Giuseppe Damiani Almeyda's Architecture: Constructing the Modern Restoring the Ancient. The Cathedral of Marsala.

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ABSTRACT: In 1892 Damiani Almeyda was invited by the major of Marsala to predispose a relation on the interventions needed for the stability of the cathedral which exhibited heavy structural damages. The crack pattern, appeared in the dome zone presumably in the early eighties of the XIX century, brought the municipality to the decision of calling a technician of great experience in the field of the structural rehabilitation. Damiani Almeyda presented his restoration proposal in the August of 1892 but, before the works could have begun, in February the second of 1893, the dome collapsed. Then Damiani Almeyda was charged of the design for the reconstruction of the dome and the reinforcement of its support structures. In this paper, besides the unknown chronicle of the damages, the collapse and the reconstruction of the dome, the magisterial technical knowledge as well as the architectural sensibility of a XIX century engineer is highlighted through the examination of the graphical and textual reports prepared by Damiani Almeyda for the Marsala's Cathedral.

INTRODUCTION

This memory intends to reconstruct somewhat in detail the chronicle of Marsala's Cathedral in Sicily with the overt purpose of investigating the operating procedures of an engineer working in the second half of the 19th century, Giuseppe Damiani Almeyda, with special reference to his intervention on existing buildings characterised by complex structural setbacks.
The information on which this study is based has been collected through an exhaustive and close examination of textual and picture material belonging to Damiani's private archive in Palermo and to the Historical Town Archives of Marsala. These documents consist of project-related material (reports, tables, calculations and specifications), pictures of the places concerned, Damiani Almeyda's correspondence with his clients and with his assistant engineers. Some on the site inspections of today's church have also enabled to understand certain details that the reading of the sources by itself had not clarified.
Damiani Almeyda took on a central role in the chronicle of Marsala's Mother Church in 1892, at a time when the construction had shown signs of cracks for a few decades. The engineer had had a long career, and more than once had he carried out complex works of structural advice on buildings, either existing or under construction; therefore his authoritativeness in the field of constructions' structural behaviour and his ability to interpret damages and identify effective remedies must have been popular throughout Sicily.
Such technical ability is fully portrayed when reading the sources that outline an engineer-architect whose culture was still untouched by field specialisations and particularistic trends that the discipline would later acquire, and who combined the meticulous examination of theoretical issues with the practice of the construction site.

THE CHURCH BEFORE THE DAMAGES AND THE CONSTRUCTION OF THE DOME

Marsala's Mother Church was built on an earlier Norman church starting from 1626 and, after a long construction process, it was finished in the mid-18th century (Linares 1982). Although all the parts of the church were completed, it had no dome, yet this must have been planned, as proven by its layout and by the hierarchy created by the bigger vertical supports at the point where the transept crosses the nave.
The first proposals for a drum and lantern dome were put forward in 1823, and for this purpose a special town committee was set up. The project, drawn up by Pietro Russo (1754-1834), a master mason who was the maker

of other works in Marsala, was very well received for the 'magnificent design' of a dome that was to honour the cathedral and the whole town. But since the very start of the works, some perplexities were put forward regarding the stability of the existing construction that was to support the new dome. Therefore various experts were consulted, who expressed mixed opinions, but people's zeal was such that the building of the dome was not stopped.
The first cracks appeared in 1825, when the elevation reached the side of the drum; the works were suspended following the instructions given by three skilled engineers who were asked to give their opinion regarding the work's stability. Once again, they gave conflicting assessments, and again it was decided to heed the reassuring opinions, declaring the solidity of the support bases of the dome in the course of construction. The works resumed, encouraged by enthusiastic believers, and the dome was completed in 1827 (fig. 1).

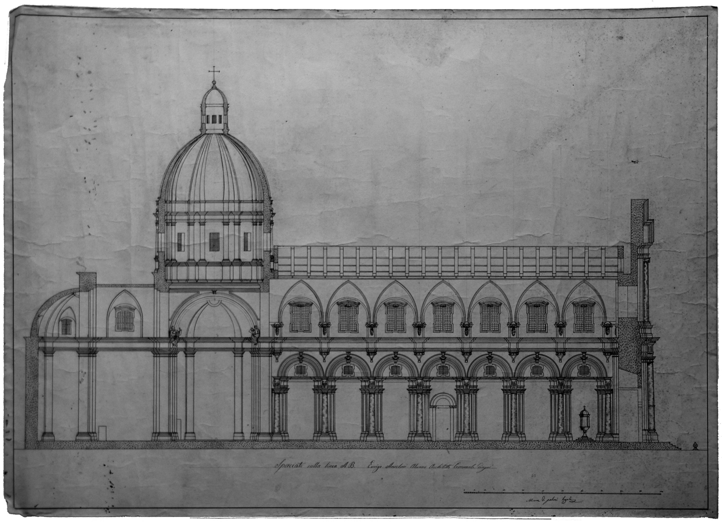

Figure 1: Section of the church with the completed dome; (DPA)

THE DAMAGES AND THE EXPERT SURVEYS

The first reports of cracks in the church date back to 1852 (Giacalone 1933); they can be seen along the two right apse walls. In 1855, the archpriest, monsignor Alagna, worried for the damages, called an engineer who drew up an alarming opinion:

> The four pylons that support the extremely heavy dome, due to the enormous load and to their non-proportional size, have sensibly sunk into the ground, signs of which are very visible. […] the foundations of all of the four pylons have been pushed down by the pressure exerted; considering the ongoing nature of the force that has produced this effect, the phenomenon shall gradually increase, and therefore the building will become more and more unsafe […].

Although the report concluded by recommending that the church should be closed for safety reasons, no action was taken for a few decades. Accounts concerning the state of damage of the church, as a matter of fact, started again only from the 1880s. In 1884, the concern with the damages - which were evidently expanding - became urgent, although the town administration took very slow measures, considering that only in 1890 did the town council deliberated "that a renown engineer shall be consulted in order to examine the state of stability of the Mother Church building" (THAM, 1892). And two years passed before, in July 1892, the mayor finally decided to entrust Giuseppe Damiani Almeyda the task of "examining and reporting on the state of solidity of the Mother Church building, following which the appropriate measures will be taken". He was called on 25 July and arrived in Marsala on 28 to visit the church; his words left not a shadow of a doubt: "The danger of a catastrophe is permanent; in order to avert it, the Dome must be propped up and the pylons' foundations must be restored as soon as possible" (DPA, 1894). Luckily, the church was immediately closed to the public.

DAMIANI, THE REPAIR AND RESTORATION PROJECT

After less than a month following his visit to Marsala, on 21 August 1892 Damiani's project was finished. His capacity to produce an exacting and problematic work in such a short time must be noted as the first striking feature of the engineer Damiani Almeyda.
The project, moreover, is complete in all its parts, a necessary condition given the urgency to start the works immediately; it is composed of a very effective report (which we shall analyse below), three tables, an approximate economical calculation.
The project report (THAM, 1892) is divided into 4 sections: in the first section, Damiani illustrated the condition of the damage, identifying its causes; in the second one, he briefly described the repair interventions; in the third,

he provided very detailed instructions concerning the phases of the work to be implemented, and in the fourth section he submitted an analytical and numerical justification of the interventions recommended.
The explanation of existing damages made reference to the construction process; Damiani remarked that the building

> at first had no dome, but only a small-sized ribbed vault or bowl vault, resting directly on the cross four main arches […] in spite of that, around 1820, a technician endowed with good imagination, but quite strange to the laws that ensure the equilibrium in construction, devised the majestic dome, perfectly beautiful and bold, whose weight - which he did not account for in terms of the pressure exerted on the pylons that were to support it – has gradually exhausted their strength, destroying their quoins that are made of a soft, friable tuff.

Damiani then listed all the interventions that should have been made before constructing the dome (from the calculation of the materials' strength to the examination of foundations), which would have highlighted the need to "secure the feet of the building […] before overloading its head […] In short, the dome's constructor should have done *before* what we are obliged to do *afterwards*, today, with increased danger and costs".
The description of the damages in the construction was based on his direct observation and their interpretation on an unmistakable scientific method that connected interpretative assumptions to their subsequent numerical assessment.
The schematisation of the structure suggested by Damiani is of great interest in order to understand the load-bearing system. To his mind, the support system for the dome should consist of 8 walls (converging two by two and forming a right angle), serving both as a support for vertical loads, and as the system resisting to the thrusts deriving from the 4 main arches. The 8 walls had been damaged by the enormous surrounding pressure, especially the one exerted on the apse side;

> […] the thrusts have immensely put the strength to the test […] and have crushed everything! […] The two apse walls are terribly broken in every way and are visibly deteriorating, in spite of their considerable 1.60 m thickness without counting the plaster, and although they were solid walls, which reveals a fault in the foundations and scarce structural consistency.

It is the outward rotation of the two apse walls that has caused the damages on the dome, so serious that they "would worry anybody".
The second part of the report briefly described the project interventions, consisting of: repair and consolidation of the eight load-bearing walls, underpinning and foundations' connection, increased size of the 4 dome pylons. As can be seen, Damiani's project included few types of intervention, but its complexity consisted in managing to carry out the works with the impending mass of the overhanging dome.
Damiani defined the two types of necessary propping, different in their function, form and material.

> The first [type of prop, *editor's note*] aims to prevent any further movement in the building, even during partial or total reconstruction, when its inner structure is assailed at its very core. And the prop, for this kind of intervention must be […] firmly laid to the ground and […] absolutely inarticulate, rigid, unbending, incompressible – such conditions […] require the exclusive use of the squared stone walled with good mortar […].

The second type of prop is the one necessary to build the underpinning of the dome's pillars. "For this kinds of detailed work, a strong-section square deal truss for the bilge keel is required […]".
Damiani then illustrated the materials and the techniques to be used:

> The foundations will be made of hydraulic concrete casting with compact limestone crushed aggregate and river gravel, the 'pastoie' [connections between pylons' foundations] will consist of a masonry element made of compact limestone splinters with hydraulic mortar, and the overground part of the restoration will all be made of individually selected Pisan bricks, red-coloured, previously covered with water for 24 hours, and walled with lime mortar, excellent sand and pozzolana, passed through a screen with a 2 mm-hole diameter. […].

The third part of the report dealt with the execution sequence which Damiani suggests should be as cautious and as economical as possible. Here the references to the project tables are available and necessary for a complete description of the working phases.
First phase: (a) repair and consolidation of the 8 walls representing the enlarged support system for the dome, building squared stone walls to close the 6 arches placed in the above mentioned walls (only the apse walls have no arches) and building buttresses in the arcades adjacent to the closed ones along the longitudinal walls of the central nave; (b) building of two pointed arches in the middle of apse walls, in order to remove the walls' load-bearing function from the most badly damaged walls (fig. 2).
Second phase: execution of the necessary propping in order to carry out the pylons' underpinning, working on one pylon at a time, by placing a suitable wooden frame in the spaces of the two arches converging towards the same pylon in order to discharge it: "these strong-section square deal props will be laid against the piers […] in three tiers, that is at three, six and nine metres from the ground, and shall have a thirties-degree slant from the vertical […]".
Damiani showed his great confidence in placing the propping in such a way as to convey the loads to effective supports: in this case, once the consolidation of the walls representing the dome's enlarged support with

curtain walls was carried out, he believed it would be sufficient to just prop each pylon with slanted wooden elements installed inside the spaces of the big arches converging towards said pylon.

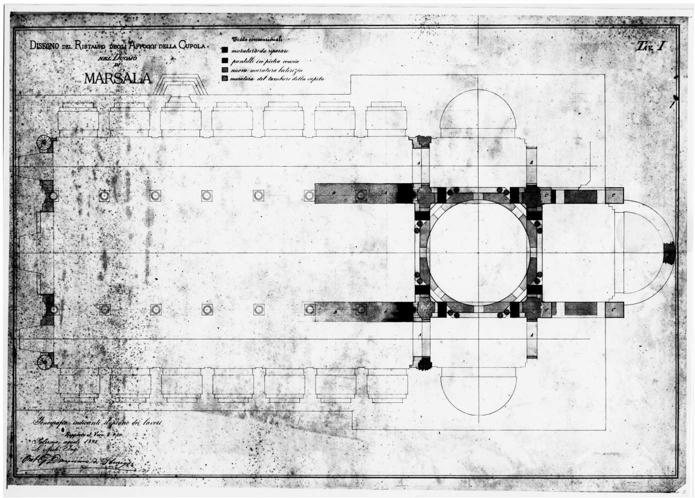

Figure 2: Restoration design of the supports of Marsala's Cathedral Dome, working plan; (DPA)

Third phase: (a) execution of an excavation up to 6 m deep; consolidation of the ground horizontal layer "with sharp splinters of compact limestone closely laid down, pointing downwards like in a cobblestone pavement, first adjusting them with small wood hand hammer taps and then shortly with an iron sledge hammer, to refusal, then with large sprinkling and bath with hydraulic mortar only. […]"; (b) filling up the foundation excavation with "excellent concrete made of pozzolana mortar and almond-sized river gravel. The compact limestone splinters shall not be bigger than an egg, and the material shall be poured from a height corresponding to the temple floor into the ditch and not laid […]".

Damiani's building experience can be detected in a number of details he added, such as roughing in the excavation walls with mortar in order to prevent any soil to fall into the concrete casting or the method to reinforce the area between the cast foundations and the pylon towering above, which should be performed with "excellent Pisan brick masonry laid in concrete with slow setting, and later filling up the space between the bricks". Before closing the description of the current working phase, he made the following recommendation: "do not repeat the same operation to the next pylon before you are sure that the underpinning already carried out in the previous one has set, in which case, and not earlier, the deal props may be removed".

Fourth phase: once the underpinning of the 4 pylons has been completed, they can be connected "with masonry made up of compact lime stones thoroughly covered with hydraulic mortar, carefully mixed and well-tapped with a hammer […] thus forming in the foundations a single closed load-bearing system" (fig.3).

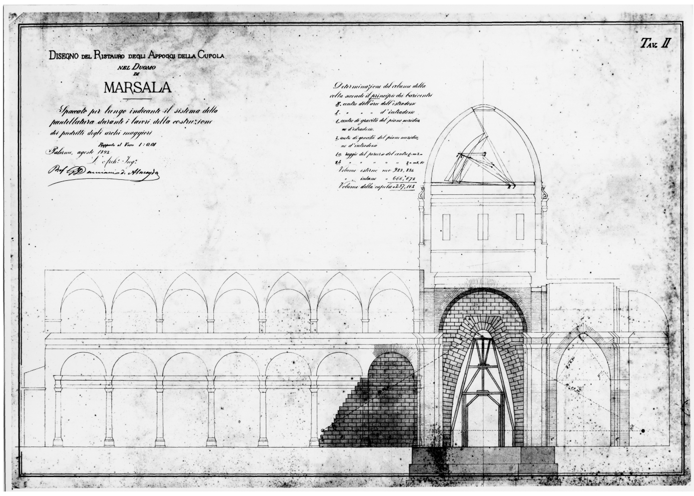

Figure 3: Longitudinal section indicating the works' propping system; (DPA)

Fifth phase: (a) the completion of foundation works enables to proceed to the execution of the main arches' propping, performed on the four arches at the same time, "with masonry work", leaving 45 cm spaces facing the pylons' surface, in order to facilitate the subsequent thickening intervention; "for economic purposes, this wall propping will have an arch in the middle, to be made in a pointed funicular curve in order to avoid side thrusts in the filling system towards the pylons, against which, as it has been said, they have no support."; (b) cutting pylons' faces so as to create denticulations where the project thickening may tooth in each pylon, as designed, made with Pisan tiles. "The utmost diligence must be used for these operations, in order to make sure that these new works do not cause any further movement in the construction system, which may worsen the alarming condition of the current state".

Sixth phase: thickening will be first performed on the 8 pylon faces towards the main arches, by firmly toothing the added tiles. In so doing, a complete thickening of each pylon shall be carried out metre by metre, and so on, working along the area until the impost of the main arches is reached. While performing pylon thickening, the walls departing from pylons will be repaired and the cracks shall be filled in 'as deeply as possible' from the pylons(fig. 4).

Seventh phase: reconstruction of the 4 main arches, "partially or completely, depending on each individual condition, […] the drums and all damaged sub-works, […] restoring and reinforcing the half-dome on the main altar with tie-rod and closing the dome's cracks with Pisan brick gains".

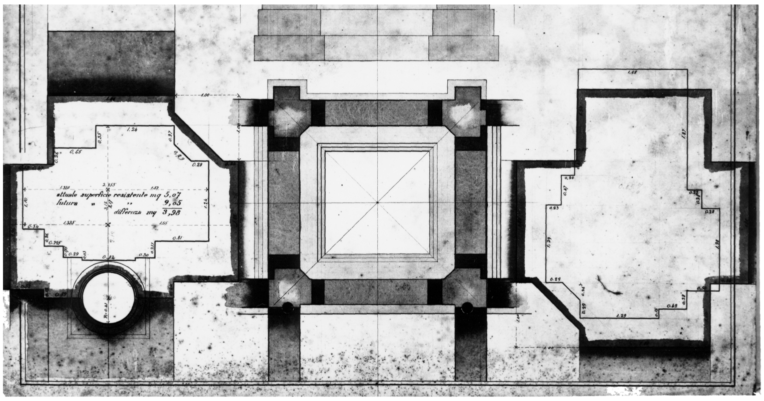

Figure 4: Details of the pylons' current state compared to the enlargement proposed by Damiani; (DPA)

The fourth and last part of the report includes an explanation of the works' "artistic and technical convenience". In Damiani's opinion, the description of the reasons on which the project choices are based is an integral part of the project itself, it is the way by which he overtly displayed "the conscientious analysis made by the author".

In order to show that his project proposals were necessary, Damiani explained the results of the calculations made. The load analysis – which deserves to be mentioned at least for its use of the ancient theorems of mass geometry (Guldin's theorem, used to calculate volumes), which today have been completely replaced by the numerical procedures of any spreadsheet – supplies a compressive stress at the foot of the pylons amounting to 17,316 K/cm^2.

By comparing such values with experimental data available on the breaking tensions of Sicilian stones (Lopez Suarez), downstream of the safety coefficient application (10) suggested for masonry by the technical literature at the time, not only is it possible to identify the reason for the cracking along the vertical structures, but this also suggests a remedy. As a matter of fact, "once the load-bearing surface has been enlarged to 90,000 cm^2 (from the initial 50,000 cm^2, *editor's note*), the load remains unchanged […] therefore the unit pressure will amount to 9,620 Kg/ cm^2". Damiani thus rationally supplied effectiveness of the intervention he had put forward; in fact, the bricks he intended to use to thicken the pylons can bear with safety more than 10 kg. In this way he proved that current condition exceeded the crushing limit and the restoration would bring back the building to safety conditions.

After proving the solidity achieved by the building after the intervention would be carried out, Damiani tackled the formal issue: "the issue of aesthetics, of primary importance in a Temple, second to its necessary solidity, that for constructions means Existence and Safety. We should remember the excellent saying: in Art, the Beautiful is always Advisable, and the Advisable is always Beautiful".

Damiani remarked how the strengthening interventions put forward would alter spatial proportions: the light in the main arches would be reduced (passing from 10.90 m to 10.00 m), the pylons would be thicker (from a 5.00 sq m surface to 9.00 sq m) – but on the other hand, an exact demonstration has proven that an enlarged resistant surface is strictly necessary for the safety of the construction.

> This increased load-bearing capacity – necessary in mechanics and therefore advisable in art – ensures double stability, real and apparent, and thus stands for architectural beauty of the whole, based on a sound and safe look. Such qualities, which are now lacking, make this a frightening, rather than an extremely daring building, due to its very slim pylons that have already been crushed by it.

Finally, Damiani made a few remarks concerning the composition, which were also based on the need to strengthen it: "For mechanical reasons and aesthetic laws, I have had to fix the last column on each side of the arched colonnade of the main nave to the axis of the first two pylons. […] Symmetry and analogy will require the same adjustment in the two remaining columns next to the two entrances of the main façade". Yet Damiani could not help adding something, thus further proving that the job was one and only and it was not possible to strengthen without designing the whole: "Incidentally, I shall say that such adjustment endows the main door with a tribune that may host a big orchestra and a great organ, which would enhance the Temple's usability and beauty".

THE COLLAPSE

On 9 February 1893 at 10.34 am the dome collapsed without damaging the surrounding buildings, without causing any casualties, sweeping away three of the four pylons that supported it, three compact limestone columns in the nave, and about one third of the whole roofing vault. The degree of the collapse is shown by the 9 pictures kept in Damiani's archive (fig.5).
The pylon that caved in was the one on the left of the main altar; when starting the construction site during the foundation excavations to rebuild the pylon, they would find out that it was standing on a non-compact soil containing the ruins of an ancient building, and that its foundations were inadequate.

Figure 5: The collapse of the dome, looking at the main façade (left) and at the apse (right); (DPA)

Besides providing information regarding the area of the collapse, these photographic images highlight another flaw in the pylon that caved in first and initiated the collapse: the inappropriate wall structure, made of small-sized stone elements and an overabundant amount of mortar. A letter by Damiani to the mayor of Marsala (dated 10 February 1893) clarifies the engineer's attitude towards the collapse:

> […] I would have grieved deeply over it if the collapse of the dome had caused any casualties […] Instead, rather than regretting and recriminating, we may be comforted […] rebuild what has been lost recovering the same beauty of forms, but with the due solidity, making sure that no extra money is to be spent for the new works than it was planned for restoring the old building. Personally, as a constructor, I am now in a brighter position, that is to rebuild from scratch and perfectly workmanlike what I was to do somehow or other, repairing that massive structure, and this for the sake of art. […].

THE RECONSTRUCTION PROJECT

Damiani accepted the task of designing the cathedral reconstruction as the archpriest asked him to do in early March 1893 – a task he felt represented a unique occasion for him:

> I must first of all thank you for the honour […] of getting such a rare opportunity to work on an outstanding construction to which my modest name will be attached, and notify you of my acceptance of such task to which I have already worked, and hereby promise that with the utmost promptness as is compatible with the difficult subject, I shall complete the project […].

The project consisted of 4 plates and the report entitled: "Drawing of the reconstruction of the dome of the Marsala Cathedral", composed of the chapters: Reasons for the forms and structures adopted, Assessment of stability conditions; Artistic and administrative conditions (THAM). In the introductory chapter, Damiani illustrated the basic principles on which the project had been drawn up:

> […] The first duty of the designer was to reproduce the Dome in its ancient size and fairness, adding the lantern that was lacking before, so that the top of the round surface on which the cross serving as lightning rod is fixed is now 48.15 m from the ground, instead of 41.12 which used to be the ancient height of the vault peak. In so doing, we have gained 7.03 m, which will make the monument stand out even more visibly from far away.

Damiani projected a double-calotte vault on a drum – octagonal on the outside and cylindrical on the inside - and explained the reasons for his choice: the external calotte

> serves as a cover of the internal one, which for this reason cannot be damaged by the rain humidity spoiling the frescoes of the face to be seen. Frescoes that, in order to be visible in all their height […] must be painted on the surface of one hemisphere instead of on the surface of a rotating paraboloid as is the outside cover, thus constructed in order to make it higher, to avoid the horizontal element on top, to be at the

same time lighter and more solid. Italy's major domes are not constructed otherwise – excellent examples of which are S.M. del Fiore's and the Vatican's.

Figure 6: Drawings for the project of reconstruction of the dome, 1893

As one should expect, considering the subject - the construction of a dome – as well as Damiani's figure, the part of the report devoted to structural aspects – entitled 'Assessment of stability conditions' – is the longest: in it, the most up-to-date know-how concerning vaulted structures are summed up. Suffice it to look at the amount of quotations from the classics and contemporary authors, with reference to both the study of materials and the behaviour theories for domes.

Such quotations outline Damiani Almeyda's complex figure both as a scholar and as a designer – he certainly owned a very up-to-date library even on an international level.

The structural report consisted of 35 handwritten pages in which Damiani explained first the several methods of assessment used for the domes, discussing the relevant starting assumptions and commenting on the developments and the results obtained; then he assessed the dome he designed using the method he considered the most suitable and reliable.

In drawing up the report, Damiani created a clear system of remarks that enabled him to illustrate the structural reliability of the new dome. First of all, he showed that the stress at the foot of the new pylons – slightly lower than 10 k/cm^2 – is compatible with the load-bearing values of the materials that would be used for construction (based on experimental literature available at the time): the breaking safety coefficient was at least 10 for the overground section, and 8 for foundations – although the latter value is conservative (pro-safety) as it does not account for the presence of the foundation offset of about one metre on each side. The problem of pylons stability was dealt with in just a few lines, placed at the very end of the report: the presence of the apse walls and of the transept and the arched walls in the central nave represented an extremely powerful counterfort system collecting with absolute safety the thrust of the arches which support the dome.

The core of the report was devoted to the dome's stability.

The conceptual inconsistencies of the independent arch model, developed about one century earlier for the study of round-based domes, and still used at Damiani's time (maybe because of the authoritativeness of those who had widespread its notion – including, among others, Rondelet and Navier), are here discussed using a very concise logic and showing the need for a different model that may be explicitly account for parallel actions.

This model, that was put forward by Scheffler and studied by Levy, was presented by Damiani with exemplary clarity and accuracy, thus showing his thorough know-how of the mechanical problem associated with double-curved structures, and, most likely, his long experience with it. This is made obvious, for example, by the reference to the tensile stress developing along the parallels next to the springer, by the metal arches, where one cannot help identifying an allusion to the iron dome of Palermo's Politeama (Barbera, 2008). In addition, the hypothesis he adopted in order to prevent any indeterminate curve caused by pressure (absence of tensile stress on each joint), as an alternative to the various minimum principles existing in literature (more or less implicitly characterised by a vaguely theological content), shows how Damiani constantly combined scientific culture and technical practice, preventing abstract calculations needed to control the structures from cancelling the physical reality determined by the construction methods adopted.

His concern with the work's physical reality and its interaction with mathematical modelling was further attested by his choice of connecting the two domes, using properly textured masonry, next to the springer,

where the curve of the inner dome pressures tended to exceed its thickness. This solution, as Damiani pointed out, made it useless to employ any metal rims.
The stress caused to the dome, to be assessed accounting for the parallel actions, would be much lower than the acceptable values associated with the masonry material used and characterised by a far higher safety coefficient than the one obtained for pylons. This result, which may be systematically detected in the domes built, confirms that the increased stability of the new structure lies – as Damiani had already stated when referring to the previous structure now collapsed – in the need to guarantee the utmost solidity of the support system: arches, pylons, foundations.

CONCLUSIONS

Through the reconstruction of the troubled building chronicle of the dome of Marsala's Cathedral – from the cracks appeared when the construction was still underway, to the collapse that dramatically involved three of the four dome pylons, until the drawing up of the reconstruction project – this memory has analysed the tools and working methods of a 19th century engineer, Giuseppe Damiani Almeyda.
The element that seems to characterise Damiani Almeyda's professional activity the most, in terms both of dealing with existing constructions and of planning new ones (please refer to the companion paper, Barbera), lies in his global planning approach, which sums up under the single operation of making architecture issues at times quite varied – from a formal, technical and economic perspective – with the implicit conviction that such issues are either to be solved altogether or they are not to be solved at all.
The expertise with which he handled building site techniques, the clarity and accuracy with which he tackled mechanical problems related to stability and load-bearing capacity, his sensitivity to the formal implications of the consolidation interventions represent a warning to our technical culture, increasingly fragmentary and scattered among a thousand specialised sub-branches.
In this historical moment when the need for a rational approach while carrying out interventions on exiting constructions is ever more pressing, based on the recovery of a technical culture that has enabled to build the works that we are willing to restore, a new reading of the documentation relevant to Damiani Almeyda's project for Marsala's Cathedral is inspiring. In said documents this very culture can be integrally found, maybe even more clearly than in the construction they describe, as they explain in an extremely didactic manner the whole planning process, whereas the construction is just an expression of its final outcome. In particular, as far as structural aspects are concerned, it is worth, in conclusion, reasserting the extraordinary topical interest of the mechanical modelling suggested for the dome. The fast sequence of statements that, starting from an understanding of the load-bearing mechanisms, leads to the definition of a more realistic calculation model, reminds us of the more mindful developments that modern culture has been able to conceive on these subjects (e.g. Heyman's studies, to quote the most famous scholar, yet not the only one).

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The archivist data quoted in this paper are stored in: Town Historic Archive of Marsala (THAM) and Damiani's Private Archive (DPA).

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