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The Crack Pattern in Brunelleschi's Dome in Florence: Damage Evolution from Historical to Modern Monitoring System Analysis

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Abstract The aim of this paper is to show the potentiality of the historical analysis mixed with the experimental data elaboration in identifying the mechanical behavior of an ancient monument. Firstly, an ideal route through the crack pattern of Santa Maria del Fiore dome in Florence is presented herein: the conclusion of the historical debates about the mechanical behavior of the dome are analyzed in light of the statistical interpretation of the last 55years cracks monitoring data. The recall of some historical debates has been fundamental in the comprehension of its mechanical behavior, showing the validity of the empiric-experimental method in ancient master builders solution (the "*art of building*" rules) to the main problem of the masonry domes: their primeval and ineradicable horizontal thrust on supporting structures. The final aim is to present some results on the beneficent effect of the scaffolding installed on the dome from 1980 to 1996, which seems to confirm the prevision made by Vincenzo Viviani at the end of XVII century on the future consolidation of this dome.

Keywords: Brunelleschi's dome, monitoring system analysis, historical analysis, empiric-experimental method, art of construction, encircling strengthening intervention.

Introduction

The Brunelleschi's dome is a deeply studied monument. Considered for centuries the widest masonry dome in the world (the distance between two opposite corners measures about 42.2 meters, or else 72 *florentine braccia*), it is one of the fews huge masonry domes ascribable in engineering masterpieces (as the Roman Patheon, Hagia Sophia and Sulemain Mosque in Istanbul, Saint Peter in Rome). These magnificent structures have been all realised referring to the empiric knowledge based on the "static sense" of ancient master-builders and to the experience of previous collapses of similar structures. A reappraisal of this type of knowledge is really desirable even today in order to identify the real mechanical behavior of ancient monuments which often can find their structural interpretation in the "*art of building*" rules, more than in the modern concepts of new building science.

Numerical models, in fact, - even very precise and complex - can hardly describe the real behaviour of masonry ancient buildings, mainly considering the rough approximations at the base of "masonry" modeling as a modern material: its homogeneity, isotropy and linear behavior. By observing any ancient wall is immediately clear that considering this material as "homogeneous" is a far-fetched concept. Its great resistance to compression and no resistance to traction get complicate when it's necessary to study its behavior by modern science of construction, based on perfect and well known materials. Due to the very limited number of tests which can be carried out on an ancient building, a reliable definition of material mechanical characteristics, normally deducible by statistic formulas is even more difficult.

The translation into quantitative parameters of the several changes, displacements and reconstructions phases which have occurred to masonry ancient buildings is really complex and often unreliable. Numerical models, in fact, are still unable to consider the capability of the ancient structure to not collapse even in presence of severe damages thanks to a progressive adaptation to new geometrical shapes, more and more deformed, which soon represent new equilibrium states. This consideration, with the evidence of the ancient monument secular stability, clearly shows that is always necessary a mutual support between numerical methods and empiricism, in order to reduce

uncertainties of assessment. In keeping with this, the recent Italian law for seismic protection of architectural heritage (*Direttiva* 2008) stresses the importance of empiric-experimental methodology as fundamental instrument in historical buildings mechanical behavior evaluation and in their consolidation intervention definition.

The description of the analysis path carried out on Brunelleschi's dome seems to be a good occasion to demonstrate the efficiency of this method, considering also the "time effect" on the tensional and strain state, in which the creep phenomena keep for centuries. Affected by a complex crack pattern, which had appeared on it as soon after its construction, the Brunelleschi's dome has been for centuries at the centre of numerous debates on the "secrets" of its genial builder and on the causes of its widespread cracks phenomena. These cracks had been increased and modified during centuries and numerous monitoring systems have been positioned on them in order to control their development in time. The most impressive is probably the last one - which has been installed on the dome in 1987 by ISMES (162 instruments) and which is still controlling the evolution of the cracks in relation to environmental conditions, but very important, in particular for the long-period of time registered, is also the mechanical monitoring system (22 instruments) placed on the dome by Opera del Duomo in 1955.

Through an accurate analysis of cracks thickness measurements both considering the historical data and the more recent ones, it has been possible to establish a connection between the actual configuration and the static movements developed in the monument during the centuries, finding a theoretical justification for the examined crack pattern and considering its correlation with environmental phenomena. Indeed, a depth study of the history of these cracks represents the fundamental step for the complete understanding of the static behavior of a monument, considering that "*static analysis is, first of all, historical analysis*" (Di Stefano 1990). Starting from the first documents of Giovan Battista Nelli survey, to the further precision measurements by Ximenes (in 1757), passing through the relation on damage made by Gherardo Silvani (in 1693), up to the last century Scientific Commissions reports (Nervi in 1936, Sanpaolesi in 1975 and Chiarugi in 1988) it's possible to trace the evolution of cracks during centuries, critically examining also the suggested hypothesis for their causes. In this paper, the results of the statistical analysis carried out on the monitoring data of the two last monitoring systems are presented, in order to further clarify some relations previously established between the cracks widths and environmental variables (as temperature variation and changed boundary conditions). Previous studies have already examined the data recorded by these monitoring systems until 1996 (Blasi 1990, Blasi and Ceccotti 1984, Chiarugi and Foraboschi 1995, Chiarugi et al. 1998, Gabbanini and Vannucci 2004) finding the global trend of the deformometers and suggesting a relation with temperature. Here a further step is proposed, which partially confirms the structural conclusions reached in these previous works. Moreover, for the more numerous data available at this time (thanks to the strict support of Opera del Duomo and of Ximenian Association) some new considerations are added on the dome structural interpretation and possible consolidation opportunities.

Brunelleschi's Dome "Secret" Perfection? Some Preliminary Issues

Formed by an octagonal structure which includes an internal dome and a thinner external one, structurally linked by joining masonry elements, the surfaces of Brunelleschi's dome are cylinders with a straight elliptic section, generated by oblique projection of circumference arches (Quilghini and Chiarugi 1984).

The original project of Santa Maria del Fiore cathedral and of its magnificent dome dates back to the end of XIIth century, in gothic age, as shown by the frescoes realised about one century before the dome construction, in first decades of XVth century, by Filippo Brunelleschi. The famous architect had been charged, by a contract, to complete the cathedral by superposing an octagonal tambour with circular eyes and "a sesto di quinto acuto" dome on the existing structure: by this fact we can say that

the original idea of the dome shape is attributable to the XIVth florentine master-builders knowledge, while the structures conformation and their accomplishment are Brunelleschi's own "inventions".

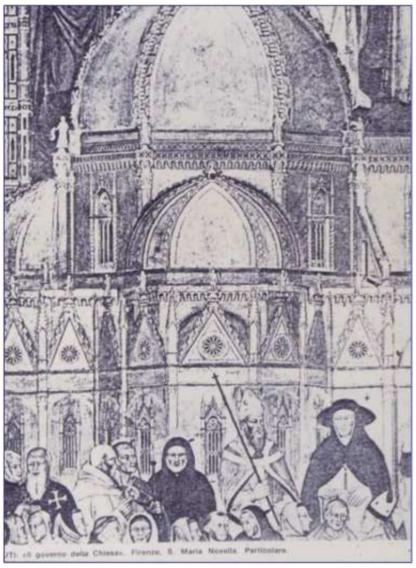

Figure 1: Fresco by Andrea Di Bonaiuto (1365) representing the original project of Santa Maria del Fiore, in Santa Maria Novella, Florence

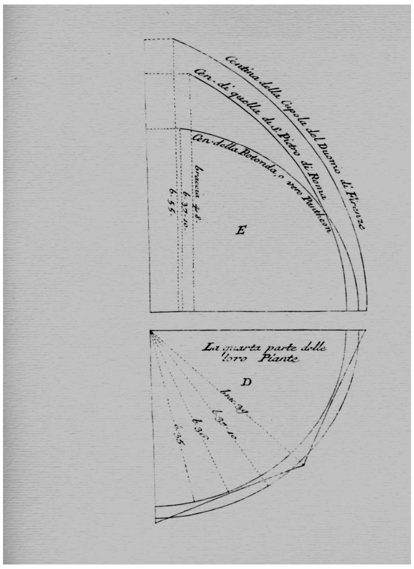

Figure 2: Comparison between the different centrings put on the edges of Pantheon, Saint Peter and Santa Maria del Fiore domes, in a drawing by Bernardo Sansone Sgrilli (1733)

The complex geometry proposed for the dome confirms the deep knowledge of ancient architects of XIVth and XVth centuries and their competence in realizing huge structures by following shared proportional rules. They certainly couldn't have a precise idea of the mechanical behavior of masonry, but, for sure, they must have figured out the "forces path" inside these huge structures. The geometry of Florence dome is known since a long time, thanks to the historical documents available and to the precise surveys carried out during the centuries on this structure (Dalla Negra, 2005). Nevertheless, some "naive" hypothesis are periodically proposed, regarding its geometry and tracking.

As for all the ancient polygonal domes, the geometry is tracked on the edges, in virtue of the more easily realisation and control. Considering the plan, in fact, the simplest geometry is the circumference, in which is easy to inscribe a regular octagon, while in elevation the centrings are placed on the edges for the curvature definition. Brunelleschi's dome lays on a 90 braccia square, as the border circumference at the base, while the octagon circumscribed circle measures 72 braccia.

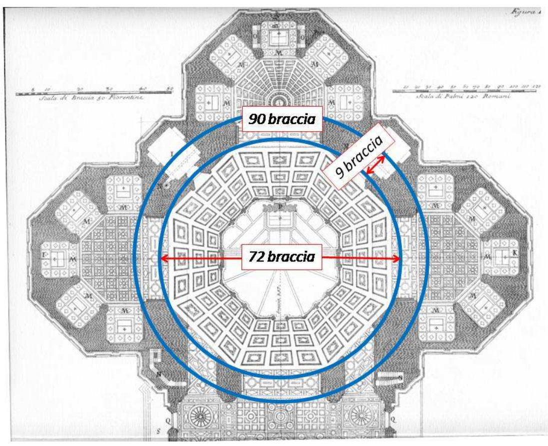

Figure 3: Metrological study of the Brunelleschi's dome in plan

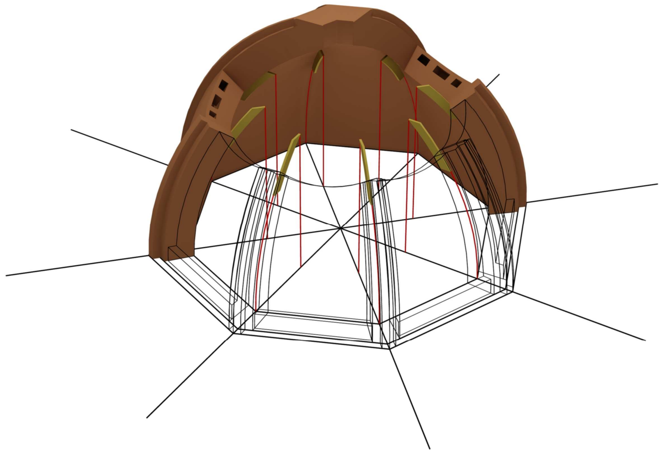

Figure 4: The rampant scaffoldings system reffered to a unique central point for the eight edges tracking probably used by Brunelleschi

On the edges, the thickness at the base measures 1/10 of the external diameter - as for the near Giotto's baptistery which surely had been taken as example by florentine builders – while at the springs the dome's thickness decreases to 1/12 of the diameter of extrados circumscribed circle and 1/10 of the internal one (that is the edges distance). All the ribs of the structure focus in the centre.

Is well known that the dome was built without using bearing scaffoldings and this fact doesn't constitute itself a real innovation: it was clear that, for the height and the involved loads, scaffoldings with bearing function would have been unfeasible for such a huge structure. Brunelleschi's real innovation stays, rather, in the use, also for the geometrical outline of his dome, of rampant scaffoldings system (*centine rampanti*) referred to a unique central point, in order to control the mutual shape and position of each scaffold (as is shown in the Fig. 4) which reveals his deep geometrical knowledge.

The corroboration of this constructive technique hypothesis comes from the finding of anchorages on the centring scaffoldings and from the ancient description made by Gherardo Da Prato in his parchment (Gherardo Da Prato, 1421), which referred of a *sesto acuto* dome realised by Brunelleschi by materialising only the media centre, in which all the ribs were converging.

In a masonry building is impossible to separate the structural aspects by the architectural and formal ones because shape and structure are coincident. In the Brunelleschi's dome, conversely, the complex bearing structure has remained hidden for centuries. It is formed by huge and articulated ribs between the two domes (the internal and the external one), in which the bricks have been arranged in different and complex geometry in order to achieve the best structural behaviour.

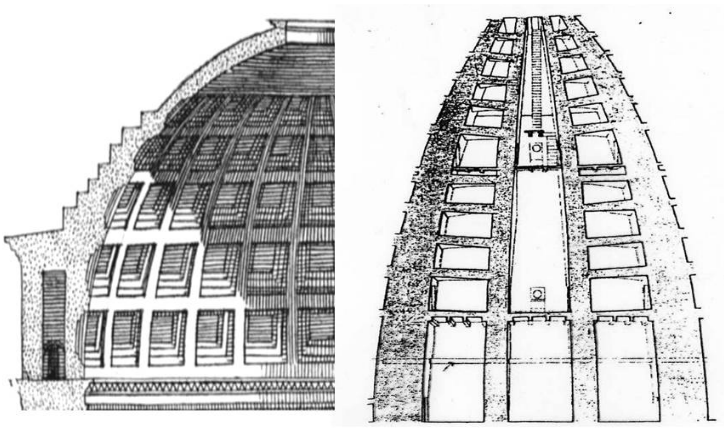

Figure 5: Comparison between the visible ribs of the roman Pantheon (left) and the hidden ones of Santa Maria del Fiore (right)

Certainly, he should have well investigated the semi-domes system of Hagia Sophia for dome thrust contrasting and the perfect circular geometry of the roman Pantheon together with its complex ribbed system, and he replicated the technical solutions of both these exemplar structures in his extraordinary dome (in the perfect application of the empiric-experimental method of the age). Moreover, he surprisingly seems to have anticipated, in the disposition of the masonry inside his dome, the perfect stereotomy applied by Rondelet in his French Pantheon, three centuries later.

His well known technical “tricks”, *corda branda* and *spinapesce* apparatus, have been object of several studies and both the bricks dispositions aimed to assure masonry resistance and homogeneity. Automatically determined by the intersection between conical and cylindrical surfaces, the bricks laying on curved “beds” (corda branda) constitute conical and continuous surfaces which, combined to the adoption of angular staggered bricks in correspondence to the corners, are able to guarantee a masonry texture without discontinuities in the building rings. The final aim of Brunelleschi was to avoid negative interruption of the masonry texture, which would have represented risky weak zones in the angular ribs, causing the start of the cracks (Chiarugi 1984). Despite some new acquisitions by recent georadar investigations (Giorgi and Matracchi 2008) which have testified some irregularities in the “perfect” Brunelleschi apparatus (different bricks inclination on the eight faces of the dome and

between the two shells, discontinuities and variable thickness of the mortar joints) the disposition of vertical bricks in radial helixes (*spinapesce*) is nothing else than the translation of the octagonal Brunelleschi's dome into a rotational one, assuring the final equilibrium of the dome during its construction.

Certainly Brunelleschi couldn't have the mechanical cognitions necessary to understand the risk of bending behaviour of the huge octagonal tambour (a “beam-wall”) at the base of his dome, which, loaded by the dome and lantern weight, and supported in a discontinuous way by only four pillars, would have soon become the future collapse mechanism trigger (Fanelli and Fanelli 2004).

The cracks evolution started soon after the construction of the dome, possibly after the strong earthquake of 1453 (Blasi, 1996) and different hypothesis on its cause during centuries have been made, stimulating structural historical debates.

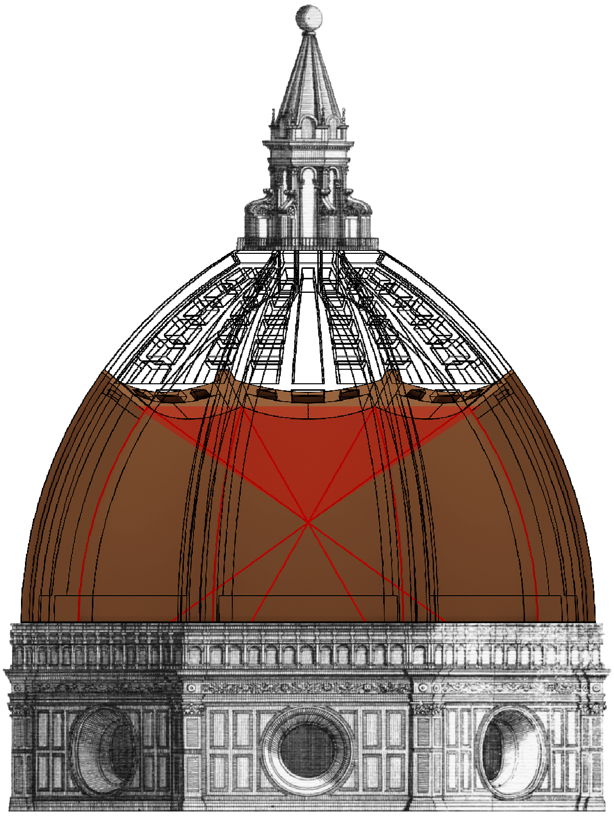

Figure 6: The bricks laying on curved “beds” (corda branda) constitute conical and continuous surfaces, combined to the adoption of angular staggered bricks in correspondence to the corners

The Crack Pattern Analysis and Its Causes: a Structural rRoute Through Historical Debates

The widespread crack phenomena which had interested the Brunelleschi's dome during the centuries has pointed out a substantial symmetry, which finds even notable variations, with a concentration on the “peer slices” due to the different underlying bearing structures (the huge pillars instead of the wide arches). It seems to confirm the well known collapse mechanism typical of the domes: a droop of the top of the structure under its own weight.

Following the classical numbering of the webs (web 1 facing the nave, and proceeding in clockwise direction) the main passing cracks of Santa Maria del Fiore are on the webs 4 and 6, while other two, quite symmetric, are visible in webs 2 and 8. Moreover, inclined cracks near the eyes, above the keystones of the underlying arches, constitute a minor cracks system in the uneven webs, and not passing cracks stand in the 8 edges of the dome.

This complex crack pattern has evolved during centuries. The first information about it date back to Gherardo Silvani report (18th September 1639) which refers about “hairs” (peli) “through which

air and wind can penetrate inside the dome”. Nevertheless, a long series of indirect evidences (like frescoes, the external cornice called gabbia dei grilli) testify that the crack pattern has begun short time after the dome construction.

In 1695, Gianbattista Nelli and Vincenzo Viviani, after some alarms about the statical situation of the dome, were charged to carry out a survey of the cracks and in his report Nelli wrote about two major cracks reaching a 2,9 cm maximum thickness (un soldo di braccio). During the survey (February 1694) he put stone spies on the main cracks (the first monitoring system of the dome) and after the seismic event of 22nd September 1695, this primeval “deformometers” testified, with their breaking, the displacement of the structure and the cracks width evolution.

In the same report, Nelli and Viviani attributed the cause of the cracks opening to the weight of the dome, and consequently to the horizontal thrusts on the pillars: the installation of iron encircling ties would have constitute the solution for its cracks evolution. After the construction of the first encircling element, the debate on cracks causes started again, between the “obscure architect” Alessandro Cecchini, who attributed the cause of the cracks to foundation differential settlement phenomena, and the mathematician Vincenzo Viviani, who first applied, in this historical occasion, the Galileo's theory about materials resistance. For the first time, he quantitatively “calculated” the restraint action of commonly used iron ties on the slices of the dome, establishing in the horizontal thrust at their springs the collapse mechanism typical of domes. This debate represents, even before the more famous one on Saint Peter dome, the first application of science of construction to the classical empiricism (Chiarugi 1996).

In Nelli's report, as in Silvani's one, “major” cracks are referred and this fact implies that some minor cracks should have been present on the dome at those times. A complete description of the crack pattern is available only in 1757, when a precise survey is made by Leonardo Ximenes and 13 different cracks are reported and fully described. The two main cracks, at that time, were in webs 4 and 6 and we can trace their development by comparing the present surveys to the Ximenes's one (Guasti 1887). By describing the cracks Ximenes also gives an interpretation of the structural behaviour of the dome, writing that “In this way the dome results divided into two parts: the first one, which comprises one quarter of the dome, is completely detached by the other one, on the western part, which represents the three quarters of the whole dome”. From his words we can deduce that the two other main cracks (nowadays present in webs 2 and 8) have been developed after 1757. It isn't possible to establish exactly when they have been formed, but the literature finds a probable cause in the seismic event of 1895 which could have primed the opening process.

Anyway, the structural conclusion suggested by Ximenes was that the cause of the damage had to be attributed to the downfall of the pillar n.4 and he supported his hypothesis by a theoretical demonstration of a circular ring breaking subject to springs action (*elastri* and *molle)* at its centre, which nowadays seems to be an imaginative structural interpretation. However, the wrong hypothesis of differential settlement and downfall can be comprehensible if we think to the strongly asymmetric crack pattern, with only two main cracks, present at those times.

We can't, at this time, establish exactly the starting of the minor cracks which involved the dome but, comparing the conclusions and observations of the different commissions charged of Brunelleschi's dome cracks interpretation, we can collect quantitative historical informations from which it's possible to trace a linear progression of the cracks widths in about 5 or 6 mm for century.

In 1934, a special Commission nominated by the Opera del Duomo describe a cracks situation very similar to the present one, even if the crack on the web 2 hadn't been surveyed. The Commission worked for three years, surveying with extreme accuracy the relation between the cracks width and the temperature measurements and suggesting an annual and daily periodicity of displacements. The Commission's conclusions on damage causes are not unambiguous but we recall here the theory advanced by P.L.Nervi who refused the hypothesis of initial breaking of the circular ring at the base of the dome, and who individuated in the thermal variations the main cause of damage (Di Pasquale 1977). Only in 1985, after some studies with numerical models on circular rings (Ceccoli and Merli 1976) the Ministerial Commission De Angelis D'Ossat – Cestelli Guidi, reached the conclusion that

the main cause of the crack pattern was the dead weight of the dome combined to the lack of tensile resistance of masonry, confirming the intuition of Vincenzo Viviani (Chiarugi et al. 1995).

The Monitoring Systems

In order to deeply investigate the behaviour of the cracks in relation to environmental and mechanical events on the structure, in this study we have analysed the data recorded by the two monitoring systems nowadays still working on Santa Maria del Fiore dome: the mechanical one installed by Opera del Duomo (O.D) in 1955 and the digital one placed by ISMES in 1987.

The first system (O.D. From 1955 to 2009) is composed by 22 mechanical deformometers placed on the main cracks of the dome (Fig. 7) which register the crack width variations four times a year (214 recorded data are available for each instrument at present time).

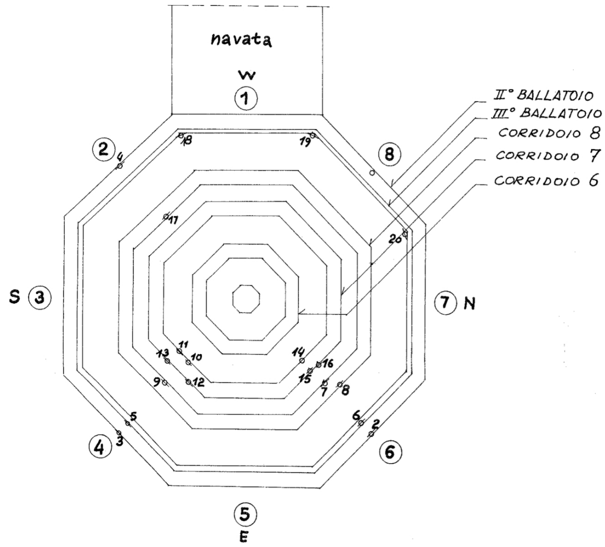

Figure 7: Positions of the 22 deformometers installed on the dome by O.D. (1955 – 2009)

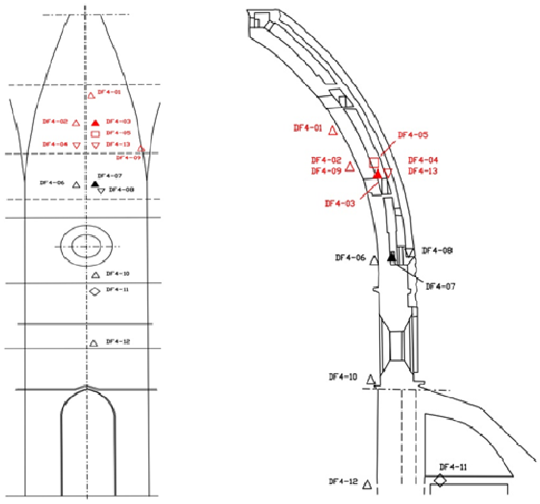

Figure 8: Positions of the deformometers installed by ISMES. (1987 – 2007).Web. n. 4

The ISMES system, more articulated, is composed by 166 instruments and it registers not only the cracks width but even the structural movements most important in the description of the dome conditions. 72 displacements transistors (Dfn-mm) inductive types, with a precision of +/- 0.02 mm, are positioned on the main cracks, and near the edge of the dome, at five different levels, and in different positions of the inner and outer domes as shown in Fig. 8.

The system is completed by 8 plumb-lines at the centre of each web, which measure the relative displacements between pillars and tambour, 8 livellometers and two piezometers, near the web n. 4, and below the nave, in order to evaluate the variation of the underground water level.

As highlighted before, former studies (P.L.Nervi) hypothesised the temperature to be the main cause of the crack width variations; in order to fully understand this problem, both air and masonry temperatures have been monitored during the last 20 years: 60 thermometers on each web, at the second corridor level, have recorded masonry and air temperature in the two domes (TMn-mm and Tan-mm) with a precision of +/- 0.05°C. The acquisition system registers data every six hours, starting at 6.00 a.m every day and 20 years data, recorded from 8th January 1987 to 31st July 2007 (about 31373 measures for each instrument) have been here analysed.

The Experimental Data Analysis

The primary goals of the monitoring systems were to give a complete description of the cracks movements and width variation, with particular attention to the correlation between environmental actions (as temperature) and structural response.

A statistical analysis have been carried out, at the same time, on the two series of experimental data, trying to clarify some aspects of the global structural behaviour, referring to instruments directly interrelated for their position on the dome.

As a first step, a statistical analysis has been carried out on the 55years data of the O.D. system trying to underline the trend of cracks width variation in time. A linear regression has been applied to the 22 instruments, showing an increasing of crack width equal to 3 mm per century, which only partially confirmed the results of previous investigations (Bartoli et al. 1993).

In Fig. 9, the crack width registered from 1955 to 2009 at deformometer DF5 placed on web 4 is plotted. In the same figure, the linear regression of the experimental data is also shown and it confirms the increasing of the crack width, but the agreement between this regression and the registered data is quite poor. Therefore, we tried to use the historical analysis to improve this statistical interpretation. In 1980 the very contested encircling scaffolding was put in work for the restoration of the dome frescoes (Dalla Negra 1995) and this suggested a possible different interpretation of the data.

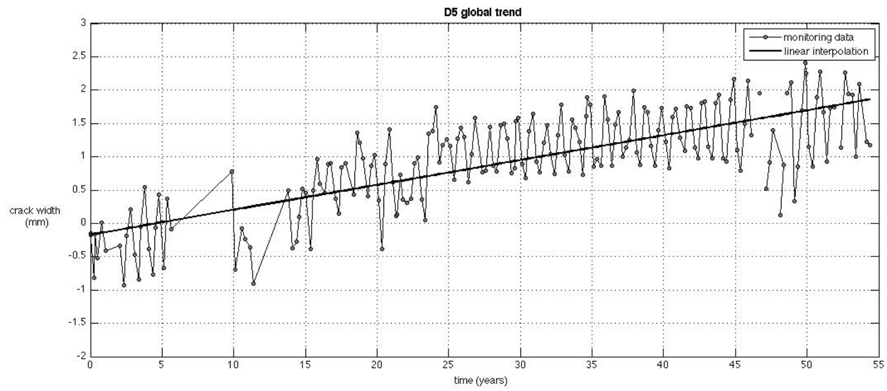

Figure 9: Global trend of DF5 in web 4 in the last 55 years (from 1955 to 2009): the linear regression stresses a crack width increasing of about 3 mm per century

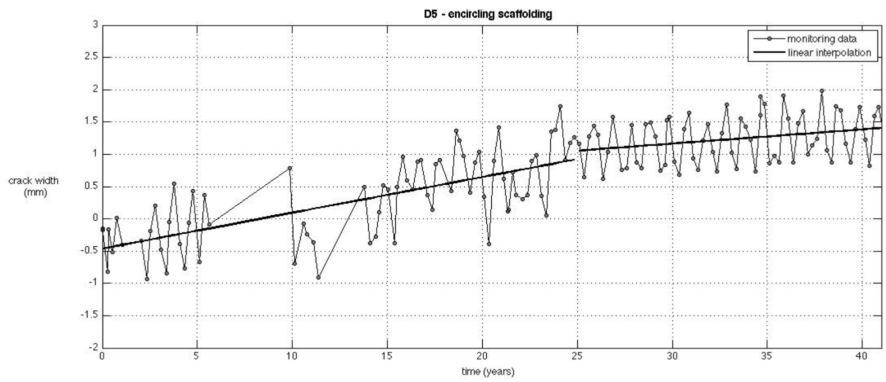

Figure 10: Linear regressions of DF5 in web 4 in the two analysed periods

In Fig. 10 two different linear regressions are plotted: the first one is made considering the period from 1955 to 1980 whereas the second one is made on the following period (1980-1996).

This second statistical interpretation shows a better agreement with the experimental data; moreover it also highlights a variation of the crack width trend which passes from 6 mm per century (before the installation of the scaffolding, confirming the Chiarugi's results) to 2mm per century during the encircling presence on the inner dome.

Here (Fig. 10) only the results of DF5 in web n.4 are reported, but similar findings have been obtained in the other instruments analysis. This deformometer, for its position, can be directly compared to that installed by ISMES in 1987 (DF4-06).

These data allows to clearly evidence the long-term evolution of the cracks (for the extraordinary long period of measurements) but they are not able to reliably describe their relation to environmental

loads variation, as temperature and water levels. Then, a further statistical analysis has been carried out on ISMES instruments, firstly considering the deformometers variations during time.

This preliminary operation has clearly shown an annual periodicity (Chiarugi et al. 1996) reliably due to thermal variations, well approximated by a linear plus harmonic interpolation which seems to represent a "good perform" of experimental data (Rsq is around 0.8):

$$f(x) = a + b \cdot x + c \cdot \sin(d \cdot e) \tag{1}$$

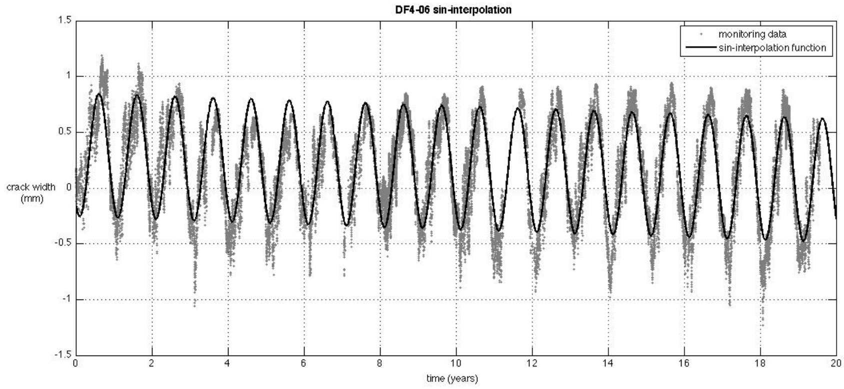

Figure 11: The experimental data of DF4-06 (1987-2007, from 0 to 20 years) interpolated by the Eq.1 shows the periodicity due to the temperature effect on crack widths variation

Once established the influence of temperature on cracks width variations, the eventual increasing of the cracks width in time can be evaluated only "purifying" the experimental data by the investigated thermal effects.

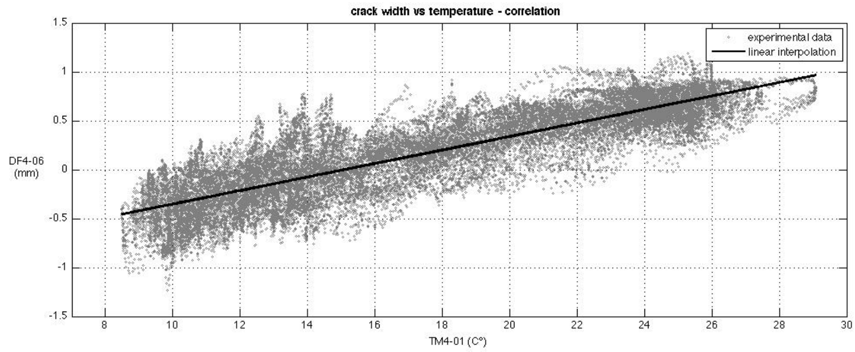

Figure 12: The linear correlation between crack width (DF4-06) and temperature (TM4-01)

By examining displacements (DF4-06) and temperature data (TM4-01) in the same position of the dome, a cross correlation curve is well represented by linear interpolation (Fig. 12):

$$f(T^{\circ}) = a + b \cdot T^{\circ} \tag{2}$$

Cracks width variation can be seen as the result of a series of phenomena (T°, water levels, seismic events, wind forces, changes in structural boundary conditions):

$$f(\text{time, T°, water level, boundary conditions,...}) = f(T^{\circ}) + f(t) + f(wl) + \ldots \tag{3}$$

By substituting Eq. 2 in Eq.3 we can reliably obtain the "purified" experimental data (Fig. 13).

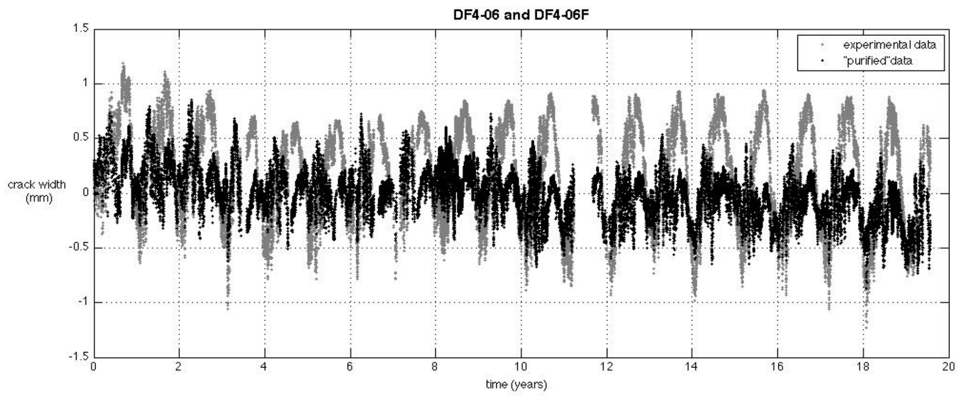

Figure 13: The experimental data recorded by DF4-06 (in grey) and the "purified" ones, after the removal of the temperature correlation function

This procedure has led to a more precise evaluation of the crack widths trend values (even if some residual periodicity can still be traced in the data) and the results obtained by the previous analysis are confirmed evidencing two different behaviour in correspondence to the presence and the removal of the encircling scaffolding of the inner dome. As stated before, if we examine the linear regression of the "purified" data on the whole period we find a global increasing trend of crack width (here, conventionally, the openings of cracks are negative) of about 2 mm per century (Fig. 14).

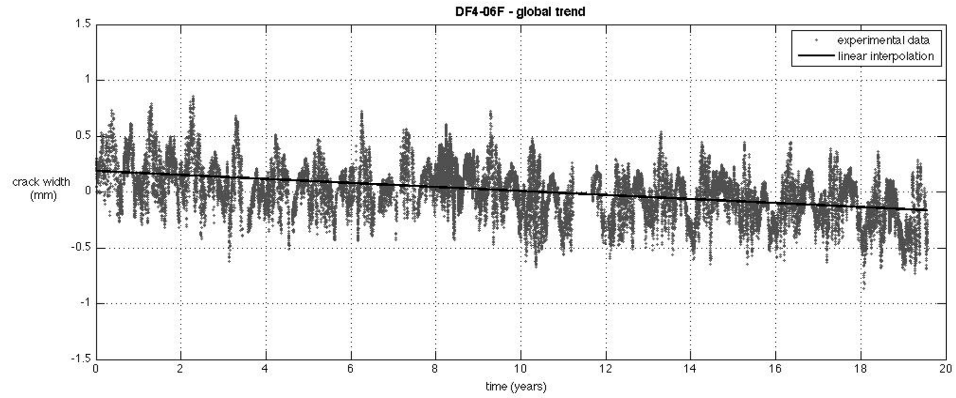

Figure 14: Linear regression of the experimental "purified" data recorded by DF4-06 on the whole period of measurement

However, if we slip this analysis into two different periods, considering the effect of encircling scaffolding on the structure (1987-1996, from 0 to 9 years in the x axis) and its removal (after 1996, from 9 to 20 in x axis), we obtain the real trend of the crack width increasing, of about 2.5 mm per century, underlying the beneficent effect of the scaffolding which seems to have confined the cracks opening to a nearly horizontal trend (less than 1 mm per century is the value found by examining the first period, Fig. 15).

Conclusions

The crack pattern on Brunelleschi's dome, has progressively modified the mechanical behaviour of this structure, which has passed from a monolithic dome to eight separated slices, not working anymore as a circular shell but as four drifting half-arches, linked at the top.

Looking at the crack pattern, the different behaviour between even and uneven webs is evident, due to the different underlying bearing system. The variation of cracks widths can't be ascribed only to thermal action, interpreting the cracks as thermal joints, especially considering that generally temperature data show trend values quite negligible. Cracks behaviour, which evidences a phase

displacement between the internal and the external domes as in lower and upper parts, is more elaborate and it is related to the complexity of the structure.

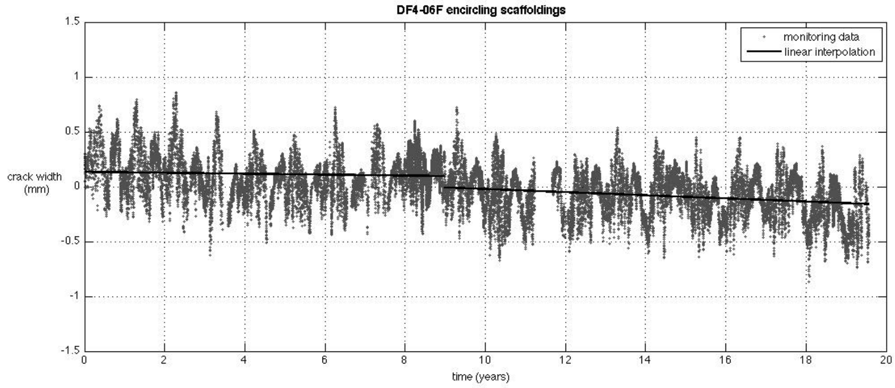

Figure 15: Linear regressions of the experimental "purified" data recorded by DF4-06 relative to the two periods: during the scaffolding presence and after its removal

In this paper, the results of the statistical analysis carried out on the data of the two last monitoring systems installed on the Brunelleschi's dome have been presented. Thanks to the larger number of data available (from 1956 to 2009), the structural conclusions reached in previous studies have been partially confirmed. Moreover, some new considerations on the dome structural interpretation and on possible consolidation opportunities have been added.

From 1980 to 1996, a really contested encircling scaffolding was put in work in the inner dome for the restoration of the frescoes and this has suggested a possible different interpretation of monitoring data trend. In a route from historical debates investigation to statistical monitoring data analysis, a more precise evaluation of the crack widths trend values have been established, evidencing two different behaviour in correspondence to the presence and the removal of the incriminated encircling scaffolding. Therefore, the historical analysis has been used to improve the data interpretation and in this ideal route, the trend analysis of cracks has represented, unexpectedly, only the final theoretical justification for the premonitory understanding of dome mechanical behaviour, made by Vincenzo Viviani at the end of XVII century, prefiguring the effects of a conceivable encircling consolidation intervention.

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