An inquiry into an unbuilt monument: the mausoleum for the kings of the Italy of Alessandro Antonelli

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ABSTRACT: The study presented herein addresses an unusual theme: would it be possible to design a building of gigantic proportions, conceived by a great architect-engineer of the 19th century – Alessandro Antonelli – in keeping with the views and the specific techniques adopted by the author. The building in question is the temple-mausoleum for the Kings of Italy, imagined by Alessandro Antonelli, of which all we have is a few tables with sketches. In this paper, the significant signs taken into account for purposes of formal simplification are illustrated, and the hypothetical results are correlated to the respective stylistic references of Antonelli’s life-size projects. Based on the foregoing, the concept of “consistency model” is formulated, to serve as a possible “validation” tool for architectural/historical virtual models. The first part is followed by a study of the structural check performed on the reconstruction hypothesis of the mausoleum for the King of Italy.

1 THE CULTURAL GENESIS OF THE PLAN

“It was in fact in these last years (after 1880, —) that he went ahead with his unyielding intelligence touching on and carrying out new and bold ideals; but there were two projects in particular that he dedicated his thoughts to, one was the façade of the Milan Cathedral and the other the mausoleum-temple dedicated to the Kings of Italy, which was to be erected in Rome either on Monte Mario or on Monte Cavi on the site of the ancient temple dedicated to Giove Laziale. But death, which he encountered while still standing in the breach, in spite of his being ninety years old, also interrupted the thread of thought of these two projects, even though of the latter and most grandiose there still remains the plans and the sketched altimetry which he had outlined and completed” (Crescenzio Caselli, Alessandro Antonelli, Architect – born Ghemme 14 July 1798, died 18 October 1888, in “The Civil Engineer and Industrial Art”, 1888, page 160 sgg.), (Caselli, C. 1884), (Caselli, C. 1889).

“There are basically two hypothesis that can be proposed for the six drawings that remain (one of which had already been put in fair copy): one in the form of a Greek cross with wings extended to various degrees, covered by a gigantic circular dome with a very ogival arch (…); the other is a circular plan with deep radial apsidal chapels. The first proposal, also developed in height, could be the introduction to the second; but at the same time it cannot be excluded that it refers to another topic”.


Even though the critical classification of these designs can go no further (as the chronological discordance between the national competition on the theme and the testimony of Caselli make the observation by Rosso legitimate – op cit., page 232-, this being supported by the date of 1887–1888 affixed by Costanzo Antonelli on the only table to be completed, which deals not of the monument dedicated to Vittorio Emanuele II, but “if anything, perhaps, of a project that wanted to be a piece of criticism”), these records of an “interrupted architecture”, in which Antonelli proceeds in his faith in the rationalistic assumptions of art in unusual opposition to the trends of that time, seem to stimulate some hypotheses on those developments, that do not occur.

This was surely due to the advanced age of the architect, but perhaps also to the set of circumstances that we know nothing about, that led to the work being uncompleted. On the other hand, it is not possible to identify the topic of the mausoleum-temple dedicated to the Kings of Italy in the programme of the monument dedicated to Vittorio Emanuele II and the Unity of Italy, already achieved in 1885 at the
beginning of the works on the Vittoriano, on the project by Sacconi. The hypothesis of a specifically created mausoleum-temple was plausible, in consideration of the limits of capacity of the Pantheon where Vittorio Emanuele II had been buried, and which would have celebrated – apart from the foundation of the reign of Italy – the destiny of the dynasty (as had occurred for the Kings of Sardinia for almost two centuries with the Superga Basilica). However, it is also possible to object to the opportuneness of reaffirming the Piedmont supremacy, creating a symbolic building constituted of the extraordinary emphasised synthesis of the old and new buildings that symbolised Turin and Novara. The Antonelli approach to the theme was also in irreconcilable contrast with the eclectic tendencies of Italian culture at that time (those that produced the Palazzaccio and the Vittoriano, but also the concepts of D’Aronco and Basile); at least as far as his project for the Italian Houses of Parliament in Turin (1861) is concerned – an austere and rational project, functional and exemplarily economic in costs and in the use of spaces – another which was constructed was preferred with the stylistic imitations of Guarini buildings and the emphatic juxtaposition of a complex stylistic elaboration in memory of the French Renaissance and of constituent inventions. On the other hand, in an era of diffused eclectic typological-stylistic research, as those years were, the rigorous faith of Antonelli in Enlightenment rationalism, in the arrangement composition according to Durand’s trend, going beyond the courage and innovation of the construction and of the walled structures, programmatically leaving ornamentation to the refined and exclusive elaboration of the classical syntax (the only language of the “modern” architect, who does not give in to the allure of historicism, of exoticism, of variously mixed vernacularism) was exactly the opposite of the linguistic orientations of that time. The weary incomprehension of the works of Antonelli by the critics of architecture, such as Camillo Boito, and also the majority of Italian historiographers, who, of all his works only mention the Mole and describe it as either gothic or metallic, was no different from that of the more competent experts, such as Tatti and Clericetti, who advised precautionary demolishing the pavilion of the Mole to substitute it with a light metallic neo-Moorish trellis; and analogous considerations can be made for the subsequent reinforced concrete consolidations for the Mole and for the Dome in Novara: “It is not the Dome that needs to be reinforced – but rather the spirit of those who are afraid of that courage”.

Among the six drawings for the presumed theme of the mausoleum-temple that are kept in the Antonelli Archives in The Gallery of Modern Art at the Turin Civic Museum (department S48, cupboard 6, shelf 2, file A, –5739-5739), two studies in pencil can be found, respectively for the horizontal sections and the half raised and half in prospective sections, in a scale of 1:400 (Fig. 1), which outline a temple in the form of a Greek cross covered by an immense ogival dome with a double calotte closed by the lantern, of an overall height of about 225 metres (the lower level would have measured 23.60 metres, the internal beam of the ogive would have been 51.20 – eleven metres more than the Pantheon – and the double closing lantern would have developed from a level more or less in correspondence to the height of the Mole, which would therefore have been able to be completely contained within the internal space – Fig. 2). These drawings prevail to show, amongst others, in that they are connected to the exhaustive definition of the project idea (the other drawings are made up of a water-colour pen drawing of the considered plan and of a smaller version, of another plant articulated in Latin crosses – of a more specifically ecclesiastical type-, of a central plane on which a complex articulation of eight absidal chapel wings are imposed, of another different and even bigger plan where a wide exedra symmetrical to the temple and surrounded by other monumental buildings can be recognised.
The scrawl of the two here considered drawings suggestively register the taking shape of the project in the assiduous autographical elaboration of the architectonic invention and stimulates two different considerations: on one hand the critical classification of this "interrupted architecture" in Antonelli's production and in the context of history, and on the other, the curiosity of knowing or imagining more: what shape would it have had? Would its sublime dimensions allowed it to be made? These latter hypotheses have recently been developed from two standpoints, starting from the assumption of Antonelli's designing as being a combination/elaboration of defined and constant constructive elements, intended prefiguring the building in a virtual manner (Fig. 3), from both the internal and external prospective points of view, building it with typical elements regularly used in Antonelli's works, demonstrating the compositional coherence and architectonic relevance, among analogous constructions of his time and in the continuity of the historical series of large domes from the Renaissance onwards (in particular it can be seen how - apart from the dimensions - the structural conception of the double dome is simpler and more experimented than that of the relationship between the ogive and conical towers of the Novara dome and of the square planned double pavilion of the Mole).

All these indications are in nuce and unequivocally present in the original drawing, the elaboration intended developing the graphic evidence without adding anything that was not present or which could reasonably be attributed for analogy reasons. In particular, the theme of the large dimensions (that recall the considerations of Galileo on the proportions of the colossal and the criticism of Boullée on the Vatican Basilica) is here resolved as in the Novara Dome and the Turin Mole not in the gigantism but rather in the multiplying and articulating of the members, with an unusual prevalence of thickly linked voids which give these large constructions a feeling of lightness and elasticity without comparison, conditions which are essential for their feasibility. On the judgement that one could make on this unprecedented conception, if it could have been put into concrete form, it is necessary to observe that its excellency would not only have consisted of its incredible dimensions and of the suggestion of a titanic site which would have been able to recall, in the progressing beauty of the in fieri building, the Tower of Babel by Brueghel, but also and even more so of its architectonic proposal which, like the other works by Antonelli, can be seen as a concept of ideal continuity, in the Enlightenment project rather than the heterogeneous tables that were prepared in his time, such as the Capitol in Washington. The sense of composition quality of the design is obvious and cannot be limited to the suggestion of incomparable dimensions.
Its compact syntactic articulation leaves no room for the redundancy or arbitrariness of the definition of its elements, of the most minute components; and it is based on the rigorous connection to the principles of classical composition and neoclassical rationalism: for example, in the indisputable Albertian identity between external order and internal order or in the classical predominance of axial moduli (an arrangement that Benedetto Alfieri had adopted on the Geneva Cathedral façade and which Crescentino Caselli had adopted for functional reasons in the Charity Hospice building in Turin). All the stylistic-syntactic questions would have found the principles to be developed with exemplary elaborations of the language of the orders, already experimented by Antonelli in many religious and civil buildings. The mausoleum-temple, contemporary of the Eiffel Tower, would have really sealed the season of Architecture of the Sublime and Reason, and would have reconnected — through the concepts of Boulée and the Enlightenment architects — with the Sainte-Geneviève by Soufflot and with the large domes that had progressively preceded them, as can be demonstrated by the continuing topicality of traditional construction in bricks and stones in the face of new technologies, in the intent of “attributing light to the progress in lateritious and stone construction for the large coverings”, in that “it is the most consensual for our Italian customs, the most convenient for our interests and duties, to preferably use the materials that nature has been lavish with” (as Antonelli himself wrote on other occasions).

The second legitimate curiosity was obviously to verify the feasibility of the project, from what could be deduced from the sketch. Obviously it is not possible to imagine which elaborations Antonelli would have made to the original idea (as he continued to do with open sites for the Dome and the Mole: it is possible to observe, but never in a restrictive manner) confiding almost exclusively in the intuition and experience of the architect (as it was for the Dome and the Mole) and which devices he would have gradually introduced to resolve the criticalities that have appeared from a verification method, which with respect to those of Antonelli’s time, has greatly reduced the difference between phenomena and hypotheses (and where it is difficult for those macroscopic differences in judgement that had caused difference on the part of scientists in the past to appear again). The invention, still at the draft stage, especially for the single development in sections, appears to be elaborate, above all for the definition of the volume and the internal spaces, rather than for the resolution and the joining of the members.

2 THE STRUCTURE

In view of clarifying the main problem, concerning the static equilibrium the second part of the study addresses the problem of the stability of the building, and, in particular, it tries to determine whether static equilibrium could have been ensured with the knowledge and techniques available at the time. To this end, a series of FEM numerical models have been developed to reproduce the material and structures of the mausoleum identified during the first part of the investigation. The purpose of the models was to explore the numerous problems that would have had to be solved to create a structure so much bigger than any masonry building ever completed till then.

The computation code used applies to compression- and tension-resistant materials in the linear elastic field. This choice might appear unsophisticated, but in actual fact it was motivated by the consideration that the aim of a stability study is to identify the orders of magnitude of the parameters governing the behaviour of a construction and the efficacy of the spatial organisation of the resisting skeleton; accordingly, the purpose of the computation code is not to permit refined checks on the materials and the structure, but rather to serve as a quick tool to pin down the shortcomings and weaknesses and to identify the changes necessary to overcome the problems detected by the analysis.

In keeping with the results of earlier tests performed at our laboratory on materials from the Antonelli school, a Young’s modulus of 2,000 MPa was assumed for the masonry, with density of 18 KN/m³; the values assumed for granite were 55,000 MPa and 28 KN/m³ respectively, and for iron they were 210,000 MPa and 80 KN/m³, (Mattone, R., Pasero, G., Pavano, M., Pistone, G., Roccati, R., 1982), (Pistone, G., Roccati, R., 1988), (Pistone, G., Roccati, R., 1991).

2.1 Modelling the structure

For the sake of convenience, the model was subdivided into two parts, corresponding to a hypothetical subdivision of the building: the dome, including the drum and the lantern, and the base.

2.1.1 The dome, the drum and the lantern

The dome consists of two concentric ogive-shaped skins, 1.30 m thick and ca 70.0 m high. The 38.0 m high drum consists of three orders with binate columns, curtain walls with huge windows in them, and low columns arranged in three rows. The double lantern, measuring ca 54.0 m including the roof, also uses binate columns and repeats the visual motifs of the drum.

2.1.2 The base

The base, consisting of three orders, rises to a total height of ca 66.0 m. The entire plan is characterised by isolated columns spaced apart according to modules measuring 6.70 m, save for the central one, which measures 7.80 m. The model leaves out several elements
(the stairs, the pronaos, the small lanterns on the roof, which represent extensions of the stairs) whose absence does not affect the statics of the building. Initially, we assumed that the dome was supported by 4 big arches (Fig. 4) with pendentives, via a ring. The model was created on the basis of a highly simplified drawing, consisting of one-dimensional “beam” elements for the representation of columns and pillars, two-dimensional “plate” elements for the walls and the dome, and “brick” elements for the arches and the ring on top of them. These three elements are linked to one another at each common node in the frame. The two-dimensional and three-dimensional elements have been subdivided in their turn by means of a mesh running parallel to the reference axes, fine enough (ca 150–200 cm) to reveal clearly and in greater detail the behaviour of the structure under the load-effects; brick elements in particular make it possible to visualise the evolution of the state of stress inside them.

The horizontal elements – structural parts of which nothing is known – have been replaced with a hypothetical mesh consisting of “St. Andrew’s crosses”, conceived as infinitely rigid elements that can be used to simulate, by changing their dimensions, conditions as close as possible to the real situation (Arrigoni, R., Nasce, V., Pistone, G., Strona, P.P., 1989). These stiffening elements are also used between the outer and inner skins of the dome, where, in similar cases, Antonelli used to place stairs and pathways to simulate the action of the arches (including rampant and inverted arches – Fig. 5) and to make the two domes integral with one another.

The initial approach is based on a careful reading of Antonelli’s documents and the virtual model was defined on the basis of our knowledge of the techniques and construction principles available to the architect. This choice was dictated by the lack of sufficient evidence, in terms of surveys and records. Then, by identifying the structural function of each element, the most probable solution was identified account taken of the “language” of the building as a whole, and, above all, in accordance with the critical-scientific outlook of statics and the behaviour of materials.

The initial results were disappointing: through a careful scrutiny it became apparent that the reading was not so immediate and that the possible solutions could have been different.

Hence, it was decided to maintain this design approach as a starting point and then proceed through subsequent steps involving a continuous comparison.

Figure 4. San Gaudenzio. A view of the two arches supporting the dome.

Figure 5. San Gaudenzio. Arch and inverted arch.
between the results and the most convincing hypothesis that gradually emerged. This method, strangely resembling Antonelli's ways of working by successive "adjustment", proved effective and, over time, yielded results of considerable significance, even though they differed from what we had anticipated.

For a better understanding of this approach, let us go over the different stages so as to provide a schematic overview of how the study evolved. It should be noted that the hypotheses described are the ones that proved most significant.

2.2 1st Hypothesis

The building is assumed to be made entirely of bricks.

The deformation configuration reveals an overall subsidence of the building $\Delta l = 136$ cm, with a symmetrical evolution in the transverse ad longitudinal axes $y$ and $z$. In addition to bulging conspicuously, the dome tends to sink vertically; in the drum this tendency meets with no obstacle, as the columns, vertical supports and windows yield under the enormous weight of the dome.

2.3 2nd Hypothesis

It is assumed that the structure as a whole has to be stiffened. The dome still tends to "sink" into the base, which, in its turn, is unable to support it. The "beam" elements, initially conceived as made of bricks, are replaced with stone: this is motivated by the need to enhance the stiffness of such a huge structure and to add a "precious" material befitting the aulic destination of the building. At all events, the materials are used according to functional criteria (placing the most precious materials in the most critical points). The only one-dimensional elements that are not replaced with stone are those making up the uprights of the windows, where bricks seem more fitting.

At the same time, granite ribs, conceived according to the same criteria adopted by Antonelli for Mole, are added to the dome and anchored to the masonry structure. Moreover, always with reference to the Mole, retaining chains are installed and connected with ties linking the two skins.

The deformation configuration shows an overall subsidence of the construction $\Delta l = 85$ cm. A slight improvement is observed, especially in the zone of the arches and the piers underneath. Maximum principal stresses are seen to decrease in the entire structure, especially in the dome.

The problem of how to carry the enormous thrust of the arches supporting the dome is still unsolved.

2.4 3rd Hypothesis

The great problem posed by the thrust of the dome and the arches that are unable to support it could not be solved by fitting supporting elements, whether visible (something unconceivable in Antonelli's system) or hidden at the top of the arches, due to the lack of filling in the extrados of the pendentives. Nor would it have been possible to resort to retaining chains, even huge ones, and therefore the different attempts made did not yield any appreciable improvements. From an analysis of the plan, the presence of stairs at the four corners suggested the idea of linking adjacent columns in a double continuous wall, so as to obtain a system of symmetrical buttresses for the dome, forsaking the idea of having isolated fulcrums in these zones.

The deformation configuration reveals an overall subsidence of the construction $\Delta l = 74$ cm. Two considerations should be made at this stage: the first is that the situation has improved greatly, in terms both of the deformation configuration and of stresses. The deformation configuration clearly shows the favourable contribution of the partition walls, especially at the ring, though the latter is badly warped internally. The maximum values of the (tensile and compressive) principal stresses are also reduced, especially where brick elements are concerned. From the stresses in the vertical elements, it is possible to determine the evolution of the stresses inside the walls.

The other consideration is a persistent tendency of the dome to move away from the pendentives and assume a rhombus like shape (Fig. 6). This will be monitored during the subsequent stages.

2.5 4th Hypothesis

The next hypothesis entailed the use – as was often the case in Antonelli’s system – of stone legati (linkage by stone) at the critical points of the structure. In this particular case, the critical points were the arches, having zones characterised by very high stresses, particularly at the keystone.

From the graphic viewpoint, the arches were already subdivided into 12 blocks, 6 in every half arch, but there was no "odd" block at the keystone; this was remedied by considering two blocks, one per side, plus two more blocks at the reins. The deformation configuration showed a reduction in the overall subsidence of the building of $\Delta l = 62$ cm, more significant than might have been logically expected.

The stresses in the vertical elements are smaller than under the previous hypotheses. From an analysis of the deformation configurations we find that the most important change has occurred in the brick elements (simulating the arches and the ring) which are directly affected by the legati. The ring displays a reduced tendency to warp internally, with a milder slant, and the arches appear less deformed. The values of maximum principal stresses and vertical stress are more acceptable, without substantial variations.
2.6 5th Hypothesis

The arches supporting the dome are assumed to be rigidly restrained: this stage of the investigation was designed to explore the behaviour of the dome/arches system.

The deformation configuration indicates an overall subsidence of the building $\Delta l = 50$ cm. This stage proved fundamental to define a few essential points:

1. the arch displays a progressive lowering, which increases from the restraint to the keystone;

2. the deformation configuration reveals a settlement of the pendentives that increases with increasing the distance from the arches: a weakness already observed in the previous hypotheses, which is clearly reflected in the states of stress in the ring;

3. the windows, the only beam elements made of bricks, sag under the weight of the dome.

Based on these studies, it is felt that the only two solutions that can still be proposed are: the variant with from 4 to 8 arches, and the conversion of all columns to stone.
2.7 6th Hypothesis
The number of arches supporting the dome is raised to 8.

2.8 7th Hypothesis
All vertical elements are converted to stone.

2.9 8th Hypothesis
The arches supporting the dome are assumed to be rigidly restrained (as in the 5th hypothesis) to be able to assess the benefits arising from the changes introduced with hypotheses 6 and 7. The deformation configuration shows a total subsidence of the construction \( \Delta l = 35 \) cm. As for the other values, displacements are seen decrease further. A significant difference can be observed in the upper part of the drum, precisely at the three crucial points of the windows, where the values, as mentioned above, increased abruptly.

At these three points, in fact, the displacements are reduced to about half, from 43 to 28; from 46 to 28; and from 61 to 37. In view of the much greater incidence on the results of hypothesis 7 compared to hypothesis 6, it can be concluded that the choice of material plays a fundamental role in buildings of this type.

2.10 9th Hypothesis
As a final hypothesis, let us consider the possibility of moving the stairwell, ignoring the constraints imposed by the plan: this is done by moving back the partitions walls, so that they now oppose the 4 arches directly and perpendicularly, creating a sort of confining buttress. Both the stairs included the helicoidal one are moved by one module.

2.11 Results of the analysis
The analysis was performed by making successive changes to the original scheme, always using materials and structural elements that were available at the time of Alessandro Antonelli, in keeping with his structural conception.

The various steps achieved substantial improvements in terms of structural response, in addition to a general improvement in the distribution of the states of stress, and strains also gradually diminished. In this connection, see table 1, that shows how the lowering of the uppermost point gradually reduced to about one third of the original value (Fig. 6).

A number of basic problems remain unsolved.

a) The problem of the dome:
Its thrust cannot be carried with traditional methods. Metal chains cannot be used, because they would have to be gigantic, posing insurmountable problems in the connections between the various segments, which could not be solved with the technologies available at the time.

b) The problem of the arches:
The arches cannot bear the exceptional load of the dome, both in terms of stresses, that exceed the failure strength of the material, and in terms of thrust, that cannot be effectively opposed. The impossibility of using visible supporting elements and hidden ties makes the problem insolvable. Though the use of partition walls might seem promising, it is not a viable solution for a building of this size.

c) The problem of the columns at the base:
The columns at the base are subject to extremely high stresses, that they cannot withstand, if they are made of brick masonry. But there is another aspect, of a practical nature, to be taken into account: if made of stone, the columns cannot be one-piece elements, but have to be conceived as a series of perforated blocks stacked on top of one another. This would entail stacking an extremely high number of blocks, given the height of the columns. A solution of this sort, might translate into a kinematic chain that would pose yet another challenge to the stability of the structure, regardless of the other problems already present in the mausoleum.

3 CONCLUSIONS

Seen through the eyes with which we had wished to examine it, the problem seems unsolvable.

But perhaps this is also the last project of Alessandro Antonelli, elaborated on a few tables that were not divulged to his contemporaries, but consigned to the memory of others who would come after him.

We therefore like to think that Antonelli wished to give shape and proportions to a dream that was
to be consigned to the new century, which was then close at hand, to the new materials that in those years were being tested for the first time and others which, little by little up to the present day, would have obtained increasingly better performances in the world of Construction Engineering and finally, for other designers, perhaps for constructors, who, looking again at his indications, would resolve the problems that appeared in our unsolved study, and bring his idea to a conclusion.

NOTE

This work has started from two degree theses, recently developed at Politecnico di Torino, under the supervision of G. Pistone and L. Re: Borra, D., 2003, Architettura interrotta, Architetture virtuali; Etzi, Antonella, 2003, Ipotesi di stabilità di grandi strutture a volta: l’ideazione antonelliana per il mausoleo ai Re d’Italia.

REFERENCES


