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## Can the dome of Florence cathedral be saved?

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*An Italian expert warns of the peril to Brunelleschi's great engineering feat and masterwork of art, since the staging holes of the cupola were filled with cement.*

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Five hundred and fifty years have passed since the convening of the Ecumenical Council of Ferrara-Florence, which was not only a turning point in world history, but perhaps one of the greatest scientific conferences ever held. The Council began in 1438, and led, in July of 1439, to the acceptance by the Greek Orthodox Church of a basic tenet of Latin Christendom, the *Filioque* clause of the Creed, which had long symbolized the Western commitment to the necessity of technological progress. Some of the greatest Greek scholars of ancient natural science were present at the Council, where they shared knowledge of geography and mapping with Western merchants and navigators, leading to the later voyages of discovery.

The ceremony of Union was celebrated under the recently constructed dome of Santa Maria del Fiore, the cathedral of Florence, which was designed by the first Renaissance architect, Filippo Brunelleschi. Brunelleschi's dome, built between 1420 and 1436, probably contributed as much as the learned arguments of Western churchmen, to convincing the Greek delegation from Constantinople to accept the Latin doctrine of the Trinity, which laid emphasis on the role of Man in continuing the work of Creation. His solution to the challenge of the dome was uniquely suited to a republic, as it depended upon developing the skills of free citizens to realize the design of an individual genius.

Brunelleschi began construction on the dome in 1420, after winning a competition for a design that could span the 41 meters of diameter which the Cathedral Works committee of the preceding generation had left. The Cathedral Works demanded a dome that would not only be high and imposing on the inside, but would also be beautiful on the outside, putting all the surrounding territory in its shadow. Domes of such size had not been built since antiquity—the Pantheon in

Rome was an example at hand—and no one knew any longer by what technique. Moreover, the Pantheon had a low exterior profile.

In his own day, Brunelleschi was applauded above all for solving an insurmountable *economic* problem. The traditional approach would have been to build an armature, a kind of mold to hold the masonry in place while the dome was under construction. There was probably not enough timber in the Florentine domains and certainly not enough money in the municipal coffers for such an armature, to fill a hemisphere 41 meters across. Brunelleschi constructed a double-shelled octagonal dome using a light, movable scaffolding, by applying the methods of projective geometry which he had developed for painting.

The first individual in Western history to hold a monopoly patent on an invention (a marble-transporting barge), Brunelleschi also invented numerous new machines to hoist blocks into place and alleviate manual labor. He is said to have enraged the masonic lodges which had monopolized the knowledge of geometry, by making this knowledge available to the workmen who carried out his designs. The artists' workshops of the Florentine Republic became "national laboratories" to solve the technical problems posed in the dome construction. The young Leonardo da Vinci was trained in such a workshop, working on the casting of the bronze ball at the top of the dome.

Brunelleschi was denounced by the "environmentalists" of his day, who predicted that the dome would fall, and was even jailed at a critical point in the project on the flimsy pretext of failure to pay guild dues. From what Dr. Lando Bartoli, the engineer and Brunelleschi scholar interviewed below, has to report, his enemies may have not given up even today.

# Brunelleschi's Florentine dome after the stopping of the staging holes

*Professor Lando Bartoli, one of the principal experts on the Renaissance architect Filippo Brunelleschi (1377-1446) and on Brunelleschi's famous cupola of Florence Cathedral, was interviewed at his office in Florence by Anna Fontana and Claudio Ciccanti.*

*The interview reconstructs the fight Dr. Bartoli has waged for the earliest possible undoing of the damage to the dome of Santa Maria del Fiore. As has been reported in the press, in February 1979 the 48 staging holes left by Brunelleschi to allow the expansion and contraction of the dome owing to changes in the weather, were stopped up with concrete. This operation was decided upon unilaterally by then-superintendent of the Opera del Duomo (Cathedral Works) Boldrini, on the pretext that it was needed to support the scaffolds of the counterdome set up to allow restoration of the Vasari murals on the inner face of the dome.*

*The interview was granted in October 1987. Since then, three meetings have taken place of the "Study Commission for Safeguarding the Monumental Complex of the Cathedral of Santa Maria del Fiore in Florence, with Particular Regard to the Static Problems of the Dome." Ignoring the facts which Dr. Bartoli presented, the commission decreed "that the scaffolding and the works put into effect, particularly the filling of the staging holes with cement, turn out not to have influenced and do not now influence the static arrangement of the structure and that therefore, in the light of the facts under consideration, no effective damage to the statics of the structure itself has resulted."*

**Fontana:** We heard some years back about the operation of stopping up with cement the staging holes of Brunelleschi's dome, which in effect has cut off the building's "breathing," and threatened its survival. Since Brunelleschi had intended the building to survive for over a thousand years, we would like to hear from you what really happened.

**Bartoli:** From 1984 on, as soon as I joined the Dome Commission, I began to ask for information concerning the operation carried out in 1979, and about which rumors were beginning to fly. That my worries were not well received, transpired from a number of things. For example, I had asked, whether the project had called for stopping up the staging holes, and little by little, I learned that this was not the case. Why then was it done? The project had called for locking into

place the iron brackets which were to serve as scaffolding for restoring Vasari's tempera paintings, and by perfectly acceptable means: i.e., drawers which contained mechanical jacks well suited for locking the brackets in place, and protected by neoprene cushions in order not to damage the staging holes of the dome. Instead of this, the jacks were not placed into the staging holes, due to differences in their dimensions, which in fact exist. The cupola is not a regular, but an irregular octagon; between the largest and smallest vaults, there is more than an 80-cm difference. Thus, the holes are not evenly distributed. So, they could not carry out the original project. So what did they then do? They acted in a rash, unthought-out way, without even a project which should have been submitted to the Minister of Cultural Patrimony for his approval, to the [Dome] Commission, to the Higher Council on the Arts, and without even telling the Commission.

**Fontana:** Didn't the experts have anything to say about this?  
**Bartoli:** They could have. This is where the plot thickens. The fact remains, that the person who was at the time Superintendent, seems to have talked to the then-chairman of the Works on the Dome, and they decided "to stop the whole thing up with cement," period. What an absurd operation. And away they went, and blocked all the staging holes. This happened in early 1979, but absolutely nothing was said about it at the time. The press paid no attention. When, in 1981, the job had been done, a short documentary was filmed by the then-Superintendent, and the whole thing came to light. Shots of a worker, shoveling up the cement and pitching it into the hole, then another worker turning the shovel over and pushing the cement right down into the bottom of the hole, 4 meters deep.

In 1983, I wrote an article in the *Bollettino Tecnico degli Ingegneri*, where I said: "What would Pier Luigi Nervi have said?" In the 1930s, as he carried out his observations on the lesions on the dome, he expressed the fear that tiny bits of stone might slip down into the cracks which are designed to expand in winter and contract in summer, and where tiny elements might get in, for example, bits of crumbled stone. He recommended that one always pay attention to that sort of thing, because the present condition of delicate balance might change and worsen. What would Pier Luigi Nervi have

said, had he been able to imagine that, not just bits of stone, but that the very holes themselves, 60 centimeters wide and 4 meters deep, had been stopped up? The operation was carried out in winter, when the holes are wider, and so are the cracks.

In 1982, others among my colleagues, like Fondelli and Parronchi, had made negative remarks about the operation in the magazine *Paragone*. This operation is wrong from start to finish. Its image, inconceivable, indescribable to me, has remained there to torment my brain.

When, in 1984, I joined the Dome Commission, I began to ask around, to pick up more information as to how something so serious had happened. Thus, it came to light, that the project as originally agreed upon, had not called for this at all, that someone had just done it, unthinkingly. . . .

**Fontana:** Why do you say that it was not at all thought through?

**Bartoli:** I am quite sure that the simplest mason would not have made that mistake. None of us would ever have dared to lay a finger on the work of Brunelleschi. How could something like that happen? At one point, a decision was made to take an initiative. In Nervi's era, all the most severe points of damage were kept under observation, with four readings a year: i.e., the winter and summer solstices, and the two equinoxes, to keep watch on just how the deformations shifted as a function of the temperatures, and these operations, carried out on 20 bases distributed inside the cupola, were always respected, save for short interruptions due to the war, and the flood [1966].

Before the present crime was perpetrated, the most modern systems, using computers and so forth, were used to investigate those operations. They confirmed that in summer the cracks closed up, while in winter, they opened; it was also found, that between the opening and the closing, there was always a tiny difference, of hundredths of a millimeter perhaps, but a difference, which naturally over the years, the decades, the centuries, led to ever-greater drift, to the point that it had become a danger. That is, the difference between the opening and the closing had become ever greater.

Out of this danger arose the need to set up a Commission to study the phenomenon and advise on what steps should be taken. [Premier Giovanni] Spadolini did so, in 1975, namely, four years before the misdeed. The Commission, with its chairman, with three commissioners from Rome, and a number of Florentine commissioners, both public officials and private experts, accepted a new member from time to time due to people becoming unavailable for the work.

There were one or two new members in 1983, and four new members in 1984, from the Engineering Faculty, including myself.

Given the worrisome data which had already been revealed before 1978, I asked that the data from 1979 onward also be made known, to see what had taken place. The latter data, examined by a restricted committee, gave results which

were disconcerting for me, although described by the other members of the committee as "reassuring."

I then responded, both in the sessions where the data were discussed, as well as in written texts—I wrote over 30 memoranda—stating that the data had to be reviewed. I have never received a reply. Everyone seems totally satisfied. Worse: Every time I advanced alarming arguments, they repeated that the data had turned out to be "reassuring." And we marched on to that tune. Then they tried to toss me a sop. They said: Let's go see the state of the staging holes, which, after having been stopped up, and once the counter-dome had been mounted, were no longer visible, hidden as they were by a wooden walkway where the people who were mounting the counter-dome were working.

Around November-December 1986, the holes were uncovered, and the architect Petrini, from the Superintendency, was put in charge of making the survey. He did this, most diligently. He worked for months. He made photographs, took measurements, described the situation. It was a very fine report, which confirmed what I already suspected.

In the first hole which I went to visit, I saw that the architrave was broken. It turned out, that of the 48 holes, 47 had broken architraves. But even the forty-eighth was probably broken. The only difference was, that at times, the break was not visible. The old-timers, once a break started to become visible, called it a hair: this vault was bald. But no one else had noticed this earlier.

So when the news came out that all the architraves were broken, it caused great surprise. It even surprised me, in the sense, that it confirmed to me that something was fishy, whereas the others were reassured, or better, "comforted" in their views. They had worked out, step-by-step, a weird theory. They said, it may well be, that the architraves were already broken much earlier. To which I replied, how could it be, that Father Alfani, Pier Luigi Nervi, and their assistants never observed the breaks?

One of the assistants, Engineer Ferdinando Rossi, who today is president of the College of Engineers, had been entrusted with the task of photographing all the cracks, and at that time, he took the pictures as best he could, because there was no scaffolding up then. So, he worked with binoculars, and then with a camera with a telephoto lens. It is unimaginable that he should not have photographed [the holes], since no instrument was needed, given the fact that the staging holes emerge from the last gallery. There are three galleries inside the dome, one precisely at the height of the staging holes. No one ever noted the broken architrave there. Thus, even allowing for the possibility that the breaks were so tiny that no one could even have seen them, there is no doubt that now, they are all too visible. It seems to me that there is no point, at this stage, running off for equipment and scientists, the thing is so elementary. . . .

How would people have reasoned at the time of Brunelleschi, or in the 1500s? I will tell you: They had no instruments, they had another means, the brain. They were rich in



*Brunelleschi's dome in its Florentine setting. Inset: Plan of the 48 staging holes left open by the architect at the base of the cupola, to support scaffolding for maintenance work, and allow the cupola to "breathe."*

spirit of observation, they were rich in real experience, because these people had lived, from infancy, to childhood, to youth, the life of masonry structures in a way that is no longer known. No one today really knows how wood behaves, how stone masonry structures behave. No one builds that way anymore. Their spirit of observation and knowledge was at that time, highly refined. Today, we are simply dropping such personal virtues. We have become insensitive. People think, why bother? We have electronic instruments. Watch out if the electronic brain, which is of great usefulness, stultifies the human brain!

In any case, at this point, the data which seemed to confirm the correctness of my argument, were opposed on the basis, that the architraves had already broken at some earlier date.

Another decision was taken in June 1986 by the Commission. The Commission was only meeting in little groups of four to five persons, who were following the question, and naturally, we could not come to an agreement, because I refused to give in. At one of these meetings, where Prof. Cestelli Guidi from Rome was present, they said: "All right, let's throw another little sop to Bartoli. Let's put deformometric bases on the lesions, and see whether it is really true that they dilate or not." This was in June. I suggested at the time: Let's be careful. This is summer, when the lesions close up. These readings should better take place from winter over to summer. But on we sped, regardless. Petrini, poor fellow, rushed out and bought a Swiss deformatometer, beautiful piece

of work, state-of-the-art for the task at hand, and big enough to span the holes. Thirteen bases were set up taking a reading: one on the hole, and the others on the biggest lesions. The reading was taken after the 16th and 17th of June 1986, every two hours for 24 hours. And the results showed that I was right. After this, since nothing else was to be done, I asked Petrini to go ahead and take further readings. This was done—it was mid-July—on July 28, 29, 30 and 31, and then on Aug. 1. Then there was a break for the holidays. As soon as we got back, we found that that year, the highest temperature was 38° C, to be precise, Aug. 3; after which, temperatures dropped. We met, with this data in hand, and I showed this reading, as well as the tables supplied by the Superintendency, which I had drawn up in the form of graphs. The "reassuring" information emerged, that the lesions opened in summer, when in fact, they were supposed to close.

I took the argument to the headquarters of the Commission. The reaction was: "It is not possible, we cannot give credence to such data." They wanted to know the heat variations of that period. So I went off to the Ximeniano and asked the director of the Observatory to give me all the temperature readings for Florence from June to September, and these readings confirmed, that the maximum temperatures Petrini had found, did in fact occur. Was it ever possible to bring the problem up with the Commission? No. In spite of repeated appeals made by myself, in spite of the promise made to me, that a meeting would be held in December [1986], which in fact never took place, and another in Feb-

ruary which also never took place, and another on April 10 which never took place, there was no meeting at all until a circular arrived from the Superintendent, announcing that it had been put off until April 29.

At that point, I sat down and wrote a nasty letter. From that moment on, I said publicly, within the Commission, my intention, given the way things were going, to disassociate my responsibility, from that of the Commission. On April 29, when the meeting finally took place—it was the last meeting—I informed people that I was not resigning from the Commission, but rather simply changing my interlocutor, and that from then on, I would address myself to the Minister for Cultural Patrimony. An attempt was made to shut down the whole debate, by means of a vote.

From that moment on, I regained my freedom of action vis-à-vis the Commission. Initially, we were to refrain from publishing anything, save for joint, agreed-upon communiqués by the Commission. From then on, my articles and interviews began to come out in the international press as well as in Italy, and I threw the Commission onto the defensive. When I received notice, that the meeting had been put off to April 29, I wrote an accusatory letter. Had someone dared to address to me the sort of accusations I made against the Commission, I would have sued them.

**Fontana:** Does their behavior stem from the fact that they know they are wrong?

**Bartoli:** Of course. I accused them of beating about the bush and putting up a big smokescreen, with the obvious aim of covering up the truth. The Commission has put their trust in the ISMES, the firm which has been setting up new reading equipment, and they say that this will bring the truth to light. But all that equipment will not suffice to repair the broken architraves. They cannot correct the damage. The damage which has already occurred and is worsening, is the serious thing. It is intuitive. Had we not already warned that the drift was worsening, well before the staging holes had been stopped up with cement? After the holes were plugged, in 1979, what happened was that the cracks could no longer close, and from that year on, they continued to open still further, even in summer.

In order to get back to the initial measurements of the greatest opening in winter, with the yearly deformations something like 15 to 20 years would be needed. We have lost the last 20 years. We, who were entrusted with keeping watch over the dome, in order to plan out the measures required for its health, what have we done? We have hastened its death. We have not only lost 20 years. Mark this.

The 20 years were lost for the four main cracks. But the holes are 48 in number, and all of them are called upon to open. We have observed this, thanks to the deformato-meters applied over the 4 main holes, then the others. All the architraves are broken, or, better said, all the openings over the architraves have appeared. What does this mean? It means, that these cement blocks tend to dilate, widthwise, and even

in depth, and the lesions actually lengthen out. Thus, in the body of the masonry, there have appeared these three-meter long, 50-cm wide prisms which extend right out to the outside surface of the building, which is not only exposed to temperatures which three years ago actually hit 40° C, last year 38° C, and this year a maximum of 35-36° C; you also have to take into account solar radiation, which increases temperatures from 10 to 20 degrees. These blocks of cement act like wedges over all eight sides of the dome. We are dealing with an alteration of the entire base of the dome, which is now suffering from an anomalous situation which did not exist before. This is the physical damage we are faced with.

I believe that I have found, in fact, I am sure of it, the crux of the error into which the others have fallen. Intuitively, I had always rejected the thesis according to which, after 1979, it was said that everything was doing fine, that the data were "reassuring." I have understood where the error lies, and I hope it was in good faith. The real problem, is that people have abdicated the responsibility of their own brain, in favor of that of the computer. The computer has a great characteristic: It is perfect and works well, but it never doubts. As for ourselves, when we are at work, we are constantly checking the operations of our method of reasoning, and if, while we are working, data turn up which cast a shadow of doubt, we hold off and try to understand why. But this operation, of doubting, and then changing one's data, is precisely what the computer cannot do. It is already programmed. . . . This is the error—they approached the post-1979 readings with the same parameters they had used before.

**Fontana:** It does seem odd, the high-handed way your diagnoses have been rejected. . . .

**Bartoli:** Let me tell you why. I told you about the disastrous intervention of February 1979. I told you also, that the Commission, the same one we have now, apart from a few members recruited afterwards, had been set up by Spadolini in 1975. I have written many memoranda, because I realized that the so-called minutes of the meetings, were not even signed, still less approved or re-read, absurd things occurred. . . . I would like to be a publisher. I could keep a steady supply going into one of the best humor papers you could imagine. I have read all of the so-called minutes of the Dome Commission. This Commission, which now has 22 members, is divided up into Committees, depending on people's qualifications and their cultural interests.

There is a committee on structure, a committee on painting, for the problem of the frescoes (rumor has it that something will one day be done, but restoration has not yet started, because they don't have the scaffolding), then there is the committee responsible for taking the readings, and the committee on painting is all topsy-turvy because there are herds of young researchers who would like to make microscopic analysis because it seems, that the paintings are masterpieces, though—among other things—they cannot be seen because the dome is dark inside.

**Fontana:** Vasari's temperas don't strike us as great works of art.

**Bartoli:** No. But no one admits it. It's so much the case, that after 1981 a movement was sparked by [Italian art historian and publisher] Carlo Ragghianti which advised that they be whitewashed, or detached from the wall and stuck off somewhere in a warehouse for art history. This would have brought light back to the dome, and this would have been lovely, because Brunelleschi hadn't intended to put up frescoes. His idea was to decorate the inside of the dome with tesserae of glass, with Venetian-style mosaics, like those of our Baptistery, which shed reflected light. Only a little is needed to shed light over the walls, using brilliant colors, gold, tesserae of gilded glass, or colored stone, which would make a reflective surface. Such a small amount of light was supposed to be reflected, so the decorations could somehow be seen. . . .

**Fontana:** Let's get back to the Commission.

**Bartoli:** I am sure that right from beginning, no thought whatsoever was given to what the problem was, because when I brought it up in front of some of my fellow engineers, some of them, upon hearing that the holes had been stopped up, almost fell off their chairs, swearing that it was simply outrageous, even for purely technical reasons.

Others objected, saying, "these are just isolated facts, I can't believe it's a problem." But when we put pressure on one of them to reason the thing out, on the basis of purely logical reasoning, like the fact that cement, when waterlogged, dilates, i.e., on the basis, of the dilation-coefficient of cement, which is twice that of stone or brick, they had to admit we were right. I mean to say, that having had this experience, I am not in the slightest surprised that some, who were Commission members in 1979, were stunned by my denunciation. But I made it in 1985. The proof that I was right, came only in 1986. Six, now seven years have gone by since that lamentable intervention. I provoked them, saying that they are first, trying to hide the truth, but the longer they try to cover it up, the worse the scandal will be when it finally comes out.

**Fontana:** What will happen to the dome if action is not taken without delay?

**Bartoli:** The static problem is not the risk. When I said that 20 years had been lost, during which the dome had prematurely aged, this does not mean that it is going to collapse on us. The real danger is that unless the cement be removed, the life of the dome, which, according to Nervi's view, would originally have held another thousand years, will be cut back to 500, maybe only 400 years. This is because the dome, due to the action of dilation of the lesions, was previously opening by only that tiny degree of drift which one has normally every year. Now however, we no longer have those spaces to make up, in summer, for the swelling in winter. I do not claim the spaces made up for the drift 100%, but it was enough. Now,

with all 48 holes trying to dilate, inside of accomplishing what they were designed to do, the dome is tending to balloon out, and none of us has any solution in mind save reining the whole thing in with chains.

With these 48 wedges which tend to expand in summer, we have obtained the precisely opposite effect. We are helping to have the dome pop like a balloon. . . . There does in fact exist a project, which I myself prepared, to rein in the dome with chains, but I never managed to have it discussed by the Commission. In 1600, [engineer Domenico] Fontana had already planned to chain the building, but he also wanted to carry out heavy works on the masonry which would actually have damaged some of Brunelleschi's original structures. My project is more elegant. . . .

**Fontana:** Dr. Bartoli, you mentioned that the notorious concrete wedges could be taken out. This would be both expensive, and a very tricky operation indeed. What of that project?

**Bartoli:** I have already gone over that idea with certain firms which are expert in the field, and it is a complicated, lengthy, and delicate thing to do.

It has to be done using a core lifter, the sort which are used for taking samples of ore. You separate the stone-masonry from the cement. This would be the most urgent thing to do. From a conceptual standpoint, it is not hard to do. The hard bit is the operational profile, and it would be better if Titular Professors stayed away from it and left the job to people who know how to work with both their hands and their minds. Basically, you need good carpenters, and there are still some around.

Today, we stand idly by, paralyzed by problems which you can't even call just problems anymore—they have turned into "problematics," and that is a whole different kettle of fish. No one has the guts to go out and do what has to be done, the way they used to.

The dome is for me a being which I have worked on for many years, to find out its secrets, and save its life. Its present state torments me: It is the last thing I think of before I fall asleep, and the first thing when I awake. Let me turn to men of culture. I told this to an expert in art history, who sits on the Commission. I said to her, "You are responsible for this, you are to blame." She replied: "What do you accuse me of?" "Well, it is quite simple: You are doing nothing, you have said nothing, although you have been asked to say what you think." The answer was: "We are not experts." How can you not understand? This is the dome of the Cathedral, the dome of Brunelleschi. I am not asking you to judge the technical fact in itself, but the concept, the principle. Have you nothing to say, when you find out, that every hole left there by Brunelleschi, was filled with cement? Do you find that acceptable? Have you all lost your tongues? Do none of you even have an opinion? Nothing. So, the first injury to the dome is a moral injury, on the level of culture. Then we can get onto the technical questions and cross swords with the so-called "structurists."