflections on the nature and use of this new tool for the comprehension of the circumstances of the construction of Brunelleschi's dome are offered as an indication of the directions possible for systematic study of the sources now assembled.

This examination will proceed by comparison between the two kinds of voices available: those of the mythmaking narrators on the one hand and those of the administrators on the other. The latter's story is embedded in the institutional archive that was created and conserved to justify the massive expenditure of public funds in the structure that, more than any other, would become the symbol of the city of Florence. This approach grows out of an earlier study on Santa Maria del Fiore which argued that the Manettian tradition could provide a key to interpretation of the archival sources known and published at that time.[11] The historian's task is certainly not to disdain partisan accounts, but to attempt to understand how the assumptions of their

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of the Fachhochschule of Cologne, led by Robert Fuchs, and from the support of the ECHO (European Cultural Heritage Online) program. The project has received major grants from the Getty Grant Program, the Tuscan Region, and the Andrew W. Mellon Foundation. It has benefited from the exceptional archival and historical skills of its team of scholar-editors: Gabriella Battista, also special assistant to the director, Lucia Sandri, Rolf Bagemihl, and Patrizia Salvadori. Visitors to the website will find a fuller account of the project's development and the numerous collaborations that have contributed to its realization.

[11] HAINES 1989, 89-125.

authors and audiences endowed them with verisimilitude.[12] In this light, for example, the forced sharing of supervisory roles over the cupola between Brunelleschi and Ghiberti can be understood as the logical extension of the time-honored insistence on plurality in the search for broad consensus in crucial and controversial matters of cathedral planning, according to the civic model. These expectations were deeply imbued in the republican mentality of the Florentine statesmen and enfranchised citizens who were protagonists in the city's cathedral-building enterprise.[13]

The cupola supervisors

Let us focus first, then, on the role of the two project supervisors of the dome (*provveditori della cupola* was the most common formulation of their title in the Opera documentation), a topic that is treated both in Manetti's *Life* of Filippo Brunelleschi and in the autobiography with which Lorenzo Ghiberti concluded his review of the artists of his age in the *Commentari* (Figs. 2 and 3). Insistence on the matter of titles and respective salaries characterizes both sources. Manetti writes that after a building crisis, already in 1423 Brunelleschi was singled out as "inventore" of the cupola, and that his dominant role was finally recognized and rewarded in 1426, when his salary was increased from 36 to 100 florins a year, while Ghiberti's remained at 36 and, after a year, was terminated.[14] Ghiberti, on the other hand, claims that he was co-

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[12] In this vein see Cyril Mango's elegantly historicizing evaluation of the legends of the *Diegesis* as a source on Hagia Sophia: MANGO 1992, 49-50 ("the boundary between fact and myth is not a fixed line").

[13] HAINES 1989. These concepts are further developed in HAINES 1996; HAINES 2002; HAINES 2008.

[14] MANETTI 1976, 91-92, 95. The 1423 vernacular document he quotes from a no-longer-extant expenditures ledger corresponds to the Latin allocation of funds still conserved in AOSMF, II-1-83, c. 68h, published in GUASTI 1857, doc. 177. The famous revised building program of 1426 and new salary pacts are AOSMF, II-2-1, cc. 170vb and 171a, published in GUASTI 1857, doc. 75. Both acts, together with the numerous previously unpublished sources, are now available in modern critical transcription in *Cupola*. In the present essay reference to documents in this edition is made by archival classification and folio number followed by the letter ascribed to specify progressive position of the act on the folio. Previous editions are cited in the bibliography of the individual entries. Often more than one redaction of an act is preserved in various series of the Opera archives, and, since these relationships are systematically indicated with active links in *Cupola*, references here are normally limited to one series or to the most informative text.

supervisor with Brunelleschi for 18 years, always at the same salary.[15] Neither of these statements turns out to be exact, but Guasti's edition of the archival sources failed to set the record straight because it privileged the annual re-election documents, which are indeed missing for both *provveditori* after 1432, while a note with reference to the actual salary payments incorrectly stated that Ghiberti's ended after 23 January 1433.[16]

With the complete documentation in hand it is now certain that Ghiberti's salary, like Brunelleschi's, continued through the end of the cupola construction in the summer of 1436.[17] However, significant temporary interruptions emerge for both *provveditori*. Ghiberti was docked for 1⅔ months' pay in the autumn of 1424, when he went to Venice in the retinue of the Florentine ambassador, the rich, refined, and powerful Palla Strozzi.[18] His salary was once again withheld, this time by decree of the wardens, for the entire second semester of the following year, during the crisis period leading up to the revised program for construction above the second walkway, while Brunelleschi's payments continued without interruption.[19] Immediately following the

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Regarding Manetti's terminology, it should be noted that, despite his sensitivity to the titles and epithets ascribed to his hero in the documentation, in the thick of his narrative he generally reverts to the term *capomaestro*, from traditional Florentine parlance for the cathedral head architect, ignoring the distinction between *provveditore della cupola* (architect, project supervisor) and *capomaestro* (head builder/foreman) observed in the Opera documentation during Brunelleschi's tenure.

[15] "Poche cose si sono fatte d'inportanza nella nostra terra non sieno state disegnate et ordinate di mia mano. E spetialmente nell'edificatione della tribuna fumo con correnti, Filippo et io, anni diciotto a uno medesimo salario, tanto noi conducemo detta tribuna": GHIBERTI 1998, 97. The expression "concorrenti" may allude to the competitive nature of the two artists' coexistence in this role. For the competition for the Baptistery doors, Lorenzo chose even stronger terms, "conbattimento" and "conbattitori": *ibid.*, 93.

[16] GUASTI 1857, 42-45. Guasti's own correction of this error, 188, has often escaped critical notice. See, for example, the otherwise accurate review in IPPOLITO and PERONI 1997, 17, probably the source of its most recent exhumation in CORAZZI and CONTI 2011, 62.

[17] The hundreds of records of salary payments disbursed to the cupola supervisors at various intervals over the 16-year duration of the building effort can be reviewed in *Cupola* by searching Topics, Personnel, pay - internal. Entries are found not only in the administrators' books of allocations, II-4-8, II-4-9, II-4-12, and II-4-13, extant for the entire cupola period, but also in the semestral registers kept by the notaries up through mid-1425, II-1-78 through II-1-86, in a personal notebook of two administrators for 1432-36, II-4-4, and in the treasurer's cashbooks preserved for the second semesters of 1434 and 1435, VIII-1-1 and VIII-1-2.

[18] HAINES 2001.

[19] *Cupola*, II-1-86, c. 25vb. Brunelleschi's election to the city's highest office, the Priorate, for May and June 1425, may have provided leverage for this temporary victory in the Opera.

program's ratification in February 1426, a new election of the two cupola supervisors, both praised for their "genius and virtue," introduced the salary differentiation mentioned by Manetti, obligating Filippo to full-time presence on the worksite and Lorenzo to a one-hour visit each working day, a proviso that probably intensified the scrutiny of service required for salary payments in the following years.[20]

The hierarchy of the cupola architects had nevertheless been evident from the outset, for out of the hundreds of extant salary documents there is only one case in which Brunelleschi's entry does not precede that of his colleague.[21] The scribes, like the biographers, were sensitive to the matter of titles and personal qualifications. It is perhaps revealing of the artists' comparative dedication to the architectural task at hand that Lorenzo is normally qualified as goldsmith as well as *provveditore della cupola*, while Filippo, whose original profession was the same, is remembered as *orafo* only in three early instances.[22] The term "inventor," reserved for Brunelleschi in the document quoted by Manetti that awarded him special recompense for designing the dome's wood chain, was never attributed to either supervisor in the regular salary payments.[23] Variations on the concept of governing, however, crop up in the series, sometimes referring to both officials, other times perceptibly favoring Brunelleschi.[24] The formulation "procura sopra la cupola" in some of the payments to Ghiberti in 1427 and 1428 may reflect the less demanding if prestigious nature of his role

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Cf. ZERVAS 1979, 630-635. It is to be noted that his necessary absence from the worksite during his tenure as prior, which required constant residence in the Palazzo dei Signori, had no effect on his Opera salary.

[20] *Cupola*, II-2-1, c. 171a.

[21] The exception, present in the notary's redaction for the second trimester of 1422, is probably due to a slip of his pen, as the specification of the office ("electo in provisorem cupole maioris") appears only in Filippo's entry: *Cupola*, II-1-81, cc. 65va and 65vb.

[22] "Filippo orafo" in three entries of 1422: *Cupola*, II-4-9, cc. 29i and 37vc; II-1-81, c. 72vc.

[23] The document in question is in *Cupola*, II-1-83, c. 68h, 27 August 1423. Vasari's statement that both artists were called "inventori" up to 1426 is an undocumented elaboration on Manetti's point: VASARI 1971, 167, both redactions.

[24] In 1423, a salary payment for "provvisione e ghubernatione" to both artists (*Cupola*, II-1-82, cc. 76d and 76e); in the last trimester of 1425, to Brunelleschi serving alone "sopra el governo della tribuna maggiore" (II-4-12, c. 2a); immediately following the 1426 revision, to Brunelleschi as "ghovernatore della cupola maggiore" and to Ghiberti "sopra ghoverno della cupola," but in the next two installments Filippo kept his title while Lorenzo was called "orafo" (II-4-12, cc. 11f, 11g, 16e, 16f).

(Fig. 4).[25] After this the only title normally used in the salary payments was *provveditore della cupola*, sometimes referring to both colleagues, but with greater frequency to Filippo from 1433. As the cupola effort was nearing its conclusion in 1435 the erudite modern title of "architect" was attributed to Brunelleschi in a single occurrence, and its spelling clearly presented a challenge for the administrator.[26]

After the institution of the new regime in 1426, both supervisors are documented as being regularly paid until 1430, when a series of circumstances upset the smooth running of the cupola worksite. Brunelleschi was the first to absent himself for a cause which must have seemed greater than the cupola itself, putting his ingenuity at the service of the Florentine Republic in its ill-starred war with Lucca. The architect had proposed a scheme to force the enemy into submission by flooding the walled city with waters channeled from the nearby Serchio river, and the Florentine war council decided to gamble on this audacious tactic.[27] After a first reconnaissance trip in March, reflected in the punctilious deduction of ten days from his salary, Brunelleschi returned to the swampy country around Lucca in April to direct the construction of dikes and earthworks required for his plan.[28] The result, however, was not the hoped-for expeditious victory of brainpower in the controversial war, but the disastrous inundation of the Florentines' own encampment in early June. Various versions of the event are recounted in early histories of Florence and Lucca, most notably Machiavelli's *Istorie fiorentine*, but not, to be sure, in Manetti's *Life*

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[25] *Cupola*, II-4-12, cc. 40vb, 76vb, 84f. The sole instance of "procuratore" attributed to Brunelleschi on c. 60ve appears to be a scribe's lapsus.

[26] *Cupola*, II-4-13, c. 97vh: ("proveditore e archighetore dell'Opera"). For the same period Lorenzo is simply "proveditore della chupola," c. 97vi. The only other instance of this classicizing term in the *Years of the Cupola* documentary corpus is in the description of advisers consulted for the wardens' resolution of 3 March 1432 (II-2-1, c. 155vc) to award the commission for the bronze reliquary tomb of St. Zenobius to Ghiberti ("audirent omnes scultores, pictores, architectores ceterosque eorum rerum eruditi"), a text whose *all'antica* language was influenced by the humanist Matteo Strozzi, the leading member of a special committee in charge of that project (HAINES 2008, 162).

[27] The remarkable episode is the subject of an exemplary interdisciplinary study by BENIGNI and RUSCHI 1980, 517-533; see also a more correct earlier edition, BENIGNI and RUSCHI 1977, 55-82, 337-358.

[28] The wardens authorized his service in the field with the condition that his cupola salary be reduced proportionally: *Cupola*, II-2-1, c. 124g. In the administrator's book for the first trimester his pay was docked for "dì dieci quando andone a·lLucha"; in the following trimester no entry is present for Brunelleschi, while the salary of Lorenzo di Bartolo "orafo" is recorded as usual: II-4-12, cc. 130b and 137d.

of Brunelleschi, nor in the ever more heroic reworking of this source by Giorgio Vasari.[29] It has been demonstrated that the humiliating setback in Filippo's civic and technological career was not caused by a flaw in the architect's idea ("concetto"), which was based on an accurate trigonometric survey of the terrain around Lucca, but was brought on by poorly financed and organized execution, under enemy fire, of the system of earthworks and by the premature opening of the waters, perhaps by enemy saboteurs.[30]

If, however, even at the time Brunelleschi was not held personally responsible for the debacle, his protracted absence from the cathedral payroll and worksite in the following months may betray his sense of shame or fear of disfavor. The devastating plague that raged through the city in the summer of 1430 would also have constituted a credible excuse for flight.[31] Filippo would return to his cupola responsibilities only when summoned from the upper Arno valley town of Figline by an Opera messenger in early September: he reappeared on the cathedral payroll from the 15th after an absence of six months.[32] As the dire year of 1430 drew to a close, the wardens and Wool Guild consuls in a joint session, citing the plague as the reason for not having done so sooner, retroactively renewed his annual contract, which had expired at the end of March 1430 when he was already in Lucca.[33] Although this act confirmed the usual salary and conditions, a subsequent resolution of 16 February 1431 slashed his pay from 100 to 50 florins per year, "for good and just cause."[34] Meanwhile, Ghiberti, who had been paid regularly during Filippo's tour of duty in Lucca, disappeared from

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[29] The latter omission is the more notable because the same author mentions the war with Lucca as the reputed cause for the dissipation of the funds left by the Scolari heirs for Brunelleschi's temple at Santa Maria degli Angeli: VASARI 1971, 186 (1568 edition only).

[30] BENIGNI and RUSCHI 1980 and 1977. Nevertheless, the event marked the collapse of Filippo's flourishing political career, as reconstructed by ZERVAS 1979, 635-636.

[31] CARMICHAEL 1986, 34, table 2-1. Ghiberti's trip to Venice with the Florentine ambassadors in the autumn of 1424, another dangerous plague year, would later be portrayed by him as an escape from the "morìa" and adduced as justification for the delay in the consignment of his bronze reliefs for the Siena Baptistery: HAINES 2001, 57.

[32] *Cupola*, II-4-13, cc. 2va, 5va.

[33] *Cupola*, II-2-1, c. 176vb, 14 December 1430. In order to facilitate the dispatch of Opera business, two additional *operai* "extra numero" had been drawn for the office in November 1430: Archivio di Stato di Firenze (hereafter ASF), Arte della Lana 160, c. 20 (dated 29 November); names recorded in Arte della Lana 39, Tratte, c. 10 (dated 18 November).

[34] *Cupola*, II-2-1, c. 137va. The actual salary allocations show that the reduced rate was applied only from 14 March through June 1431: II-4-13, cc. 10va, 13vi.

the Opera payrolls for twelve consecutive months from 1 July 1430.[35] Only at the end of June 1431 would both *provveditori* be reinstated to their previous roles and salaries because, it was affirmed, the cupola could not be completed without the reconfirmation of its usual, well-informed supervisors, nor, in consideration of their past service, would it be just to scrimp on their recompense.[36]

This prolonged turbulence in the roles of the cupola supervisors reflects a new crisis period in the building process; it coincides, in fact, with the dating to around 1430 of an interruption in construction, corresponding to discontinuities in the masonry above the third walkway.[37] Brunelleschi's absence during the spring and summer of 1430 was undoubtedly a restraining factor on the progress of work. The circumstances recall the story recounted by Manetti of Filippo's feigned illness that brought construction to a halt, exposing Lorenzo's incompetence to direct the worksite.[38] That event, which the biographer dates in accordance with the Opera documentation to 1423, may in fact be a narrative conflation of several episodes demonstrating how the architect's continual presence was essential to the progress of construction. As Manetti tells it, Brunelleschi did not obtain the elimination of his rival, but the division of tasks at hand, Ghiberti choosing the wood chain, which he botched, Filippo, by exclusion, the new masonry and work platforms.

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[35] Without the full documentation of the salary records, the duration of this lacuna has never been fully perceived. Krautheimer focused on the artist's personal life and works rather than his tallied presences and absences as cupola supervisor at the Opera when suggesting windows of opportunity for trips to Rome and Venice (KRAUTHEIMER 1970, 5-6, 357-358, 412). His analysis of the eccentric Olympiad system for the dating of a Roman sojourn mentioned by Ghiberti in the *Commentari* places the event in or before mid-1430; in addition, he cites an undocumented reference to a possible trip to Venice in that year. When drawn for the office of consul of the master builders' guild on 30 August 1430, "Lorenzo di Bartolucci intagliatore" was recorded as absent from the city (ASF, Mercanzia, Tratte 83, c. 127). I am grateful to Amy Bloch for references and reflections on Ghiberti's activities and whereabouts in 1430-1431; see also her study, BLOCH 2008, 145-147.

[36] *Cupola*, II-2-1, c. 177b. It should be noted that Ghiberti, although not in office at the time, had served as consultant on the nave chains in the period leading up to the decision to construct these reinforcements according to the indications of a model by Brunelleschi: *Cupola*, II-2-1, c. 136e.

[37] GIORGI and MATRACCHI 2006, 296 (illustration), 310, without specification of the nature of the discontinuities. A date incised in fresh plaster under the third walkway has been read as 1430, as it seems in the photograph published by its discoverers: FALLETTI and PAOLINI 1977, 57-58. A better on-site reading of the roughly scratched date appears to be 1429; since nonstructural tasks such as plastering were often carried out in dead periods on the worksite, its strict significance can only be as a *terminus ante quem* for the area under the walkway.

[38] MANETTI 1976, 92-95.

After the completion of the wood chain in 1424, attention turned to the stone chain under the second walkway, begun in June 1425 on the eve of the first lengthy interruption of Ghiberti's salary (Fig. 5).[39] A prolonged consultation process during the following semester forged the revised building program that was formally undersigned by both supervisors and approved by all the Opera authorities in early 1426.[40] It laid out the specifications for the rising structure above the second walkway, with the introduction of the famous herringbone brickwork and the so-called horizontal arches intended to stabilize the two ever more inclined shells of the dome during construction, which was to continue as begun without supporting armature. Provision was made for stone and iron circumferential chains and for enclosed work platforms to insure the workers' safety. The institutional and heroizing significations of this pivotal moment in the planning of the great dome coexist in the notary's redaction of the final act: in the main text he dutifully enumerates all the participants in the deliberations and the signatories of the revised project, but the succinct marginal title indicates his understanding of the program's essential authorship, indicating that work will continue "according to the design of Filippo di ser Brunelleschi."

On the basis of this document, building resumed apace until 1430, around the level of the next walkway, the third. From here, the continuation of the last, breathtaking segment of the vaults would have been an intimidating task under any circumstances, but the situation was complicated by fears for the stability of the unbuttressed nave vaults, unduly stressed by the thrusts of the rising dome. In January 1431 the decision was taken, in consultation with Brunelleschi, Ghiberti, the Opera's trusted foreman Battista d'Antonio, and other qualified builders, to install an extensive system of iron and wood chains (tie rods) to secure the cracking nave vaults, a project that would continue for another six years.[41] Furthermore, although big orders of bricks in the distinct sizes employed in the cupola's herringbone fabric were awarded in early 1431,[42] by June a major liquidity crisis of the Opera

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[39] *Cupola*, II-4-9, c. 101va.

[40] *Cupola*, II-2-1, c. 170vb: "Quod laborerium cupole magne sequatur secundum disegnum Filippi ser Brunelleschi."

[41] *Cupola*, II-2-1, c. 136e and subsequent documentation searchable under Topics, Objects, chains. For the whole story with analysis of the structures, see GIORGI and MATRACCHI 2006, 303-308.

[42] *Cupola*, II-2-1, cc. 135vd (January), 137g (February), 140vd (April).

prompted a countermand, restricting the consignment of bricks and lime for mortar to the bare minimum necessary to carry on construction.[43] All of these causes of concern contribute to our understanding of the importance and the cost of reinstating both cupola *provveditori* at this time. That work on the cupola had come to a standstill, though never explicitly stated in the documentation, can be deduced by statements of intention to resume construction in February and again in August 1431.[44]

Contrary to what has been affirmed in a number of recent studies of the cupola, building above the third walkway must have been back under way at a steady pace by mid-1431.[45] Only brief absences of the supervisors are documented in the following years. The first of these was Brunelleschi's authorized trip to serve Niccolò III d'Este in Ferrara and Gianfrancesco Gonzaga in Mantua in the spring of 1432; the wardens wrote to these rulers, asking them to respect the time limit of one and a half months for the architect's absence in view of the Opera's need of him ("allegando necessitatem Opere").[46] Filippo had in fact returned before the next major design decision was taken in hand in the summer of 1432: the question of the exact dimension of the oculus opening for the lantern at the dome's summit and the structure of the closing ring intended to stabilize the whole structure.[47] A hitherto

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[43] *Cupola*, II-2-1, c. 143va, 15 June 1431.

[44] *Cupola*, II-2-1, c. 137e (slaking of mortar); c. 138a (new list of 39 workers to start on 1 March); c. 148b (order to have work begin on the cupola). Despite all the difficulties, the end must not have seemed far off if a model of the altar of the chapel of St. Zenobius was urgently ordered because "the cupola will soon be closed": II-2-1, c. 136vb, 26 January 1431.

[45] A misinterpretation of a document recording the completion of a stone chain in the summer of 1433 (*Cupola*, II-4-13, c. 60a: "misono la chatena de macingni e serarola in su la chupola") as referring to the ring embedded under the third walkway instead of the final bond incorporated in the closing ring has given rise to a string of excessively late chronologies for the upper reaches of the vaults and the closing ring, starting with Saalman 1980, 132; followed by Ippolito and Peroni 1997, 36-37; Fanelli 2004, 30; Corazzi, Conti and Marini 2005, 13-14; Giorgi and Matracchi 2006, 310-311; Corazzi and Conti 2011, 56, 86-87, 110. Giorgi's calculations of the construction rate in the upper reaches of the vaults are therefore subject to revision.

[46] Brunelleschi turned first to the highest echelon, the consuls of the Arte della Lana, to obtain release from his obligation to the guild and the *operai*: ASF, Arte della Lana 164, Atti e partiti, c. 48v, 27 March 1432 (unpublished). The Opera documents are in *Cupola*: leave of absence of one month and 15 days granted on 2 April 1432, corresponding to salary interruption from 1 March to 19 May 1431: II-2-1, c. 157a, and II-4-13, c. 29vn.

[47] *Cupola*, especially II-2-1, cc. 163a, 167g, 201g. For the specially cut stone blocks and the chronology of this structure, see pp. 78-80 below, under "Building supplies," and Haines

unrealized disappearance of Ghiberti from the payroll in July 1433 seems, on the other hand, to have required no authorization, perhaps because his services were not vital to the worksite at this point.[48] Brunelleschi's final absence from the cupola payroll in April 1436 was duly authorized in response to a petition presented by him and the marquis of Mantua.[49] Months earlier major construction work on the dome and closing ring must have been sufficiently completed to allow the removal of equipment and the paving and preparation of the crossing area for the solemn consecration ceremony of the cathedral in the presence of Pope Eugenius IV on 25 March 1436, the first day of the new year according to ancient Florentine calculations. The mandates of the two *provveditori* terminated at the end of June, and the achievement of the miraculous dome itself merited a new ceremony presided over by the bishop of Fiesole on the following 30 August.[50]

The workforce

Another rich category of documentation yielded by the new edition concerns the composition of the workforce over the twenty years covered.[51] In anticipation of the detailed and systematic presentation that

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and BATTISTA 2006, 59-71, as well as the recent revision and amplification of this material in HAINES and BATTISTA, online (2012).

48 Cf. Brunelleschi's salary for same period: *Cupola*, II-4-13, c. 61vf. In March 1432 Ghiberti had contracted for the bronze reliquary chest of St. Zenobius, but work seems to have been slow in starting. His only payment for this commission in 1433 was allocated on 10 July with the clause that it be disbursed on 1 August after another debt to marble suppliers: II-4-4, c. 24s; II-4-13, c. 59ve.

49 Leave for 20 days granted 3 April 1436 with salary interruption from 5 April to 1 May 1436: *Cupola*, II-2-1, c. 251vg; II-4-13, c. 127m.

50 The final salaries of the cupola supervisors are in *Cupola*, II-4-13, cc. 131vd and 131ve. The consecration has been the subject of important recent scholarship, including KENT 2000, 122-128, on Cosimo's appropriation of the center stage in an achievement from which he had been largely absent; SMITH and O'CONNOR 2006, 30-48 and 305-359 on Giannozzo Manetti's account of the event. The full Opera documentation is now available in *Cupola*, under Topics, Events, extraordinary, consacrazione. The more intimate benediction ceremony, with a rare multi-course meal for the Opera workers and officials, is recorded in *Cupola*, II-4-13, c. 136g. The diary of Bartolomeo DEL CORAZZA (1991, 36) describes the repast as having been served in the workyard behind the cathedral.

51 A word about terminology. When referring to the skilled workers employed on the cathedral worksite, the Opera documents most commonly employ the generic term *maestri/magistri*, i.e., master workmen of undefined specialization, mentioned individually or in groups.

these sources merit, a concise overview will be offered here of the numbers and categories of the workers and the policies regarding their service, to suggest how this data can modulate the "mythic" story of the cupola that has come down to us.

Twice yearly the Opera issued rolls of the workers authorized to serve in the cathedral works with their individual daily wage rates, typically higher for the summer months when days were longer and lower in the winter. The number of laborers listed fluctuated considerably over the years. For example, in 1420 the figure dropped from 87 workers employed in the pre-cupola push to complete the third radial tribune arm to a select list of 48 master masons assigned to the new cupola effort in the late summer. Between lists, continual hiring, dismissal, and transfers of workers responded to the ever-changing circumstances. Nevertheless, if used with circumspection, the biannual rolls provide a useful index of employment patterns over the whole period of the dome's construction. The table provided here facilitates visualization and references for this class of documentation. For the 31 semesters from the beginning of the cupola effort in the summer of 1420 to its completion in the summer of 1436, 28 rolls are recorded, listing 43-85 qualified workmen per season, with an average presence of 65.

More precise qualifications are routinely furnished only for specialized trades: smiths (*fabbri*), sawyers (*segatori*), and occasionally woodworkers and construction carpenters (*legnaiuoli* and *maestri di legname*). The specifications for stone carvers (*maestri di scalpello*, *scalpellatori*) occur more frequently, but with little regularity, even within the careers of given individuals. Builders/wallers are only rarely specified as *maestri da murare* or *muratori* in the documentation of the Opera worksites, although the same sources commonly used these terms to describe contractors of fortifications. Many of the workers may have been able to perform various tasks and were prepared to do so in order maintain steady employment as the Opera's requirements changed over time. Often even in the election documents it is difficult to distinguish between *maestri* (skilled master artisans) and *manovali* (a more elusive category in the Opera sources, including generic unskilled workers as well as specialists in mortar and other ancillary tasks), whose salary levels often overlap those of the *maestri* in the mid-to-low range.

In view of the ambiguity of the sources, the application of standardized terminology, such as that proposed by GOLDTHWAITE 1980, xiv-xv, motivating the distinction between stonecutters and wallers, would have been misleading, if not impossible. In the following discussion, besides general terms such as "workers," "workmen," or "workforce," which make no attempt to single out the various skills, the term "master" is sometimes used as a direct translation of *maestri* in the original texts, i.e. otherwise undefined skilled artisans. The term "mason" is also employed as an alternative indication of the master builders on the worksite. "Stone carver" has been employed only when unambiguously justified by the qualification or specific activity stated in the documentation. On the roles and status of various workers in the construction industry, see also Giuliano Pinto's survey of the situation across north-central Italy in the late Middle Ages (1984, 71-96).

Workers' rolls in the period of construction of the cupola of Santa Maria del Fiore, 1420-36

Semester	*Total workers*	*Opera non-quarry*	*Quarry*	*Observations*	*Source in* Cupola
1420 summer	87 Cut to 48 for cupola	–	–	incl. *manovali* (?)	II-1-77, c. 31vd II-1-77, c. 45vb
1420-21 winter	–	–	–		book missing
1421 summer	43	–	– 18	incl. *manovali* Quarry assignments begin	II-1-78, cc. 24b, 37va II-1-79, c. 6a
1421-22 winter	55	37	18	incl. *manovali*	II-1-79, c. 35vb
1422 summer	71	–	–	incl. *manovali*	II-1-80, c. 24va
1422-23 winter	79	– Cut to 34	13	no ref. to *manovali*	II-1-81, c. 24va II-1-82, c. 2c
1423 summer	57	40	17	excl. *manovali*	II-1-82, c. 11b
1423-24 winter	71	44	27	excl. *manovali*	II-1-83, c. 9ve
1424 summer	61	37	24	excl. *manovali*	II-1-84, c. 14b
1424-25 winter	58	35	23	excl. *manovali*	II-1-85, cc. 4a, 4va
1425 summer	73	45	28	excl. *manovali*	II-1-86, c. 12va
1425-26 winter	72	47	25	excl. *manovali* and *maestri* on fixed salaries	II-2-1, c. 14a
1426 summer	55	43	12	excl. *manovali* Firing and hiring *maestri*	II-2-1, c. 30a II-2-1, cc. 29va, 32vc-e
1426-27 winter	63	50	13	excl. *manovali*	II-2-1, c. 44g
1427 summer	75	52	23	excl. *manovali* 42 *manovali* listed	II-2-1, c. 55d II-2-1, c. 56vg
1427-28 winter	62	–	–	excl. *manovali*	II-2-1, c. 69vn
1428 summer	71 Cut to 67	–	–	excl. *manovali* *Manovali* cut by 6	II-2-1, c. 82vc II-2-1, c. 84l
1428-29 winter	70	–	–	excl. *manovali*	II-2-1, c. 94va

1429 summer	76	–	–	excl. *manovali*	II-2-1, c. 104ve
1429-30 wint.	85	58	27	excl. *manovali*	II-2-1, c. 114vc
1430 summer	82	50	32	excl. *manovali*	II-2-1 c. 125g
1430-31 winter	66	53	13	also 4 *manovali*	II-2-1, c. 130va
1431 summer	73	52	21 Cut to 10	excl. *manovali*	II-2-1, c. 141b II-2-1, c. 143c
1431-32 winter	51	41	10 (?)	excl. *manovali*	II-2-1, c. 150f
1432 summer	67	56 Cut to 34	33	General revision of workers	II-2-1, c. 159a II-2-1, cc. 160h, 160vd
1432-33 winter	–	–	–	*Operai* control *manovali* hirings	II-2-1 neg. for rolls
1433 summer	–	–	–		II-2-1 neg. for rolls
1433-34 winter	64	44	20	excl. *manovali*	II-2-1, cc. 207vf, 209a
1434 summer	53	–	–	no ref. to *manovali*	II-2-1, c. 214a
1434-35 winter	60	–	–	excl. *manovali*	II-2-1, c. 224va
1435 summer	–	–	–		II-2-1 neg.
1435-36 winter	56	–	–	excl. *manovali*	II-2-1, c. 243f
1436 summer	–	–	–		II-2-1 neg.
Semesters present	28 semesters	18 semesters	19 semesters		33 semesters, 32 documented
Average number of workers per season*	65 workers	44 workers	20 workers		

* In the case of rolls recorded as having been cut to a lower number of workers, the calculation of the average is based on the second number.

However, the first factor that needs to be considered in the analysis of these numbers is the institution in the spring of 1421 of a separate Opera workforce at the newly leased quarry of Trassinaia, which would provide the *macigno* sandstone for the structural elements of Brunelleschi's dome.[52] In the following years, 18 of the recorded rolls distinguish between workers employed in the Opera and those deployed at the quarry. Non-quarry workers number between 58 and 34, with an average presence of 44. For the quarry, recorded numbers range between 33 and 10, averaging 20. These figures imply that only about two-thirds of the workers present in the total rolls in the years after the activation of the quarry worksite could have been deployed in and around the church.

Additional variables need to be taken into account in any attempt to deduce the size of the cupola workforce from the periodic payroll lists. For example, crews were sent out to work on outside projects assigned to the Opera by the Commune. These missions could range from minor repairs to public buildings or urban clearing to the construction of massive fortifications in the countryside. The latter, though normally executed by local contractors and laborers, typically involved the occasional participation of some Opera payroll personnel. The Opera itself had a number of satellite properties requiring remodeling and repairs, and these operations blended almost imperceptibly into the running of the cathedral worksite. Sometimes the fast-rotating wardens claimed the patronage prerogative of nominating new workmen to the lists, and their appointments could prove to be ephemeral. All of these circumstances mean that the lists of non-quarry master workers should be considered the maximum available for onsite construction, whose number needs to be adjusted according to other demands present at any given moment. A profile of the minimum complement of skilled workers at the Opera worksite is provided by the resolution of January 1423 cutting its number back to 34: 22 *magistri di chazuola* (a rare specification of wallers), two carpenters, two smiths, and eight stonecutters. Sig-

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[52] The importance attributed to the regular supply and quality of this stone (later known, by extension of one of its varieties, as *pietra serena*, but invariably called "macigno" in the Opera documents) is demonstrated by this unprecedented operation, a departure from the traditional acquisition of *pietra forte* (arenaceous limestone) building stone from individual quarrymen and suppliers. For this quarry site in the hillside above Villa I Tatti along the Trassinaia stream, see the joint study with geologists of the University of Florence: Coli *et al.* 2008, 214-221.

nificantly, the same number of 34 was the target of the cutback decreed nearly a decade later, in the summer of 1432.

It is, however, necessary to determine to what extent the category of *manovali* (roughly translated as unskilled workers), a grade down from the master builders, is represented in the statistics of our table. Through the summer of 1422 most payrolls explicitly state that they regard both "magistri" and "manovales," although the distinction of qualifications is not individually indicated. After the mention of the unskilled category disappears from the general rolls, most *maestri* payrolls are paired with authorizations to the best-informed trio of Opera personnel, the foreman (*capomaestro*), the administrator, and the paymaster, to set the wages of the *manovali* separately, typically by averaging the indications of their three independent lists.[53] The fact that no systematic collapse is registered in the numbers of workers listed in the rolls following the exclusion of the *manovali* after 1422 would seem to be a measure of the modest entity of the group concerned, a deduction apparently supported by other sporadic mentions of their number: ten were fired in the winter of 1421-22, only two allowed in the quarry during the cutback of December 1430, all but seven excluded from the Opera in the winter of 1432-33.[54] However, the only recorded roll of *manovali* in the cupola period, that for the summer of 1427, belies this impression, listing no less that 42 such workers.[55] Even in relationship to the relatively high number of 75 masters enrolled for the same season, these so-called manual laborers account for 36 percent of the authorized workforce.[56]

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[53] Payrolls with such arrangements are indicated in the table as "excl(uding) *manovali*." This practice antedates the cupola effort, see, for example, *Cupola*, II-1-70, c. 17a, the first example in the edition.

[54] *Cupola*, II-1-79, cc. 34vb, 34vf; II-2-1, cc. 134g, 194va.

[55] This exceptional document is the result of a special procedural formulation, subjecting the usual fixing of this category's wages by the foreman, paymaster, and administrator to the approval of the wardens: *Cupola*, II-2-1, cc. 56b, 56vg. These *manovali*, like the master workers, would have been distributed around the various worksites managed by the Opera.

[56] As has already been suggested, the category is unhomogeneous. The two top wages of 15 and 13 soldi a day regard a *maestro* working in this less qualified capacity and a smith. Others are in the range of 11 to 7 soldi, except for two boys at 3 and 5 soldi. Eight of the category had wages matching or exceeding some of the master workers of the same summer, whose pay ranged from 20 to 10 soldi. It was fairly common for master masons to work temporarily as *manovali*, whether forced by order of the foreman or simply to maintain employment, and the question of how this should influence their pay was raised (*Cupola*, II-4-11, c. 34b; II-2-1, cc. 94c, 195vl). *Manovali* who performed special tasks were usually rewarded with

There is no assurance that this semester was typical, nor is it possible to derive a ratio between master workers and the assistants who served them, since many of the manual laborers must have been deployed in independent tasks such as managing and positioning loads of building materials around Brunelleschi's famous construction machinery.[57] It is, however, evident that there were never as many as two *manovali* per master mason, as assumed in a recent estimation of the cupola crews.[58] This study, which usefully posed the question of how the workers might have been arrayed on the movable working platforms in each of the eight segments of the cloister-vault dome, proposed four mini-squads per segment, each composed of two master masons and four *manovali*. This produced a population of 24 wallers per segment, making an astonishing total of 192 for the whole structure, to say nothing of the ground-based stone carvers and other preparatory workers. On the contrary, the actual number of men on and around the cupola is unlikely ever to have exceeded 50-60, including the *manovali*. This workforce comprised a dominant component of skilled workers accompanied by a smaller squadron of so-called unskilled workers, many of whom were acknowledged specialists, if not *maestri*. They may have rotated positions, gradually completing each new course of masonry around the eight segments of the dome's circumference. This understanding should help to explain what has been described as a very desultory rate of construction.[59]

We possess the documentary tools to determine the actual paid service of day laborers for only two semesters, late in the cupola effort, for which the first preserved cashbooks register each worker's credits and receipts.[60] The tabulation of individual accounts exceeds the intent of

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higher than average pay: these include a master of scaffolding (II-1-71, c. 3g), a gatekeeper of the cupola (II-2-1, c. 196vm), and the mortar specialist (*passim* under name Martino di Nanni in the 1430s). There are also instances of crossovers between the Opera messengers and this category, including an election document requiring messengers to perform manual labor once their other tasks were done (II-2-1, c. 217m).

[57] For the loose characterization of the category, cf. Goldthwaite's findings with regard to the Florentine building industry at large: GOLDTHWAITE 1980, 322.

[58] ROCCHI COOPMANS DE YOLDI 2006, 266-267.

[59] Compare the number of workers authorized for the stone construction of the lower levels of the cathedral's east end in 1382: 28 *maestri* and 20 *manovali* in the winter, 41 and 34 respectively in the summer, published in GUASTI 1887, doc. 334. A compact work crew and gradual construction rate at Santa Maria del Fiore were presumably established practice by Brunelleschi's time.

[60] *Cupola*, cashbooks kept by the Opera treasurers: VIII-1-1, second semester of 1434,

the present essay. However, a comparison of the first book, covering the second semester of 1434, with the salary list of the same period, permits verification of the payrolls as indicators of the workers actually enjoying significant employment (for the purpose of this survey arbitrarily defined as twenty or more working days in the semester). All but one man on the authorized winter roll of 60 *maestri* met this requirement, and many approached full-time employment. The difference between the payroll numbers and the 73 individual cash accounts covering more than twenty days is made up primarily of *manovali*, either explicitly qualified as such or recognizable by name or salary rate of 10 soldi or less. Many accounts in all categories record days worked at the convent of Santa Maria Novella, where the Opera was responsible for remodeling the papal apartments to house the curia of Eugenius IV, as well as in the canons' cloister near the cathedral. However, most of the workers who concentrated on these outside construction sites fall into the group of 23 additional workers who served for fewer than twenty days, a situation that suggests that they were "picked up" on the market to meet temporary exigencies.

This review of the new documentation supports the profile of the cathedral workforce formulated in an earlier study on the basis of sample statistics: although variable in size and composition, it was organized around a relatively compact "core group" of workers who enjoyed exceptionally stable employment in medieval terms, both in the number of days worked in a given period and in the continuation of employment opportunities over time.[61] Fluctuations in the size of the Opera workforce largely concern a more peripheral type of worker, summoned in response to specific needs and projects. The number of workers employed at any time was carefully pared to correspond to the Opera's financial resources, mostly drawn from the public purse and modulated by the vicissitudes of the Florentine economy.[62]

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and VIII-1-2, second semester of 1435. I am grateful to Gabriella Battista for her assistance in analyzing the material on workers' accounts presented here.

[61] HAINES 1985, pp. 89-115. The findings can now be compared with the rich sources for the cathedral of Siena, thanks to the exemplary presentation of GIORGI and MOSCADELLI 2005, 230-299, esp. 257, 286. They determined that in the periods when salaried work prevailed over piecework in the course of the fourteenth century, a similar highly qualified central group of workers enjoyed long-time employment stability.

[62] HAINES 2002, 160-161, table 2, showing the gabelle income in the cupola period contracting from 2,696 florins in 1420 to 1,732 florins in 1432.

Calls for economy in the workforce conspicuously accompanied two moments of definition and launching of the cupola effort, which was seen as taking priority over full employment in other concerns of the cathedral. The cutback to 48 men in the summer of 1420 with the elimination of stone carvers was justified by lack of funds and marble, presumably for the external revetments of the tambour, which would be postponed for decades. However, by the following year, with the new quarrying activities for structural stone for the dome, employment was creeping back to earlier levels. Again in April of 1426, when construction resumed according to the revised program, 25 men were suspended with the explanation that it would be reprehensible for the Opera to allow expenses it could not pay. Soon after, however, a dozen *magistri* were reinstated, some on the condition of being paid two months later; others were called back with wages reduced by 25 percent.[63]

The next major cutback was in the winter of 1430-1431, a moment, as we have seen, of programmatic, supervisory, and economic difficulty; but the reduction in manpower was short-lived.[64] Not surprisingly this coincides with another period of depressed income, and the provision taken in the summer of 1431 to pay the *manovali* before any other creditors seems to take into account the near-subsistence level of their earnings.[65] In August 1432 the wardens prohibited the deployment of the recently reduced roster of *maestri* on any task unrelated to the dome for six months, an exceptional measure probably dictated by enduring economic restrictions as well as by the desire to move the construction ahead.[66]

In the final years of the cupola, irregularly recorded payrolls show employment levels around or below average levels. In this period it would be particularly difficult to determine how many workers were actually deployed on the cupola since work was simultaneously under

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[63] *Cupola*, II-2-1, cc. 29va, 30a, 32vc, 32vd, 36f. Significantly, 1426 is the year with the lowest recorded income for the cupola period.

[64] The rolls proclaimed in September 1430 for the ensuing winter (see the table on pp. 62-63) were drastically reduced in December, when 24 Opera *maestri* and 13 from the quarry were dismissed. Exceptionally, the *manovali* at the quarry are also mentioned: three fired and two retained. Previous levels were restored in March, when 39 *maestri*, mostly members of the previous rolls, were authorized to return to work: *Cupola*, II-2-1, cc. 134g, 138a.

[65] *Cupola*, II-2-1, c. 147c.

[66] *Cupola*, II-2-1, c. 168i.

way on the reinforcing chains in the nave, treated as an integral part of the Opera worksite. It would be possible to separate out the days worked at Santa Maria Novella in the two surviving cashbooks, but these sources provide no criterion for quantifying the labor effort concentrated in the last year on the preparation of the vast new east end for the solemn consecration of the cathedral on 25 March 1436, on the eve of the pope's departure from his first Florentine residency. In the final years of construction, the regular quarry crew presumably dwindled when the important stone components of the closing ring were let out as piecework to specialized masons. In turn the demanding task of positioning and securing these huge blocks in the uppermost reaches of the dome was stalled awaiting late consignment.[67]

This payroll documentation can be compared to the popular stories concerning Brunelleschi's relationship to the Opera workforce. One of these is the famous question of the Lombard masons, called in by Brunelleschi, according to Manetti, in response to the unreasonable demands of local master builders.[68] Once again, the biographer's tales seem inspired by actual events, but spun out for narrative effect. He places this episode at the beginning of the cupola effort, when he says that early plans contemplated the assignment of each of the eight segments of the octagonal vault to a contracting master waller. The account goes on to describe the constant interference and pressure from these masters, which exasperated Filippo. When he realized that, believing themselves irreplaceable, they had formed a cartel in their own interests, Brunelleschi called their bluff by summoning eight Lombards, whom he trained to take their places. Seeing their error, the original eight repented and were employed (*adoperati*) on reasonable terms.[69]

There is no trace of a transient octet of Lombards in the cathedral documentation, and this contradiction might seem sufficient to dismiss

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[67] The documentation for this phase is presented in HAINES and BATTISTA 2006, 59-71, and in the revised online edition of 2012.

[68] MANETTI 1976, 96-97.

[69] This story was retold in a later temporal context and with different circumstances by Vasari; see VASARI 1971, 174-175. He places it in a phase of intense building after the completion of the chains, and describes a classic strike of presumptuous workers, irritated by Brunelleschi's constant prodding, who were maneuvering for higher wages. Their punishment of being fired and having to supplicate reinstatement, finally conceded with less pay than before, smacks of the more despotic mores of Vasari's time. His Lombard strikebreakers, who are said to have worked "for several weeks," numbered not eight but ten. This colorful reformulation, unlike Manetti's, bears little relationship to the existing documentation.

Manetti's whole story of Filippo's astute taming of the presumptuous master builders as picturesque fabrication. However, the first election of the new cupola *provveditori* in April 1420 did indeed also nominate eight master builders to execute the dome according to their orders.[70] This was no ordinary hiring of *maestri*, and our understanding of their entrepreneurial position is enhanced by Manetti's account, which portrays them as contractors of the eight segments. The eight, none present in the previous Opera payrolls, constitute an interesting group. Seven of them are documented as consultants and contractors, handsomely paid by the Opera both before and after their nominations.[71] Although none ever played a leading or stable role in the regular workforce, the fact that exceptionally high wages were retroactively fixed for four of them on the eve of the inception of the cupola effort on 28 June 1420 can perhaps be read as a record of their insistent presence, described in the *Life*.[72] None of them was included in the reduced workforce named for the cupola on the same day.

The high wages attributed to three of the rejected *maestri* in payroll additions during the following year may have been intended as recompense for occasional consultations rather than regular service, judging from a resolution of September 1421 that enjoins two of them to present themselves when summoned.[73] This kind of relationship may actually constitute the employment that Manetti alludes to at the end of his tale. Although soon totally removed from the cupola payrolls, some of

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[70] *Cupola*, II-1-77, c. 34a.

[71] Tuccio di Giovanni da Siena and Gherardo Belacqua had been paid in 1418 to monitor the construction of Brunelleschi's demonstration model; Ricco di Giovanni, Filippo di Giovanni, Niccolò di Benozzo and Belacqua were called in to review the model again in 1423: *Cupola*, II-1-74, cc. 58vc, 58vd; II-4-11, c. 13i. Niccolò di Benozzo had served as foreman in the 1419 campaign for the papal apartments in Santa Maria Novella, and Berto di Bartolomeo, Geri di Antonio Ciofi and Belacqua had contracted for large-scale works on that site: II-1-75, cc. 20b, 48g, 49va, 49vb; II-1-76, cc. 47d, 47e, 47f, 51vc, 51vd; II-1-77, c. 67h.

[72] These were Filippo di Giovanni, Niccolò di Benozzo, Belacqua and Ricco di Giovanni, to be paid 27 soldi per day, together with four other *maestri*, a group that might constitute a variation on the "gang of eight." Also listed are two assistants, a carpenter, and two sawyers, all said to have worked primarily on the third tribune: II-1-77, c. 45vb. A top wage for a master builder would normally be 20 soldi (1 lira) per day.

[73] Gherardo Belacqua at 24 soldi for the summer of 1421; Berto di Bartolomeo and Geri d'Antonio Ciofi at 25 soldi in a June addition to that season's roll; Gherardo and Berto again at 25 soldi in a retroactive addition to the winter 1421 roll: *Cupola*, II-1-78, cc. 24va, 44va; II-1-80, c. 13vb. The summons resolution is in II-1-79, c. 23vb. The Biagio without patronymic in the original election document seems nowhere recognizable by a comparably high wage in the Opera payrolls.

the dome's would-be entrepreneurs had lasting relationships with the Opera: two served as consultants on the nave chains in 1431, and Gherardo Belacqua headed the partnership that contracted to build the great elevated wooden bridge for the papal procession from Santa Maria Novella to the Duomo for the consecration ceremony in 1436.[74] The most intriguing of the eight, however, is Berto di Bartolomeo, recently identified as the mysterious patron of one of the great masterpieces of the early Renaissance, Masaccio's *Trinity* in Santa Maria Novella.[75]

In the April 1420 election document of the supervisors and the eight building masters, a third cupola *provveditore* was listed after Brunelleschi and Ghiberti, apparently as an afterthought. This was Battista d'Antonio, a stone carver who had early on emerged as particularly useful in the Opera workforce and had been serving as interim *capomaestro* since late 1418. As the appointment of the eight *maestri* soon evaporated, so too did this elevated qualification of Battista, who would remain in the position of general *capomaestro dell'Opera* (foreman and head builder) for the rest of his long and worthy career.[76] No separate squadrons led by outside experts, no Lombards. Instead, a work crew of standing Opera masons would be led for the entire sixteen-year adventure of dome building by one of their own, the trusted Battista d'Antonio. Although a hierarchy of workers is clearly reflected in their graduated pay scale (Fig. 6), there is no indication in the Opera records of standing and stable groups responsible for the separate segments of the octagon. On the contrary, Battista (and not Brunelleschi) was repeatedly empowered to deploy the workers as he saw fit in and around the cathedral, at the quarry, and at the other worksites managed by the Opera.

But the cosmopolitan slant served the legend that Manetti was fabricating. He also insists, for example, on the participation, at Brunelleschi's suggestion, of many "foreigners" in the preliminary consultations for the dome project, a term that could be correctly applied, amongst those reimbursed for submitting models, only to two Sienese masters, since Pisa, whence came two other participants, was already

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[74] *Cupola*, II-4-13, cc. 15vl, 15vm; II-2-1, c. 250c.

[75] CECCHI 2002, 46-57. See also COMANDUCCI 2003, pp. 19-20.

[76] For a thorough and sympathetic account of his nearly lifelong collaboration with the Opera, see SAALMAN 1980, 186-190.

subject to Florentine dominion.[77] One would be hard-pressed to find many extraterritorial workers in the following years on the cupola payrolls, which were composed almost entirely of local masons and stone carvers, many coming from the quarry-rich villages around Florence.[78] The hiring of a foreigner was apparently such a rare occurrence as to elicit special authorization, of which only one case is recorded, for an unspecified "Lombard" in early 1430, and it is not clear whether he ever actually went to work.[79] There was, however, a Lombard master carpenter named Antonio di Bartolino, a Black Friar from Vercelli, the north Italian city famous for its vaulted cathedral, who commanded an exceptionally high wage in the years 1421-23 (Fig. 6) and was also rewarded for the manufacture of a pulley and for a model of the elevated crane to be used in conjunction with the great hoist. This technical competitor of Brunelleschi's is mentioned and liquidated by Manetti, and his judgment is confirmed by the difference in the recompense to the two inventors.[80] In 1424 an otherwise unknown German called Averardo was paid for a model for a new hoist, following the precedent set by the competition of 1418 of reimbursing any expenses for proposals for the resolution of the technical problems of the cupola worksite.[81] Perhaps the memory of these foreign presences seeded the imagination of the architect or his biographer.

Manetti's insistence upon Brunelleschi's authorship of and dedication to the cupola project is of course supported by myriad documents

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[77] MANETTI 1976, 79, 81, 89. Cf. *Cupola*, II-1-75, c. 46a; II-1-74, c. 4va. The international composition of the consultants is characteristically amplified in Vasari 1971, 154-155 (both redactions).

[78] Provenances can be easily traced in *Cupola*, Indices, Surnames etc., Provenances.

[79] *Cupola*, II-2-1, c. 122vf. A list of workers reinstated a year later, in February 1431 (c. 138a) contains, among many familiar names, the sole appearance of a certain Giovanni di Francesco "dellamano," possibily a garbled version of "della Magna" or Germany, a term also used in a broad sense to refer to foreigners from the north. In 1423 an unskilled laborer called Agnolino della Magnia received a contribution from the Opera to go to the baths after a debilitating injury on the job: II-4-9, c. 57a.

[80] MANETTI 1976, 95, with reference to the crane model, "Fecene anche modello uno maestro Antonio da Vercelli; ma piacque più quello di Filippo": *Cupola*, II-1-80, c. 73e for the pulley; II-1-82, c. 72i, Antonio's crane model paid 1 florin; other devices in II-4-9, cc. 42a, 70a. Cf. II-1-82, c. 72h, Brunelleschi's "inventione castelleorum pro collis pro cupola magnia" rewarded with 10 florins. VASARI 1971, 173-174, elaborates on Manetti's account, describing "maestro Antonio" and others as having been introduced into competition with Brunelleschi at all stages by stubborn and poorly informed supporters of Ghiberti.

[81] *Cupola*, II-1-84, c. 44vf; cf. the 1418 competition bans, II-1-74, c. 9va.

that record the architect's involvement in consultations, models, contracts, purchases, disputes, and the control of supplies, as well as in the invention and constant revision of ingenious machines for the extraordinary work conditions.[82] But the author's desire to demonstrate the heroism of his protagonist necessarily diminishes the contributions of others. The workers are portrayed as conservative and slow-witted in understanding the complex specifications of components designed by Filippo, timorous and accident-prone in the high reaches of the rising walls.[83] This is a workforce that for sixteen years inhabited the upper reaches of a building project without precedent, starting 54 meters above the ground and rising another 33, while inclining its self-sustaining double vaults over the 45-meter-wide central void. Its leader, the competent and trustworthy Opera foreman Battista d'Antonio, constantly at Brunelleschi's side, is never mentioned in the *Lives* of the architect.[84] The rank and file encompassed such assiduous master builders as the best-paid and appropriately named Perfetto di Giovanni, or such versatile and enterprising workmen as Jacopo di Sandro, singled out in a recent study as a figure representative of the exceptional qualities of the cathedral workmen (Fig. 6).[85] Jacopo possessed both supervisory skills, often serving as special foreman over parts of the work crew, and courage, certainly required for the lighting of torches on the outer shell of the dome on festival occasions; he contracted for wood and marble supplies and, in the last year of the cupola effort, was appointed supervisor for the construction of the fortress, designed by Brunelleschi, in Vico Pisano.

References to highly qualified workers abound. See, for example, the justifications for permanent salary increases in May 1425 in favor of the smith Piero di Francesco, considering his huge workload ("la-

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[82] The references are too numerous to be reviewed here, but it can be pointed out how the online edition permits a rough quantification of much of the material. A search in *Cupola* by Topics, Personnel gives access not only to the appointment and payment records already mentioned but also to the category other mentions - internal, containing over 5,000 documents about activities especially mentioned by standing officers of the Opera. Sorted by specification text, the 105 mentions for Filippo di ser Brunellesco (and another four under his nickname Pippo) appear in alphabetical order. These can be compared to 31 such references for Lorenzo di Bartolo/Bartoluccio (and his diminutive Nencio). The proportion is not far different from that of the two supervisors' salaries as differentiated after 1425.

[83] MANETTI 1976, 92, 97-98.

[84] MANETTI 1976, VASARI 1971. Modern scholarship has long since rehabilitated him.

[85] Battista in HAINES and BATTISTA 2006, 52-58, and forthcoming.

borem inmensum") and his intelligence and usefulness ("eius subtilitatem et utilitatem maximam"), and of the carpenter Ghino di Piero, declared the most precious person at the Opera and intelligent, industrious, and hard-working ("homo subtilis et industriosus et valde faticabilis in eius exercitio").[86] In 1427 the skill and courage of three stonecutters who worked daily in conditions of real danger, suspended from the walls of the cupola, were compensated with increased, fixed wages of 20 soldi per day.[87] Even some of the manual laborers emerge from the rich documentation with their individual virtues and personalities. Piero Sanza Paura must have earned his fearless epithet, while Martino della Calcina, who brewed the high-quality mortar that held the structure together, even if under the "maravigliosa" supervision Manetti claims for Brunelleschi, probably deserves as much credit as the bricklayers he served. The "heroic" architect undoubtedly had one of the most highly qualified workforces of the time at his disposal for the realization of his innovations and inventions.

The Opera officials

At the other end of the socioeconomic scale, the Opera was directed by prominent merchant statesmen, selected from the members of the powerful Wool Guild which, since 1331, had been charged by the Commune of Florence with the administration of the new cathedral construction. Called *operai*, these wardens served brief, rotating terms and reported back to the Wool Guild consuls, who maintained jurisdiction over certain important matters. The Opera staff included a treasurer, drawn from the guild membership for a semester of service, as well as professional salaried personnel, especially the notary-scribe and the administrative *provveditore*, or purveyor, as well as a paymaster and messengers, debt collectors, and other occasional officials.[88]

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[86] *Cupola*, II-1-86, cc. 16a, 16b.

[87] *Cupola*, II-2-1, c. 67va. One of these, Nanni di Berto called "Ferro," received another raise to 22 soldi for the same reason in 1432: II-2-1, c. 164f.

[88] On the structure of the Opera see HAINES 1996, 267-294. For the cupola period, Gabriella Battista has contributed in-depth profiles of the salaried administrators: BATTISTA 2012. An Italian translation of the doctoral thesis of Andreas Grote (GROTE 2009) reproposes that pioneering study of the prehistory and early history of the institution.

On the eve of the dome construction campaign in 1419, the guild instituted the magistracy of the four cupola officials (*ufficiali della cupola*), expressly nominated from its most qualified members to monitor this greatest challenge in the building of Santa Maria del Fiore.[89] The first group was praised at the end of the year for its excellent service and renewed in office for three annual terms; its successors constituted a tight group of competent and prominent citizens and authoritative counselors to the *operai* and guild consuls through the end of 1426, when their duties were fused with those of another special committee elected to oversee the sacristies and defend the Opera's authority in the liturgical governance of the cathedral.

In Manetti's narrative the wardens are portrayed as prudent but skeptical bureaucrats, whose resistance Brunelleschi wore down with his knowledge and eloquence, his diplomatic skills and patience, his ability to demonstrate his proposals in small-scale structures.[90] The four cupola officials' voices seem to be heard in the *Life* not only as *ufficiali* but also through generic references to "citizens" called upon to advise the consuls and *operai*. All of this directional elite is portrayed as being divided between supporters ("amici") either of Brunelleschi or Ghiberti, the Opera a locus of partisan struggle rather than a supervisory organ engaged in the concrete planning and building process.[91] Such a subtext may underlie many of the decisions taken over the years, particularly those regarding the two cupola *provveditori*.[92] And yet the daily records of the Opera show the wardens constantly involved in the mundane matters of commissioning models and building materials, hiring and regulating personnel. The four cupola officials, with longer terms and a more focused mandate, must have been still more intensely in contact with the worksite and its supervisors as decisions were hammered out, although their own proceedings, if ever recorded, have not been conserved in the Wool Guild or Opera archive.[93]

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[89] These and other special officials instituted by the guild to assist the *operai* in the management of major projects are studied in HAINES 2008.

[90] MANETTI 1976, esp. 78-83.

[91] MANETTI 1976, *passim*, esp. 93-95.

[92] Caroline Elam helpfully reminds me of the dissimulation of conflictual meetings in the official records of many a self-respecting institution.

[93] Occasional records of the cupola officials' activities are present in the general Opera books: see *Cupola* under Indices, Names and roles, Role strings. It is noteworthy that the weekly drawings of their *preposto* (delegate with powers for the whole magistracy) are excep-

Simone di Leonardo Strozzi provides an interesting example in the Opera documentation of a competent exponent of both magistracies. Charter member of the cupola officials, serving from 1419 to 1423, he was also an *operaio* in the autumn of 1421, when he negotiated the abrogation of a contract for sandstone beams for the base of the cupola (Fig. 7). Although the original contract of October 1420 has been lost and its amendment of April 1421, undersigned as required by the wardens then in office, makes no mention of Strozzi, an exemption granted to the contractors the following July declares that Simone negotiated the terms of the commission with the quarrymen. Those detailed terms specified not only the dimensions and delivery schedule of 600 beams, but also the quality of stone from which they were to be cut, of which not more than one-sixth could be of the less desirable *masso* type. But when the first 89 beams arrived at the end of the month, they were all of the poorer quality, accepted at discounted prices. Strozzi and his colleagues on the cupola committee remained actively involved in the matter, renegotiating with the contractors to accept *masso* beams beyond the prescribed quota at a further reduced rate. Simone had simultaneously taken up office as warden when he received the mandate to rescind the whole contract and settle up with the suppliers, considering that the Opera had found other means of supplying itself (namely, direct quarrying with its own personnel).[94] Strozzi was undoubtedly a savvy building patron and alert manager, probably able to spot *masso* as well as any of the quarrymen.[95] He was also a realist and enjoyed the confidence of the small artisan enterprises with which he dealt.

Perhaps the best example of an active and influential cupola official is the hitherto scarcely known Giuliano di Tommaso di Guccio Martini, whom I have described as an Opera activist for his assiduous participation in Opera tasks over decades.[96] From 1419 to 1426 he served

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tionally registered in the resolutions of the *operai* for the pivotal year 1425 up through the activation of the new program in April 1426, indicating the importance attributed to the office in this time of intense planning and probable tension between supporters of the two *provveditori*.

[94] *Cupola*, II-1-78, cc. 59va, 71ve; II-1-79, cc. 5a, 7va, 29a, 29vb.

[95] He himself was a supplier of *pietra forte* building stone for the base of the dome, in which the first *pietra serena* stone chain was embedded, and his companions in office selected him to draw up the agreement with the lessee of the Montoliveto quarry: *Cupola*, II-1-78, c. 75h; II-1-79, c. 56c.

[96] HAINES 2008, 156, 158, tables 1-2.

five year-long terms as cupola official – the vital first four and the last, beginning in 1426 when the revised cupola program was approved. The original vernacular report, which, once ratified, was copied by the notary in the official Opera books, had been composed and undersigned by this cupola official, and its authors are named as Giuliano di Tommaso, Brunelleschi, Ghiberti, and Battista d'Antonio.[97] He also served an overlapping term as *operaio* for four months beginning in May 1426, during the crucial verification of the new herringbone masonry and other innovations in the construction of the rising vaults.[98]

Although the cautious and gradual decision-making procedures of the Opera are presented by the mythmakers as a constraint on the intellectual liberty of the cupola's inventor, they were not without benefits for Brunelleschi himself. The Opera "bureaucracy," as I argued in an earlier study, ultimately guaranteed the execution of the architect's project, which, once approved, became binding and commanded the force of the whole institution in its realization.[99] What can be added here, in the light of the complete Opera records, is that the special skills of the institution constituted an essential ingredient in the successful realization of the audacious project that it embraced. The administration of the vast and complex building site was a matter of financing, accounting, organization, discipline, and rectitude. A directional elite, an administration, and a workforce with proven experience in cathedral planning and construction put a powerful tool at the disposition of the innovative architect.

Building supplies and "brick mania"

The new sources have much to tell about the day-to-day material history of the construction of the cupola of Santa Maria del Fiore, and the process of analyzing them has just begun. For example, it is now possible to consult the accounts that detail nomenclature, weights, and prices of the manufactured iron components acquired over the duration of the construction. The extensive presence of metal, both grazing the surface of the inner vault and deeply embedded within

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[97] *Cupola*, II-2-1, c. 170vb.

[98] ASF, Arte della Lana 39, Tratte, c. 9.

[99] Haines 1989, 124-125.

its masonry where neither form nor function can be ascertained by metal detectors, cries out for comparison with the archival documentation.[100] Detailed specifications of terminology, materials, and prices for the components of the building machines are also now available for verification against the reconstructions of these devices, based largely on post-Brunelleschian graphic sources.[101] There is a vast documentation on the acquisition of building materials, from the supplies of mortar and bricks to quarried stone and marble. Sample analyses of two groups of documentation have yielded interesting results that can be summarized here.

The first of these regards the ultimate stage of the realization of the cupola, the closing ring (called *serraglio* or *serratura*, meaning "keystone" or "lock") constructed at its summit. This structure played a crucial role in the statics of the dome, being devised to bind the two shells together and lock in their thrusts while providing a strong and rigid base for the lantern that was to rise over the central oculus. It embraced the fourth walkway and, like the other stone chains under the walkways of the inner spaces between the two vaults, it was constructed of expressly cut interlocking stone beams. The full-scale wood model of this structure, fabricated by Antonio di Manetto Ciaccheri in the summer of 1432 to specifications of the *provveditori* and *capomaestro* and mounted "in the air" above the rising masonry, not only fixed the octagonal shape and 10-braccia (ca. 5.83-meter) diameter of the oculus opening, but treated the arrangement of its stone components.[102] After the Opera workforce was instituted in the Trassinaia

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[100] Cf. the excellent results attained for the mapping of the iron chains of the dome of St. Peter's in a recent study where technological surveys are coordinated with the documentation of metal supplies: ROCCHI 2009, esp. 66-88. The first systematic search for metal elements in the cupola of Santa Maria del Fiore was reported by Riccardo Dalla Negra, with the mapping of rings and brackets, partly visible and partly sunk in the plaster of the sixteenth-century frescoes, identified as the anchoring for hanging scaffolding and for curvature templates applied in the eight corners of the rising masonry: DALLA NEGRA 1995, 15-22. His recommendation that such examinations continue in the space between the two shells after the removal of the metal scaffolding mounted for the restoration of the dome's frescoes, has been taken up by CORAZZI and CONTI 2011, 284-291, who report on previous and subsequent investigations with metal detectors. The massive supply of lead documented throughout the dome's construction also needs to be considered in relation the search for metallic substances in the cupola masonry.

[101] GALLUZZI 1996; LAMBERINI 1994a, 478, 486; and 1994b, 106-121.

[102] *Cupola*, II-2-1, cc. 163a, 167g. Antonio received 5 florins in various payments for his work on the model, including II-4-13, c. 43o, "chome àno a stare le prietre de l'occhio della lanterna." Graphic proposals for the structure of this area are in IPPOLITO 1997, fig. 22; CORAZZI, CONTI and MARINI, 2005, Fig. 18.

quarry in 1421, replacing outside contractors in the execution of the long beams (4 braccia = ca. 2.33 meters) of the first stone chain, specifications for stonework rarely appear in the Opera account books;[103] in fact the documentation concerning transport is often the only indication of the rate and quantity of supplies of structural sandstone over the following decade. However, the *serraglio* presented extraordinary demands that were met by special commissions to independent stonecutters for its principal stone components.

Although no written contracts have survived, the collation of 73 documents regarding the acquisition of *macigno* from various suppliers permits detailed reconstruction of the procurement of the stone blocks for the closing ring over the period 1432-36.[104] Not surprisingly most of these pieces were ordered in multiples of eight, reflecting their symmetrical arrangement in the octagonal structure. Some are mounted in plain sight, such as the 16 oculi (diameter about 1 braccio, price 4 lire each) that open onto the spaces between the two shells on either side of the eight stairways ascending the steep inner vaults above the third walkway. Others are partially visible, such as the 128 exceptionally long beams (6 braccia = 3.48 meters), eventually supplied by two teams working separately in Trassinaia and Fiesole for prices at the quarry respectively of 6 lire 16 soldi and 6 lire. Sixty-four of these must correspond to the huge radial slabs, eight per segment, that form the visible ceiling of the walkway and, as the documentation repeatedly states, the base (*piano*) of the lantern (Fig. 8). Might the other 64, some of which were the very last deliveries in 1436, be mounted over them? These prices and specifications can be compared with previous orders for 32 large blocks for the central oculus, paid at 3 lire 6 soldi each, about half the price of the big beams, and another 48 blocks paid at 2 lire, whose position in the structure is not specified, all supplied in 1432 and early 1433. Orders placed from 1434, besides the 6-braccia beams and the round oculi, include 16 stone blocks for the closing, whose price of 5 lire per unit approaches that of the long beams, 18 blocks for the cupola closing at 2 lire 17 soldi, and 24 or 16 big slabs (*lastroni*) worth 2 lire each. Hopefully this synthesis of the documentary data can

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[103] An exception is constituted by the commission for stone beams for the new, third chain in 1428-29, *Cupola*, II-2-1, c. 98vf; II-4-12, cc. 92g, 97i, 102vd, 106vc. The last three acts refer to a transaction with a quarry in Fiesole.

[104] Haines and Battista 2006, 59-71, and revised edition online 2012.

serve not only to recognize the stones in evidence on the surface of the closing ring, but also to probe the depths of its still enigmatic structure, offering the possibility of verification and articulation of recent technological soundings in the interest of an authoritative interpretation of the cupola's structure.

The contracted pieces were not the only stone supplies procured during this period, and the documented presence of the Opera quarry team at the Trassinaia quarry for the summer of 1432 and winter 1433-34 indicates that the production of routine stonework carried on. However, the specially commissioned pieces for the closing ring involved extraordinary challenges. The quarrying, finishing, transport, and emplacement of the 128 radial beams presented a daunting sequence of logistic problems, from the search for *macigno* beds of the necessary quality and dimensions to the hoisting of the oversized blocks through the dome's central oculus, whose diameter had been further reduced from 10 to 9⅔ braccia (ca. 5.64 meters).[105] Brunelleschi, undoubtedly the principal inventor of the *serraglio* system, sometimes appears in the records as the sole supplier of the stonework specifications, but he was often joined in this role by Battista d'Antonio; and the *operai* themselves did not disdain to ride to the quarries with a barrel of wine to celebrate the opening of the campaign, nor to negotiate the rental of the quarry for its duration. This crowning achievement of the cupola construction altogether escaped the attention of the architect's biographers, who seem to have been more fascinated with his struggles with personal opponents than with the technical challenges of his monumental feat.

The second sample analysis of building materials concerns the acquisition of special, oversized flat bricks, called *quadroni*, employed for the continuation of the dome above the base structure that was built in traditional cut *pietra forte* limestone.[106] The original building program, a detailed recapitulation of Brunelleschi's specifications for the realization of the cupola that became binding for the whole institution when it was copied into the official acts of the Opera and Guild in

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[105] *Cupola*, II-2-1, 201g, 25 June 1433.

[106] A preliminary formulation of this material was presented in a lecture entitled "Managing Supplies for the Construction of Brunelleschi's Cupola at Santa Maria del Fiore" at the conference "Building and Knowledge: Contributions to an Epistemic History of Early Modern Italian Architecture," coordinated by Hermann Schlimme for the Bibliotheca Hertziana and the Max-Planck-Institut für Wissenschaftsgeschichte in Rome in September 2003.

1420, foresaw the changeover to brick, tufa, or some other material lighter than solid stone at the level of 24 braccia (ca. 14 meters) above the dome's base. In order to further reduce the weight of the rising structure, this mark was lowered to 12 braccia (ca. 7 meters) in a packet of amendments approved in March 1422.[107] Despite the uncertainty expressed in the first program, negotiation for an important commission for *quadroni* destined for the cupola had begun with one of the Opera's habitual kilnmen, Pardo da Volterra, in August 1418, before most of the competition models had been presented and two years before the actual inception of the construction of the structure's stone base. An agreement was finally reached in December 1418 with a contract for 200,000 units to be supplied over two years at the price of 19 lire per thousand, for which an advance of 200 florins (about one-fifth of the total value of the commission) was immediately forthcoming.[108] The awareness of the huge volume of material necessary for building the "maggiore cupola" and of the long lead times of the complex brick-manufacturing process must have prompted this early commitment.[109] The risks to both parties emerged the following year in September, when the Opera informed Pardo that, since it had not been

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[107] Guasti knew the famous program of 1420 from the copy Manetti had made from a lost book of the Opera administrator, and he annotated his edition of its text with the variants present in Vasari: GUASTI 1857, doc. 51; cf. MANETTI 1976, 85-88 and VASARI 1971, 160-162. Alfred Doren subsequently published a contemporary authenticated copy conserved in the books of the Wool Guild: DOREN 1898, 258-261. This precious document (ASF, Arte della Lana 149, Atti e partiti, cc. 59v-60, registered under the date of 30 July 1420 but presumably composed in the preceding months) will be integrated with the *Cupola* database only if, as would be natural, the project can be extended to the acts of the mother institution of the Opera. The amendments approved on 13 March 1422, which had been redacted, like the 1426 revisions, in the hand of that most diligent of Cupola officials, Giuliano di Tommaso di Guccio Martini, are in *Cupola*, II-1-80, c. 17va.

[108] *Cupola*, II-1-74, cc. 5a, 19vg, 29vf, 44d, 53b. Some of the *quadroni* documentation was presented by SAALMAN 1980, 78, 114, 197-198, but the unsystematic selection of texts for citation and study prevented him from telling the crisis story that follows here.

[109] The exceptional scale of the cupola contracts tabulated in the following paragraphs emerges in comparison to the data available for other worksites of the Florentine Quattrocento. For example, the largest contract known to GOLDTHWAITE (1980, 185) was for 50,000 bricks in five months' time for the convent of San Miniato in 1446; the maximum annual delivery from one supplier to the massive Palazzo Strozzi never exceeds this amount. GOLDTHWAITE (1980, 171-212) describes the Florentine brickmaking industry as characterized by high operating costs, complex organizational requirements and low profit margins. Although the first offer to Pardo involved an exclusive clause which was subsequently dropped, the requirements of the cathedral's dome were exceptional and potentially monopolizing of a kiln's output for the duration of the pact.

decided whether the cupola should be made of brick or other material, he should produce no further bricks beyond those already fired or molded. At the end of 1419 he was awarded a small partial payment as well as compensation for six months' rent on the kiln paid to the abbot of Settimo while production was suspended. After another advance in April 1420, a go-ahead to complete the order was issued in May 1420, but by the end of the year he had delivered just 20,950 bricks, duly paid for, leaving the advances on the books.[110]

The decision in favor of brick, never explicitly recorded, must have been reached by January 1421, when the *operai*, considering that a very great ("maxima") quantity of *quadroni* was required for the dome, commissioned another kilnman, Antonio "Ferro" from Campi, to supply 1.2 million units over six years' time at the higher price of 20 lire per thousand. By April Pardo had renegotiated his contract, raising the price to 19 lire per thousand for 200,000 per year over a five-year period, for a total of another million units. Despite this increase, still more bricks were needed, it was said, and a new commission was awarded for 500,000 units over five years at the same price to four partners in a kiln at Lastra. In September, constrained to reduce his commitment following the death of his father, Cambio di Antonio Ferro renegotiated to furnish 300,000 *quadroni* over five years, and an old supplier, Bartolo di Marco da Campi, signed on for 240,000 in four years, both at 20 lire per thousand. At this point the outstanding orders for bricks totalled 2,040,000, scheduled to be delivered at 420,000 per year for the next four years and 360,000 for the fifth, but even this dizzying total did not seem sufficient. At the close of the year the wardens empowered their administrator to contract for additional commitments with the Lastra partners and Pardo.[111] In 1421 Pardo alone had received over 3,000 lire in advances and payments for deliveries.[112]

Brick mania seems to have seized the Opera planners as the revisions to the building program, making the changeover from stone to brick construction doubly imminent, were being considered and finally approved in March 1422. In February the Lastra kiln's contract was increased by 50,000 per year for four years: 200,000 more units. Still

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[110] *Cupola*, II-1-76, c. 15a; II-1-77, cc. 52d, 52ve, 66vc, 40e; II-4-8, c. 94vd.

[111] *Cupola*, II-1-78, cc. 57b, 60va, 27a, 62c; II-1-79, cc. 57a, 58b, 48va, 50e.

[112] *Cupola*, II-1-78, cc. 69e, 71vb, 75vi; II-1-79, cc. 65a, 68va, 70d, 70e, 72va, 74d, 77c, 91ve.

more bricks were needed, and the enterprising Pardo was judged to be capable of doubling his production to 400,000 per year for the next four years: an increase of 800,000 units, making the unprecedented total for a single contractor of 1.6 million units, for which the agreement was finally ratified in May with a price increase to 19 ¾ lire per thousand and a handsome advance of 500 florins, including 300 already received on the previous contract.[113] This was the last escalation in brick orders before the problems with the quality and size of bricks that had begun to pour in to the Opera brought the whole supply chain to a halt in the summer of 1422. Calculation of the myriad and complex documentation for payments and deliveries of *quadroni* destined for the cupola through May 1422 reveals that 8,745 lire had been paid to the four contractors, over half of it as advances, and only 189,183 bricks delivered, less than Pardo's first contract of 1418.

All of the contracts issued had specified bricks to be made of the clay-rich earth of Settimo, Campi, and Lastra[114] and delivered at the maker's expense to the worksite, properly fired, conforming in size and shape to the model supplied by the Opera; and all orders included the standard percentage (2 percent) of corner pieces (*angoli*). Wooden forms, called *modani*, sometimes reinforced with metal casing, were produced throughout the cupola years, and eight such models are still conserved in the Opera museum, including four corner forms with the 135° angle corresponding to the dome's octagonal plan (Fig. 9).[115] All

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[113] *Cupola*, II-1-80, cc. 55va, 26va, 58va.

[114] This specification is fully compatible with the findings reported for microscopic examination of the brick samples taken above the first walkway of the cupola, said to indicate at least three different sites of clay supply, all thought to be in the highest-quality Pliocene deposits in the area of Signa: BARDI *et al.* 1986, 54, 66. It should be observed that no building bricks for the cupola came from Impruneta, although the fame currently enjoyed by that production center has inspired statements to that effect: cf. MOROLLI 2009, 135 n. 26. In the *Cupola* database Impruneta appears instead as the nearly exclusive source of roof tiles (*embrici*) for the tribune vaults, the papal apartments, and other unspecified destinations. Such systematic choices on the part of the Opera reflect consolidated convictions about the different virtues of the two kinds of clay. The Opera's own urban kiln in via Ghibellina produced ordinary bricks for other applications, including Brunelleschi's scale model of the dome, but not *quadroni* for the cupola. In this case the selection is presumably related to the convenience and size of the kiln.

[115] Although it is unlikely that the extant models are to be dated centuries after the cupola effort, as has sometimes been proposed, there is no certainty of their relationship to individual contracts or actual bricks in the structure. The four rectangular forms present the following internal measurements, in ascending order expressed in centimeters: $37.2 \times 18.5 \times 5.5$; $39.5 \times 20.5 \times 5.5$; $49 \times 24 \times 5.5$; $49.3 \times 26 \times 6$. The four corner forms have more complex dimensions: the longest side ranging 30 to 32.5, the width 17 to 19.5, the height 7 to 7.5. Three

these specifications seem to derive from procedures consolidated during the construction of the cloister vaults of the three tribune arms.[116] Modest discounts on shipments of *quadroni* delivered through early 1422 regarded imperfect firing, excessive breakage, and insufficient size, but nothing suggested the scale of defects soon to be contested.

The first reference to the dispute between the Opera and the kilnmen over the specifications for *quadroni* appears in a resolution of 17 July 1422 to convoke the wardens who had been in office in the first four months of 1421, when three major contracts were awarded, together with Brunelleschi, Ghiberti, and Battista d'Antonio, in order to quantify the damage caused to the Opera by the delivery of defective bricks. The group gathered (with the exception of Ghiberti, who had been consulted separately) and declared that the many of the bricks in stock did not conform to the valid model, which they identified with a wood *modano* conserved in the Opera.[117] Considering that the bricks actually delivered varied in weight from 11 pounds 5 ounces to 14 pounds, the consultants recommended that the matter of price adjust-

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of the models were present in the exhibition *Il cotto dell'Impruneta*; see BERTONCINI SABATINI 2009 (cat. III.6: 145), stating that two rectangular forms would have produced bricks measuring about 39 × 20 and 50 × 25 cm, loosely related to the second, third, and fourth cited above.

116 A 1409 contract for bricks for the second tribune vault, for example, specifies corner bricks according to forms to be supplied by the Opera: GUASTI 1887, doc. 454. The numerous expenditures for *modani* documented in the *Cupola* edition under Topics, Objects, models/designs include angular forms acquired in 1417 and 1418, well before the initiation of the cupola campaign and so presumably destined for the third and final tribune vault, then under construction: II-4-8, cc. 3va, 30va.

Recent studies that have pointed out the absence of angular bricks providing continuity in the dome masonry at the convergence point of the corner piers are based on observations made above the second walkway, where the fitting of standard corner pieces in the progressively inclined brickwork would have been impractical. The masonry under the second walkway, for which their purchase is documented and their use feasible, has not been examined from this point of view. Cf. DALLA NEGRA 1995, 24-26; CORAZZI, CONTI and MARINI (2005, 11, n. 34) inexplicably state that the documents consulted in the *Cupola* database never mention special bricks, while citing contracts specifying just such *angoli*: *ibid.*, 7 nn. 25-26. See FANELLI 2004, 207 for the problems of laying radial masonry with angular bricks.

117 Copies of this prototype had been distributed to the all the suppliers as mentioned in their contracts. The actual working forms necessary to produce the desired dimensions after shrinkage during the drying and firing process would have been proportionally larger, depending upon the composition of the clay employed and maximum firing temperature. cf. ROVIDA 1996, 47, 57. The 1544 statutes of the Florentine Università dei Fabbricanti contemplated increased dimensions of the working *modani* with respect to standard specifications when the clay employed was particularly subject to shrinkage. They also refer to official metal forms "a uso di modani" chained in the guild office for verification of the fired, finished products: ROVIDA 1996, 38-39.

ment be referred to professional builders and brickmakers, and they suggested that manufacturing *quadroni* of the exact dimensions required would enable just arbitration of the shortfalls by weight comparison.[118]

For whatever reasons, the *operai* did not follow this advice but decided upon an across-the-board price reduction of all the stock by 25 percent or to 15 lire per thousand, the only mitigating factor being that the reduction was not cumulative with the other discounts already applied. The ratification of the guild consuls required for the revocation of existing agreements was promptly forthcoming on 7 August. At the same time it was decided not to accept any future shipments that did not conform to the model specifications.[119] More drastic steps were taken the following week with authorizations to negotiate new contracts for *quadroni* and rescind the existing ones. The first victim of this hard-line stance was Pardo, who saw his lease of the kiln at Settimo cancelled by the Opera, although his brick contract remained in force. Simultaneously the Opera awarded a new contract to Antonio di Vannozzo for at least 600,000 pieces to be fired in the same kiln over three years as soon as Pardo's rights expired in April 1423. Not surprisingly the new contract insisted upon the bricks' dimensions, which would be transmitted in the form of a *modano* marked with the Opera's seals, and it is also the first agreement to specify that the clay be not only well fired but also well seasoned. Corner bricks are no longer specified, a change which would characterize all future orders. A generous 500-

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[118] *Cupola*, II-1-81, cc. 5d, 6vb. Nowhere in the Opera documentation are the exact measurements of bricks expressed in numbers, but only by reference to the models for the various types. This practice differs, for example, from the specifications for stonework, normally expressed in Florentine braccia, or for marble, normally by weight and/or format. The lack of real measurements of the brickwork under the second walkway, which is largely covered by plaster, prevents estimation of the dimensions of the first *modano* and appreciation of the range of defectiveness accepted and employed in the building fabric. For measurements taken in the higher reaches of the dome, see note 133.

Although the *quadroni* employed in the cathedral represented a special, oversized format compared to the standard bricks on the Florentine market (*mattoni*, *mezzane*, *quadrucci*, etc.), the definition of dimensions by reference to model forms was normal practice throughout the period, and pricing by number inevitably encouraged skimping on the form size. For a useful entry to the specialized literature on the mensiochronology of kiln products in Tuscany, see the acts of the conference *La brique antique et médiévale* 2000, especially the papers of PARENTI and QUIRÓS CASTILLO (2000, 219-235) and BALESTRACCI (2000, 417-428); see also QUIRÓS CASTILLO 2003, 388-402.

[119] *Cupola*, II-1-81, cc. 8b, 8va, 10va, 10vb.

florin advance was offered, but the price per thousand had fallen to 19 lire.[120]

The contested brickmakers, Pardo, Ferro, Bartolo di Marco, and the Lastra group, still received payments in September and early October, round sums without accounting details totaling 1,600 lire, presumably against the minimum worth of the defective shipments. Meanwhile, the moment for the passage to brick construction was fast approaching; vats were being prepared for soaking bricks and reinforced tubs for hauling them up to the worksite. On 21 October 1422 bricklaying began above the level of the lintels of the first walkway (Fig. 10), and the Opera offered a barrel of wine to the workers to celebrate the occasion.[121] However, the sudden and resounding silence of the documents on *quadroni* in the following months betrays the precariousness of the supply system for this new phase of construction. Whatever their failings, the kilnmen could not be expected to acquiesce to the unilateral slashing of their earnings on production that required long-term investment and entrepreneurial commitment.

In the end, the neglected advice of the first advisory committee to test the cost basis of production seems to have been the factor that contributed to the resolution of the *quadroni* standoff. An experimental firing, carried out in March 1423 at the Lastra kiln under the direction of the enterprising Opera workman, Jacopo di Sandro, is documented in a cache of payments that detail expenses for the purchase of 16,000 raw units and their firing, totaling over 190 lire.[122] Although other costs, such as kiln overhead and transportation, contributed to the price of the cupola's *quadroni*, the results of this trial were sufficient to enable the conclusion that imposed cuts had been excessive. If bricks of the required dimensions could not be produced at the prices and delivery rates demanded by the Opera, once again the pacts had to be modified. The operative words in the wardens' decision of 23 April to revoke Antonio di Vannozzo's substitute contract and reinstate Pardo at a compromise price were the damage ("detrimentum") to both the Opera and the kilnmen caused by the controversy and the need to reach a constructive solution ("salubriter providere") for the completion of the cupola.[123]

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[120] *Cupola*, II-1-81, cc. 10vc, 11e, 13va, 56a.

[121] *Cupola*, II-1-81, cc. 72a, 72b, 72d, 72f, 73d, 73h, 73vd; II-4-9, c. 40vd.

[122] *Cupola*, II-1-82, cc. 70va, 70vb, 70vd, 70ve, 70vf, 70vg, 70vh, 71a, 71b, 71c.

[123] *Cupola*, II-1-82, c. 12a.

The ratification of this conciliatory policy, which had been mandated by the guild consuls, is contained in the joint resolution of both offices taken five days later. This is a remarkable document that recapitulates the long story of the dispute and articulates the Opera's dual priorities: first, to bring the cupola to its ultimate perfection and, second, to pay a just price to suppliers. Both the advice of experts and the results of the firing experiment argued that the contractors could not afford ("non possunt cum eorum salvatione") to supply bricks at the reduced price, nor indeed could the overextended Pardo be expected to respect his quota of 400,000 units per year ("ad impossibile nemo tenetur"). The commission to Pardo together with his former guarantor, Gherardo Canneri, was reformulated: the price was reduced to 18 lire per thousand, the delivery schedule to 150,000 per year, the advance from 500 to 187 florins. No precaution being too great to obtain the desired product, the mandatory measurements were drawn on a sheet of parchment attached to the contract and carved in a specimen cased in iron, chained to the wall of the Opera audience hall. The brickmakers humbly accepted ("humiliter ratificaverunt") this compromise pact.[124]

Pardo's solution would be the model for dealing with the other colleagues, the revision of whose contracts, with a price ceiling of 18 lire per thousand, was immediately authorized by the consuls; and indeed on the same day the wardens rewrote the agreement with the Lastra partners.[125] Their annual quota fell from 150,000 to 70,000, their price from 19 lire to 18, applicable even to bricks already manufactured but not yet consigned. In June the contracts of the two brickmakers at Campi, Cambio di Ferro and Bartolo di Marco, were both halved from 60,000 to 30,000 per year for four years and the now standard price of 18 lire per thousand applied.[126] Regular and substantial payments to all four reinstated contractors show that the great initial brick crisis of the "cupola maggiore" had been put to rest and that vital supplies of building materials were once again feeding the construction effort.[127]

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[124] *Cupola*, II-1-82, c. 13a.

[125] *Cupola*, II-1-82, cc. 15b, 15va.

[126] *Cupola*, II-1-82, cc. 19b, 19va.

[127] *Cupola*, II-1-82, cc. 72va, 72vb, 72vc, 75e, 75f, 75va, 77a, 77b; II-1-83, cc. 66b, 68d, 68e, 70e 71a, 71c, 71vh. The payments for *quadroni* in 1423, taking into account the reduction on advances amortized against deliveries, totaled 6,076 lire 12 soldi 5 denari. Over two-thirds of this amount went to Pardo da Volterra, consistently the biggest supplier.

The whole episode is an interesting example of mismanagement, involving unrealistic demands on suppliers prompted by poorly estimated consumption and construction rates, and of its correction within the structures of the institution itself. In fact, there was little reason to flood the work yard with huge stocks of bricks when, as we have seen, financial restrictions limited the workforce and other resources, but steady deliveries were essential for the smooth progress of work. It should be noticed that Brunelleschi's name occurs just once in the hundreds of written acts that tell the story of the cupola *quadroni* through 1423. Although Manetti gives all the credit for monitoring supplies to his hero Filippo, declaring that not a single brick was laid that he had not personally inspected for proper shape and firing,[128] the Opera sources tell a choral story, in which the entire administrative hierarchy was involved in procuring supplies of the quality and cost determined to be necessary and honorable for a public institution.

However, as in other contexts, the myth contains elements of truth that are useful in interpreting the administrative sources. If payments and deliveries of the standard broad bricks continued at a brisk pace through 1424, it may not come as a surprise that an interruption of *quadroni* supplies is recorded for the second semester of 1425, while the building program was under review and the contest between the dual *provveditori* under scrutiny. The recasting of supervisory roles that resulted, with Brunelleschi in the dominant position, corresponds to his constant presence and increased authority in the daily running of the worksite, down to the matter of the bricks, which became more complex with the introduction of herringbone masonry (Fig. 11). New forms and dimensions were required, and in August 1426 for the first time the wardens empowered Brunelleschi, called "solicitor of the great cupola," to contract out directly for new and larger *quadroni*, at the prices and terms he deemed advantageous for the Opera.[129] A trial firing for this new type, whose projected weight at 25-30 pounds was over twice that reported for the old format, was under way for most of the year at the Settimo kiln, no doubt with the intention of determining the specifications and price of this exceptional product.[130] The go-ahead is-

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[128] MANETTI 1976, 98-99.

[129] *Cupola*, II-2-1, c. 40va.

[130] *Cupola*, II-2-1, c. 170vb; II-4-12, cc. 10ve, 14a, 23vb, 18c, 29a. Cf. FANELLI 2004, 189, where this weight is inexplicably connected to the smaller herringbone bricks (22 × 22 × 5).

sued in January 1427 to the Opera administrator to commission new *quadroni grandi* (also called *tabelloni*, alluding to their large, flat form) at the hefty price of 42 lire per thousand with the requirement of a minimum weight of 25 pounds, certifies the authority of Filippo, named as the person who will provide the forms and instructions.[131] Breakage of these oversized bricks immediately seemed so inevitable that it was decided to accept and pay for broken *tabelloni* amounting to up to 10 percent of each shipment.[132] If such a provision points to careful surveillance at the worksite, it also reveals greater flexibility in the acceptance of materials than the myth allows.

Ample supplies of this new large format, alongside orders according to the old specifications, are documented from familiar kilnmen and new contractors in the next years. If a real count of all the *quadroni* received for the cupola is now feasible with the complete edition, that is not the intention in the present essay, which is rather to indicate complexity of the question, in the face of changing formats and unrecorded dimensions that invite systematic comparison with data that can be gleaned from the construction itself.[133] The range of brick types documented is further enriched, at the top level of the cupola over the third walkway, with the introduction in 1431 of yet another format, the middle-sized *quadrone*. At this point the price of the old-type smaller pieces sometimes fell below the standard 18 lire per thousand, and that of both large and medium formats, if always the same in any given contract indicating comparable cost of production if not size, varied be-

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[131] *Cupola*, II-2-1, c. 49va. In the past, the administrator and foreman had provided specifications.

[132] *Cupola*, II-2-1, c. 65va.

[133] A contribution to the knowledge of the brick composition of the cupola shells, largely concealed not only by the frescoes that decorate the inner surface of the dome but also by plaster applied to the surfaces between the two shells and by tiles on the outside, was made during the restoration of the frescoes in 1989-95. The brickwork, temporarily exposed for reasons of conservation in four zones above the third walkway, was examined and recorded in direct casts, while endoscopic soundings in the same areas probed the projection of the various bricks in the depth of the inner shell (Fig. 11). Although a variety of dimensions was observed, the predominant formats were determined to be, in centimeters, 28×22 and 22×22 in the vertical herringbone courses and 44×22 and 34×17 in the *corda blanda* courses laid between them (the opposite of the expected applications), all with a thickness of 4.5-5 cm: DALLA NEGRA 1995, 22-26. As is well known, the smooth brick surfaces displayed on the piers and other parts of the corridor between the two shells, with their precisely fitted joints, appear to be superficial and cosmetic, while the patches of brickwork unintentionally exposed by loss of plaster on the extrados of the inner shell correspond to the rougher-laid masonry with thick mortar joints observed by Dalla Negra in the intrados of the inner shell.

tween 40 and 39 lire.[134] Brunelleschi and Battista d'Antonio are cited as having advised awarding these new contracts, and one can suppose that the challenges presented by the last, vertiginous stretch of steeply inclined masonry reaching out over the void of the cathedral's crossing inspired ever greater refinement of the bricklaying techniques. The pairing of Brunelleschi as supervisor and Battista as foreman epitomized the team skills that contributed to the appropriate solutions.

Support for the genius

The voice speaking in the sources gathered in *The Years of the Cupola* is not that of the inventor, but of the administrative structure that managed the realization of his project or, better, myriad projects, for the dome of Santa Maria del Fiore. It is to be expected that this narrator should tell a different story from that related in more or less imaginative reconstructions of the protagonist's words, as they have come down to us through the heroizing tradition. Although the institutional documentation may cast light on that tradition, seen as a whole it has a different reality to recount which, rather than disclaiming the story of the misunderstood genius, tells about the sustained daily effort of those who accompanied him to his ultimate success. This is not the place to plead for the virtue or interest of such a perspective, nor to insist that historical "truth" is contained in this or any other documentary account. However, the importance of the reality recounted here can perhaps best be grasped by a comparison of the achievement of the great cupola to the non-successes in the career of Filippo Brunelleschi.

It has already been seen that Brunelleschi's scheme to flood the city of Lucca backfired not because his concept and calculations were erroneous, but because he was unable to control the conditions of realization of the specified works on the battlefield. Another egregious failure, passed over in silence by the architect's partisan biographers although it was directly connected to the cupola effort, also occured in a situation in which Brunelleschi was operating outside the supportive structures of the Opera del Duomo worksite. This was Filippo's revolutionary river vessel, designed to convey Carrara marble up the Arno from

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[134] Examples in *Cupola*, II-2-1, cc. 140vd, 158c.

Pisa to the river port at Signa near Florence.[135] Already in 1421, the architect had obtained a pioneering patent from the Commune of Florence for exclusive use of the invention for three years.[136] At that time it was described as a machine or ship ("quoddam heditifium seu navigii genus") capable of transporting any cargo in all seasons on the Arno or other waters at lower cost than usual and with other benefits for merchants. The project for the oversized craft, nicknamed "il Badalone," was the object of a polemical exchange of sonnets between the cupola's architect and his acrimonious rival and challenger, Giovanni da Prato, thought to date to or before the crisis year of 1425.[137] The vessel seems to have become a reality only in 1427 in response to the urgent need for marble blocks for the great white ribs of the rising cupola, when its brief career is documented in the registers of the Opera del Duomo. Filippo here appears not in his role as salaried Opera official with consolidated authority over the cupola project, but as an outside contractor, competing with the bargemen, who plied the course of the lower Arno in the erratic moments when the water was sufficient to float their cargoes, and otherwise with the more costly carters, who drove the loads overland in their oxcarts.

Once again, although some documents concerning this venture have long been published and studied, the complete Opera sources supply the depth and contextualization essential to their correct interpretation. For example, the authorization on 12 June 1427 to contract to Brunelleschi the shipment of 100,000 pounds of marble from Pisa to the Opera contains important specifications not included in the summary provided by Guasti: the shipment was to take place at the height of the dry season, half in July and half in August, and the price was not,

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[135] The basic study remains the thoughtful if ideological essay by PRAGER and SCAGLIA 1970, 111-134. Transport in the lower Arno valley in the early Renaissance is a subject that has received some attention in the literature, fueled by the interest for Michelangelo's famous marble supplies for the façade and new sacristy of San Lorenzo. Nevertheless much is still uncertain, including the actual course and degree of navigability of the river in the fifteenth century, the aspect of the various cargo vessels, and the mixture of forces that drove them up the current. The recent publication of FERRETTI and TURRINI 2010 provides the appropriate bibliography.

[136] The 19 June 1421 *provvisione*, approved by a majority of 218 to 7 in the city council, was published in GAYE 1839, Appendice II, pp. 547-549.

[137] BRUNELLESCHI 1977, sonnets I and II, 21-22, and relative commentary, 6-9. Giovanni ridicules Filippo's "Badalon che in acqua vola." This term, probably carrying derogatory and ironic overtones, is found in the Opera documents only after the failure of the enterprise.

as has been affirmed, less than land transportation but, at 4 lire 14 soldi per thousand weight, slightly *more* than the standard rate allowed for carters in this period. This generous offer to the entrepreneurial inventor, accompanied by advances totaling 55 florins (nearly half of the value of the contract), was justified both by the impossibility of normal river barge transport in the summer and the pressing need for marble so that construction could proceed.[138] It was a short-lived gamble, and doubts about its success are written into the pact, which would be automatically invalidated if delivery was not made on schedule, as indeed it was not.

The failure may have been almost immediate, since advance payments were being distributed to carters to bring marble from Pisa from early July 1427, and their deliveries for a total of 164,738 pounds are recorded at the rate of 4 lire 10 soldi per thousand through the following December.[139] The defaulting Filippo, however, was treated with delicacy by the Opera. In September the Opera had to order a replacement for the rope lent to him "pro suis navibus," but allowed a moratorium in determining the cost for which he would be held responsible; on 4 December 1427 it issued Brunelleschi a renewed contract to transport marble, including that already halfway up the river, this time at the same rates as ground transport, to be delivered by 15 January of the new year.[140] The new pact was justified not only, as before, by the Opera's need of marble, but also as a "subsidy for the invention of his boat, which would bring the greatest honor and benefit to the Commune." This lofty theme, recalling the rhetoric of the origi-

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[138] *Cupola*, II-2-1, c. 61c: "actendentes quod isto tempore extivo marmorem album conduci non potest propter penuriam acque Arni et quod Opera indiget maxima quantitate marmoris dicto tempore alias redundaret in maximum dampnum et verecundiam dicte Opere" – passage not present in GUASTI 1857, doc. 107. The advances are recorded in II-4-12, cc. 43vf and 45ve. PRAGER and SCAGLIA (1970, 120) incorrectly compare the rate allowed Brunelleschi for transport of marble from Pisa to the cathedral worksite with the prices agreed upon with the marble contractors for complete supply from the Carrara quarries to the Opera, at 7 lire 10 soldi per thousand weight if shipped by water, or 2 lire 6 soldi more if by land. This misunderstanding has been repeated in all the subsequent literature. In all considerations of price per weight, it should be recalled that the pre-metric Tuscan pound (0.3395 kilos) was considerably lighter than the modern pound (0.4636 kilos).

[139] *Cupola*, II-4-12, cc. 53d-53l, 3 July 1427; II-2-1, c. 63va, 14 July 1427; c. 64d, 5 August 1427; c. 65vf, 21 August 1427; c. 67vb, 12 September 1427; c. 69e, 10 October 1427; c. 69vm, 20 October 1427; II-4-12, cc. 63vd-63vg, 19 December 1427; cc. 64a-64g, 23 December 1427.

[140] *Cupola*, II-2-1, c. 68ve; c. 72vi, both acts unknown before the online edition.

nal patent, had already been aired in two decrees of the previous spring, when leave of absence without loss of salary had been granted to the cupola's architect and instructions to assist Filippo in every way sent to the Podestà of the Arno valley town of Castelfranco.[141] The Opera was evidently prepared to make allowances for its proven architect and for a project marketed as prestigious and compatible with the institution's civic identity.

Nevertheless, the foundering Badalone appears to have resisted attempts at reactivation even in what should have been a season more favorable to flotation on the river, and no deliveries are recorded on Brunelleschi's account. Instead, on the eve of his deadline the wardens authorized additional cartage or, if possible, traditional barge transport at rates starting at 33 soldi per thousand weight for full cargoes.[142] A new contract issued in February for the supply of large quantities of marble for the cupola ribs includes useful information on the cost of transport. The contractor's price of 7 lire 10 soldi per thousand weight included basic river transport at the rate of 32 soldi. The Opera would cover the difference of higher rates demanded by the bargemen for the Arno tract from Pisa to Signa, if previously authorized, and it would also pay the additional cost whenever it ordered land transport.[143] This continued to be a common occurrence: a series of payments to carters cover 38,476 pounds of marble delivered from late January through February, and an authorization to apply the usual price to some of

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[141] *Cupola*, II-2-1, cc. 54ve, 59b, respectively 2 April and 7 May 1427.

[142] *Cupola*, II-2-1, c. 76d, 14 January 1428. This is a problematic document, in which the rate of 4 lire 10 soldi is described as corresponding to a cartload (*carrata*) rather than a thousand weight, probably a lapsus on the part of the notary. On the elusive weight of a *carrata* of marble, see KLAPISCH-ZUBER 1969, 72-73; she describes cartloads of upwards of 2,000 pounds in this period, defined as what a pair of oxen could draw on flat terrain, and this is confirmed for the route along the Versilia shore from Carrara to Pisa in the Opera documents (e.g. II-4-11, c. 68e). The capacity on the inland voyage to Florence was probably less. The considerable difference between land and river rates (typically 90 soldi vs. 32 soldi per thousand weight) needs to be adjusted for the cost of land carriage from the Signa port to the Opera, documented as "l. 2 s. 5" (45 soldi) per *carrata* (e.g. VIII-1-2, c. 27vb). Furthermore, the cost of barge transport for small loads could soar to 4 lire (80 soldi) per thousand weight according to the authorization of 14 January cited above.

[143] *Cupola*, II-2-1, c. 77vf, 9 February 1428, awarded to Checco d'Andrea Fraschetta and Meo di Cecchino for the supply of 900,000 pounds of white marble over a period of 19 months. Similar terms are to be found in a commission awarded to three separate contractors in June 1433, where the base price of 7 lire 10 soldi per thousand weight would be increased by 2 lire 6 soldi (31%) if the marble had to be shipped from Pisa to Florence by cart, resulting in a total delivered price of 9 lire 16 soldi: II-2-1, c. 201e.

the newly contracted supplies mentions the low water level in the Arno that made this necessary.[144] In May 1428 the Opera issued a new ultimatum to Brunelleschi to send the marble stranded around Empoli and Castelfranco by barge, after which time the Opera would do so directly.[145] The rains must have come at last, because the Florentine captain in Pisa was instructed to enjoin the bargemen there to load marble or, if carrying salt – always the competing cargo – to include at least a few pieces of the precious stone.[146] But rain or shine, the Badalone marble seems to have remained mired at midpoint, and only in October 1428 was land transport authorized at Filippo's expense.[147]

While the struggle to secure a regular supply of high-quality marble to the cupola worksite continued with the familiar alternation of river and roadways in the following years, the matter of Brunelleschi's open account seems to have been discreetly set aside until the end of 1432, when two *operai* were empowered to review the final reckoning of the venture.[148] The new complete edition of this act reveals that the architect had not only transported some of the marble in his original contract to three points along the lower Arno valley, Castelfranco, Fucecchio, and Empoli, but had also delivered part of it to the Opera in Florence. The price to be allowed for thousand weight consigned was the first and highest offer, 4 lire 14 soldi per thousand. The surviving documentation does not enable monitoring of the Opera's income in this period, including redemption or repayment of the 55-florin advances, which Filippo had regularly declared as deductions from his capital worth in his tax declarations of July 1427, when they were fresh in his pocket, and in January 1431, when he had returned to supervision

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144 *Cupola*, II-4-12, cc. 72vd-73h, 13 April 1428, payments to carters at 4 lire 10 soldi per thousand weight; II-2-1, c. 80e: 19 March 1428, decision to calculate that price for land carriage from Pisa to the Opera of Fraschetta's marble "propter penuriam acque Arni." Most of this marble could have been loaded on a single *scafa* of the bargeman Lorenzo di Tingo, documented in 1435 as having carried 35,000 pounds: VIII-1-01, c. 27vb. In Michelangelo's time the trip up the Arno of a marble-laden *scafa* is recorded as taking from seven to thirty days: cf. WALLACE 1994, 54-62.

145 *Cupola*, II-2-1, c. 83vf.

146 *Cupola*, II-2-1, 84c. A partial payment of 40 lire for barge transport is recorded: II-4-12, c. 78ve.

147 *Cupola*, II-2-1, c. 92g: "qui marmor est in Commune Castri Franchi et Empuli." Once again, however, it seems that not even the Opera was able to move the stranded blocks, for no payments to carters indicate such halfway trips.

148 *Cupola*, II-2-1, c. 191va.

of the cupola after the Lucca fiasco. On the second occasion he also declared 15 florins still due to the contractor, Bertino di Piero, for marble lost in the Arno.[149] At the time of his next report in May 1433, Filippo must have settled with the Opera, which is no longer mentioned, but he now owed 8 florins to a bargeman and 4 to a carter for transporting marble from Empoli, probably the last of the lot to be salvaged.[150] The greatest loss of the Badalone enterprise must, however, have been the investment in the vessel itself, whether wrecked or run aground, and the disgrace and disappointment over the failure of the much-vaunted invention.

This is not the place to deal with the possible reconstruction of the Badalone, except to point out that the complete documentation indicates that it was conceived to negotiate the Arno even when the shallow-draft barges could not in the driest summer months, although, once blocked, it could not proceed even when traditional vessels were able to make the trip.[151] The possibility that Brunelleschi's invention entailed an amphibious structure has been suggested on several occasions and is the subject of a study completed with the support of the new Opera del Duomo documentation.[152] Filippo shared the passion for hydraulic engineering and inventive aquatic vessels with the school of early Sienese engineers, epitomized by Mariano di Jacopo Taccola. This quixotic inventor's notebooks contain designs of boats equipped with wheels as well as the transcript of an inflamed declaration by Brunelleschi concerning the necessity of shunning ignorant detractors, al-

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[149] FABRICZY 1892, 510-516. His liabilities in 1431 also included 16 florins for the rented bed that he lost in the Lucca flood.

[150] FABRICZY 1892, 516-519.

[151] These considerations alone rule out the attempt to visualize the Badalone as the round-keeled boat with paddle wheels, unsuitable for the Arno shallows, portrayed in a Leonardo-school drawing (Uffizi, Gabinetto di Disegni a Stampe 4085A), a proposal that has enjoyed a certain fortune in the literature. See, for example, GALLUZZI 1991, 187, entry I.b.4 (illustration on 186). Similar objections can be raised against the reconstruction proposed by Massimo Ricci, who envisioned a barge like those used in the Arno in the early years of the last century, outfitted with paddle wheels and windmill power inspired on the Leonardesque sketch. Ricci's model was exhibited at the Palazzo Medici Riccardi in Florence in 2003 and in Valencia in 2004 (illustrated and discussed in the catalogue of the latter occasion: RICCI 2004, 178, 180, 188-189), and has been much publicized since. Ricci assumed that all 100,000 pounds of marble were shipped in a single load, while, as we have seen, Brunelleschi's contract gave him two separate deadlines for half the total, which could have been transported in multiple shipments.

[152] NANNI and VESTRI 2011, 68-75.

ways ready to turn around and plagiarize the very ideas they have ridiculed.[153] Such a profile of Filippo resonates with the Manettian tale of interpersonal strife, but also with the Opera's ultimate tribute to the architect in his tomb monument, which centered not only on the architect's constructed achievements but also on the intelligence and technical creativity that enabled them, through innovative machinery that would be admired and copied by followers of the stature of Leonardo da Vinci.

Although even the failed inventions may have been an expression of genius, they certainly did not bring honor and profit to the Florentine Commune nor indeed to their creator. The cupola of Santa Maria del Fiore, on the other hand, achieved both of these glorious goals (Fig. 12). I submit that the Opera support structure available to, if not to say forced upon, the architect at the Florentine cathedral was the factor that determined the difference. The disciplined and deliberate building site became in a sense a vast laboratory where new problems could be tackled under controllable conditions. There, Brunelleschi's ingenious hoist and cranes did not collapse or betray the workers. His carefully considered working platforms protected the builders from all but one fatal accident. His ideas, constantly refined during their application in the company of intelligent and experienced craftsmen, just as the first building program had foreseen, were pursued prudently and patiently to the *optatum finem* of the completed, successfully self-supporting vault. The documentation of the Florentine Opera del Duomo is our "virtual" scaffolding to the understanding how the myth of this achievement was constructed.

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www.operaduomo.firenze.it/cupola (Florence, Italian)

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[153] GALLUZZI 1996, Introduzione, esp. 11-56, and for Mariano's interview of Filippo, 28. For the notebooks of Taccola, the relevant editions are 1969 (BECK) and 1972 (PRAGER and SCAGLIA).

Fig. 1. Florence, cathedral of Santa Maria del Fiore in the Florentine cityscape, view from the south.

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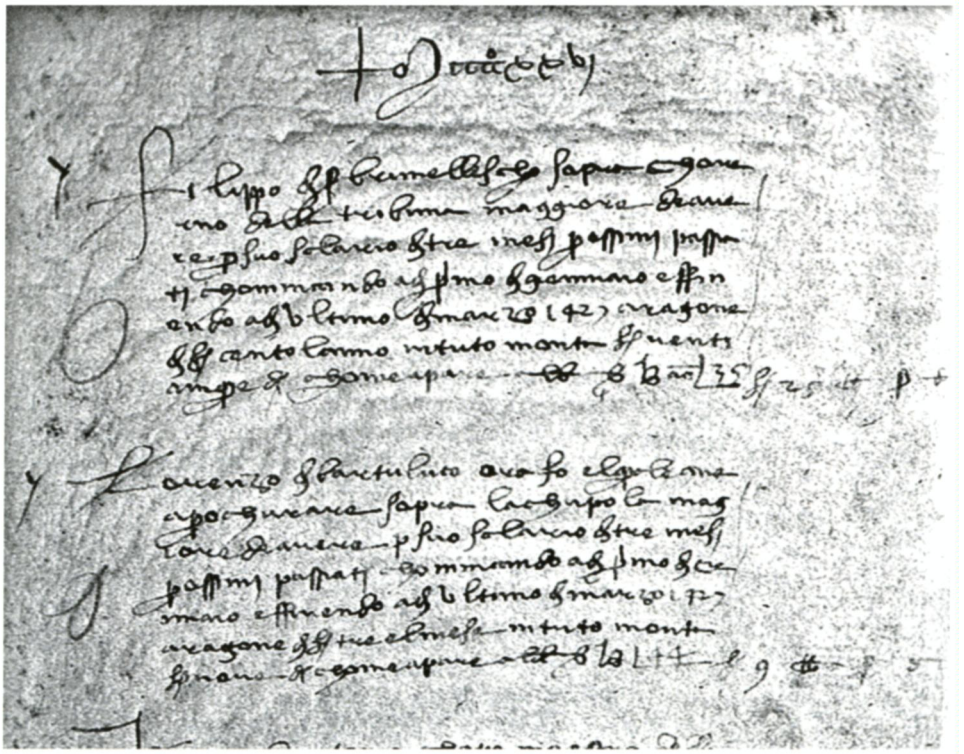

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Fig. 2. LORENZO GHIBERTI, self-portrait, gilded bronze. East doors of the baptistery, Florence.

Fig. 3. ANDREA DI LAZZERO CAVALCANTI, commemorative portrait of Filippo Brunelleschi, marble. Cathedral of Santa Maria del Fiore, Florence.

Fig. 4. Salary payments to "Filippo di ser Brunellescho sopra ghoverno della tribuna maggiore" and to "Lorenzo di Bartolucio orafo el quale àne a prochurare sopra la chupola maggiore" for the first trimester of 1427. Brunelleschi's salary amounts to 25 florins, Ghiberti's to 9 florins. Ultraviolet photograph of flooded book of allocations, Archivio dell'Opera di Santa Maria del Fiore, II-4-12, c. 40v.

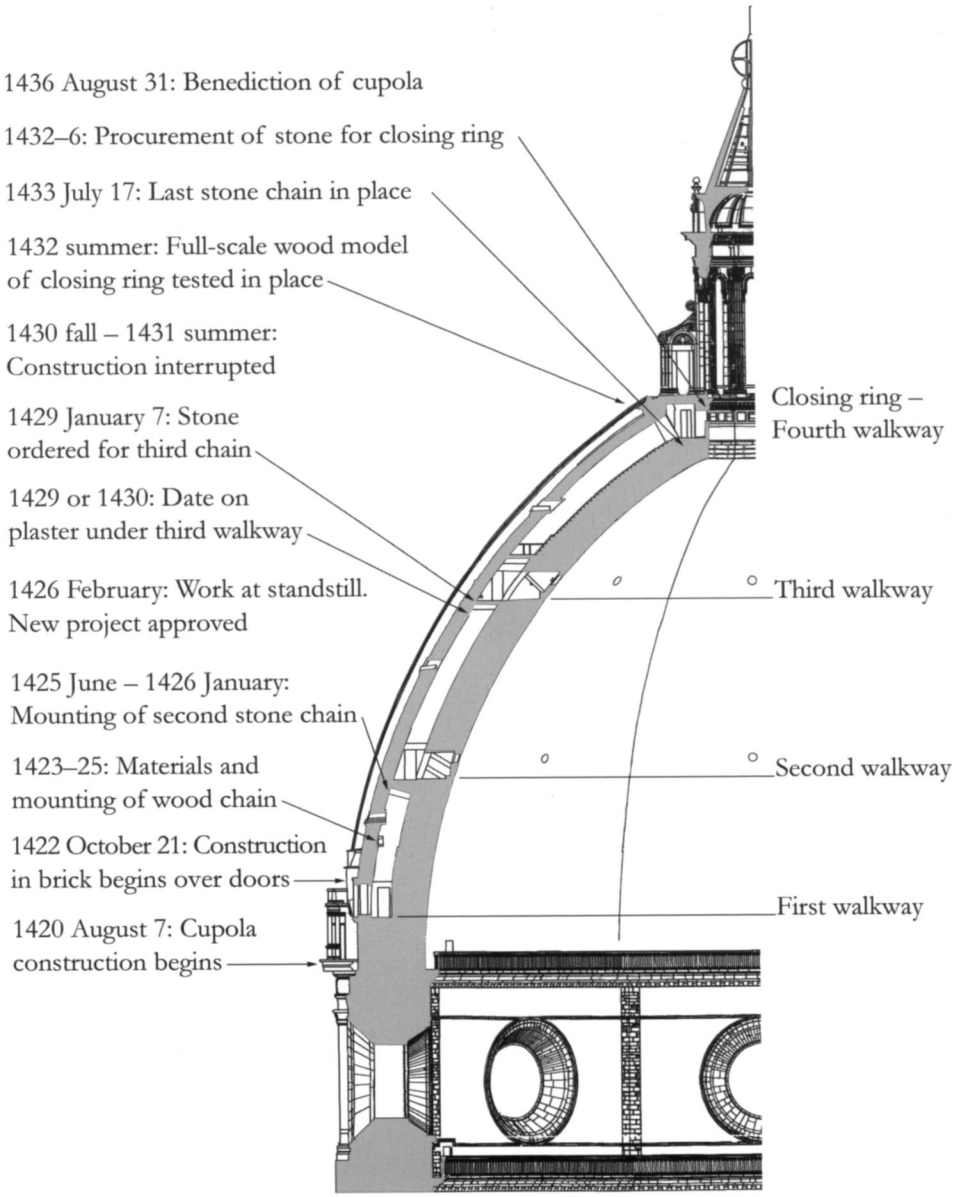

Fig. 5. Cupola section with essential documented chronology.

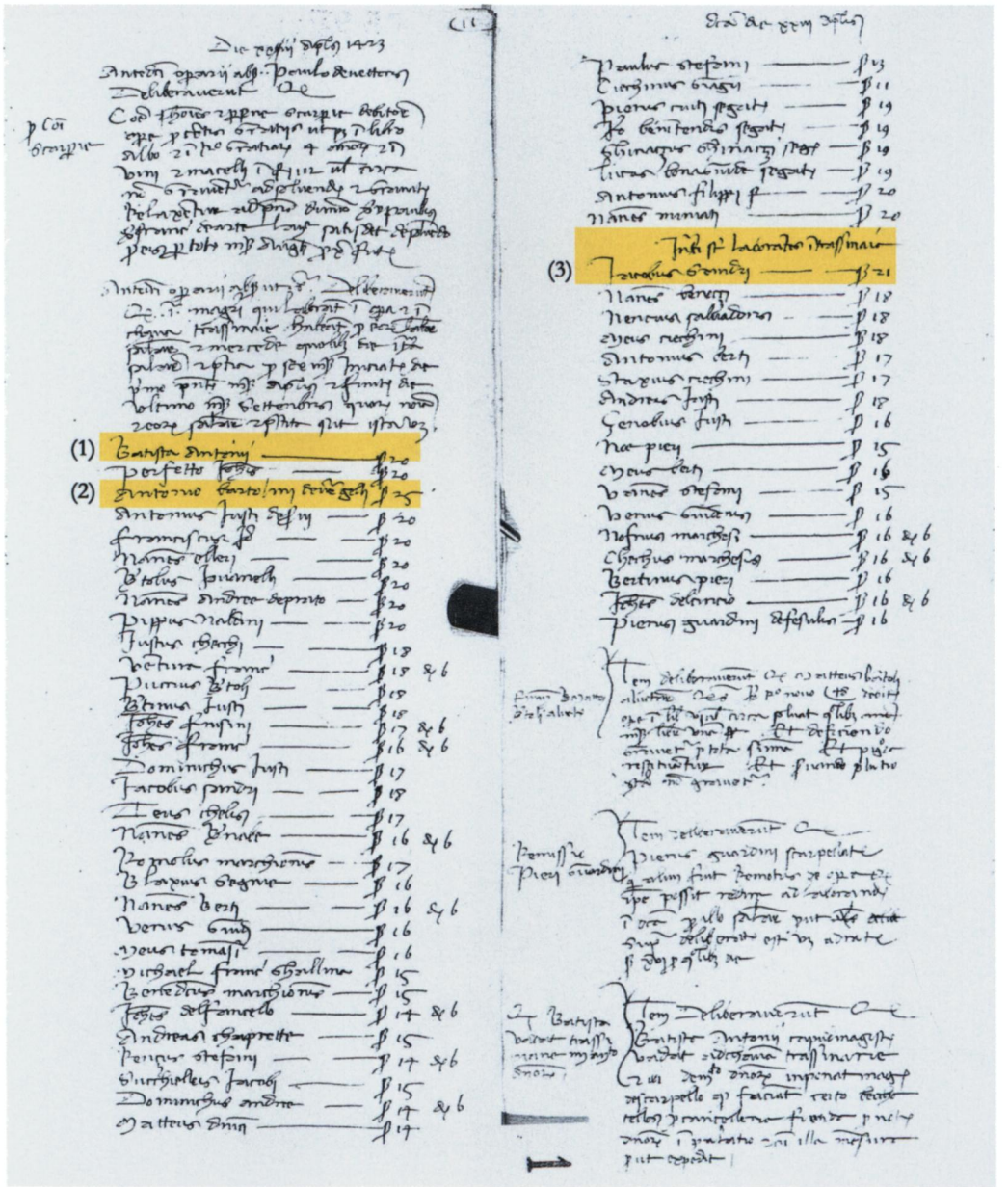

Fig. 6. A roll of workers for the summer of 1423 shows (1) Battista d'Antonio and Perfetto di Giovanni at the top of the list with their customary high daily wages of 20 soldi, followed by (2) Antonio di Bartolino da Vercelli with his exceptional wage of 25 soldi. The separate listing of the personnel for the quarry at Trassinaia is led by (3) Jacopo di Sandro with 21 soldi. Archivio dell'Opera di Santa Maria del Fiore, II-1-82, cc. 11-11v.

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Fig. 7. Santa Maria del Fiore, protruding stone beams, forming part of the first stone chain embedded in the *pietra forte* masonry at the base of the cupola, visible where the marble frieze was never executed.

Fig. 8. Santa Maria del Fiore, view of northeast segment of closing ring with stone components. On left, opening to access stairway between dome shells, flanked by oculus opening onto lateral section. Center, door to adjacent segment with interlocking lintel and jambs. Far right, opening to eye of the lantern area, with interlocking joint visible. Above, radial slabs forming ceiling of closing ring and base of lantern.

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Fig. 9. Wooden model forms (*modani*) for oversized rectangular and corner bricks (*quadroni*). Museo dell'Opera del Duomo, Florence.

Fig. 10. Santa Maria del Fiore, transition from stone to brick masonry above the doorway of the first walkway of the cupola's south segment, visible on unplastered pier surface.

Fig. 11. Santa Maria del Fiore, herringbone brickwork in the upper reaches of the dome at the corner between the north and northeast segments, temporarily exposed during the restoration of the frescoes (1988-95).

Fig. 12. Santa Maria del Fiore, cupola viewed from the west.

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