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FLORENCE CATHEDRAL AND ITS DOME:
THEIR STORY TOLD IN PICTURES

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James Michael Bredeck

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Webster Smith
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FLORENCE CATHEDRAL AND ITS DOME: THEIR STORY TOLD IN PICTURES

By

James Michael Bredeck

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ABSTRACT

FLORENCE CATHEDRAL AND ITS DOME: THEIR STORY TOLD IN PICTURES

By

James Michael Bredeck

This thesis is a response to a perceived need for better illustrations documenting the architectural history of Florence Cathedral and its Dome. What might the Florentines have seen of the great Dome as it was being built? What had they seen in the century leading up to the Dome's beginning? To answer these questions is the aim of this thesis. I have attempted to create a series of illustrations that offer plausible reconstructions of the Cathedral of Florence prior to and during the stages of the Dome's construction. It is hoped that these illustrations may facilitate the teaching and study of this important monument.

In addition, the thesis explores the potential of teaching architectural history through three-dimensional computer-based models integrated into interactive programs. This portion of the thesis is being published in the form of an interactive CD-ROM (or CDI).

The thesis also hopes to provoke discussion regarding what constructive procedure may have been used to raise the Dome, circa 1418 - 1436.

ACKNOWLEDGMENTS

I wish to thank the Department of Art, Michigan State University for accepting this unconventional thesis and for supporting me with every kind of assistance. This thesis would never have been started without the encouragement and support of Janice Simpson who ably manages to direct the Visual Resource Library (VRL) and the disorganized lives of many graduate students. Professor Webster Smith, the thesis director, deserves special recognition for his patient and valuable guidance of the project. I know of few individuals as generous when asked to contribute their expertise and time in the amounts Dr. Smith has, and for which I am indebted.

The additional committee members' contribution, usually requested at a moment's notice, of Professors Ray Silverman and Roger Funk, is gratefully acknowledged.

Pat Thompson, director of Michigan State University's Art Librarary, and her staff have been repeatedly helpful from the start. Their cooperation has made the task a great deal easier.

Professor William Simpson's mathematical expertise enabled me to verify that the cupola's builders may have used a string control device similar to one proposed by Rowland Mainstone. For contributing the geometric proof (Appendix III), Dr. Simspon's aid is gratefully acknowledged.

In Florence, my greatest debt is to Richard Fremantle for the many kindnesses and useful suggestions he has volunteered since we first met. Through his good offices, the library and staff at Villa I Tatti were made available to me and for which he has my deepest thanks.

For years Camilla and Oskar (Carottino) Baines have assisted my research activities in Florence, Bagno a Ripoli and Cortona.

Ricardo Settisoldi provided me with valuable access to the Dome and Seraglio where I was allowed to create original video footage.

Professor Massimo Ricci, Universita degli Studi di Firenze, deserves special recognition. The thesis could not exist, in a sense, without his explanation to me of his ideas concerning the construction of the dome. These ideas and, above all, his model of the dome being constructed on the banks of the Arno have become essential guidelines to me in this project.

Lastly I wish to thank Henry and Virginia Bredeck who together endured (among other things) my driving, chilly spring temperatures, being separated in the Rome Metro, and a two-hour wait on the runway before departure – all to visit their son in Italy.

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LIST OF ABBREVIATIONS

G: Guasti, *Cupola*, 1857

SMF: Guasti, *Costruzione*, 1887

S: Saalman, 1980

INTRODUCTION

The original subject for this thesis was not Florence Cathedral and its cupola but the Pazzi Chapel. Only while reviewing literature relating to the latter monument did I become familiar with Howard Saalman's monograph on the Dome.[1] Saalman has made exceptionally generous contributions to Italian Renaissance architectural studies and his *Filippo Brunelleschi : the cupola of S. Maria del Fiore* is essential reading for students of the Dome, or cupola, of Florence Cathedral. The genesis of my thesis can be traced to my reading the mixed review of Saalman's work by Marvin Trachtenberg. While praising Saalman's contributions Trachtenberg noted that "the problem lies not in the valuable subjects that are presented, but in the missing visual apparatus, especially explanatory drawings . . . needed to navigate much of the text."[2] But this criticism can be made of most other works on the cupola: Trachtenberg suggests that readers of Saalman's book equip themselves with copies of other, better illustrated works, and yet, singly or together, these works, too, fail to provide an adequate set of illustrations.

Having worked as a newspaper artist I am familiar with the problem of illustrating difficult subjects, and the Cathedral and cupola of Florence seemed to me particularly challenging. I have attempted illustrations of the building history of Florence Cathedral that plausibly reconstruct the church and cupola's building using a computerized model of both. The aims of this thesis are:

[1] To tell the story of the Cathedral and its cupola again, this time according to a coherent sequence of illustrations that I have created especially for this thesis. Taken together they may offer a more tightly-knit history of cathedral and cupola

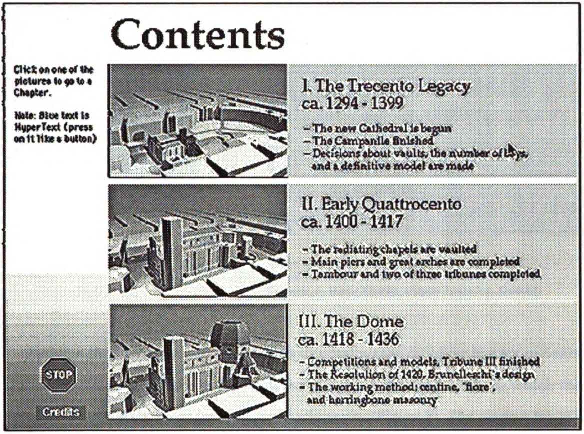


Figure 1
Contents screen. Computer program of thesis

than available before. These illustrations appear as a sequence of colored plates (see List of Plates, pg. vii).

[2] To combine the aforementioned illustrations in an interactive computer program with a building history of the Cathedral and cupola *(Figure 1)*. The program should exploit its color and motion (video and animation) features when appropriate. The program is contained in a CD-ROM that is attached to the inside back cover of this volume.

In effect I have produced two theses: one in conventional form, the other a computer program.

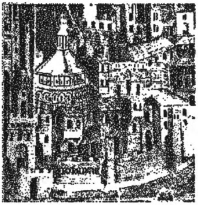


Figure 2
Detail of Misericordia Fresco, Florence, Bigallo oratory (1342)

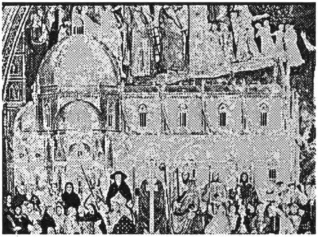


Figure 3
Andrea Bonaiuti, **The Church Militant and Triumphant,** *Florence, S. Maria Novella, chapter house (ca. 1366-68)*

Perhaps the first attempt step towards illustrating the building history of Santa Maria del Fiore was taken in the so-called Bigallo fresco of c. 1342, in which the partially-built structure appears in the background*(Figure 2)*. The project for the cathedral had encountered delays soon after its 1294 inception and by the 1340's work had reached a standstill except for the belltower. The fresco depicts what was probably standing ca. 1350 when attention returned to building. What can be seen are portions of the façade's lower section as well as the first bays of the south wall and the campanile's lower regions.

A small miniature in the Codex Edili, Biblioteca Laurenziana (ca. 1340-1350), provides us with a glimpse of the cathedral façade. It features only a single portal but this simplification may be a convention employed by the illuminator who appears to have deleted (or greatly reduced) the side aisle entrances.

A fresco by Andrea Bonaiuti of c. 1366 represents the Triumph of the Dominican Order in the Spanish Chapel of S. Maria Novella *(Figure 3)*. It shows the cathedral complete with a cupola although final decisions regarding the project were still being made in the 1360's and construction on the cupola would not begin in earnest until 1418. The fresco, then, depicts what is likely an idealized version of the cathedral project as the artist saw it in 1360 when competing designs were being debated. Vasari wrote that Arnolfo had left a model for the projected cathedral and that the Spanish Chapel is a picture of this model, which has given rise to a body of literature (cf. Paatz III, p.432 n.28).

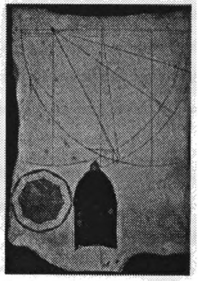


Figure 4
Giovanni di Gherardo da Prato, project drawing for cupola of S. Maria del Fiore, Florence, Archivio di Stato (late 1425)

Two wooden models contemporary with the Dome's construction survive: (i) of the Dome with apse parts (ca. 1420-1452) and (ii) of the Lantern (1432-36). Both are generally attributed to Brunelleschi who on many occasions was requested to fashion models to clarify points of construction for all concerned.

The pictoral record of the cupola project is sparse. We have only one contemporary visual record of its construction: the parchment drawing by Giovanni di Gherardo da Prato prepared in late 1425 and now preserved in the Archivio di Stato, Florence *(Figure 4)*. It is the only surviving drawing of the cupola contemporary with its construction. It was first published by Guasti in 1874. The parchment has handwritten comments and several drawings, two sections and plan of the octagon areas, which are ostensibly eyewitness accounts of work-in-progress ca. 1425. Giovanni argues that the cupola, as it was being built, would not allow enough light to enter and illuminate the crossing which he illustrates. He also criticized the inclination of the masonry courses and the cupola's curve which (to him) deviated from the agreed-upon plan and model which all building supervisors swore oaths to follow faithfully. The document has come to be known as 'The Accusation of Giovanni' as it accuses Brunelleschi of deceiving the Opera and building the cupola incorrectly. The parchment reveals clearly the geometric means of determining the cupola's pointed-fifth, or 'quinto acuto', profile as well as suggesting the location of the work platform erected at the cupola's base. Close inspection of the document may reveal clues as to the nature of building control mechanisms used in the cupola but never before depicted.

One of the earliest written accounts of the cupola is by Leon Battista Alberti who praises it and its creator in the dedication to the Italian edition of his treatise *On Painting*. Alberti visited Florence for the first time in 1428 and was struck by what he saw– the cupola under construction! He praised its size as well as the technical ingenuity of this new creation.[3] He tells us the cupola was somehow built without aid of a fixed interior wooden formwork. This formwork (also referred to as falsework or centering) is normally supported on an armature of wooden beams. Brunelleschi's achievement, given lasting prominence by Alberti, continues to provoke research and to present problems for those who would understand how the cupola was constructed. Few scholars are forthright in suggesting exactly how this was done. Several contemporary depictions exist of the unfinished cupola: Domenico di Michelino's *Dante and the Three Kingdoms* (ca. 1465), Giovanni Battista Utili's painting which shows scaffolding spread out over the cupola (ca. 1470), and Biago d'Antonio's *Archangels in a Tuscan Landscape* (ca. 1465-70) are three examples. They are documentary in the sense that they reveal various stages of ongoing work at the cathedral, but their impact on subsequent depictions appears limited.

Brunelleschi's biography was written in the 1480s by Antonio di Tuccio Manetti who probably saw the cupola rising as a young boy.[5] His account of Brunelleschi's life lacks technical details but remains a significant work in its recounting of the drama of the cupola's building. Later biographies add little to our knowledge of Brunelleschi or the cupola. Giorgio Vasari's became the most widely read account though based almost entirely on Manetti.[6] Together, Manetti and Vasari initiated an anecdotal tradition that would continue until the 1850's at which time scholars gained a wealth of documented historical facts relating to the cathedral and cupola.

The first mention of techniques and machines used in the cupola's construction is in Bartolomeo Scala's *Historia Florentinum* written in the 1490's. He describes the rope curvature and brick alignment control system vividly:

"Filippo Brunelleschi, an architect of great genius, discovered a system *(ratio)* shortly before our time whereby it [the cupola] was easily completed without any supporting formwork *(adminicula)* whatever. For, having found and marked the centre, he stretched a cord from the centre to the circumferences. Carrying on (this process) around in a circle, he determined in what order and according to which curvature *(quoque orbe)* the bricks and mortar were to be laid *(ducenda)* and placed on the wall." [4]

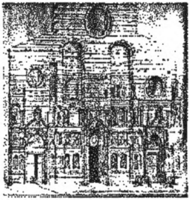


Figure 5
Bernardino Poccetti, View of the Cathedral façade, drawing, Florence, Museo dell'Opera del Duomo (ca. 1587)

The next significant visual record is a drawing attributed to Bernardo Poccetti, ca. 1587, of the Cathedral façade which appears as an updated depiction of the Bigallo fresco *(Figure 5)* . The drawing is the most detailed of the old façade and provides us with the most accurate record of the cathedral's façade appearance of any mentioned thus far. It may have been prepared at the request of Bernardo Buontalenti who headed a project to complete the façade which required demolishing the old work. The project was initiated by the provedditore of the Opera, Benedetto Uguccioni, who felt the old façade was clumsy and old-fashioned and encouraged the grand duke, Francesco de' Medici, to assist in the project. With the duke's death in 1587 and the completion of the cladding of the cathedral's side walls, the façade project was given new impetus. For his part, Buontalenti may have sought to record and honor the earlier design by means of

Poccetti's drawing which he used as the basis for a commemorative relief. (Discrepencies between portions of the façade visible in the drawing and those of the Bigallo fresco have not been adequately explained.)

In the first half of the 16th century a new episode was introduced into the story of Brunelleschi and his building of the cupola. G.B. Gelli described how Brunelleschi levelled off one of the banks of the Arno to trace the cupola's profile out in full scale, a story that would not reach a wider audience until published in 1896.

The lantern required reconstruction in 1601 and as a result we have several drawings of it under repair. An anonymous drawing in the Uffizi (A 248) and an engraving (after 1611) by J. Callot both show scaffoldings for the reconstruction in place. The scaffolding suggests the appearance of the cupola when the lantern was originally being built.

The first measured survey of the cathedral and cupola were drawn by Giovanni Battista Nelli (1661-1725) in 1688. The drawings were later engraved by Bernardo Sansone Sgrilli in *Descrizione e Studi dell'Insigne Fabbrica di S. Maria del Fiore* in 1733, after Nelli's death. A second edition with a different title was published in 1755 with comments by Nelli's son.[7] I have been privileged to see a set of the original publication of these thanks to the kind and patient assistance of the library staff at the Villa I Tatti (Harvard Uni-

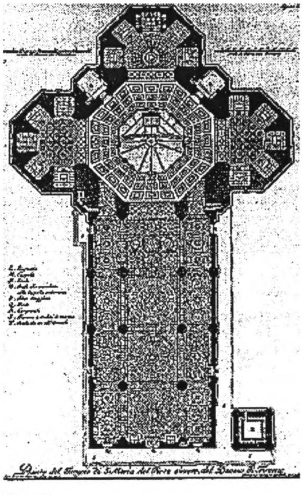


Figure 6
Florence, Santa Maria del Fiore. Plan (Nelli)

versity Center for Renaissance Studies in Florence). Reproductions of them were used as the basis for my model. Unfortunately specimens of these are rare and most reproductions of them are very small in comparison to their original size. There seems a need for a large format reprinting of these important drawings for scholars and students alike.

Not all of the drawings of the cathedral published by Sgrilli were based on Nelli's drawings which apparently have been lost. Sgrilli produced several works of his own concerning the cathedral, including a topographical plan of the Piazza del Duomo. The images thought to be based onNelli's drawings include: a detailed measured plan showing the pavement design of the cathedral *(Figure 6)*, a plan taken at the level of the first interior balcony (B1), sectional views and elevations of the cathedral, a plan of the drum, a plan of the cupola, a section of the drum and cupola, plans and section of the lantern, as well as an analytical bird's eye view of the cupola. The engravings based on the drawings remain some of the best illustrations of the cathedral yet produced and are described by Saalman as 'the best sectional views of the cathedral yet made' whose value is 'difficult to overestimate.' While they make no attempt to depict the building under construction, they do reveal hidden structures and features (as in the sections and bird's eye view) of the cupola never before recorded.

As Italian nationalism and hopes of unification grew in the mid 1850's Florence became, temporarily, a candidate for the national capital's location. Civic pride led to competitions (won by Emilio De Fabris) to complete the unfinished façade. De Fabris made observations and discoveries about the façade that contributed to the discussion of Arnolfo's design. Afterwards, the question of the façade remained a major theme in the literature.

To assist the various architects involved in the façade project, Cesare Guasti - working at the time in charge of the *opera* (board of works) archives - published a selection of cathedral documents in 1857 that pertain to the cupola's construction.[8] These published documents are the most important contemporary source of information about the cathedral and cupola, produced as records of various administrative decisions regarding the work. Because different groups shared responsibility the documents fall into three categories: the Signoria's (regarding financing and administration), the Wool Guild consuls' deliberations, and (most importantly) the records of the *operai* and officials of the *Opera di Santa Maria del Fiore* , the subcommittee charged by the Wool Guild to oversee the projects. Guasti's publication introduces the first firm basis of historically documented fact for scholarly studies of the cathedral and cupola. In 1887 a second edition was published which is more comprehensive and gives more details of the early history of the cathedral.[9]

By the mid-19th century, the tradition of assigning Arnolfo di Cambio credit for designing the cathedral was beginning to be seriously challenged. Camillo Boito reopened the question of authorship of the cathedral in 1865 by publishing a plan that superimposed a reconstruction of the Arnolfo project on the final plan.[10] He prepared it by comparing the recorded measurements taken of the cathedral under construction in 1357 (Doc. 70, pp. 94-95) with the Spanish Chapel fresco. Boito's plan had considerable impact on later thinking as he became the first scholar to deny Arnolfo di Cambio's complete authorship of the Duomo, suggesting that Francesco Talenti enlarged the original plan. Although far short of a complete reconstruction of the Arnolfo project, it did establish a precedent to which subsequent scholars would continually readress themselves.

The work of scholars (Frey, Nardini, Stegmann-Geymüller, Durm, Fabriczy) in the late nineteenth century made further advances towards our understanding of the cupola. Karl Frey's 1885 translation of Manetti included several new documents overlooked by Guasti.

Aristide Nardini-Despotti-Mospignotti attempted to write the complete build-

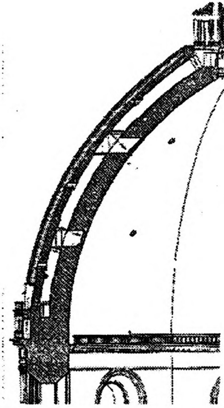


Figure 7
Florence, Santa Maria del Fiore, Detail of drum and cupola, elevation and section (Stegmann-Geymüller)

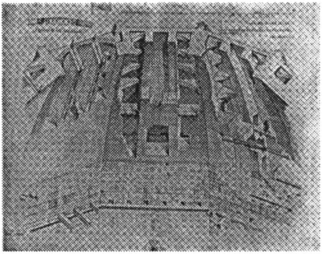


Figure 8
Cupola. Analytical view, J. Durm (1887)

ing history of the cathedral as early as 1885 in his *Filippo Brunelleschi e la cupola di S. Maria del Fiore* .[12] With Nardini we are positioned at the beginning of the long and contentious history of interpretation of the *opera* documents as well as the first questioning of the Manetti-Vasari tradition that gives Brunelleschi sole credit for the cupola. Nardini's work deals exclusively with the cupola.

In 1885 Ernst von Stegmann and Heinrich von Geymüller created a series of measured drawings of cathedral, cupola and lantern published for their work*Die Architektur der Renaissance in der Toskana. (Figure 7)* Their survey of the cathedral continues to offer the most widely available large-scale renderings of the cupola (a poster of their sectional view was used for this thesis).[15]

Joseph Durm used his technical training as an architect to produce detailed sketches in 1887 that helped explain the basic components of the cupola and the arrangement of the stone chains mentioned in the 1420 documents.[14] His analytical view of the cupola includes, at the bottom, beams inserted at the B3 level meant to support a work platform *(Figure 8)*. It is, perhaps, the first visual to speculate upon the appearance of previously undepicted aspects of the structure.

Cornel von Fabriczy's contribution (primarily his 1892 Brunelleschi monograph) lies in his compilation of known documentation and of contemporary literature and historical sources.[13]

Concern for the physical stability of the cupola became a concern of scholars of the early twentieth century. Pier Luigi Nervi led a team of engineers in 1934 who examined and surveyed the structure. Their results were published in 1939.[16]

Measured drawings and another survey of the cupola were carried out in 1936 in preparation for the five hundreth anniversary celebration of the cupola consecration. An assonometric projection of the cupola was created for the 'Congresso di Storia dell'Architettura' held in 1936, and published in 1937.[17]

Walter and Elisabeth Paatz refined exisiting theories of the original Arnolfian scheme for the cathedral and contributed new façade, plan, and elevation reconstructions.[25] In 1937 Paatz attempted to combine earlier theories of the 'Arnolfo plan' with Boito's of 1880, rejecting the notion that the Spanish Chapel fresco reflected Arnolfo's design. By comparing the incrustation of the older eastern bays to motifs found on upper zones of the campanile Paatz dated the incrustation of the bays to the Talenti period. He concluded, however, that the raw masonry beneath the incrustation must have existed before Talenti.

In 1938 Peter Metz reopened the question of authorship for the cathedral façade in rejecting the notion that Talenti had began a new façade in the 1350's. Metz argued that the Bigallo fresco and the Poccetti drawing are identical and may go back to Arnolfo. Confining himself solely to the façade question, he suggested that the new cathedral design and bay system under consideration ca. 1355 were consequences of a decision to add vaults to a previously timber-roofed plan. He presented a schematic reinterpretation of the Bigallo fresco as well as an alternative reconstruction of Arnolfo's façade.[11]

Piero Sanpaolesi's *La cupola di Santa Maria del Fiore* (1941) was the first work since Nardini to focus solely on the cupola.[18] The inclusion here of photographic details revealing the interior structure of the cupola and an axonometric view of the cupola structure are noteworthy. Although he based himself primarily on his predecessors, Sanpaolesi departed from them by suggesting that a large wooden scaffolding beneath the cupola had been used to support curvature templates, known as *centine*. These centine were needed to assist in determining the cupola's curvature as it was being built and Sanpaolesi's suggestion to this effect is perhaps his most valuable one. He expressed the opinion that although the program of 1420 called for stone chains, they were never built. For Sanpaolesi the herringbone masonry bond explained how the cupola was self-supporting as it was built. Giovanni di Gherardo da Prato's accusation may appear legitimized by Sanpaolesi's observation of the inclination of the bricks, which suggested that the cupola had been begun with a semicircular rather than a pointed fifth curvature.

In 1950 Frank Prager was the first to make clear that the stone chains are arranged in pairs and that there are not six chains but three *pairs* of chains actually built within the cupola.[19] Prager realized these chains are, in part, visible. Gustina Scaglia contributed information in 1960-1961 on the machines employed in the cupola construction, making connections between machines illustrated in Buonaccorso's Zibaldone to others de-

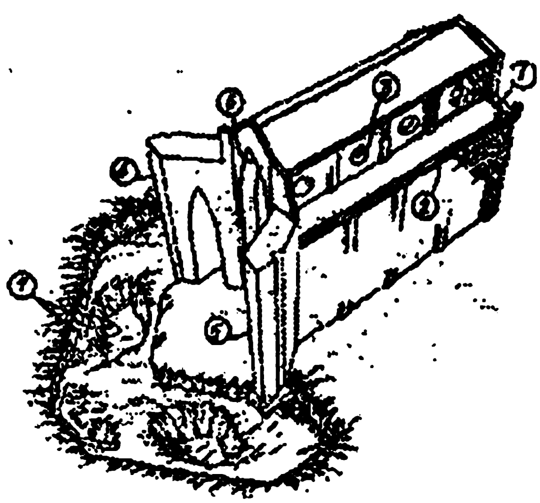


Figure 9
The Dome in 1390. Schematic reconstruction of its apperance seen by young Filippo Brunelleschi. Drawn by G. Rich, 1969. Reprinted from Prager (1970), p.14

signed by Brunelleschi.[21] Working together in 1970, Prager and Scaglia collaborated to produce descriptions and reconstructions of Brunelleschi's machines, also, a depiction of the cathedral under construction ca. 1390 which envisions excavations under way at the east end with two of the four main piers raised.[20]

In 1959 Howard Saalman proposed that the chief contribution of the 1366-1367 painters subcommittee project was the introduction of a drum.[28] He later (1964) constructed an extremely helpful early building history of the Cathedral.[28] In appendices he gave recent views of Santa Maria del Fiore, discussed the issue of what occurred during the 1350's, revisited and revised the dominant themes of scholarship pertaining to this period, and critically reviewed the 1961 contributions of Gottfried Kiesow.

Kiesow closely observed the external patterns of incrustation on the cathedral and produced drawings in 1961 that intend to reconstruct Arnolfo's designs. His explanation of building activity in the 1350's differs from previous theories in suggesting that not only the raw masonry but the incrustation as well (of the eastern bays) were raised at the same time and preceded Talenti (discussed by Saalman, 1964, p. 494).[26]

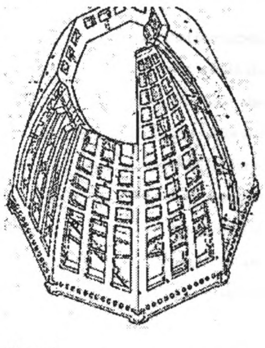


Figure 10
Cut-away view of the dome to show the principal features of construction. Reprinted from Mainstone (p. 160)

Decio Gioseffi's *Giotto Architetto* of 1963 produced another reconstruction plan (to that of Boito's) of the Arnolfo project, this time combined with a revision of the 1330's. Gioseffi theorized that the façade was thickened internally to support the thrust of a new system of vaulting being adopted, probably in the 1330's. He also created draw-

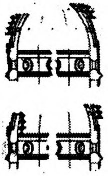


Figure 11
Conjectural reconstructions of working platforms constructed inside the dome. Reprinted from Battisti (1981), p. 123

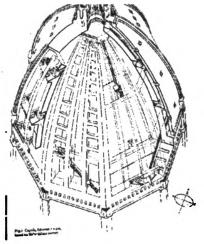


Figure 12
Cupola. Schematic view, based on Seibenhüner survey. Reprinted from Saalman (1980), frontispiece

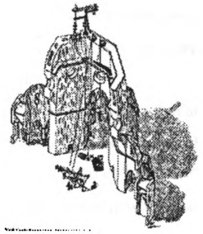


Figure 13
Cupola. Reconstruction of loading platform in place and the great hoist (1420-21) and great crane (1423) in operation at the U2 level. Curvature control templates (centine) in octagon corners are not shown as their form is uncertain. Reprinted from Saalman (1980), p. 152

ings of an Arnolfian façade design that would be closely related to the lower Campanile zones.[27]

Rowland Mainstone's contributions include his 1969 suggestion that the cupola was self-supporting because it incorporated a complete circle (inscribed within the octagonal thicknesses) within its dimensions at all elevations.[24] Mainstone also reasoned that the only means to avoid breaks in the masonry fabric of the vaults was to align each side's brickwork toward a common center - and not perpendicular to that side. With Howard Saalman, Mainstone measured and analyzed the masonry inclinations, noticing that the masonry for any horizontal course is higher at its corners and dips slightly in the center. Mainstone published his findings in 1977 and postulated several devices that could have been used at the cupola to maintain curvature control and the radial disposition of building elements *(Figure 50).*

Eugenio Battisti supervised a group of architectural students from the University of Florence in a project to survey the cupola's south-east side. Their drawings are published in Battisti's monograph on Brunelleschi of 1975. A second edition was later published in English.[23] It included hypothetical reconstructions of work platforms at various levels used in the cupola's construction.

Saalman's 1980 monograph on the cupola is noteworthy for its transcription of new documents never before published. The frontispiece is a schematic view based on measured drawings by Hans Siebenhüner made in the 1930's*(Figure 12)*.[22] Saalman collaborated with architect Thomas Mucha to create several new illustrations that reconstruct the cathedral and cupola under construction *(Figure 13)*. They depict Brunelleschi's building machines in operation, clearly presented in four different figures. By sifting through vast amounts of documentary sources and summarizing their contents, Saalman performed a great service. His discussion and diagram of the first stone chain has been particularly valuable to me in my effort to reconstruct it in this thesis. The Appendices provide valuable contextual information relevant to the cathedral and cupola's building; they range over a number of topics, from Guild Control during the Quattrocento to building machines used in the completion of the Lanterna.

Salvatore Di Pasquale confirmed many of Mainstone's theories regarding the disposition of the masonry through a series of observations concerned with cracks in the cupola. With assistants from the Istituto di Costruzione of the Faculty of Architecture of Florence University Di Pasquale has made extensive measurements and investigations of the vault and its behaviour. His findings were presented at the congress celebrating Brunellechi's six-hundedth birthday in 1977 and were later published.[29]

Franklin Toker contributed archeological evidence in 1975 from the church of Santa Reparata beneath the Cathedral. He made plans and sections of the Santa Reparata. Based on these he reconstructed views of it showing the appearance of the apse. He identified five distinct phases in the construction of Santa Reparata which

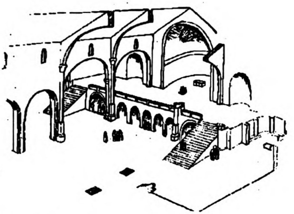


Figure 14
Reconstructed view of the Romanseque church in the thirteenth century. Reprinted from Toker (1960), p.35

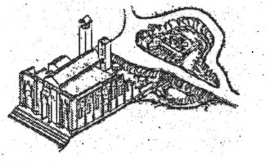


Figure 15
Elements of the original project for Florence Cathedral, hypothetical view of the suspended project after 1310. Reprinted from Toker (1983), p.108

he discusses in detail.[30] In 1978 he published again on the early building history of the Cathedral, including reconstructed views of the state of works during the early decades.[31] After a second series of excavations, in 1983 he published on the subject of early construction at the Cathedral and contributed reconstructed drawings of a plausible, still much-debated, 'Arnolfian scheme'.[32]

Massimo Ricci proposed a theory of how the cupola may have been constructed that utilized a 'fiore' or string control device fixed on the base loading platform.[33] Ricci hypothesizes the existence of a geometrical rule (regola operativa) invented by Brunelleschi for the building of the cupola of the Cathedral of Florence and includes an appendix with a mathematical verification of this rule. He is currently constructing a one-fifth scale masonry model of the cupola on the banks of the Arno utilizing only the simplest of masonry tools and techniques to implement his theory which is discussed here in Appendix II.

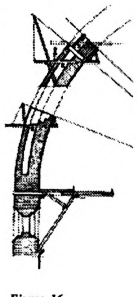


Figure 16
Hypothetical reconstruction of service platforms. Reprinted from Ricci (1983), p.80

Portions of Ricci's research have been published by a former collaborator Lando Bartoli.[34] Based on conversations with Ricci my view of Bartoli 's work is critical, as it proposes questionable additions (e.g. a wooden tower [fig. IVb] which Bartoli presumes was built in the octagon's center to assist in measuring).

The most recent set (1988) of authoritative measured drawings of the cathedral nave and façade structures are those by Giuseppe Rocchi and others contained in *S. Maria del Fiore: Rilievi, documenti, indagini strumentali.*[35] The work provides what may be the best selection of large, measured drawings since Nelli of the cathedral nave and façade, unfortunately discovered late in the creation of this thesis.

* * *

My first efforts were to compile a chronology of building at the Cathedral which would follow Prager (1970), Saalman (1964), and Toker (1978 and 1983). In cross-referencing these sources it became apparent that certain key documents are interpreted differently. I will note these divergent opinions in my conclusion.

Meanwhile, I started to construct a three-dimensional model of Florence Cathedral on the computer by compiling as many measured drawings of the site and structure (plans, elevations, sections, details) as possible. Throughout the project these drawings were referenced and cross-checked. The drawings had to be translated into a digital form to allow their manipulation (scaling, cropping, etc.) by various computer image-editing programs. The first step in this translation process was a scanning, or 'digital photocopying', of the drawings using a flatbed scanner.

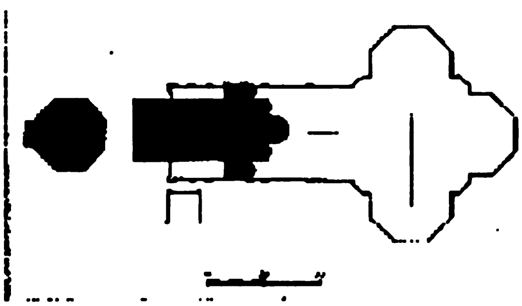


Figure 17
"Raw" digitized image of Cathedral and S. Reparata plans

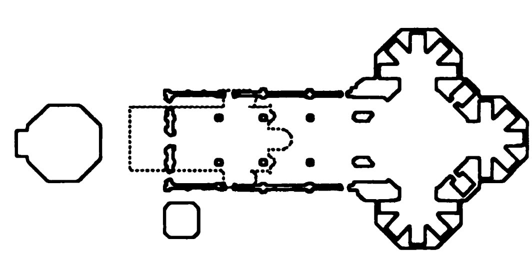


Figure 18
"Clean" drawing of Figure 17 made using computer graphics program

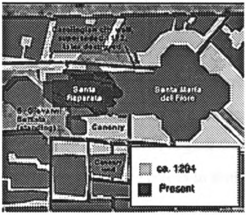


Figure 19
Cathedral district, 12th century. Reconstructed view

The pictures were laid on a flatbed scanner and scanned. Afterwards, the grainy black and white images appeared on the computer screen as digital images which I then used as templates for new computer-generated drawings.

Computer-drawn images were required for the modelling program. Three-dimensional model programs could not accept (with great success) the raw data represented by the original scanned image. Scans had to be 'cleaned up' first - redrawn - a process very much like tracing a drawing onto a vellum overlay. Once the original scan was traced over (using a graphics drawing program) the underlying scan was hidden from view leaving only the line drawing generated by the computer. This procedure was a relatively fast means to accurately reproduce digital images which allowed me to manipulate them afterwards.

The computer drawn files were now ready to be exported to the three-dimensional program where the model was to be assembled. The individual 'pieces' were one by one, scaled, given dimension, assigned material properties (i.e. surface color and texture) and slowly assembled. A complex model (a 'virtual cathedral') was slowly built from the ground up which could be viewed from any angle and might also be animated.

Illustrations were rendered and saved into an image editing program (PhotoShop) as PICT files. The illustrations are placed into an interactive program illustrating the Cupola (MacroMedia Director) where motion video and audio files may be included as well. The illustrations were incorporated as full-screen images in the computer program where viewers may choose to see notes and labels relevant to the pictures. Viewers may also 'play' short animations and video segments pertinent to the illustrations which have been arranged chronologically and are intended to be 'read' sequentially. Each illustration represents a span of years (for example: "ca. 1365-80") during which a particular phase of construction was carried out. The images are containd within both the conventional and the computer versions of the thesis. When viewed using the computer, the illustrations' quality is markedly higher due to the greater clarity of the screen and the ability to use many more colors in their renderings. In either form they are to be viewed together with the written narrative that follows here in Chapters 1, 2, and 3.

CHAPTER ONE

TRECENTO LEGACY: Plates 1 - 4

By the end of the thirteenth century the Florentines begin building a new cathedral and town hall on a scale unprecedented in the city *(Figs. 20 and 22)*. The motivation to replace the church of Santa Reparata with a cathedral appears to be at once sacred and secular; the church is dedicated to Mary and meant to be "worthy of the prosperity of the citizens"(SMF 24). The project is partially inspired by Florence's rivalry with Siena and Pisa and intended to outdo their large domed cathedrals.

The building of the Cathedral begins shortly after 1293, with the sculptor Arnolfo di Cambio as capomaestro. Arnolfo is the acting supervisor and is considered a "famous builder of churches" whose reward is exemption from paying taxes. This initial period (ca. 1294 - 1300) is one marked by generous financing and rapid progress in construction, culminating in the blessing of the rising masonry walls in September 1296 and the praising of Arnolfo by a communal council of Florence in April 1300 (SMF docs. 5–24).

According to Toker, "the first objective of site design was to open up the narrow piazza between S. Reparata and the Baptistery, in order to permit circulation to the north suburbs through the Via degli Spadai (today Via Martelli and Via Cavour), a route which was laid out in 1285."[36] This required the demolishing (probably in 1293-4) of the porch, façade, and two nave bays of S. Reparata *(Plate 1)* which made the immediate raising of a new façade - as a protective screen in front of the remains of the old church - a priority. The cathedral is not aligned exactly to the Baptistery

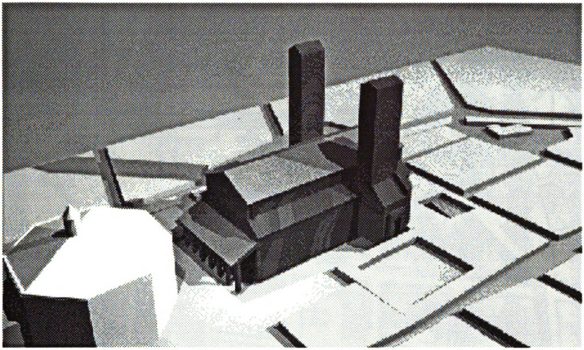


Plate 1
Church of S. Reparata. Reconstruction ca. 1290.

or the former church but, rather, to the deviant (diagonal to the E-W axis) southernmost chapel wall of S. Reparata. The resulting cathedral is therefore not perpendicular to the Baptistry. Building apparently begins simultaneously at the west façade and at the projected opposite end to the east, where another church, S. Michele Visdomini, stood near the cathedral's present-day crossing. The canonry lies between these two sites and may have been left undisturbed by Arnolfo at the outset to appease the influential cathedral canons.[37]

The old church's pavement lies about a meter below the street level. As foundations are dug nearby for the cathedral, dirt is carried inside Santa Reparata and covered with brick to raise the floor elevation about a meter above the street and level with a cemetery immediately south of the site. The south Duomo wall is erected from the façade to the first side door by 1302 as was a shed roof covering the wall up to the surviving clerestory of the old church. Work on the north aisle wall seems to

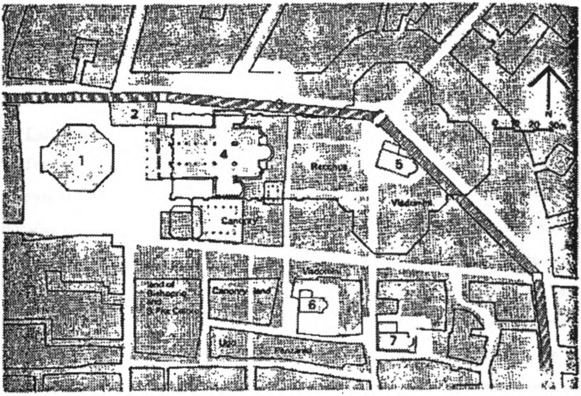


Figure 20
The Cathedral district, 12th c., Reprinted from F. Toker (1978), p.220

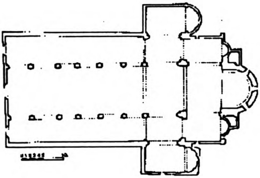


Figure 21
Reconstructed plan of the Romanesque church of S. Reparata, Reprinted from F. Toker (1975), p34

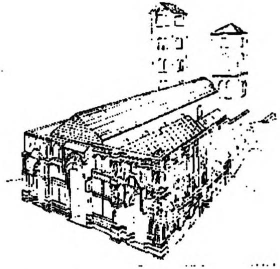


Figure 22
Construction of S. Maria del Fiore around S. Reparata, mid-14th century: integration of the views of 1342 and 1587 with archeological evidence (drawing A. Bigazzi, revised F.T., redrawn R.S.) Reprinted from F. Toker (1978), p.220

have been finished later, the original wall of S. Reparata eventually destroyed in 1358. The new façade and side walls beginning to rise as of 1302 may have been partially encrusted.

Early Trecento Slowdown

For some reason construction stops in 1302, perhaps because of the political turmoil at this time. Also, it may have been in this year that Arnolfo dies. Several decades of near-stagnation ensue. An appeal for funds by Pope Clement V in 1310 acknowledges the suspension of the work. For an idea of what the work site looks like we consider the only visual record of the project from the first half of the 14th century - the fresco in the Bigallo *(Figure 2)*. This fresco provides us with a picture of the general state of works from Arnolfo's death up to the resumption of construction in 1355 *(Plate 2)*. It suggests that Arnolfo's façade design corresponded more to the Baptistery's clear and simple geometric ornamentation than subsequent, more ornate, designs.

Work continues only sporadically until 1334 when attention turns to the belltower under new spiritual and financial control (SMF docs. 32, 35, 39 and 45).

Interlude

The slowdown of the previous period becomes stagnation, apart from building of the campanile, 1334-59. The foundations begun for the proposed octagon to the east are abandoned, presumably because of a lack of funding since, as Toker notes, "Florence made war not buildings during the 1320's". After 1334 attention turns to the Campanile whose foundations are begun in July of 1334 with Giotto in charge (SMF docs. 39, 44, and 45).

Appointed capomaestro because he is the most famous artist of his day (he seems to have had no previous experience in building), he confines his efforts to the

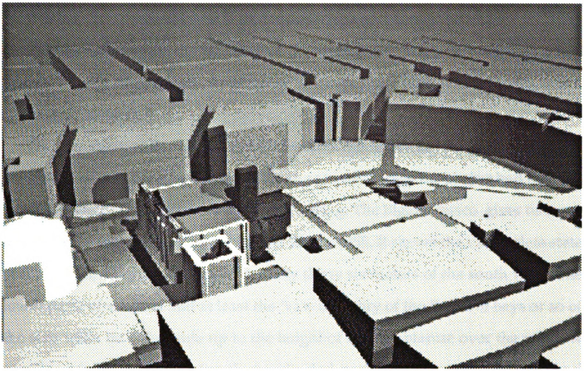


Plate 2
S. Reparata and S. Maria del Fiore. Reconstruction ca. 1340-1345

Campanile (1334-87), which stands on the site of an earlier tower.

The Campanile's second and third stories are begun by Andrea Pisano around 1342 (SMF 57; Metz, 1938, p.123), which is the probable date for a fresco in the Oratory of the Bigallo in Florence.

In 1352 a new master, Francesco Talenti, is overseeing construction. As of November, 1353, however, no thought of returning to the building of the church itself seems to have come up as yet.

<u>1355: Return to Work</u>

In 1355 the problem of how to continue the church finally returns to the fore with a May 29 authorization for Talenti to make a wooden model of the cathedral (SMF p.77). What the Operai wanted to see in Talenti's 1355 model were his ideas for resolving two problems:

i) What the (presumably still undefined) choir end should be like

ii) How to integrate the masonry of the already existing side walls into a bay system of new dimensions. Apparently what was involved was a formal, not a structural, problem.[38]

The document authorizing Talenti's wooden model is a key one in the history of the cathedral because it invites speculation as to what stage the project had reached in 1355 as well as what issues were then pressing. The Bigallo fresco gives us some indication of what the Cathedral looked like in 1355. It shows the incomplete state of the works, a façade and approximately thirty six meters of the south wall. The lower parts of a façade and at least the "raw masonry of the first five bays or so of the side walls on either side up to the height of the entablature over the window zone" are visible.[39] The bays (partly marble-clad, partly in raw masonry) correspond to a nave identical in overall width with the present one. It seems the width of the façade had been established by this time and the plan dimensions of the first bay had been fixed and decorated with rectangular panels of encrustation visible in the lower zones.

A much later drawing, of 1587, is attributed to Poccetti *(Figure 5)* and shows the Cathedral's façade to be still unfinished. The consensus opinion regards this drawing as an update of the Bigallo fresco although in the drawing the façade's carved, niched, and perforated appearance no longer resembles the smooth, geometrically defined surfaces of the Baptistry, as it appears to in the fresco.

On June 8, ten days after the first mention of the model, Talenti is told to keep working on it (p.81). On June 26 the operai decide the cost of the model is too high (p.82) and he is instructed to continue on only "fino poste le due colonne et volti gli archi." That is, "to the place of the two columns and the arch vaults."

No immediate action on the cathedral is undertaken. The focus of work remains the campanile, finished in 1357. As the campanile nears completion, however, attention returns to building of the cathedral proper where Talenti's main task is to coordinate the meeting of constructions at the east and west ends.

1357 - 1366: Decisions on Vaults and Bays

On June 19, 1357 the Opera del Duomo approves a new plan to erect three huge stone vaults over the new nave. The decision for a nave of three bays may simply be a corroboration of Talenti's model of 1355. It is quite possible that the original 'Arnolfian scheme' had called for timber roofing, as in Santa Croce. An aspect of the June plan that seems original is the determination of the octagon's size beneath the cupola, which was established at 62 braccia from side to side (not from corner to corner).[40] One braccia is equal to approximately twenty inches.

The new bay system agreed upon presents a design problem; it doesn't match the walls already built. It is based on a wider and higher system that makes the question of what to do with the existing walls pressing. A meeting is held 13 November, 1358 in which various proposals are offered ranging from demolishing the old walls (deemed unacceptable) to that of Talenti, who proposes to absorb the old parts into the new. This compromise represents the plan followed and what one sees today on the mismatched exterior of the cathedral which changes from narrower to wider bays *(Figure 22)*.

Talenti begins by erecting pilasters to support the now approved rib vaults over the side aisles, sinking rubble masonry into pits hollowed out next to Arnolfo's foundations. The decision on which side of the nave to begin work is made January 1359 and the determination to go ahead with the vaulting of the first bay is considered "una grande chonsolozione a tutti i cittadini." (SMF, p.123) In the meantime, parts of Santa Reparata and the adjacent cloister are progressively demolished to make room for new construction (SMF, pp102f., 122) and the problem of relocating San Michele Visdomini becomes urgent (SMF, pp. 123-124).

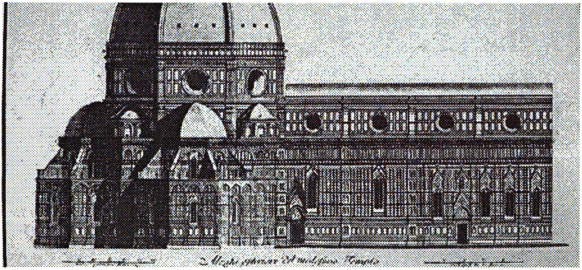


Figure 23
Florence, Santa Maria del Fiore, elevation (Nelli)

October 1362: the arches supporting the vaults of the first two side-aisle bays are under construction (SMF 93, 94).

With the side aisles vaulted by late in 1364, it is time to begin the first nave vault which leads to further consultations and questions about the shape of the new clerestory windows (round or pointed) (SMF 119, 120, 126, 128, 131, 141, 188). The windows are discussed in sessions between 1364 and 1367 with the ultimate decision to have round 'occhi.'

Vaulting specialist Ghini and his team now move into the foreground. A council of religious and secular advisors is assembled to oversee and review his work (SMF 121). Early in 1365, after ten years of debates, Ghini prepares to construct the first of two vaults over the new central nave of the Cathedral. The new, larger, basilica straddles the older, narrower, and shorter church that had been standing there and still serves as the principal church and parliamentary assembly hall of the Republic *(Plate 3))*.

<u>1366: The Fourth Bay</u>

By March 1366 the second bay is complete and excavations for the third set of piers

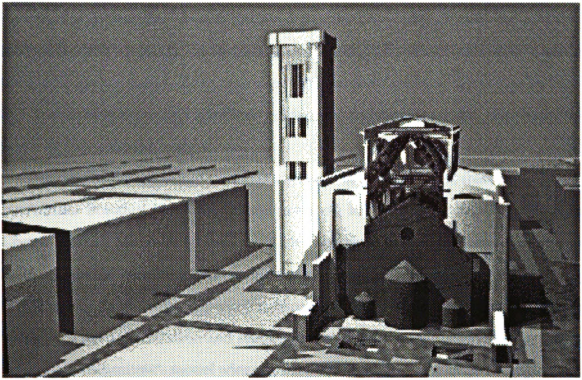


Plate 3
S. Reparata and S. Maria del Fiore. Reconstruction ca. 1366

have begun (SMF 136, 27 May 1366). Work is following a presumed model (see below) made by Giovanni di Lapo Ghini sometime before July 12.[41] Talenti is on the verge of erecting the third set of piers - which would have supported the west end of the cupola , when he is stopped, pending a decision on the third set of piers.

It seems that a debate is now heating up over the final form of the cathedral.

If the cathedral is intended to have three bays the design of the unbuilt piers must take into account the shape and dimensions of the crossing and octagon beyond them. No final design for the piers can be approved if the octagon and crossing are still being debated over. But if a fourth bay is added - a proposal under consideration at the time - then they might be built identical to the other two sets and work may continue. One may suppose that this unrecorded debate culminates in July when the Arte della Seta (goldsmiths) and the Arte degli Speziali (painters), are invited (summoned?) to meet with the Opera and submit ideas regarding the project.

Among the goldsmiths' ideas is the recommendation to add a fourth bay and this recommendation is seconded by the painters. The painters ask for, and receive, more time to prepare a design. Soon afterwards the painters' subcommittee (led by Neri di Fioravante) is expanded to include goldsmiths and master masons who together begin working on the design.

The contemporary visual record of these developments is the fresco of ca. 1365 by Andrea Bonaiuti (a subcommittee member) in the chapter house or Spanish Chapel of Santa Maria Novella *(Figure 3)*. It features a dome with exterior buttresses at its corners and may represent an ideal project for the church as he saw it in 1366-67. This essentially Gothic approach is also favored by Ghini, who submits a model of his own for consideration and remains skeptical of the subcommittee's project.

The subcommittee's model wins support as the alternative models are evaluated and discussed. Ghini's comments about the competing designs become a matter of record as the models are reviewed, and indicate that the dome and provisions for supporting it are matters of concern. The subcommittee design may be the first in the Cathedral's history to introduce the innovation of a drum supported on piers and crowned by an octagonal groin vault, also referred to as a cloister vault. Such a drum introduces substantial new weight upon the piers and may be the object of Ghini's concern and recorded comments.

The committee project for 'the Tribune' is completed in August and advances against opposition by Ghini.

Note: 'Tribune' appears in the documents as a term that at times refers to one or the other of two different parts of the cathedral. As used here, 'Tribune' with a capital 'T' refers to the octagon, drum, cupola, and radiating arms. The same word, 'tribune' with a lower-case 't' refers to one of the three side arm structures that surround the octagonal crossing and are each topped with their own five-part vaulted dome.

The subcommittee project is eventually adopted, with some modifications, as the definitive plan for the cathedral project and is faithfully followed until well after 1420 when Brunelleschi's large brick model detailing the construction of the cupola supersedes it.

The form of the fourth set of piers remains undetermined until August 1367 when final decisions regarding the octagon are settled. On August 9, 1367 the width of the intended cupola is magnified from a presumed diameter of 62 to a new diameter of 72 braccia. A year passes during which time the church of San Michele Visdomini is demolished to make way for the now approved Tribune.

These decisions effectively lock in the overall conception of the Duomo for the rest of the century and until 1420.

Late Fourteenth Century chronology:

1377-1384: Giovanni Fetti is chief during this critical period *(Plate 4)* when the fourth bay vault is completed and great pier foundations begun (SMF 279f, 293-294, 302, 309, 315)

1378: Completion of the fourth bay and erection of a temporary wall between the fourth bay and octagon. A temporary main altar and choir are set up in the fourth bay in 1380-81.

1375-1380: The old church is operational until about 1375. Five apses and chancel walls survive until ca. 1380 when the remnant is cut down and paved over with a new brick floor.[42]

1384: A minor crisis occurs over questions raised concerning the spiral stairs and sacristies in the main piers. They are thought to be weakening the octagon by a minority of advising masters who voted to brick everything up. This proposal was outvoted by the majority of masters. A second crisis develops when the ground under the projected southern arm is feared unsuitable for foundations because of ground water. Drainage and solid ashlar foundations without piles are adopted and

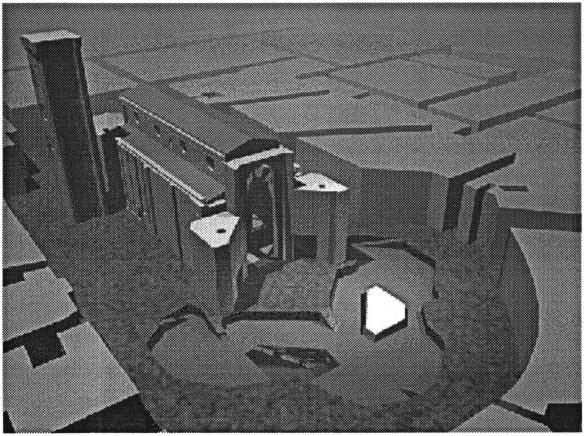


Plate 4
S. Maria del Fiore. Reconstruction ca. 1390

building continues without difficulties (SMF 170, and 352-356).

1384-1401: Lorenzo di Filippo assumes chief command over masters and during his tenure the piers of the octagon are built up and the great arches vaulted (SMF 419).

CHAPTER TWO

QUATTROCENTO BEGINNINGS: Plates 5 - 9

Work on the Cathedral ca. 1400 is focused at the east end where vaulting of the octagon's arm vaults will take up nearly the entire first two decades of the new century *(Plate 5)* . The fifteen chapels that radiate from the octagon's arms are gradually vaulted beginning sometime during the 1390's (SMF 401, 403, 406, 410), and are eventually completed by 1400-03 (SMF 423). The main piers to support the Dome are raised and great arches vaulted between them during the tenure (1384-1401) of Lorenzo di Filippo.[43] The great arches' construction begins in 1397 (SMF 404) over trussed centering (S, 5). Iron tie rods are ordered in 1400 (SMF 418), two for each of the these arches.

Giovanni d'Ambrogio assumes control after 1401 as the chief master following the death of Lorenzo di Filippo (SMF 419-420). He must develop a definitive design for the large and small cupolas covering the areas of 'the Tribune'. Buttresses are not to be allowed.[44]

1403 Giovanni d'Ambrogio (a new architect) comes into office ca. 1400, favoring Gothic forms. He completes the essential structures (foundations, walls, chapel vaults) belonging to the first or eastern tribune, located opposite the nave. In 1403, he receives timber to construct flat roofs above the recently finished chapel vaults.[45]

1404 – The Committee of 1404

Filippo Brunelleschi sits on an advisory committee of the Opera in 1404 (SMF 425). He has not been mentioned in any earlier document related to the cathedral.

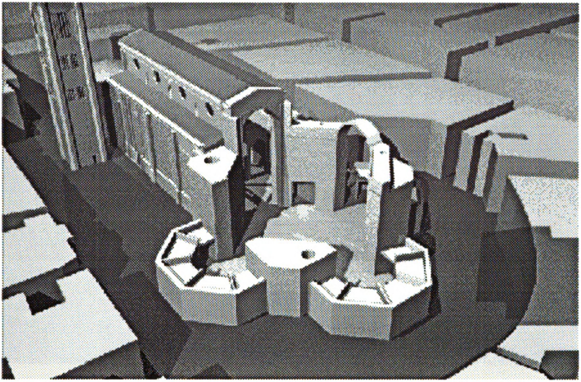


Plate 5
S. Maria del Fiore. Reconstruction ca. 1395-1400

The advisory committee, which also includes Ghiberti, finds the Gothic architect Giovanni d'Ambrogio guilty of building one of the buttresses of the tribune (perhaps the first) pitched too high. Debate centers on the form and height of the triangular buttresses between the chapels that radiate from the tribunes. It seems that Giovanni decided that the roofline, as planned, would obstruct the view of the tribune's windowed exterior from the street level. To compensate he began heightening the windows and the buttresses. This alteration would have resulted in a design that interrupted a horizontal gallery level with nave roof and pier tops. The committee obliges Giovanni to lower his projected three semi-domes to their present level *(Plate 6)*.

The shape and size of windows is also debated at this time. The entire issue may be a question resolved through the use of applied perspective, as suggested by F.

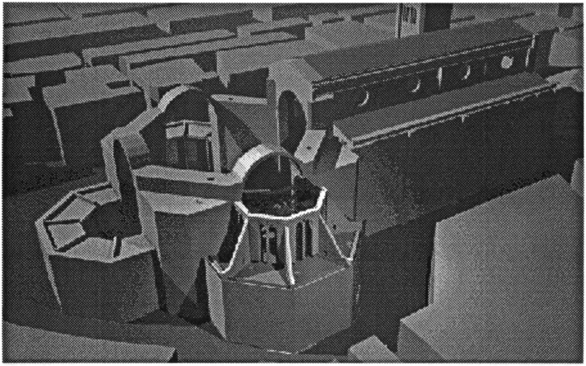


Plate 6
S. Maria del Fiore. Reconstruction ca. 1405

Prager.[46] Brunelleschi and Ghiberti continue to work on final designs for the buttresses as late as 1409 (S, 18.1).

Structural chains for the tribune vaults become an issue and are mentioned in a design-resolution for the tribunes. Saalman transcribes and relates three sets of documents overlooked by Guasti that indicate the inclusion of stone chains in the period 1400-1420 at the base of each tribune.[47] These new conclusions may be taken as support for the theory that Brunelleschi's "renewal of Roman Masonry" including his concept of stone chains forming an integral part of the masonry, was well advanced before 1410.[48]

The first tribune, Tribune I (to the north), requires nine years to build and occupies the opera from 1395 to 1406. By April of 1406 the centering is in place and by August of 1407 the vault is completed and the tie rods are inserted between the piers which tribune I abuts *(Plate 7)*.[49] The vault is decentered in 1408 (SMF 447).

Plate 7
S. Maria del Fiore. Reconstruction ca. 1407-1408

1404-1414: Antonio di Banco and son Nanni are working on the Porta della Mandorla (SMF 429).

1404-07: Brunelleschi reportedly travels to Rome with Donatello.

1407: During the period September-December a special shed is built for the storage of the centering beams used in tribune I's vault, disassembled and conserved the following Spring. By the end of the year additional sheds are being constructed for the use of marble cutters working on the clerestory of tribune II (to the east). The decision for a tambour is finalized sometime during the year, a decision usually attributed to Brunelleschi. It is unclear whether Brunelleschi should have all the credit for this decision.[50] Vasari is the first to identify Brunelleschi as the sole author of the drum and recounts an episode in which Brunelleschi advises the Opera del Duomo to 'lift the Cupola onto a Tambour.'

1409: Late in the year the Opera invites the public to give advice on work to be

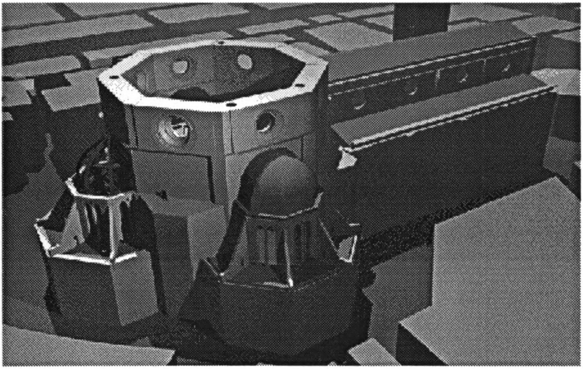


Plate 8
S. Maria del Fiore. Reconstruction ca. 1415

done or being done. Prager suggests that the Opera was seeking advice on the issue of the drum and how it might affect viewing the cupola. The question was, presumably, one of perspective. In this light, it may be seen as an opportunity for Brunelleschi to use his applied perspective to answer questions regarding the Dome's appearance. Sometime between 1410 and 1413 (SMF 457-467) the drum, or tambour, is 'put into execution'.[51] In the documents the tambour is referred to as the 'oculi tribuni maioris' (Docs. 457-467, see also Paatz III, p. 455 n.89).

1413-1414: By the end of 1413 the eastern chapels and the clerestory of tribune II (East) are complete (S, 25). Giovanni d'Ambrogio retires at the end of the year and in January, 1414 Antonio di Banco replaces him (S, 24.1).

1415-1417: Giovanni d'Ambrogio is called out of retirement (S, 31) in May 1415 when Antonio di Banco dies (S, 24.4). He serves until definite dismissal in 1418 (S, 65). The tambour *(Plate 8)* is substantially completed during this period (SMF 45).

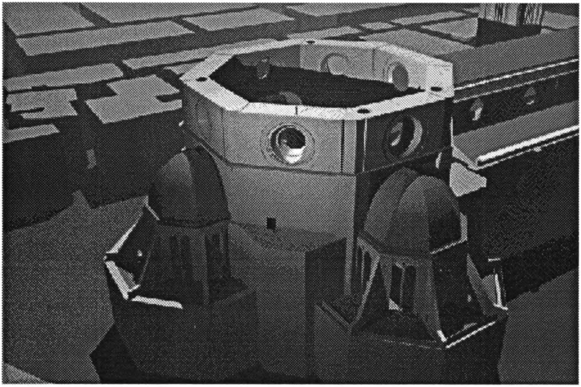


Plate 9
S. Maria del Fiore. Reconstruction ca. 1417

Tribune II is completed in 1417*(Plate 9)* and active consideration of the cupola begins the same year with payments to Brunelleschi (probably for drawings), Maestro Giovanni dell'Abbaco (possibly for mathematical calculations pertaining to the Dome's height), and the carpenter Manno di Benincasa (for a wooden model).[52]

A year passes during which the only building activity is the completion of the tribune III vault under Giovanni d'Ambrogio's supervision.

CHAPTER THREE

BUILDING THE DOME: Plates 10 - 16

1418

During the Summer of 1418 Giovanni d'Ambrogio, architect, purchases logs for the Opera, "to make scaffolds for the vaulting of the Cupola" (Prager, 1970, p.27). He needs new outer scaffolds for work on tribune III - but it is not recorded if he used the wooden logs for this purpose.

The Opera announces a major competition for further models in August of 1418 which yields 17 designs in all (Guasti, Docs. 11, 21-42; Manetti, pp.31 f.; Vasari, pp.205 f.). The announcement of a public competition suggests that the practical execution of the Dome is under discussion and that the Opera is looking for a detailed constructive programme to erect the Dome represented in the model of 1367. Their chief preoccupation is probably determining how to build an octagonal dome of unprecedented size, with or without centering, along with creating designs of any scaffolding, hoists, and other machinery needed. Two of the entries, by Brunelleschi and Ghiberti, receive special consideration from early on. For a discussion of this competition and the models submitted, see Appendix II: *The Models of 1418*.

In October (SMF, Doc. 478 f.) Giovanni d'Ambrogio is dismissed as architect and the following month (Prager, 1970, p.23) the Opera appoints Antonio di Battista as acting architect.

In December (C, docs. 15, 34) the Opera holds two meetings during which time

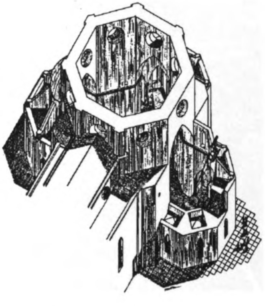


Figure 24
Cupola. Reconstruction of the Rota Magna (1398) and Stella (1413) in operation on the wall of Tribuna III (S). Reprinted from Saalman (1980), p.150

the various competitors are asked to "demonstrate and defend" their models. By the end of 1418 Saalman writes, "the southern octagon had yet to be vaulted and that work occupied the Operai during most of 1419 and 1420."[53]

1419

Wood is ordered for tribune III's working platforms in April, and more wood is ordered in July when the stone chain for tribune III is begun. Iron is ordered in August for use as tie rods to secure the vault *(Figure 24).*

1420

A series of projects are undertaken this year.

A. Completion of tribune III: The first half of the year is spent finishing this last tribune (to the south). Beginning in January the third chain is constructed (begun in July 1419) for tribune III and is in place before or during April. Throughout April and May centering for the third tribune is erected *(Plate 10)* and the vault completed in record time on June 21, 1420 *(Plate 11).*

In February (S-92) the Opera meets to discuss outstanding problems concerning the project. It is possible that the subject of lighting the interior of the octagon was under review and that as a result, a new model, "'novo et ultimo", was constructed to resolve contention over the window sizes of the eight "occhi" of the tambour. These windows are probably constructed by this time. The debate may be centered

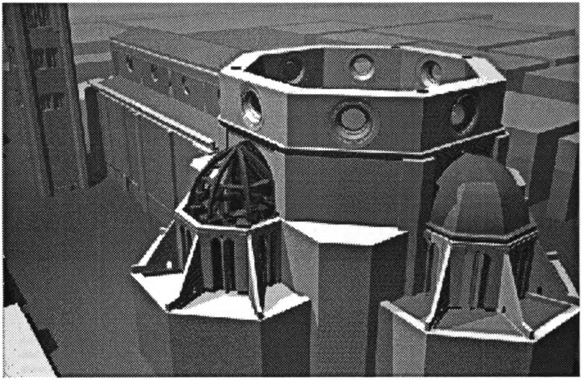


Plate 10
S. Maria del Fiore. Reconstruction ca. 1418

on the desire for additional lighting and the advisablity of adding windows to the cupola's design above.

B. The 1420 Specification: On July 30 a long specification of what is to be built is appended to a resolution (the so-called 1420 Specification) that authorizes the construction of the dome (later modified in 1422, 1426 amendments). This document clearly and concisely outlines the building project in twelve points and is the most important surviving written evidence we have concerning the cupola's construction. It describes a double-shelled structure of a certain shape reinforced by a system of ribs and chains. All materials to be used are noted as well as their intended positions and locations in the overall structure. The point is made that the cupola will be built without centering but the means to do it are not spelled out. In closing,

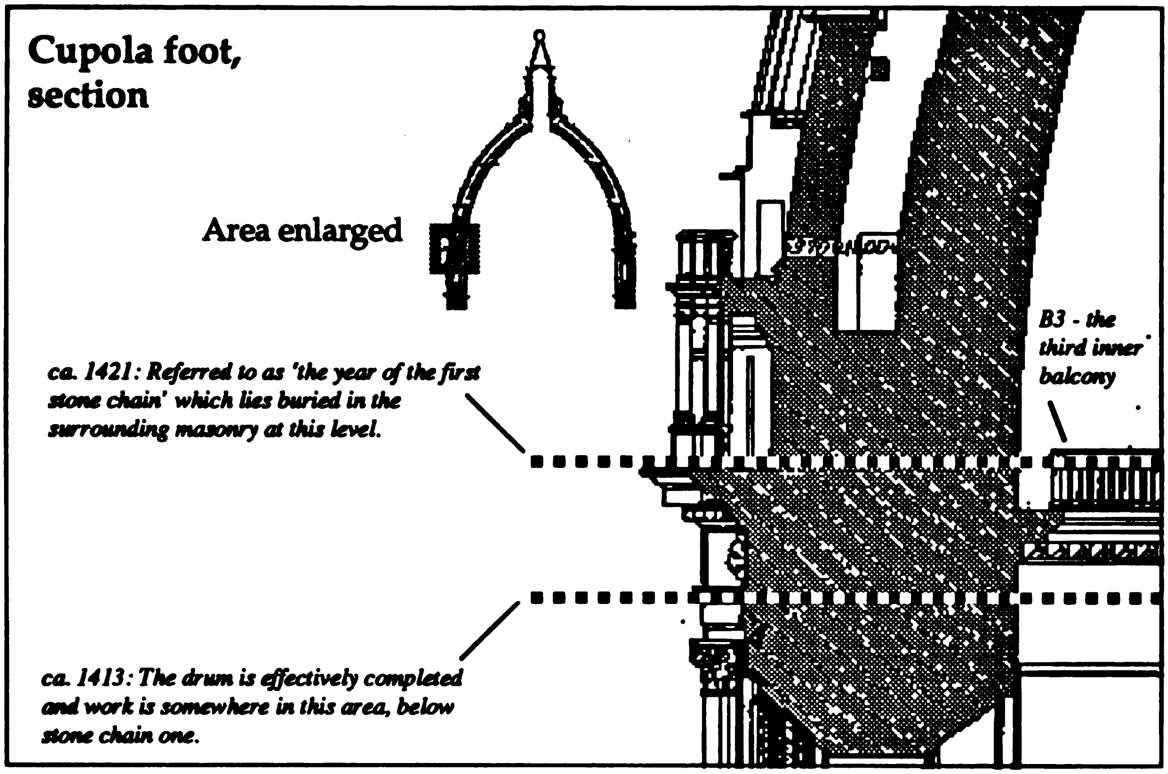


Figure 25
Cupola foot. Work ca. 1413-1420

the cupola's difficult upper levels are foreseen as problems for which no specific solution has as yet been found. When the time comes, the document advises, they are to be built "according to what shall then be deemed advisable, because in building only practical experience will teach that which is to be followed."

The entire document is probably written with reference to Brunelleschi's masonry model of 1418. Two versions of the Programme survive, a shorter (and probably earlier) one in the archives of the Wool Guild and a long draft in the books of the Opera. They differ slightly in their naming of who were to act as masters and capomaestri but agree on the pay of three florins each per month for Brunelleschi, Ghiberti, and Battista d'Antonio. A "novo et ultimo modello" is mentioned in the document, which is presumably a joint effort of Brunelleschi and Ghiberti (S-doc. 95). For a discussion of the 'novo et ultimo modello' please see Appendix II.

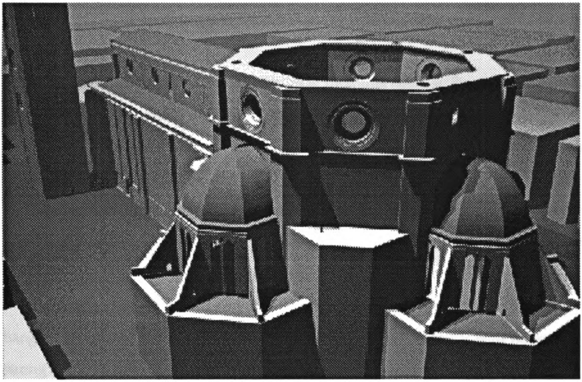


Plate 11
S. Maria del Fiore. Reconstruction ca. June, 1420

Following the Programme of 1420 Brunelleschi and Ghiberti are appointed as supervisors together with a mason, Battista d'Antonio, to build the dome. The role of Battista d'Antonio is a focus of ongoing research. Mainstone suggests that "Battista contributed practical experience rather than ideas and that he was, in effect, the clerk of works responsible for the day-to-day running of the job." Scaglia describes Battista merely as "another sculptor and goldsmith, . . . jointly appointed" with Brunelleschi and Ghiberti.

On August 7 construction is inaugurated with a breakfast of wine, bread, and melons. The first of "short" *macigno* beams for Stone Chain I (mentioned in Point 6 of the Programme) are already on the building site. Wood has been ordered and eight templates (centine) for the corners are ready to be put into place. The vault of the third tribune is complete but with its centering still in place. The old hoist of 1398 (rota magna) is still working and the old crane of 1413 (stella) is in operation on the wall *(Figure 14)*.

In October Brunelleschi and Ghiberti draw their first salaries. Brunelleschi begins construction of a new hoist that will be completed in March 1421.

During the winter of 1420 short beams intended for Stone Chain I are arriving at the Opera and are being put in place.

The first contract for marble for the cornice with rain gutter, to go at the foot of the outer shell is approved in November*(Figure 25)*. Hundreds of wagonloads of building stone for the massive foot of the cupola begin to arrive.

C. Centine : Templates, referred to as 'Centine' were likely employed as temporary hanging centerings which were attached to the completed masonry with hooks and strong cord. Used in the corners, these wooden templates are first mentioned in 1418. They are constructed in June 1420 of pine boards probably measuring 1 br. in width and 4.5 br. (2.63 m.) in length. The substantial width of the boards used suggests that they were wedge-shaped (each side one-half br. wide) and fitted into the corners though their appearance remains a matter of speculation. *(Plate 14)*

They were lined with sheets of iron. They were relatively inexpensive (11 soldi apiece) and probably flimsy. They required frequent replacement, a new set is known to have been ordered in June 1424. They apparently continued in use until the vault was completed though their last mention in the documents is September 1427.

They must have been moved upwards progressively and held firmly in place with wires or ropes attached to rings (or even nails) on intrados of the inner shell. The major problem in their design would have been in the determination of their curvature which would have required a drawing to full scale of the profile of the cupola. A sixteenth-century source (Gelli), describes how Brunelleschi levelled off one of the banks of the Arno for this purpose.

<u>1421</u>

A series of projects are undertaken this year which are discussed separatly.

<u>A. The first stone chain</u> *(Elements of the first stone chain are shown being assembled in Plate 12)* : Stone beams for the first stone chain are arriving and being placed as early as January. Documents referring to the chain (104, 109, 124) make clear that it was the very first thing built (April 1420 - June 1421) once the cupola construction was renewed. (S, p.12, 22, 25, also Prager, p. 57) The raising of the level of the drum with the construction of the first stone chain begins in earnest during the autumn.

The chain is essentially two octagonal concentric rings composed of stone beams measuring 4 br. (2.6 m) long and .44 meters square in section. The beams are large sandstone blocks interconnected by metal clamps, and were intended to tie the walls and ribs together to prevent outward spreading. The rings rest on shorter, transverse, beams similar to the arrangement of a railroad track. The whole assembly serves as an inner tie meant to constrain the Dome's crown thrusts as opposed to the exterior buttressing used in Gothic architecture. The Opera had a long-held preference for building with such 'hidden ties' which would not obstruct the vault or cross it.

Short beams to be used a ties to support the first stone chain *(Plate 12)*are arriving and being placed as early as January 1421. These 'short' beams measure 3/4 braccia (0.44m) square in section and protrude 0.50 m. from the rising masonry over the drum. They are located 13 - 15 cm above the B3 (Balcony 3) level. The long beams measuring 4.5 br. (2.63 m.) long and 3/4 br. (0.44) square in section were, in turn, lain across the short beams. The long beams form two concentric octagonal rings but are nowhere directly visible, being entirely embedded in the masonry of the Cupola foot. Their presence is inferred from stone beams that span the holes in the intrados at B3 (S, p.99). The fact that the long beams are nowhere visible may be explained by the possibility that where the chain is interuppted by passageways (at level B3 for

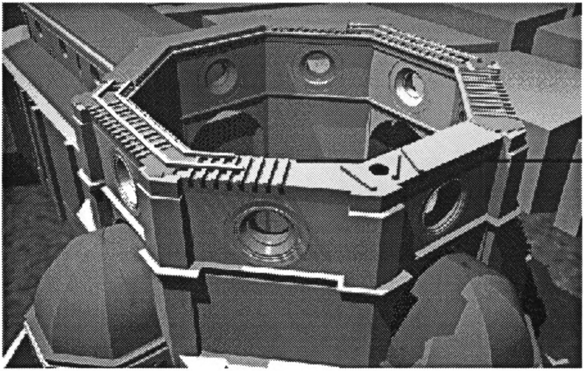


Plate 12
Cupola. First stone chain. Reconstruction ca. 1421

example) the chain was interrupted as well. (For diagram, see S, p.99)

While the long beams of the chain are now nowhere visible, the transverse beam ends do appear on the exterior. There are twelve to a side and they are aligned on either side of 1 braccia-square openings in the intrados of the Dome at B3. The openings were used to support work platform beams. The transverse beam ends protrude from the exterior of the cupola masonry .5 m. and may have been intended as a support for the planned external balcony. (Plate 13)

Unfortunately the arrangement of these chains or rings isn't well known though its been studied in this century by Nervi (1934). It may be possible to locate these blocks and their metal connectors within the solid masonry of the foot of the cupola but so far this has not been done.

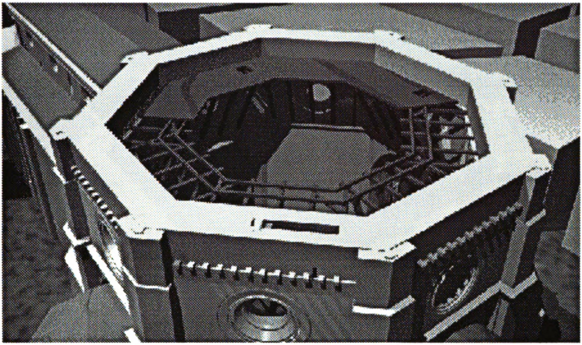


Plate 13
Cupola. Loading platform. Reconstruction ca. early 1422

The reintroduction of metal-connected tie rings (which hold the long beams together) in a cellular vault fabric by Brunelleschi at the end of the Gothic age appears to Prager and Scaglia as a major aspect of his "renewal of Roman masonry" (Prager, pg. 59).

B. Loading Platform *(Plate 13)*: In July 1421 the vault of tribune III is decentered and wood becomes available for a loading platform referred to as a 'ponte' or 'bridge' (S, 109, 151). Wooden decks are constructed at the base of the cupola, supported on beams inserted into large put-holes at the B3 level. The holes are easily observed to this day.

Shortly after the First Stone Chain was in place work probably began on the Loading Platform. Beams were suspended from large holes (1 braccia square in size, six to a side) located on the inner faces of the balcony and used to support a work/ loading platform. These beams could not actually be inserted until Chain 1 was in

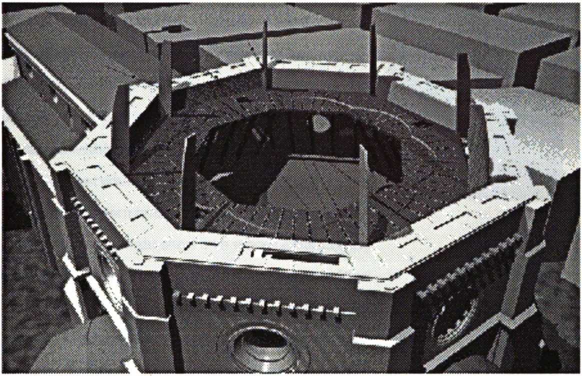
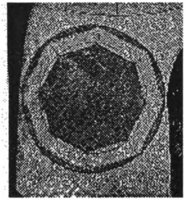


Plate 14
Cupola. Centine, and string control device. Reconstruction ca. 1422

place (Summer 1421) and it is probable that they were cantilevered out into the interior as much as five meters. The platform built on these beams was made ready just in time to aid in the hoisting of materials for the 5 1/2 braccia high solid cupola base. This platform probably remained in place until 1442-43.

C. String Control Devices: Some kind of system, most likely using wire or string, working with the centine, was devised as a means of determining the placement of the individual parts, large and small, of the structure *(Plate 14)*.Saalman refers to the system as an 'inclination and radial control mechanism' (1980, p.114). A string back-up device for the corner templates seems to have been in use by Autumn of 1421 (S, p.114). One such possible string system is discussed by Mainstone, 1977 (see Appendix III for related geometric proof).

In reviewing the documents, scholars have found clues to the possible string control mechanism used. Massimo Ricci closely examined the parchment drawing by Giovanni di Gherardo da Prato which contains three drawings, one of which is a plan of the octagonal work area inscribed within two circles (Figs. 4, 26, and 27). Ricci observed that while the outer circle drawn in the plan was indeed drawn with a compass, the inner circle is in fact a series of eight short arcs whose ends slightly overlap. By redrawing the plan with these arcs, Ricci constructed a diagram whose central feature resembles a flower not a circle. Each of the eight segments of the flower, according to Ricci, served as a guide for strings attached to it. The free ends of the strings were then carried across the octagon to align with corresponding points on the opposite side. All the strings converged at the center of the octagon where they crossed each other.



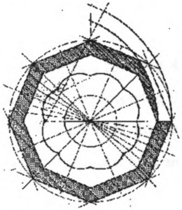


Figure 26 (top)
Giovanni di Gherardo da Prato, project drawing for cupola of S. Maria del Fiore, Florence, Archivio di Stato (late 1425), detail of plan of octagonal drum

Figure 27
Plan of octagonal drum with geometric locations for cupola centers of curvature. Reprinted from Ricci (1983), p. 21

Briefly stated, the strings (or wire cords) may be pivoted in two directions: back and forth or up and down. Moving a cord horizontally (that is, back and forth along a flower) the string controls the radial disposition of building elements. All elements aligned in this manner converge towards a common center. The strings may also be pivoted vertically (as long as they intersect the center of the octagon) which allows measuring for the vault's curvature in the corners. Using such a string control system Ricci is demonstrating that a cupola similar to the dome of S. M. del Fiore can be built self-supporting without benefit of advanced technologies.

In September: reinforced cord and ten skeins (tregieruole) of "building string" (corda da murare) are paid for shortly after the work platform is installed. The masonry base up to the first ambulatory over the frst stone chain is begun.

D. Requisition of Lumber: Preparations for the first Wooden Chain are begun with a search for suitable wood, oak beams had been prescribed in the 1420 programme. Eventually chestnut was used perhaps because it was more readily available. Orders are placed for twenty-four chestnut beams required by the first wooden chain.

1422

A March amendment was added to the written specification of 1420 reducing the width of the intermediate piers (from four to three braccia thick) and lowering the starting point for brickwork (from 24 braccia to just over the doors at the first ambulatory level (U1). The amendments are intended to reduce the total load and weight of the shells.

A new method of distributing the building materials takes effect above U1 as the shells divide. Unlike the First Stone Chain's members - which are aligned perpendicular to the sides - building materials are now radially disposed around the center of the octagon. Saalman writes that "this system was essential for unbroken continuity of the brick masonry around the octagon corners" (S-p.114).

The working level rises along inner curves and masonry becomes inclined *(Figure 28)*. Some form of control is needed to maintain the prescribed curvature in the corners, as well as the geometrical disposition of the radially aligned elements. The 'quinto acuto' could be checked with centine in the corners, doublechecked by a string device.

Two skeins of 'building string' acquired in August and another reinforced cord three weeks later (S, 177). This was probably a system utilizing cords of metal or rope stretched across the octagon.

Construction with bricks begins in October. Downspouts of the rain gutter and

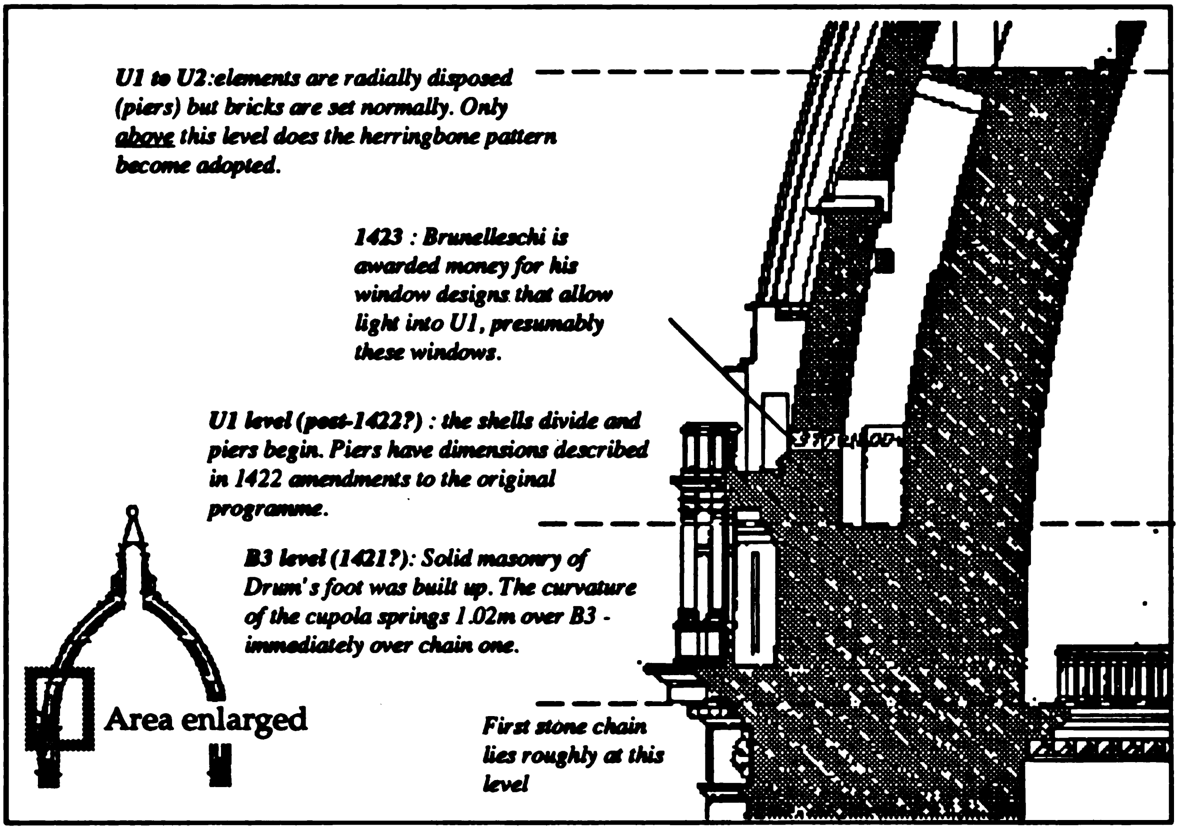


Figure 28
Cupola foot. Work ca. 1421-23

a door from the first ambulatory to the projected upper level of the outer walk are under construction in December (S, 165.1-4, and 184).

1423

As of January work is stopped for the winter and boards are used to cover the rising walls because of snow (S, 185). With work at a standstill Brunelleschi concentrates on the design of a new crane (Castello II) constructed the following Spring and in probable use by July (S, 186.9).

A series of summer meetings clarify several points in the 1420 Programme concerning how the wooden chain is to be fastened together.

Brunelleschi and Giovanni da Prato work during July designing joining mechanisms for the wooden beams (S, 189.1).

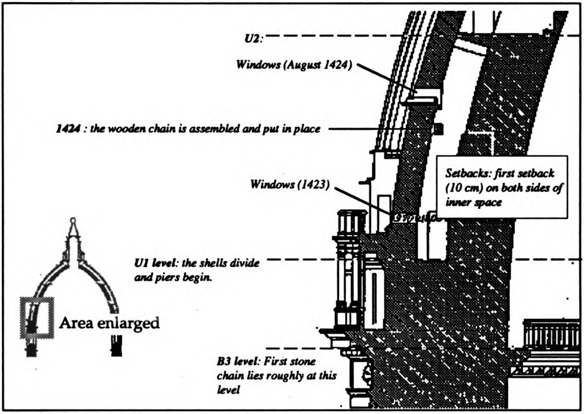


Figure 29
Cupola foot. Work ca. 1423-24

27 August: Four of the eight masters working on the eight sides of the cupola meet with other invited experts and decide on monetary awards to Brunelleschi for the following: his "new model" of the wooden chain, his design for the windows to allow light between the shells, his method for constructing the second stone chain, and, lastly, his detail design of the exterior marble ribs for the cupola's eight corners (S, 190). The decision is then made to construct Stone Chain II without radial barrel vaults beneath it, as the 1420 Programme prescribed, because they are now deemed redundant (S, p.116).

April 1422-April 1424: A large number of "macigni grandi" were delivered to be used partly for door fames of the first ambulatory and also for the stone beam footing to go under the marble cornice at the top of the outer cover of the solid stone base at U1(S, 165.2, 195.1-3). At the same time "hundreds of bushel baskets of additional

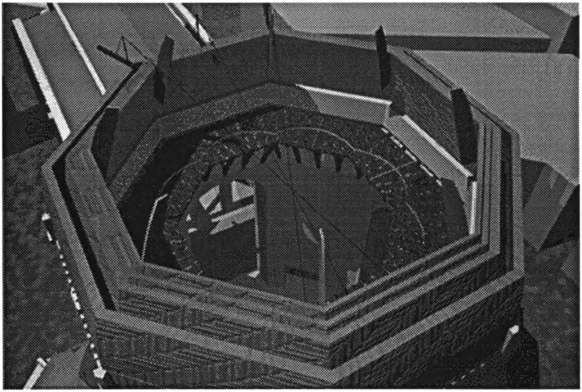


Plate 15
Cupola. Rising masonry walls. Reconstruction ca. 1425-1427

building stone" begin arriving and continue to arrive until February 1425 for "sealing over the (outer) cover of the cupola" (S, 188.1-8).

<u>1424-1426</u>

Construction of the vertical facing of the foot of the exterior shell is begun early in 1424 and the outer openings of braccia-square penetrations are closed. Assembly of wooden chain and oak 'angoli' designed by Brunelleschi continues until September. An iron plate is is acquired to serve as a template for the marble ribs.

1424 is the year that the wooden chain of the Cupola is put into place. The only other work at this time is copncentrated at the foot of the outer shell (S, p.118).

August 1424: The first tier of stone windows are "put into work" with delivery expected in December (S, p.118) Worn-out corner templates (centine) are replaced

(S, 126.7)

September 1424: Ordering of new long beams for the second stone chain begins; they begin arriving March 1425.

1425 is the year the second stone chain is begun. By March, preparations for the building of the second stone chain are well advanced. Brunelleschi constructs a model of the second chain. Work is inaugurated 6 June.

9 March 1425: Wooden parapets are required to be built so as to project from the intrados of the inner shell due to the increasing lean of the vault. It is also decided to substitute horizontal arches for the originally projected barrel vaults between the shells.

November 1425: New brick forms are ordered. They are required for the corners where the heringbone system is soon to be implemented pending completion of stone chain II.

Giovanni di Gherardo da Prato submits his protests and accusations against Brunelleschi *(Figure 4)*.

24 January - 4 February 1426: The requirement to build additional wooden chains is reviewed and reconsidered in light of their expense and difficulty of constuction. The decision is made by an appointee along with Brunelleschi, Ghiberti, and Battista d'Anonio to not build any more wooden chains. Decoration of the intrados is mentioned for the first time in the 1426 amendments. A reasoned response to Giovanni's accusation is included in the report presented at a session of the Wool consuls and all opera officials.

As inward lean of cupola increased, Brunelleschi and assistants design a system of herringbone masonry. The herringbone pattern is laid beginning over U2. The exact forms of the bricks are determined as is the spacing (averaging two braccia in execution) of the herringbone.

The idea of armature-supported formwork is raised again. The Cupola is

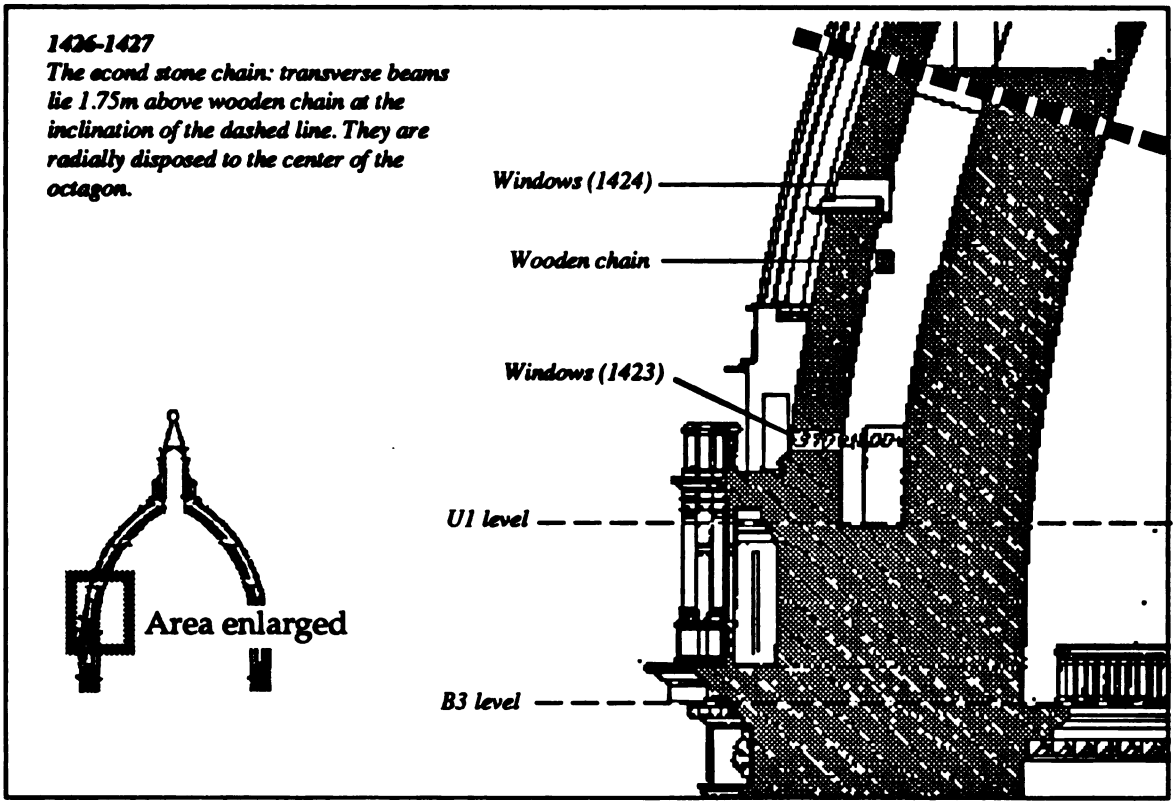


Figure 30
Cupola foot. Work ca. 1426-27

believed to have been one-third executed as of this time and the possibility of working with a fixed centering seems to have remained an open question until nearly the project's completion.

11- 21 March: Opera authorizes one-half braccio of construction following the new system.

April: 25 masters deemed least necesssary are laid off (S, 222)

August 1426 - April 1427: The great crane, on the wall at U2, is moving around the perimeter of the octagon laying beams of stone chain II (S, 226.1-4). As they are placed in an inclined position the level pavement of U2 is placed over them.

19 August, 1426: Lead pipes inserted in outer shell at U2 level to carry off water. A general slowdown in operations is in effect. Bricklaying is at a standstill and a number of masters become redundant.

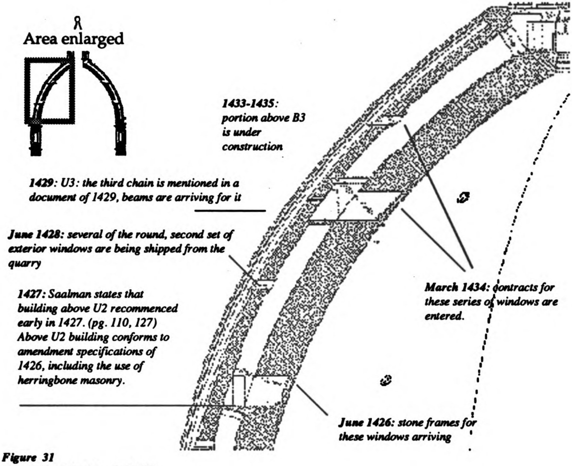


Figure 31
Cupola foot. Work ca. 1427-35

<u>1427-1429</u>

April 1427: Stone steps, perhaps for the continuation of the stairs above U2, began arriving at the opera (S, 233)

August, 1427: work resumes above U2 after a year-and-a-half long pause during which stone chain 2 wa sbeing completed.

18 August 1427: Battista recommences construction (S, 235) involving building of masonry shells and piers over U2.

September: Centine require minor repairs indicating that work on the shells is continuing.

9 December 1427: Old 'Rota Magna' (of 1398) is sold.

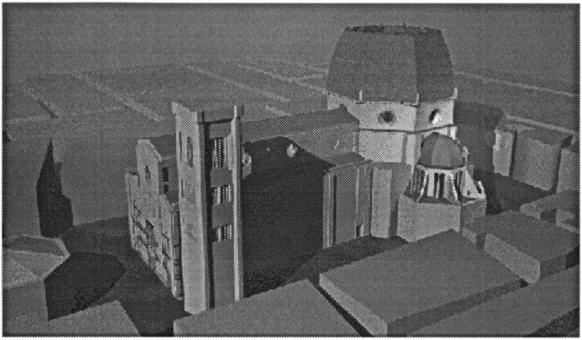


Plate 16
S. Maria del Fiore. Reconstruction ca. 1429

March 1428: Masters sent to quarry to begin carving stone for third stone chain

May 1428: Brunelleschi and Ghiberti reconfirmed in their positions

June 1428: Several of second set of exterior windows are being shipped from quarry

During 1429 *(Plate 16)* there is an increase in outlay for ironware, perhaps preparation for iron bar ties to go over stone chain. In the period February-May, stones for the third chain are arriving. They continue to arrive throughout 1429-30. In the Spring Florence wars with Lucca; work at Cathedral comes to near halt and salaries are reduced. In September Brunelleschi and Ghiberti are ordered to make a new model of the church. Cracks were appearing in the nave vaults and they suggested that the cupola was exerting force. Projected additions (never realized) include chapels flanking the side aisles of the nave.

<u>1430-1436</u>

Lead pipes for the drains of the outer shell at third ambulatory are paid for. Work is in suspension and it is referred to as "a time for planning" (S, p.132).

Work continues into May 1430 on cathedral model until the idea for exterior chapels is given up.

1431: Tie rods for the nave vaults are opted for in a resolution of 26 January 1431. The first tie rods are not forged until 1433. In 1434 Brunelleschi is ordered to design the turnbuckle for the first set of the new tie rods. Work continues on the reinforcement of the nave vaults over several years with Battista ordered to complete the second set of tie rods in March 1437.

The great model of the church near the campanile is destroyed.

June 1432: A wooden model of the octagonal closing stone ring (seraglio) is made and tested in place.

November 1432: Stone door beams for passages of third ambulatory ordered. Opera are optimisticaly projecting that services may be held in the octagon within a year.

March 1433: Interior encrustation of projected oculus is begun.

April 1433: Restraining wall between octagon and nave is ordered to be demolished.

July 1433: Third stone chain is completed.

Remainder of 1433 - 1435: Cupola above third ambulatory is under construction. Work at the closing ring is continued until 1435

September-November 1435: Paving of the octagon floor is underway.

November 1435: A temporary altar is erected in the octagon.

26 March 1436: Consecration is performed by Pope Eugene IV on Annunciation day.

20 June 1436: Announcement is made that work will be finished in a month. Roof tiling of cupola and arm vaults continues until 1438.

24 July 1436: All streets around the Duomo are walled off so that "no one could pass through" (289.1).

30 August 1436: The Bishop of Fiesole ceremonially places the last stone and consecrates the cupola.

CONCLUSION

The 16 illustrations created for this thesis are intended as a supplement to earlier illustrations concerning the construction of Florence cathedral. Unlike these earlier efforts, these new illustrations intend to elucidate not only the structure itself but also stages of its construction.

In my attempt to provide a written narrative to accompany the illustrations, I discovered several unresolved issues relating to the construction of the Cathedral and Cupola.

Plates 1 - 4

In general, these plates are a reworking of the findings of Toker and avoid much of the debate surrounding the original, Arnolfian, cathedral façade design. In the course of researching this period, however, questions arose that still lack answers.

What did the church of Santa Reparata really look like prior to its demolition? My own images are heavily based upon the work of Toker who has gone the furthest in reconstructing the church in several illustrations accompanying his articles. Can the church be plausibly reconstructed? We have archeological evidence to suggest the plan, phases of construction at the church, and the interior layout. I would like to know more about the precinct itself and those buildings (canonry properties, San Michele Visdomini, etc.) mentioned in the documents and adjacent to the area. My lack of definitive information in this area led me to leave the exterior surroundings cleared of structures and plain, suggestive of the demolition work to occur in the coming century.

Construction at the cathedral ca. 1325 has left us visual records in the form of the

Bigallo fresco and Poccetti drawing. Numerous interpretations of the Bigallo fresco were of particular help in deciding what to include, i.e. the shed roof between S. Reparata and the new south wall. In my illustration I have suggested that excavations were ongoing near the site of S. Michele Visdomini, near the present-day crossing, which is supported by Toker's excavations. The inclusion of the Campanile's lower stories is supported by the documents as well as the Bigallo fresco.

What an amazing sight the cathedral project ca. 1366 must have been – with the stone vaults of the new cathedral rising on supports that pierced the ceiling of the old church of S. Reparata! I show the Campanile completed and centerings in place for the second of the large nave vaults. We know that the older church was still in use at this time but what might it have it looked like inside? I also question how much land had been opened up along the sides of and east of the work site but imagine the areas around the nave pier excavations to be well cleared.

Plate 4 is indebted to Prager's similar view *(Figure 9)* which shows much of the same information. I decided to show foundations begun for one of the two eastern piers to suggest the stages involved in their raising. It seems unlikely to me that they would have all been built up evenly together. By experiments with one in advance, shortcuts or practical experiences could be employed for the following project. By this date I imagine the majority of the structures lining the Piazza del Duomo to have been cleared back.

<u>Plates 5 - 9</u>

This sequence of illustrations is heavily indebted to Saalman's building chronology at the cathedral and his work transcribing the original documents. They are, perhaps, the least contentious of the plates included in the thesis as they make little attempt to visualize anything radically new or much debated. Plates 6 - 9 enjoy greater continuity than most of the others by sharing a consistent viewpoint. During other periods this was not possible due to the constant movement of work around the site. Aside from the nagging question of why Prager and Saalman do not agree on the sequence of tribune construction, this period's construction activity appears agreed upon by most scholars. Still remaining to be verified is Saalman's suggestion that stone chains exist at the base of the three tribunes.

Plates 10 - 16

The final sequence of plates draws from several sources, chief among them Saalman (again, for the valuable transcriptions of primary documents) and Ricci (discussed below). The period remains the most problematical of the three in the thesis to illustrate due to the number of issues confronting anyone wishing to depict it: What was the string control device used? What did the centine look like? How many, and where, were the various work platforms used? What types of building machines were used, where were they located, when were they used and how? These questions (and many more) over time merge into a single one: How can we envision the constructing of the dome from 1418 on? The problem of illustrating the building history of the Cathedral becomes acute once one reaches the year 1418. Few illustrations and/or reconstructions exist concerning the construction from this point on. Those that do exist are often rendered in a cut-away style that emphasizes internal features of the Dome over the overall appearance of the work in progress. No attempt has been made to create a series of images as a continuous narrative sequence. A multiplicity of theories exist as to what the actual constructive procedures followed were. One is forced at this juncture to choose from amongst many explanations one which may then serve as the basis for illustrations.

The best illustration to my knowledge is Ricci's masonry model which, when ultimately completed, may hide much of its internal structure, but as it is seen now, still under construction, reveals all. Abstract concepts such as "Corde blande", centine, curvature control devices etc., are given physical expression in the model and enable observers to discuss the cupola's construction process with ease. Ricci's model offers a graphic visual aid to our understanding of the cupola and greatly facilitates the discussion of of how it was built. When completed the model is intended to house a small museum depicting the stages of the project. I have created this thesis in anticipation of such an exhibit.

Ricci's argument (quoted at length in Appendix I) is persuasive for several reasons. Armed with it he is presently building a one-fifth scale model of the cupola on the banks of the Arno outside of Florence. His main tools are merely a pendulum and measuring strings. His materials are tens of thousands of bricks. He demonstrated the system to me when I visited him in December of 1994. Using his system of string controls, each brick may be accurately positioned by any of scores of brickmason apprentices. Ricci relates that at times he has had fourteen-year old helpers laying bricks on the project.

There is more work to be done in the area touched upon by this thesis. The illustrations (if truly to join the long line of depictions of the cathedral and its cupola) need further review, and revision.

APPENDICES

APPENDIX A

Ricci's 'Fiore'

I have chosen to depict the building of the cupola along lines proffered by Massimo Ricci in his book *Il Fiore di Santa Maria del Fiore,* 1983, Alinea Editrice, Firenze. *Il Fiore* was published under the auspices of the Department of Architectural Projects at the University of Florence where Ricci teaches. This work was expanded upon four years later in the July, 1987 edition of *Le Scienze* (the Italian edition of *Scientific American*) by "Il segreto dell cupola di Santa Maria del Fiore' another article by Ricci. My project relies heavily upon Ricci's theories as expressed in these two publications.

He proposes that a device known as the randa, (originally used to determine curves, such as those found in decorative motifs made by stone carvers and illustrated in Appendix I) was inspirational to the Cupola builders. The randa is essentially an adjustable tool that generates curved lines from straight ones . These curved lines, when arranged in a circular pattern, resemble the petals of a flower and hence give their name to the 'fiore' or flower described by Ricci. What Ricci suggests is quite simple: if a curved line may be generated from a series of straight lines, then the inverse is also true. In the case of the Cupola the curved lines were represented by a series of metal rods attached to the working platform at the Dome's base. The straight lines generated from this 'fiore' were the profiles of the vertical members of the Dome, its corner and intermediate ribs. The 'fiore' could also have been used to back-up the centine (see Chapter III) as guides for curvature in e corners of the Dome.

One of the fundamental (yet rarely emphasized) truths about whatever system the Florentines adopted in the 1400's is that it must have been easily understood and communicated to a large workforce of masons and supervisors. If brickmasons should doubt the safety of the work site, and the soundness of the construction (in this case the vault), their cooperation would be difficult to obtain. Ignoring this practical yet unavoidable consideration invites weaknesses into one's explanation for the constructive procedures followed at the cupola. Ricci's acknowledgment of the realities of the bricklayers' concerns, and his proposed resolution of them, make his proposal for this author compelling.

Chapters 1 - 4 of *Il Fiore di Santa Maria del Fiore*

By Massimo Ricci (1983)

Translation by Irma Velez

With editing and transcription by James Bredeck

BRUNELLESCHI'S SECRET

Long ago there was an ingenious tool called a 'randa' which was used primarily in engraving and inlay work to trace rosette leaves but it also served to precisely design multi-petaled rosettes for drilled windowsills.

This instrument that I have managed to rebuild, can determine the geometric contours of each petal no matter the size or degree of slenderness required (Figure 32).

The principle according to which it worked was the following:

Taking a straight reference line, a sliding block is run back and forth along it. Attached to the block is a rod. One end of this rod is attached to the sliding block by a pivot. The other end of the rod passes through a fulcrum and, at a distance 'r' (radius), has a stylus. The fulcrum is fixed by an adjustable arm attached to the reference line. By sliding the block back and forth, the stylus - which remains a fixed distance from the reference line - describes a curve that resembles a stylized flower petal (Figure 32).

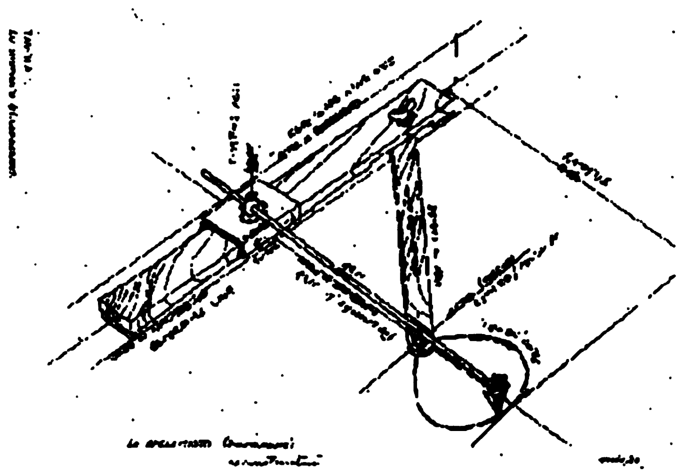


Figure 32
The randa (reconstruction). Reprinted from Ricci (1983), p.14*

The principle on which the instrument is based did not pass unnoticed by Brunelleschi, who was an expert in these types of mechanisms.

Obviously, reversing the process (moving the stylus along the drawn curve) will result in drawing the initial reference line anew .

(We can get) the geometrical translation of this mechanical principle by adding a second reference line, parallel to the first, and marking pairs of regularly spaced points on both lines equidistant from the central axis.

By linking the two lines symmetrically via the corresponding points located on them, we can build a sheaf of straight lines without a fixed fulcrum. We only need to apply a fixed radius, at will, to each of the straight lines of the sheaf to obtain the geometrical 'flower.'

It seems difficult to connect this principle to the example of the Cupola. But in the light of the following considerations we will see that, on the contrary, it is fundamental that we do so (Figure 37).

**Operation: move the slider back and forth along the reference line and the metal tip draws a flower that has as a symmetrical axis the normal axis to the reference line which passes through the fulcrum. Approaching the fulcrum on a line we obtain a more flattened 'flower'. One can, in practice, trace all kinds of 'flowers through adjusting the fulcrum by loosening the wing-nut screws and realigning the arm positions.*

* * *

The simplest way to delineate the geometry of a tunnel vault is to first determine the desired height, or radius of the vault. This measure is then drawn as a horizontal line, fixing one of its end points at the center of the vault's base diameter. This radius is then rotated which keeps the outer end an equal distance from the fixed pivot point, the locus for the vault's center of curvature. [This location of this locus for a semicircular vault lies in the center of the vault level with the base.] In this way the problems of geometrically tracing a vault and defining its thickness are always resolved, which, if fixed at the outset, will not change during the process of elevation (Figure 38).

With respect to our Cupola, this procedure allows the positioning of the vault's centers of curvature somewhere other than in empty space (at points that would have had to be 55 meters above the ground!) It could allow these centers of curvature to be fixed on a scaffolding close to the vault's springing and opposite the side [or corner] that we wished to determine.

The problem was however to define an octagonal dome, which had to taper

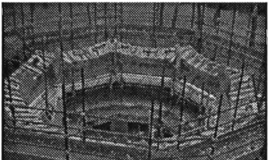


Figure 33
Florence. Masonry model of cupola, general view under construction

Figure 34
Florence. Masonry model of cupola, Demonstration by M. Ricci of string control device in operation

gradually towards the top as it rose.

The procedure described above was no longer sufficient.

Here the connection between the randa's working principle and the problem of geometrically measuring the Cupola appears; in fact it would be enough to apply some method of measuring [the vault] with radii that cross and are fixed, a method suggested by the tool's working principle.

If the pattern of lines describing the 'flower' is available on the base scaffolding we only need to plumb the [guide] lines as we vertically rotate the radii to build the general geometry of a single sail [side]. This method allows one to verify the correspondence with the predetermined pattern and simultaneously taper all structural elements as the construction moves higher (Figures 40, 41, 42, and 43).

In practical terms, these [guide] lines were probably ropes fixed to prearranged points along the vault's springing line. The marked points indicated the necessary points for defining each sail's [ribs] vertical elements (Figure 40).

By making a center in the locus of the 'flower' and by moving vertically (plumbing the cords of the base), with a single radius, we can automatically define the overall geometry of the work and the angle (inclination/slope) of the masonry

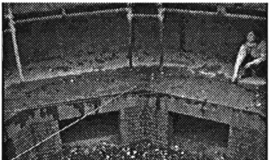


Figure 35
Florence. Masonry model of cupola, view of base and 'flower'

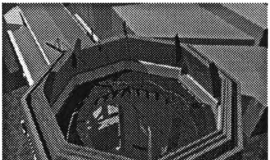


Figure 36
S. Maria del Fiore. Reconstruction ca. 1425-1427

beds. Such a procedure is flexible enough to allow one to determine the form of any cupola on a polygonal base, from a geometric and a structural (arranging the masonry desired for building) point of view. In the case of this cupola it was necessary to specify the most probable approach chosen by Brunelleschi since it was possible to define any desired slope for the masonry (bricks, masonry beds, stone chains, etc.) with such a device.

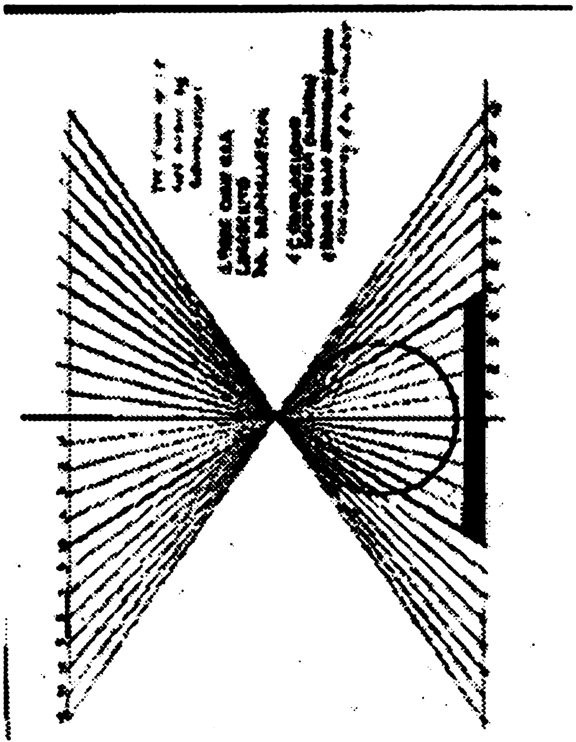


Figure 37
The 'flower' as Brunelleschi knew it. Geometric construction on left. Edge traced by randa instrument on right. Reprinted from Ricci (1983), p.17

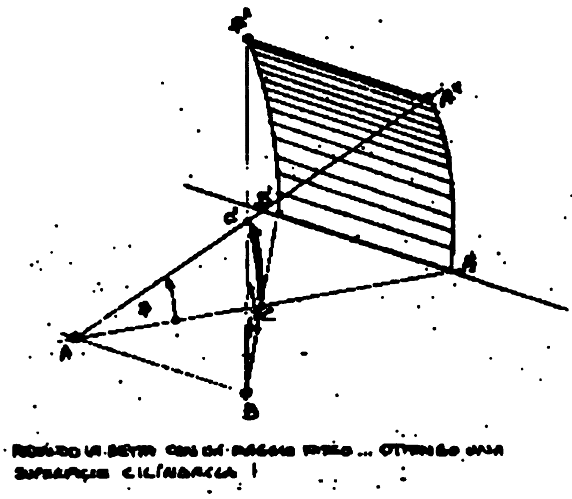
The ashlars' convergence towards a single center was the first hypothesis to frame the problem. This convergence requires, under the same height, an angle with an equal vertical inclination for all the directrices that define the ashlar. Such an angle must be checked against to the horizontal plane of the base scaffolding which was, according to the results of my study, nearly 55.1 meters above the Dome's floor.

The practical procedure to carry out such a scheme had to be the following one: two ropes were raised across the octagon each one carrying two signals [makers/flags] at their ends. The ropes were centered on points lain down for each 'flower' which marked the octagon's diagonals [diameters].

The first [inner] signal of each rope served to determine the intrados of the internal cupola, the second [outer] one to fix the extrados, where the ropes crossed marked the octagon's center.

The distance between the two signals was equal to the vault's thickness diagonally through a corner. The first signal determined the vault's curvature as equal to nearly 36 meters, a radius that was supposed to originate the 'quinto acuto'.

By keeping the two ropes at the same angle of elevation with respect to the base plane and by controlling their azimuthal direction with the plumb-line (cross-checking against the ropes stretched/lain on the base scaffolding) it was possible to simultaneously determine the vault's configuration and the inclination for the bricks so that their mortar beds converged towards a single direction. In fact, both actions were indicated from vault to vault by the same rope. Using the other references, it was even possible to determine the central elements of a brick course's configuration either in the vertical or azimuthal direction. For instance, if they had to position stone materials, their stereometry was guided accurately with this system that allowed them to determine 'a priori' the material's position and to give instructions to the quarry beforehand.



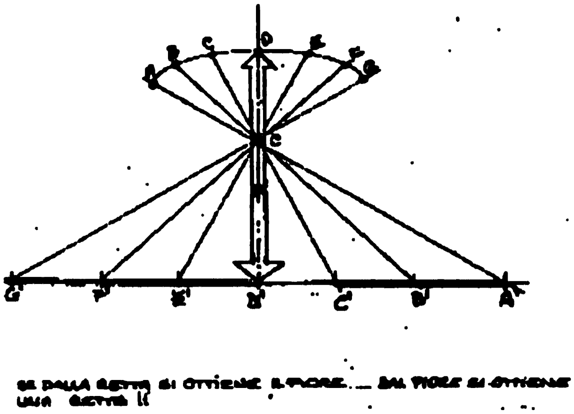


Figure 38 (top)
"Rotating the segment with a fixed radius . . . creates a cylindrical surface!" Reprinted from Ricci (1983), p.18

Figure 39
"If a flower may be obtained from a straight line . . . then a straight line may be obtained from a flower!" Reprinted from Ricci (1983), p.19

Obviously, each side had as guides the necessary references on the base scaffolding. I believe Brunelleschi singled out nine: two that determined the corners, one that determined the center, four that fixed the internal ribs, and two, one on each side, that determined the inside of the corner ribs (figure 40).

It's worth remembering that the rule required perfectly horizontal planes to work. The first one among all of them was the one determined by the base scaffolding, which, according to the constructive rule, had to be perfectly horizontal. Based on Fondelli's survey, errors of horizontality in the vault's masonry beds are visible. In my opinion this fact was tolerated by Brunelleschi only for the passages of holes for the work platform, but he was certainly precise in achieving a perfectly horizontal line for the vault's springing. Difficulties would have been caused by such a notable inaccuracy in the practical application of the building rule.

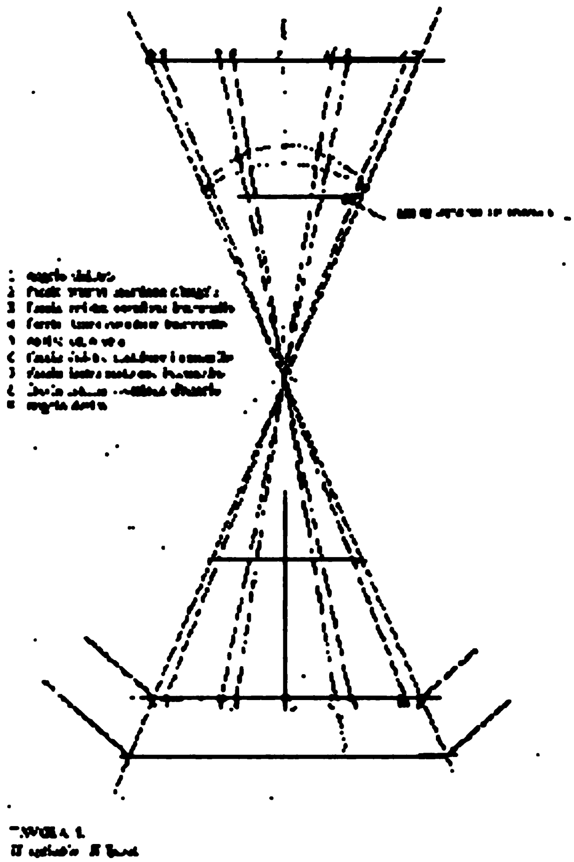


Figure 40
The pattern at the base. Reprinted from Ricci (1983), p.20

On the other hand, it was pretty easy to make a horizontal plane using a plumb-rule as a level which allowed one to check the right angle formed between the ideal plane (the tool's base) and the direction of the plumb-line.

Floor elevation errors could be simply avoided by direct references from the base to the floor of the Dome itself. Ancient's behavior teaches us that even with rudimentary means it was possible to reach a high level of precision by using those 'tricks' that we have forgotten by now.

The rule that I am proposing is such an example.

Concluding, I deem it impossible that these types of errors were made.

Returning to the constructive method, it must have been conditioned as well by strong procedural components due to the technology of the material. During the course of this research I have always focused on problems linked to practical reasons; for instance, to those due to the installation of the bricks. As many researchers have pointed out to, the need to wall up 'a stesa' [at the same time, self-supporting] the central portions of each side and the same ribs leads to a maintaining of masonry bed inclinations perpendicular to the surface of the vault at all points. This fact has originated the term 'a corda blanda' of the laying beds of the bricks and of the initial stones (Figure 44).

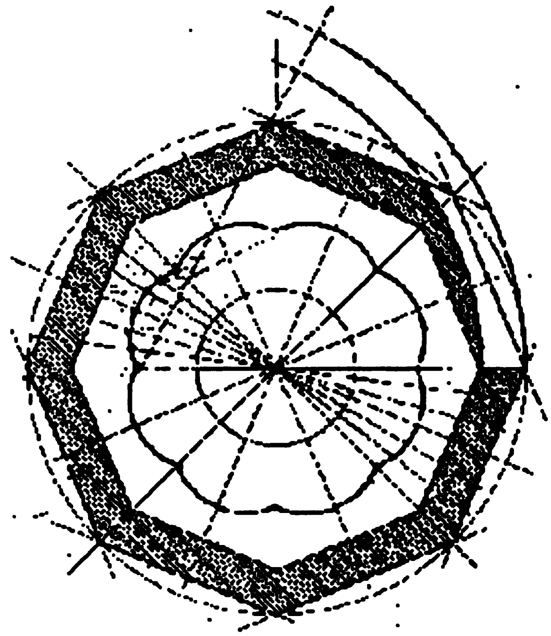


Figure 41
FLOWER: Geometric locations of the centers of curvature. Reprinted from Ricci (1983), p.21

In fact we cannot wall up without a lying continuity of the bricks, that surely could not have various dimensions nor various configurations inside a common ashlar of increment. They had recourse to the adoption of bricks with a special geometry near the inner ambulatories; indeed, we only see extremely different elements (wedge bricks, tapering, etc.) in those areas.

During visits to the Cupola, it struck us to see the enormous difference in precision (art rule) that exists between the visible parts in the passages along the inner ambulatories and the one found in the plastered areas (now visible due to the fall of the plaster). It was like there had been a will to have to visitor understand a reality that in fact did not exist, i.e. to have the work's wall texture appear as a much bigger enterprise than it really was. I would say that it was an artifice to amaze the visitor and to impose on him a sense of dismay in order to discourage any desire to criticize.

I do not mean to say that the work has been simple since I am rather convinced of the opposite, but it is still interesting to notice that even in these details some aspects of the Maestro's personality was transmitted to us other than from his own biographers.

These type of observations require, however, care in forming judgments and affirmations.

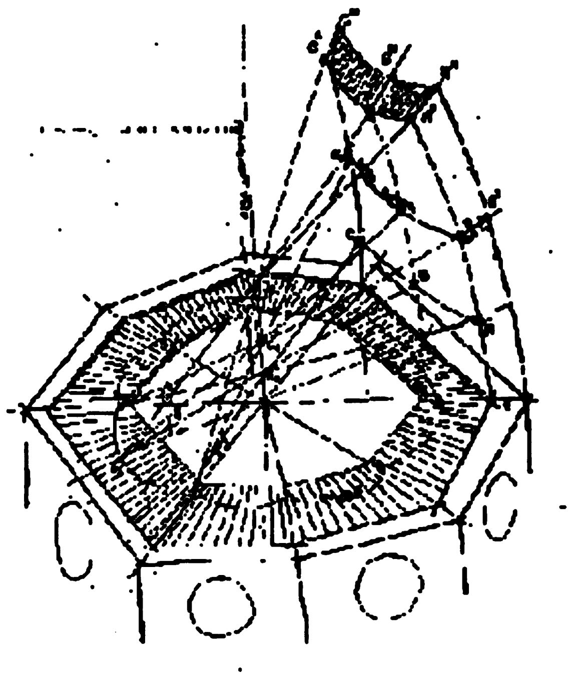


Figure 42
Schematic diagram of constructive method for the cupola of S. Maria del Fiore.
Reprinted from Ricci (1983), p.22

FROM THE MODEL TO THE RULE

When Brunelleschi started putting into practice on models the method he'd found he was astonished to realize that something wasn't working; after more than half of the vault was built perfectly (its upper edge inclining at about 30 degrees), the vault's center started to lean forward towards the cupola's axis. I say this after encountering the same surprise during initial stages of constructing a cupola model with cord and noodles (used to fix points in space). Joking aside, I mention this to show that the defect could be remedied through studying small scale models. The Maestro knew immediately what was happening. Obviously the locus used for the construction of the model was built through a segment equal to the length of the impost base. Towards the summit of the Cupola, where distances between corners grows smaller and smaller, even the differences of distance between the arrival

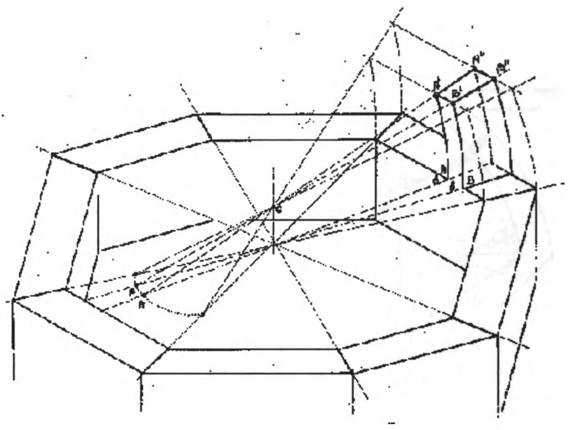


Figure 43
Definition of any vertical element. Plumbing the base cords automatically givesthe position of an element. Reprinted from Ricci (1983), p.24

points of the ropes were getting smaller and smaller from vault to vault, until it became nonexistent in the summit (Cupola's axis). Since the 'flower' at the base was built on greater distances, it was obvious that it was not working well for the overall definition of the vault. The 'flower' had therefore to be reduced on its own height; to build it accurately they only had to use the width of the front vault relative/ comparative to the reached height.

This procedure could easily have been put into practice on the Arno river bank, transferring the newly obtained 'flower'' onto the impost plank floor of the Cupola's erecting yard and proceeding on to new measurements.

During the mathematical verification it has been proven that three 'flowers' were sufficient to determine with necessary approximation the entire vault.

The procedure of the 'flower' causes in fact errors at a second level and it approximates the curve to the vault's center by 7-8 centimeters in the sole summit, while the rest of it is perfectly defined (Figure 45).

This method allows us to determine the entire axis of the ashlar masonry, of the brick inclinations and of the stone elements, that could easily be predefined and arranged once outlined in the quarries, according to the results of Guasti's writings.

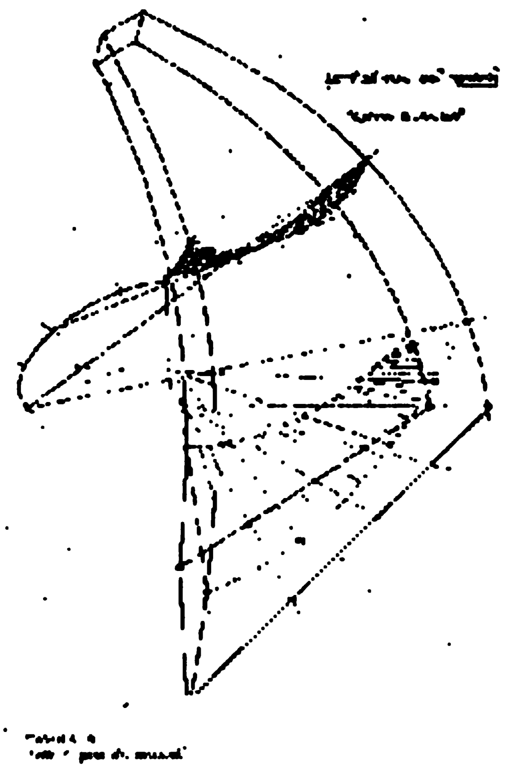


Figure 44
Position of brick masonry beds. "Corda Blanda."
Reprinted from Ricci (1983), p.28

Naturally, by proceeding with an infinite amount of 'flowers' we get the perfect curvature, but if this had been the way the Cupola was made it would still be unfinished!

Let's remember that in comparison to a vault distance of nearly thirty meters that 7 or 8 centimeters are really negligible and the maestro, who sought perfection, could very well taper the vault's center with a little cord pulled from edge to edge (of each side), once construction neared the summit.

From the outset, it should be said that raising the ribs alone was not sufficient to entirely determine the work's axis. In fact, using only centerings for each rib (never reported in the writings of that period and excluded in the 1426 report), it would have been impossible to determine the axis of the ashlar masonry, or the planes of the masonry beds, or the radial curvature towards the center.

They could not have prepared centering for the stone chain mouldings and of the ashlar masonry, that the bricklayers could not have executed if they had not been previously determined.

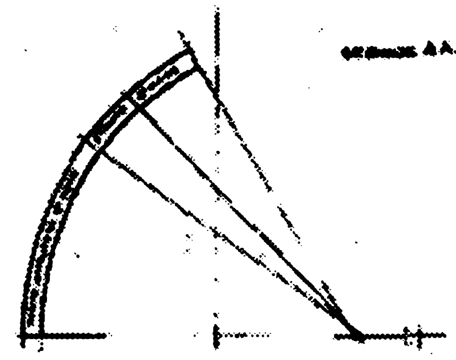


Figure 45
Cupola. Sections showing areas constructed with first. second, and third 'flowers'. Reprinted from Ricci (1983), p.17

We must exclude the hypothesis of herringbone masonry present at the base of the geometric work since around it the mortar joints are irregular, jammed, whereas they recover regularity a short distance from it; in certain areas the herringbone is completely abandoned and thus it is not maintained throughout as an essential. Had it been at the base of the structure's defining geometry it would be present at all times, and the courses of brickwork, simply because they refer to it, would have had a greater regularity near it, rather than the opposite, as it is in fact.

It is, then, a device of masonry technique turned to confer to the greater structure resistance in the vertical sense: they are secondary scraps or better, oppressed ribs, in its inner side, that will support in the keystone the lantern's load together with the ribs.

With the mathematical verification made by Andra Bassignana, we have come closer to the order's correspondence of two degrees of the highest approximation through the rise of the bland cord and the radial inclination of the ashlar masonry at different levels, raised in place, and those that have been analytically calculated based upon the rule of my hypothesis. But if this is the real approximation obtained by Brunelleschi in the construction of the work, I can support the correspondence between the rule that I propose and the state of fact that may be found in reality, that very often coincide in an incredible way with the previsions due to the rule itself.

Since the procedure that was found uses as the sole fixed centers those relative to the edges (ribs of angle), and as these and only these are directly measurable, (all other centers are placed on the 'flowers' curves), one can understand much better why, when he drew the 1420 account, Brunelleschi defined the achievement of the Cupola's geometry in this way: "initially/at first, the cupola from the inner side is curved on the measurements of the quinto acuto in the angles...."; in the light of the rule it is quite clear that there was no better way to protect oneself from accusations as Giovanni di Gherardo da Prato's ones and to determine more clearly and in an univocal manner the Cupola's 'sesto'.

It is obvious that only those who knew the rule could have some clear idea of it. Nevertheless, like many thought, this account was really written by Brunelleschi, the only one to know how to curve the Cupola without centering. I believe that Ghiberti was the one who suggested the edges' centering, but the outcome of such a suggestion had to be far more complex and expensive than a simple rope (or iron wire) of about thirty six meters and a 'flower' made out of simple wooden picks!

It is probable that the advantage of Brunelleschi over Ghiberti had been taken thanks to the knowledge of the rule that he was the only one to know. His security and his stubbornness during the disputes and during his defense from his accusations prove it just as much as the ease with which he eliminated Ghiberti during its construction, when he had to set the stone chains that demanded a much bigger accuracy than the bricks (since they had to close up within a millimeter and to be fixed a priori). Ghiberti could not do anything since he did not know the rule. Whereas Brunelleschi had acquired a lot of security by experimenting his rule on his models. This allowed him to anticipate a large amount of difficulties and problems that he would thereafter encounter.

According to his biographers (Manetti and Vasari), he had shown several times, during controversies and councils, that he had anticipated many more problems than those foreseen by most of the people who were interested in the Cupola's construction and therefore it gave all of them some doubt on the achievement of the Cupola. The practical application of the rule was supposed to occur through auxiliary measurements outside of the erecting yard, and particularly for the definition in scale to one-to-one of the vault's loci of curvature that, as we have seen, were represented from the 'flowers'.

If the Maestro really leveled a part of the Arno's river-bed to study at the real height the vault's curvature - as the biographers pretend - the rule that I am trying to illustrate makes us think that he really did it to draw the construction of the three 'flowers', as we shall see next.

THE 'FLOWERS' ON THE ARNO

As I have mentioned it before, from the beginning of his own studies on his models, Brunelleschi realized the need to change the locus of the 'flower' points to make the center and determine the structure and the geometry of the Cupola. In practical terms, it was a matter of defining the three 'flowers' that would have allowed to initiate and finish the work. I have been wondering which one could have been the adopted method. The definition of the three 'flowers' could not have been made on the erecting yard itself because, even if it had been a possibility it would have been too complicated. I have started then to trust anything reported by the biographers: i.e. that Brunelleschi would have leveled the Arno's river-bed to experiment some measurements concerning the Cupola. Reasoning with practical logic, it suddenly came to my mind that the smaller or largest height of each 'flower' had to depend on the sail's width, or better on the distance from the rib's point to the central point, as it is measured horizontally. Indeed, the defects of 'leveling' of the sail's center with respect to the rib is due to the rotation of the rib's curve with respect to the curve that defines the center of the sail. The closer the rib's point are from the mezzaria's points the smaller is the influence of the upsetting that is at the base of the leveling; this fact leads us to put in relation the sail's width to the height where we want to build the 'flower', with the same flower that must originate it; their ratio has to be proportionate and therefore directly drawable with geometrical construction.

Brunelleschi had to think about the simplest way to draw the 'flowers' ' form relative with the height of the added portion of the vault.

He probably though of doing it at the real size scale, i.e. on the Arno's river-bed, to reduce at the maximum the margin of error (figure 45).

With a level vaulting it is actually impossible to build from sail to sail the required 'flower' outside of the erecting yard, to then carry it onto the Cupola's scaffolding, to avoid having to work in the air and at such a height. He would take the width from the sail to the gained height and, by putting it onto the reticulated work which served as a base, he would measure the distance from the edge line of the vault A-B-C-D-E-F-G-H-I (see Ricci, 1983, pp.39 - 41), and precisely from the point 'A' to the point 'A2' (fixed), and he would get on the plan the required radius to build the 'flower' (projection onto the ground of the fundamental radius' height/elevation). He observed how at first the projected radius coincided with the curvature radius (nearly 36 meters) and meeting the impost size; and how the radius of the last 'flower' coincides with the distance from the Cupola's center 'O' to the point 'A2', and then making coincide the 'flower' with the through the fixed points (centers of curvature of the edges), originating a cone with the vault's closing point as the vertex (on e central axis of the Cupola), about the closing part of the geometrical construction.

In the alleged drawings, there are three phases represented in the construction of the 'flowers' for the building of the Cupola, probably defined on the Arno and then through measurements carried onto the impost plane, with small picks tat only Brunelleschi knew how to 'use' them.

With the adoption of a system with a 'fixed radius', this operation becomes therefore impossible. Besides, its simplicity made it perfectly feasible with the means and knowledge of the time. This way, we could even justify Brunelleschi's activity on the Arno's river-bed, which otherwise would be inexplicable.

All these considerations seem to strengthen the adoption of this construction rule that the present study hypothesizes.

Other considerations need to made on the basis that if Brunelleschi had built the 'flowers' in the erecting yard, sooner or later everybody would have understood his method that he put into practice, and incidents like the accusation by Giovanni di Gherardo da Prato would never have happened.

With the method to construct the 'flowers', measuring the 'bland ropes' perfectly as well as the trim of the ashlar masonry we could easily trace back to the changing points of the reference 'flower' and define, in an exact manner and in e light of the rule that I am proposing, the whole geometry of the Work and of its internal structure. We could build, as follows, more accurate models that would take into account, in an almost exact manner, the elements that shape the structure itself, increasing the reliability of the analytical results used for the restoration.

TOWARDS MORE COMPLEX GEOMETRIES

In my opinion the first defect that was seen and that would cause the inconvenience of having the center of the vault progressing towards the inside of the Cupola, has been the origin of the invention of cupolas with a more complex geometry, such as the Pazzi Chapel and the Old Sacristy of San Lorenzo. As everyone knows they are cupolas that have the characteristic to be built after curvilinear elements (sails) resting on radial (ridges) that act as shoulders.

What is of interest to us here is the geometrical definition of a sail with transversal sections (or cross sections) and not flat ones as the Cupola of S. Maria del Fiore.

The problem that arises is exactly the opposite from the one this last cupola had. While for the Cupola of SMF they had to obtain a cylindrical surface (i.e. a flat one) for each sail, for the two chapels' cupolas they had to obtain surfaces shaped like arches. Back to the study of the Cupola's models, the inconvenience that they encountered by adopting a single 'flower' that would distort the central part of the sails in the summit must have suggested to Brunelleschi the method to generate sail surfaces that would be curved. To obtain the desired effect, he only had to change the locus of the points upon which he made the center, with a fixed a radius. As a matter of fact, whereas we get a flat surface (cylindrical) by adopting the 'flowers', we get a transversely curved surface by adopting a straight line as a locus (see Ricci, 1983, p.44).

For this reason it will be interesting to conduct inquiries on the geometry of the two chapels' cupolas, since if what has been the object of an hypothesis here happened to be verified as correct, it would be therefore an ulterior proof of the validity of the construction's rule of the Cupola that I propose here.

Let's remember that even to determine the center's geometry, with which were certainly built the two chapels' cupolas, a method was anyhow necessary. We could easily demonstrate that with the help of a locus established from the sides of an octagonal it is possible to determine (with fixed radius and crossed system) the whole geometry of the sails of the two chapels' cupolas.

APPENDIX B

Models

1. The Models of 1418

Two model entries, Brunelleschi's and Ghiberti's, receive special attention. An unspecified number of bricks of normal size is delivered in October and designated for Brunelleschi's model. It is a collaborative effort involving the sculptors Donatello and Nanni di Banco - whose contribution remains an open question. The model was constructed without armature in about 90 days not far from the Campanile, on the grounds of the Opera. Four selected advisors inspected it as it was being constructed (Guasti, Docs. 18, 43 via Prager, 1970, p.27, 30). The masonry model was finished in October. The initial period of modelling ended 7 December 1418.

It was built of 1,782 standard-sized (square) bricks and 1,195 half-bricks and was - according to all indications - a great brick model of the entire cupola, not a half- or fragmentary model. The 'Chupoleta' was a small building of considerable size built at a scale of perhaps 1:8. It is not certain if it comprised the herringbone bond adopted. Not likely to have been possible to model the double-shell feature, only an inner shell. We can assume much of the detail was present and modelled in wood due to inclusion of gilded decorations, carved details. The model probably served as more than a practical structural demonstration and was meant to be definitive - THE model adopted.

Saalman concludes that Filippo required a large masonry model to demonstrate his innovative system of construction without centering. Its purpose was to clearly demonstrate in practice that an octagonal vault of this kind could be built without an elaborate interior centering and how the brickwork was to be arranged so that a continuous and unbroken fabric would result.

At roughly the same time, Lorenzo Ghiberti was constructing, with assistance of four masons of the Opera, a masonery model made of 'mattoni piccholini' or little bricks. It is, curiously, one of the few details we know of his actual participation in the whole project.

2. The 'Novo et Ultimo Modello' of 1420

A record indicates that payments were made dating from March 8 to April 22 concerning a 'novo et ultimo modello.' What was this model and what were Brunelleschi and Ghiberti doing around this time? Scholars (Nardini, 1885; Frey, 1887; Fabriczy, 1892) have surmised that the two artists had been advised to collaborate on a <u>third</u> model following those of 1418. Perhaps his model was the result of such an effort. Described as 'novo' the model was probably not referring to one of the 1418 models and 'ultimo' suggests that it was the latest in a series. There is a differing suggestion by Saalman that it wasn't a model of the cupola at all but of the drum only. Saalman deduces this based on the measure of the wood used to create the oculii of the drum. M. Trachtenberg disagrees and suggests that there was sufficient wood to produce a half-model of the dome. (Discussion by Saalman, 1980, p 63ff.)

APPENDIX C

Geometric proof

By Dr. William Simpson , Lyman Briggs School, Michigan State University

A geometric proof demonstrating how the string locations used to determine the cupola's "pointed fifth" curvature may be obtained. Rowland Mainstones theorizes that the builders of the Cupola utilized a series of string control devices to aid in controlling the curvature of the Dome as it was being raised. One set of string controls (there were probably two) may have served to check that accurate curvature was being maintained in the Dome's cormers - where the 'pointed fifth' measure was meant to be observed. I desired to know if the builders were capable of accurately determining the correct locations of Mainstone's strings which had to be placed a certain distance from each of the octagon's corners to function correctly.

GIVEN:

The radius of curvature in the corners of a vault with base of octagon O = 4/5 the diameter of O = (AC)

AC = 72 braccia, r=36 braccia

AB = 4/5(2r)

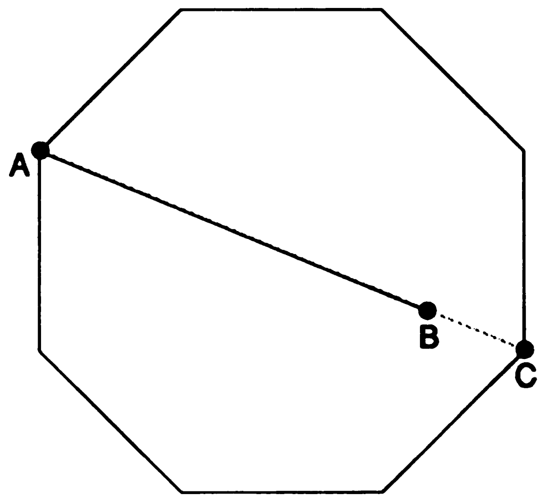


Figure 46
Octagon O

CONSIDER:

ΔGHB

$GB = AB - AG = 4/5(2r) - r = 3/5r$

$\cos(G) = \cos 45° = GH/GB = GH/(3/5)r$

$HJ = GH = ((\sqrt{2}/2) \times ((3/5)r)) = (3 \times \sqrt{2}r)/10$

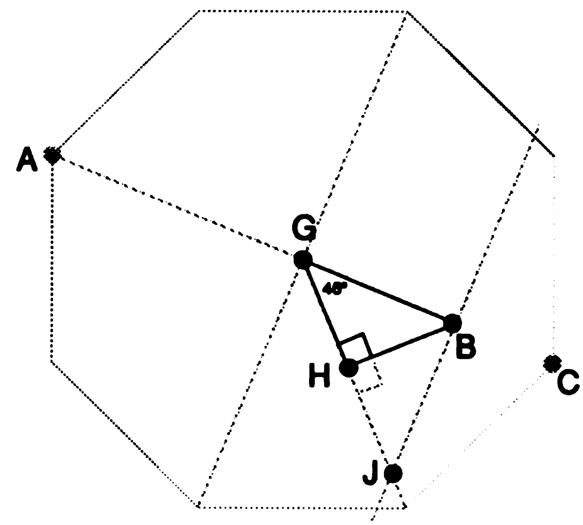


Figure 47
Triangle HGB

CONSIDER:

$\Delta\ IGD$

$GD = r$

$JD = GD - GJ = r - (2 \times GH) = r - 2((3\sqrt{2})/10)r = (1-((3 \times \sqrt{2})/5))r$

$\cos(D) = \cos 67.5° = ID/GD = ID/r$

SO:

$ID = r(\cos 67.5°)$

$FD = 2r(\cos 67.5°)$

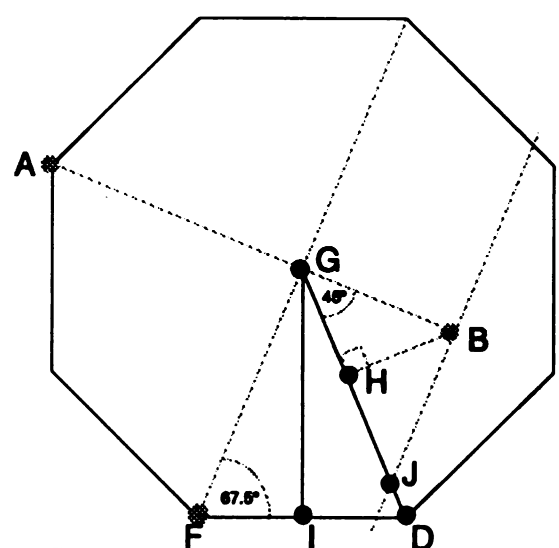


Figure 48
Line segment FD

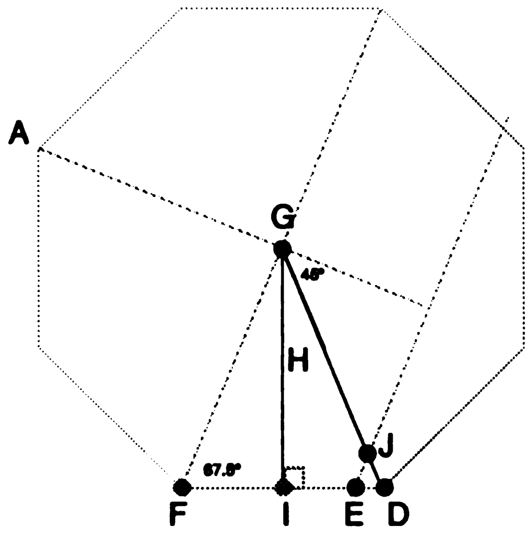


Figure 49
Line segment ED

CONSIDER:
Similar triangles ΔFGD and ΔEJD:

$$\frac{ED}{FD} = \frac{JD}{GD}$$

$$\frac{ED}{2r(\cos 67.5^\circ)} = \frac{\left(1 - \frac{3\sqrt{2}}{5}\right)\cancel{r}}{\cancel{r}}$$

$$ED = 2\cos 67.5^\circ \left(1 - \frac{3\sqrt{2}}{5}\right)$$

or $ED = .116r$
or $ED = .152FD$ (easier to use)

Point E in the Figure 50 corresponds to the circled point in Figure 51, Mainstone's diagram, reproduced below. This point is where strings would be connected to the octagon's sides to control the curvature in an corner.

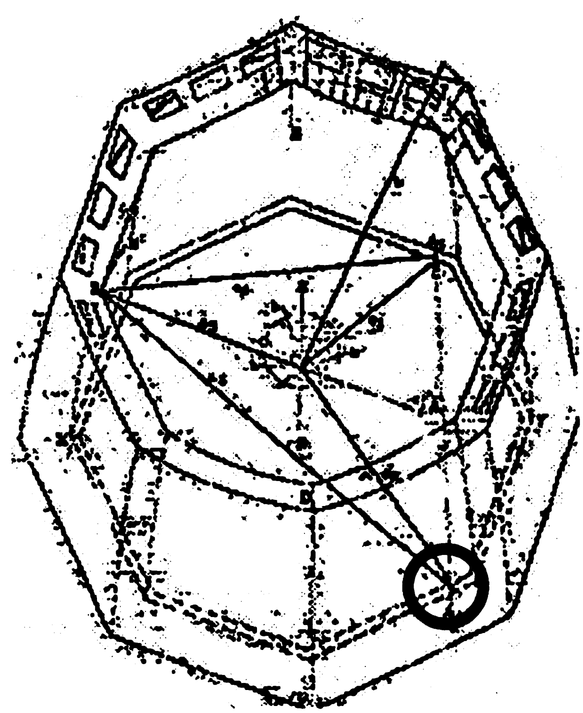


Figure 50
View of the dome cut throughout on the conical bed immediately above the top face of the first ring of arched projections fromthe inside face of the outer dome and showing possible arrangements for controlling both the basic geometry and the setting of the brickwork. Reprinted from Mainstone (1977), p.164

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[40] Ibid, p. 480
[41] Ibid, p. 484
[42] Toker, 1978, p. 221
[43] Saalman, 1964, p.492
[44] Prager, 1970, p.15
[45] Ibid, p. 18
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[47] Saalman, 1980, p.55
[48] Prager, 1970, p.24
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