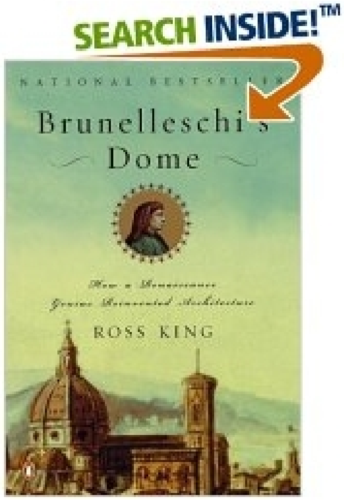


Basilica di Santa Maria del Fiore (Duomo)
Brunelleschi
Competition to design the dome started in 1419; the work was completed in 1436

Highly Recommended Airplane Reading



Brunelleschi's Dome: How a Renaissance Genius Reinvented Architecture (Paperback)

by Ross King (Author) "ANYONE ALIVE IN FLORENCE ON AUGUST 19, 1418..." (more)

Key Phrases: rota magna, sandstone chain, cupola project, Santa Maria del Fiore, Opera del Duomo, Middle Ages (m

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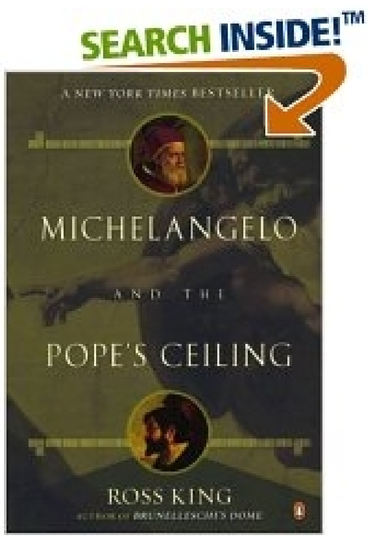

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Achievements

•~140 ft span (wider than Pantheon).
•Base of dome ~180 ft above ground (higher than in any Gothic cathedral).
•Too high and too large for any kind of centering.
•For aesthetics, built without any external buttressing.
•The cathedral design model required an octagonal dome profile with visible external ribs.

Two factors played a crucial role in the dome's construction:

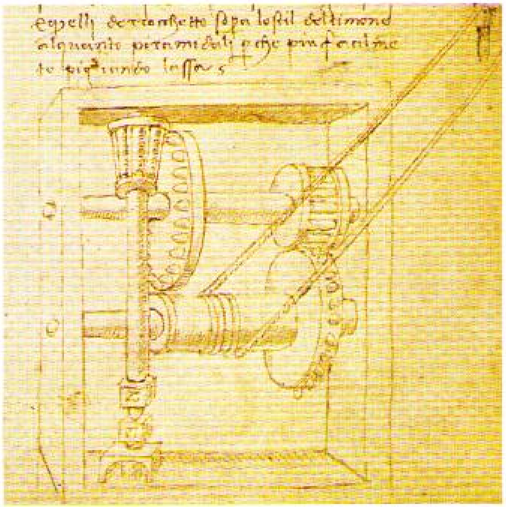
•Efficient worksite organization (construction management).
•Machines capable of heavy lifting to great heights.

**Brunelleschi left no records of his machines.
Fortunately a number of 15th century engineers,
including the young Leonardo, recorded them in their drawings.**

Museo del Duomo

Brunelleschi was inspired by the Pantheon
But he did not use concrete, nor scaffolding

I.2B.1f
FRANCESCO DI GIORGIO
Motor of Brunelleschi's three-speed hoist
Ms. Ashburnham 361 (BMLF), fol. 44v (detail)



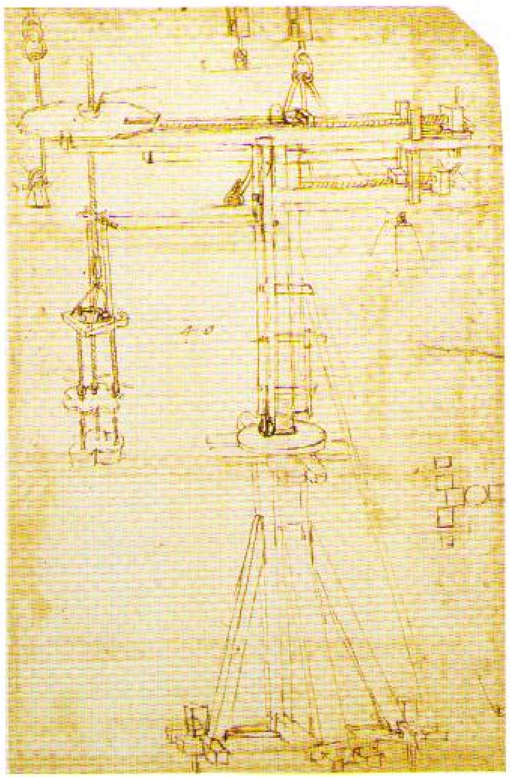
I.2B.1f

I.2B.2a[1]
LEONARDO DA VINCI
Brunelleschi's revolving crane
Codex Atlanticus (BAM), fol. 965r

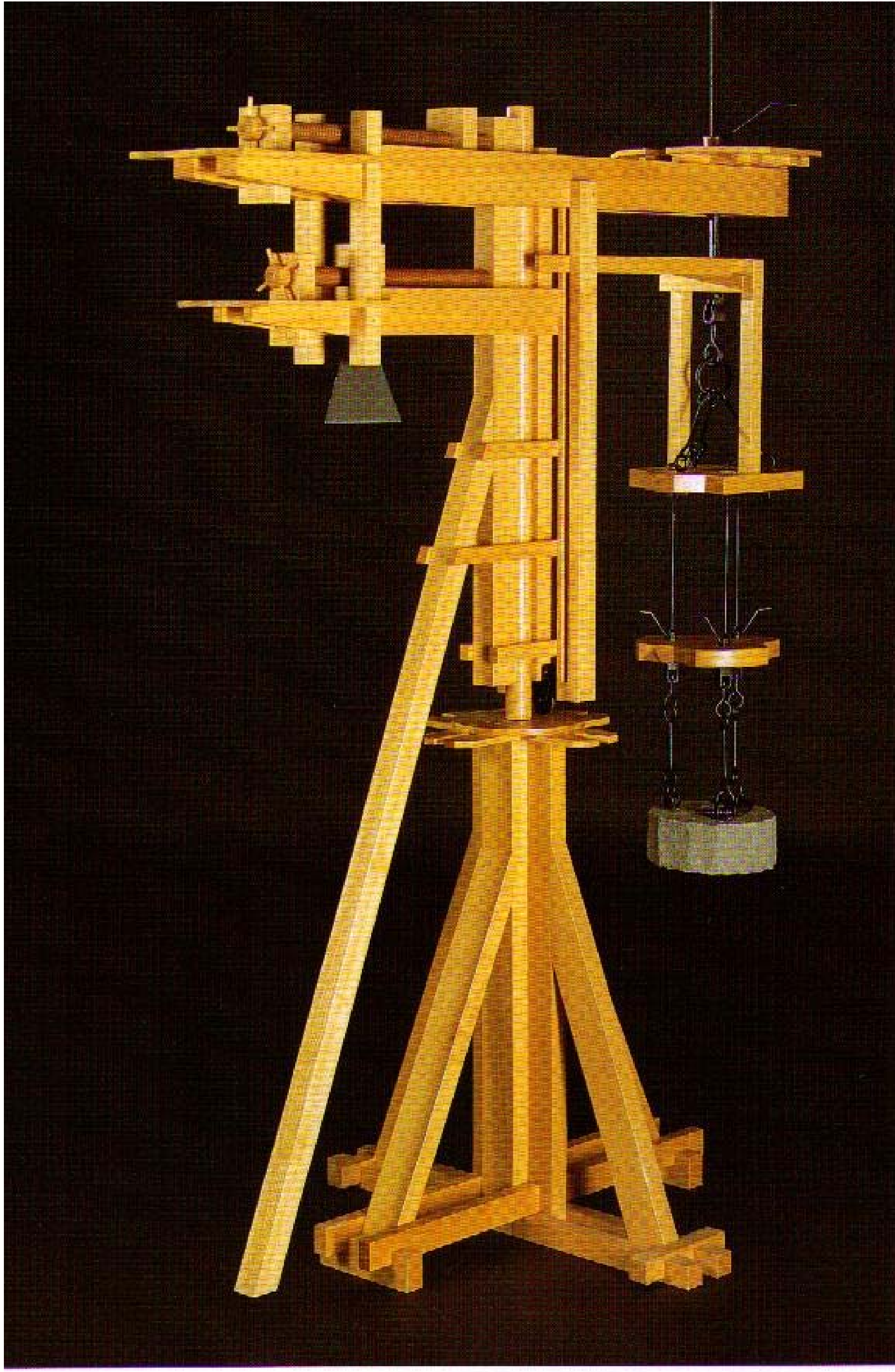
Leonardo made a detailed sketch (top left margin) of the vertical screw and lewis with dovetail wedges.

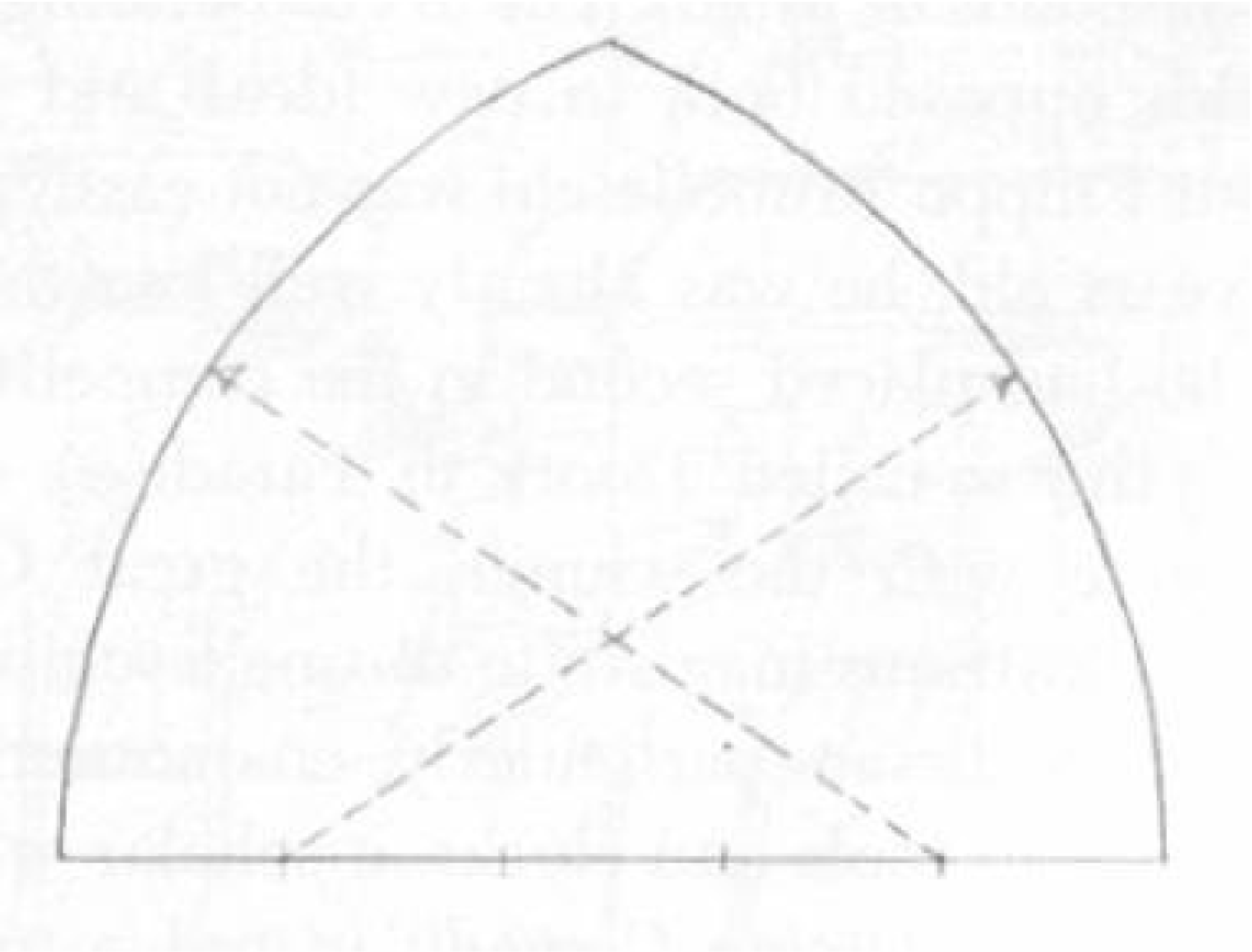
I.2B.2a[2]
Revolving crane
Working model after Leonardo da Vinci, Codex Atlanticus (BAM), fol. 965r
Beech, oak, and ilex; metal accessories
206 x 167 x 91 cm
Built by: SABI and Mariani, Florence, 1987
Istituto e Museo di Storia della Scienza, Florence

The revolving crane was at least 20 meters (65 feet) high. It was likely used to build the dome's *oculus* and to position the heavy stone blocks of the closing octagonal ring forming the lantern base. The crane's vertical shaft, guided by a long rudder, could rotate 360°. The load and counterweight were shifted simultaneously (in divergent or convergent mode) to keep the crane in constant balance on its vertical shaft. The wheel at the foot of the shaft helped reduce the friction caused by the rotation on the base platform. The load was raised or lowered by means of a vertical screw fitted with three turnbuckles to keep the load on a level plane. The crane required four teams of workmen: one to rotate the crane, two to turn the screws for the radial displacement of the load and counterweight, and one to operate the vertical screw. In the drawings of the crane by Leonardo and Bonaccorso, the load being raised is a marble block of the lantern.

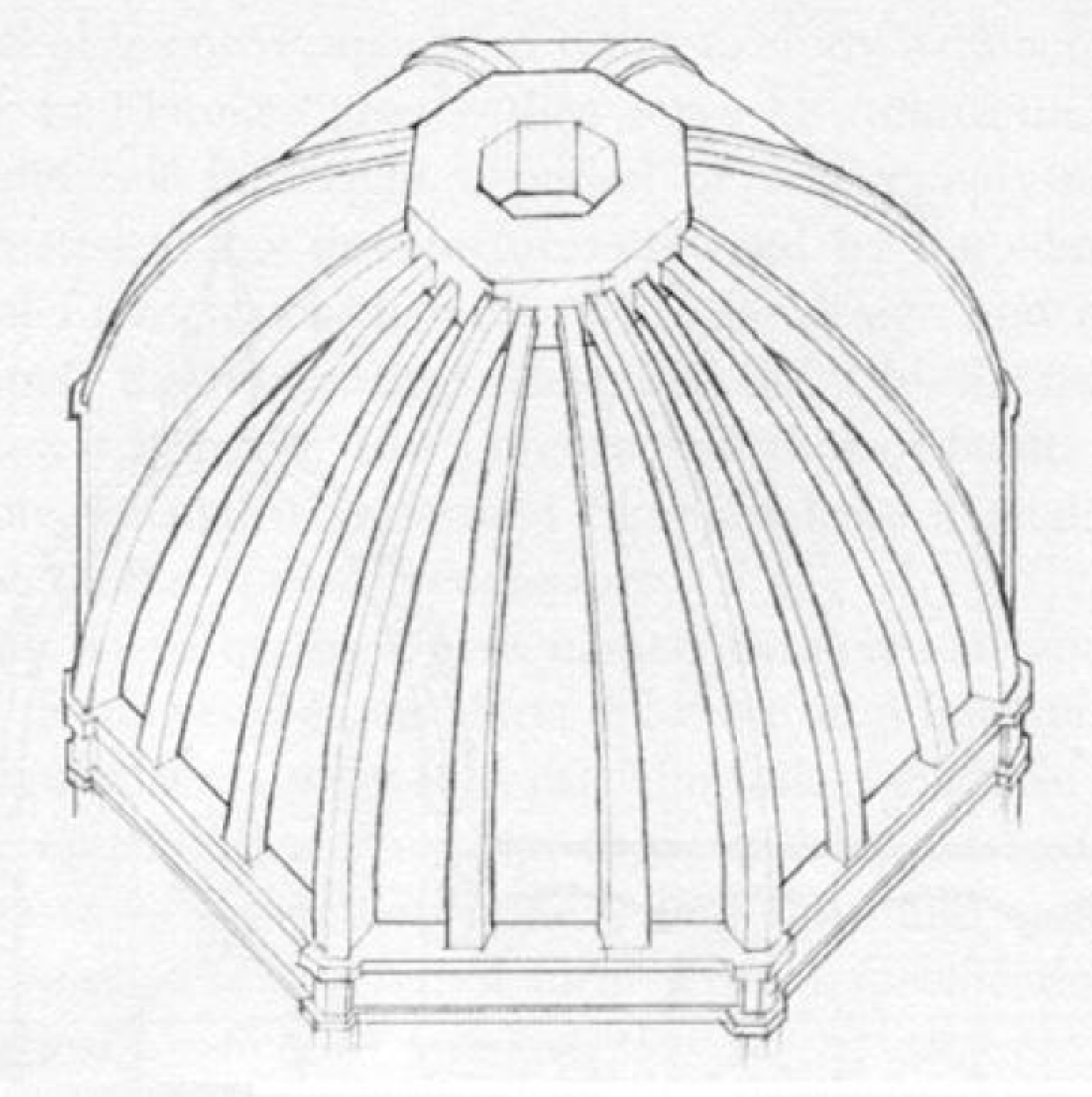


I.2B.2a[1]

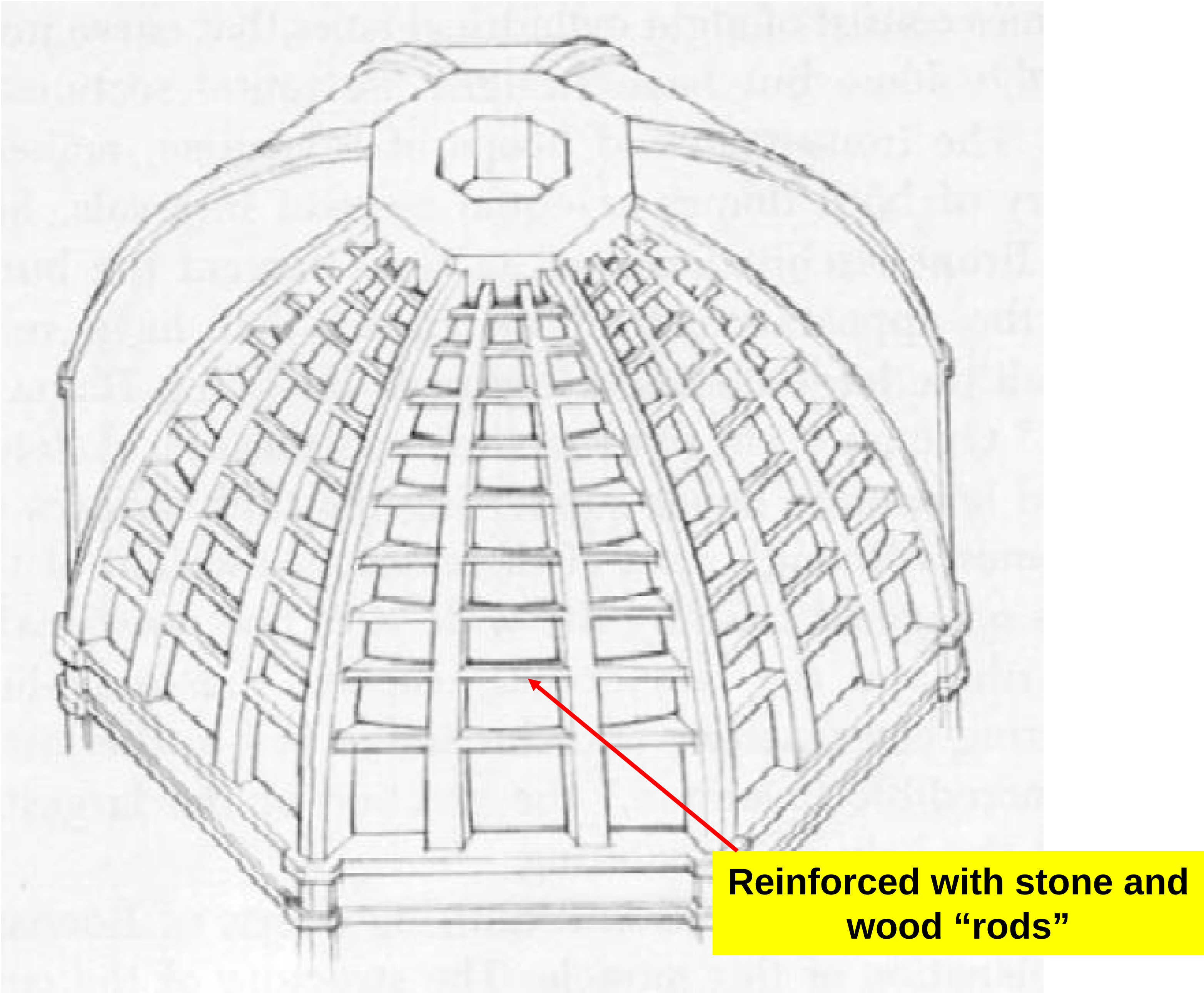




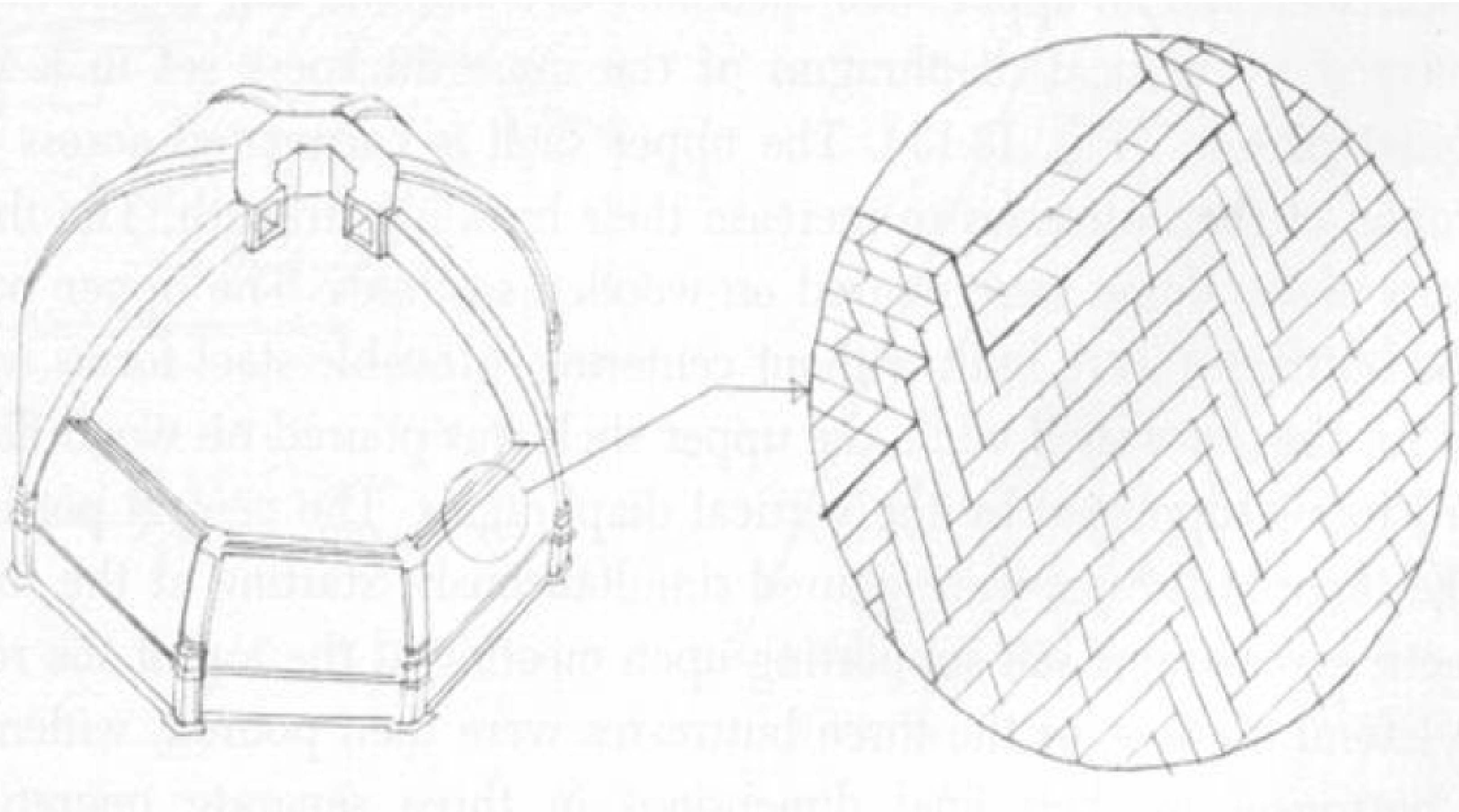
Brunelleschi chose to build the dome based on an arch known as "*a quinto acuto*".



The skeleton ribs of the dome.



The nine horizontal circles that tie the ribs together.



The brick masonry was laid in this herringbone pattern.

The New York Times
nytimes.com

July 28, 1987

Cracks in a Great Dome in Florence May Point to Impending Disaster

By ROBERTO SURO

AS the lofty cupola atop this city's Duomo, or cathedral, was being completed in 1434, a visitor from Rome described it as "a structure so great, rising above the skies, large enough to shelter all the people of Tuscany in its shadow, built without the help of any centering or of much woodwork, of a craftsmanship perhaps not even the ancients knew or understood."

In fact nothing like it had ever been built: two vaults, one inside the other, rising 299 feet, topped by 66-foot marble lantern - all held up without external buttresses.

The design was so bold and novel that a little insurance policy was built in. A bronze plate with a small hole in it was afixed at the top so that in the summer solstice a ray of sunlight shot down to a mark on the floor. Aside from its astronomical value, the device was a way of checking whether the dome was moving off its center of gravity.

The sun still strikes the same spot each year, but those caring for the dome worry that it has recently embarked on a course of self-destruction. When or if a disaster could take place is anybody's guess, experts say. What is certain is that for two years four fissures that run from the top of the dome to the church foundations church and from the inside walls to the outer skin have been steadily getting wider.

Now everything from lasers to plumb lines is being used to gather information on the dome. By the end of this summer it will be hooked up to no fewer than 300 measuring devices, giving it a solid claim as the world's most carefully monitored structure. Collection of Active Masses

Changes in temperature will be recorded in dozens of spots, as will the rise and fall of the water table beneath the foundation. But most of all the effort aims at tracking movement, up, down and sideways. Data from earlier measurements show that the giant cupola is not a lifeless stack of stone and brick. Instead, some architects see it is a collection of many active masses that generate their own thermodynamic energy. They sometimes move apart and sometimes collide, a bit like the tectonic plates of the earth's surface.

The dome, designed by Filippo Brunelleschi, is one of the great symbols of the Florentine Renaisssance. Its construction helped mark Europe's passage from the medieval to the modern because it embodied the rediscovery of science. As such, the dome has been studied over the ages by scholars who have defined its place in history, and by scientists, who with less success have tried to understand its inner workings.

"The challenge we face now," says Gastone Petrini, an architect who oversees the monitoring program, "is to use all the best science and technology available to try and understand the spirit and life of this dome. And here we are dealing with mysteries 500 years old."

Construction of Santa Maria del Fiore, best known as Il Duomo, had been under way for a century when Brunelleschi began considering how to build a dome across a space 148 feet in diameter. The only models available to him were the Pantheon in Rome and Saint Sophia in Istanbul. Both have fine hemispherical domes but they do not reach very high and required heavy structures around their bases to contain their outward thrust. Neither came close to accomplishing what Brunelleschi wanted: Neither of them soared.

Over the course of 28 years Bunelleschi carefully designed every part of the structure, from the eight arched ribs that form its skeleton to the intricate patterns of brickwork that absorb and transfer its weight. The intensely geometric logic of the structure is as complex and unseen as that of a Bach cantata. No other dome has ever been built exactly the same way.

Even before construction was finished people began noticing cracks. At least once a century since then studies have been organized to figure out what was happening. In the 1600's, after a long debate, it was decided Il Duomo did not need iron chains like those placed around St. Peter's dome to hold it together, and by 1757 a fairly detailed survey of the cracks was completed.

In 1934, Pier Luigi Nervi, the architect and engineer who helped develop the uses of reinforced concrete, made one of the first breakthroughs. Leading a study commission, he noted that the cracks opened and closed with the seasons. In the winter, when the cupola's stone and bricks contract, the cracks widened. In the summer, when the materials expand, the cracks closed together.

Most modern constructions include expansion joints, small voids that materials can fill when they expand. Brunelleschi's dome apparently developed its own expansion joints in the form of these cracks without doing catastrophic damage to the building, according to Paolo Alberto Rossi, a Florentine architect who has studied the dome for decades.

A survey completed in 1984 counted a total of 493 cracks of various sizes, sorted into categories identified by the letters A through D. All have formed in a remarkably symmetrical pattern. The most important of the cracks, says Mr. Rossi, who serves on the commission now monitoring the dome, are four dubbed the "A" fissures, which cut through the length and breadth of the dome and divide the structure into quarters.

Mr. Nervi's study noted that the major cracks, such as the A fissures, which opened to a width of about three milimeters in winter, never closed entirely when the dome swelled in summer. One supposition is that plaster used to patch the cracks over the years and crumbling building materials have jammed the fissures. Concern over this phenomenon prompted the creation of a modest monitoring program that has been gathering data since 1955.

Left to its own devices, the dome probably could have gone on for a few more centuries without needing a large-scale intervention, says Mr. Rossi. But then man intervened.

One of the mysteries of Brunelleschi's design involves 48 holes, each exactly 60 centimeters square, that were left in the base of the dome and that are open on the inside and covered by the outer skin of the dome. It has long been assumed that the holes simply served as mounts for the scaffold used when frescoes were painted on the inside of the dome.

In 1978 a government culture agency decided to restore the frescoes, and a private company contracted to build a scaffold for the work decided to fill the holes with concrete so that steel beams could be anchored in them. Alarm is Raised

In 1985, Lando Bartoli, another local architect, noticed that additional cracks were quickly forming around the holes. He loudly raised an alarm, which earned him a place on the current study commission.

"This structure could have lived naturally for a thousand years maybe, but we have gravely reduced its life expectancy whatever it may have been.," he said. In the summer, Mr. Bartoli explained, the four major masses separated by the A fissures generate energy as they expand with the heat. Previously, he asserted, those masses had room to expand into the fissures, but now, at the base of the dome, the masses run into concrete where there was once empty space. The energy that was once dissipated with the closing of the fissures is now exerted against the concrete blocks and is being transferred elsewhere into the structure.

None of the experts on the commission is sure exactly what is happening inside the dome right now, under the hot sun of the Tuscan summer. They believe the concrete acts as a fulcrum so that when the masses push together below the holes, they are forced apart above. Last summer measurements showed that the A fissures in the dome widened instead of closed during the hot season for the first time. The same phenomenon is being repeated this year.

Mr. Rossi believes that with the disruption caused by the blocked holes the dome's outward thrust at the base is being increased to potentially disastrous levels, and he proposes binding the base in some way.

Mr. Petrini, who supervises work on the dome, said: "Our first priority now must be diagnostic. We have to fully understand what's happening before devising an intervention."

Drawing showing location of major cracks in the cupola of the Florence Cathedral