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Title: The Nervi System: The Nervi System: Between complexity and ethic

Title of the monograph: Structures and Architecture. Concepts, Applications and Challenges

Editors: P. J. da Sousa Cruz

Date of publication: 01/07/2013

This paper was published in the framework of SIXXI Research



thanks to funding of



ERC ADVANCED GRANT 2011

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The Nervi system: between complexity and ethic

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ABSTRACT: The Pier Luigi Nervi system of construction is a combination of technical solutions used to define a new way of building that is both economical and rapid. Economical because it eliminates the wooden formwork required to pour reinforced concrete, both costly and impossible to reuse, and because it reduces the costs of materials, limiting the thicknesses of the load bearing elements (and thus diminishing dead loads). Rapid because it divides the building yard into two autonomous sectors, where workers can operate in parallel. One example of the application of the system is the construction of the Palazzetto dello Sport for Rome 1960 Olympic Games. Notwithstanding so complex solution and so astounding aesthetic result, the structural work was completed in a few months, with minimal cost, according to the ethical approach of Nervi on the "correctly building".

1 INGENUITY AND CONSTRUCTION

The projects realized by Pier Luigi Nervi for the 1960 Rome Olympics, a mature expression of his continuous experimentation, can be observed, in a historical perspective, as true monuments to the idea of Made in Italy. At the time, his minutely undulating or ribbed domes, shaped columns and isostatic ribbed slabs offered an ideal frame for the great spectacle of the Olympics, contributing to the global diffusion of the image of the so-called Italian miracle.

For the Olympics Nervi designed and built four masterpieces: the Palazzetto dello Sport in the Flaminio neighbourhood, the Flaminio Stadium, the Corso Francia Viaduct and the Palazzo dello Sport in the EUR.

These lightweight structures are emblematic examples of Nervi's highly personal concept of statics that, by exploiting the inherent resistance of form in an absolutely original manner, reiterates his observations on the principle of economy, even as a fundamental part of aesthetic quality.

The same principle guided the construction of these projects by Ingg. Nervi & Bartoli: the small family business known for completing its projects both rapidly and at limited costs.

A true "miracle", whose explanation is to be sought in the so-called "Nervi system": an entirely new way of building large structures that the almost seventy-year old engineer developed over his lengthy, uninterrupted experiments with statics and construction. The system utilizes a number of authentic inventions, such as "ferrocemento", "structural prefabrication" and a series of original technical solutions, including the generational process known as "grandmother, mother, daughter".

The system is both economical and rapid.

Economical because it eliminates the wooden formwork required to pour reinforced concrete, both costly and impossible to reuse, and because it reduces the costs of materials, limiting the thicknesses of the load bearing elements (and thus diminishing dead loads).

Rapid because it divides the building yard into two autonomous sectors, where labourers can operate in parallel: on the one hand the building site, home to the realization of excavations, foundations, columns and all site-cast elements; on the other, the prefabrication yard, used to prepare the pieces used to complete the structure. The pieces are small and lightweight and easy to move from the storage area to the building site, which were always adjacent.

One exemplary application of the system is the construction of the Palazzetto dello Sport.

2 BUILDING THE PALAZZETTO DELLO SPORT

In the mid-fifties, Italian National Olympic Committee (Coni) demanded to Annibale Vitellozzi, the committee's designer of reference since 1950, a prototype of a sports facility of medium size, conceived to promote the spread of the amateur sporting disciplines, to repeat in every city in Italy.

The structure he imagined would have to be capable of containing all indoor events, with a variable capacity, depending on the size of the playing area required: 4000 spectators for basketball, fencing, gymnastics and tennis, 5000 for boxing or wrestling.

The facility had to be economical: not only in terms of construction, but also in terms of use. This meant that the technical systems had to be limited only to those of real necessity, while the internal and external finishes would be "rational", to reduce costs of maintenance and to favor thorough use of the space.

Vitellozzi immediately asked for the help of Pier Luigi Nervi to resolve this complex economic-structural problem: a large roof was required at a very low cost, and no one could find the solution better than this engineer, who had amazed the international technical community with the construction, requiring a minimum of time and cost, of the gigantic undulated vault of the Salone B at Torino Esposizioni.

Nervi did not disappoint. Confirming his unswerving faith in the principles of economy and correct construction, he produced an estimate for a surprisingly low figure: 200 million lire, including design fees (about 2.5 million euro in today's currency). And these were not just technical and functional choices, but also a design solution that led to one of his masterpieces, perhaps his most famous work. the one that definitively won him a place of honor in the history of 20th century engineering.

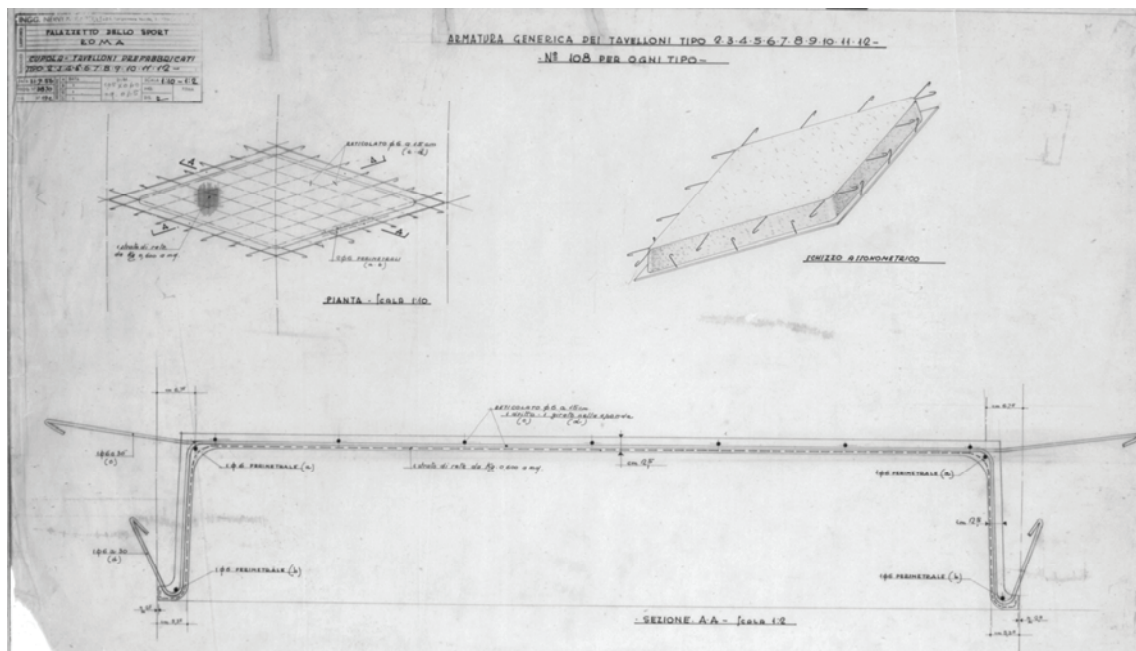


Figure 1. Working plan, precast tavelloni for the dome of the Palazzetto dello Sport, 2-12 type, 21 September 1956 (CSAC, Parma)

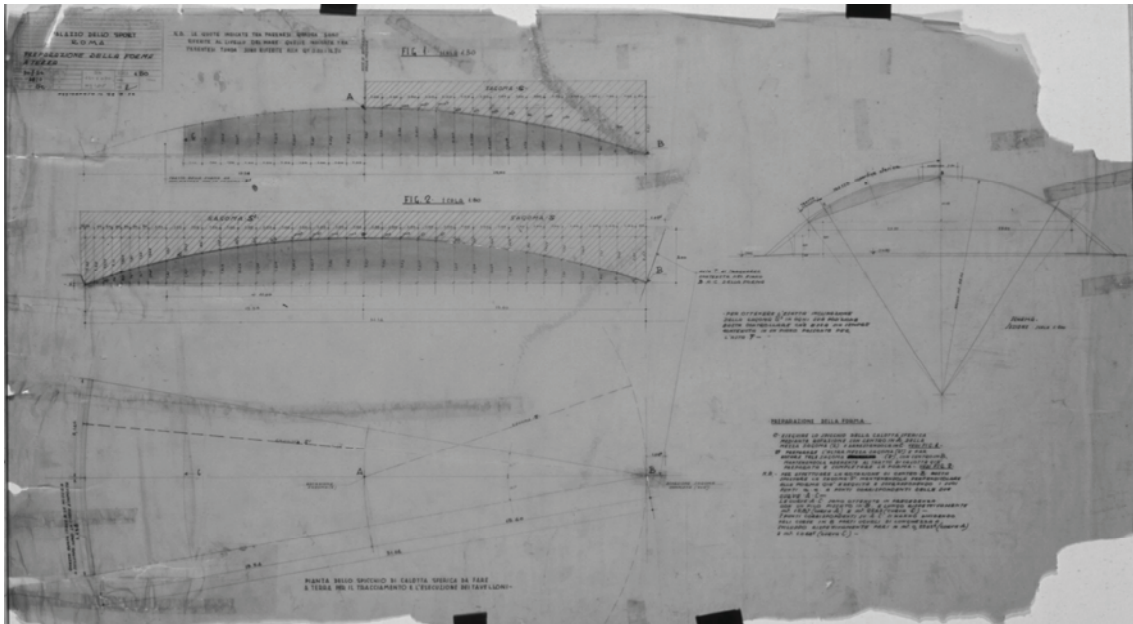


Figure 2. Working plan, preparation of the wooden template, 30 July 1956 (CSAC, Parma, Italy)

The organism is truly essential: a cupola with a circular plan, 60 meters in diameter, depressed (at least 10 meters of rise), raised on 36 radial forked trestles, one every 10 degrees. The trestles, inclined according to the tangent line on the border of the dome itself, are arranged on the floor to form a circumference of about 80 meters in diameter.

Inside, the stepped stands, organized with a crescent arrangement starting with the impost of the roof, descend to the playing field, a few meters below ground level. The narrow perimeter ring created between the inclined supports and the intrados of the stands contains the services: bar, first aid, administration office, press room with telephones, locker rooms for the athletes, for the judges and doctors (partly in the basement, which also contains a warehouse and a machine room).

The rough project was approved by the sports facilities commission of Coni on 13 April 1954. In February the board had reopened negotiations with the City of Rome that had been interrupted before the war for the use of an area on viale Tiziano, suitable for the first specimen of this prototype.

In spite of these autonomous design premises, the president of Coni, the lawyer Giulio Onesti, realistically hoped the design for the work might contribute to reinforce the candidacy of Rome to host the 17th Olympic Games, those of 1960. In effect, though the candidacy had been carefully prepared by the technical committee Costruzioni Olimpiche Roma (Cor), formed in October 1954, the city did not have suitable sporting facilities, apart from the area of the former Foro Mussolini, with the Stadio dei Centomila specially completed in 1953.

A full of promises dossier was presented to the International Olympic Committee in Paris on 15 June 1955, which in any case assigned the organization to Rome. Over the few years to come it would be necessary to design and build all the indispensable sporting facilities, as well as the village for the athletes, an intercontinental airport at Fiumicino, and many kilometers of road network. Nervi, who participated without success in the competition for the velodrome and that of the airport, won the competition, together with his son Antonio, for the reconstruction of the Flaminio Stadium over the remains of the old Torino Stadium; he would also be part of the design team for the Village, for which he created the viaduct of corso Francia; and he was directly commissioned to develop a project for the big Sport Palace at Eur, together with Marcello Piacentini.

The first operation to be completed, however, was that of the Palazzetto, initially seen just as an auxiliary facility, but later promoted for use in matches and finals. In March 1955 the Cor had already put the budget together, based on the definitive project that was then approved on 15 April.

To get the worksite started, however, it was necessary to resolve a series of controversies, in discussion for more than one year.

Only once the lot in the Flaminia area had been ceded, geotechnical studies could be conducted. Based on these results, Nervi designed a surface foundation composed of a continuous ring beam, capable of absorbing the strong thrust of the dome through a sort of chain composed of pre-stressing cables, sheathed and post-tensioned, anchored to the base of 6 of the 36 trestles.

The most delicate question regarded selection of the construction company. The approved project and associated cost estimate were based, in fact, on the use of the patented system of prefabricated elements, the Nervi system. It was this special technique, whose sequence was known only to Nervi, that made it possible to hypothesize the very low cost of just 12000 lire per square meter, when an ordinary roof slab cost more than half as much. As a result, it was impossible to open the job up for bidding : only one company could do that type of construction, namely Ingg. Nervi & Bartoli, a small family firm, the only owner of the patents involved. The executive board of Cor, therefore, had to take the route of private negotiations, not without raising some eyebrows. For the company, this was work no. 3870, as catalogued in its very orderly archives. In the contract, Nervi had to state that he had no uncertainties about the structural and functional factors, and take all responsibility for any damages caused by errors in the project.

So finally work could begin: on 27 June 1956 the first stone was laid, and on 21 July the worksite was turned over to the contractor. After the signing of the papers, it took just 420 days to complete the work.

Under the supervision of Giacomo Maccagno, an engineer of the technical department of the City, excavation began and the prestressed foundation ring was made.

This was immediately followed by the pouring of the trestles, whose anthropomorphic profile, though stylized, is a clear reminder of a man with extended arms, one leg bent, the other firmly set back, as if resisting strong pressure.

With the usual strategy of careful control of construction costs, formworks were reutilized to make repeated, identical parts. The execution of the radial supports, however, seemed too slow to the Cor supervisor, who made a quick visit on 8 November to the worksite. Concerned about



Figure 3. One of the 13 prototypes called “grandmother” in which the dome of the Palazzetto was divided (Maxxi Architecture Archives Centre, Rome)

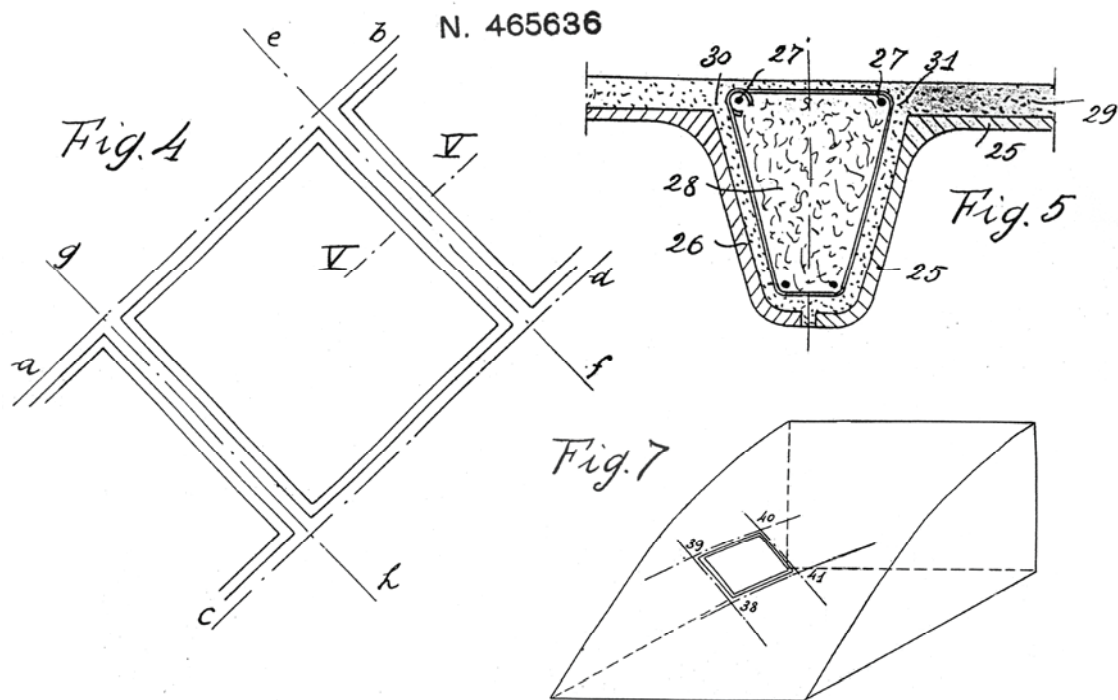


Figure 4. Patent n. 465636, Pier Luigi Nervi, Roma, 19 maggio 1950, *Procedimento di costruzione per la realizzazione di superfici resistenti piane o curve costituite da reticolati di nervature di cemento armato, completate o meno da solette di collegamento tra le nervature* (Archivio Centrale dello Stato, Rome, Italy)

the lazy pace of the construction, he wrote a very critical letter to Nervi & Bartoli, emphasizing the importance of the deadline: 14 September 1957.

The company responded in a short, irritated message, to inform the hasty technical staffer that in spite of his impression the work was almost done! Had he paid closer attention, he would have noticed that beside the site where the ordinary reinforced concrete parts were being poured, there was another, much more productive worksite of prefabrication: the Nervi system was being applied.

2.1 Applying the Nervi system

Taking advantage of the modes developed starting with the second series of the aircraft hangars of Orvieto, Nervi had broken down the dome into a myriad of little pieces to be made at the site. There were 13 different types of pieces, called *tavelloni*, in the patent dated 1950 covering the procedure: repeatable segments that could be put together, like a gigantic mosaic, to form the roof. Each block, with a triangular or rhomboidal form, or oblong at the central oculus, was sized for production by hand and for movement by just two workers. This was the key to the economy of the whole system: it avoided the use of continuous wooden centering, almost as costly in its own right as the finished work, which also imposed constraints to structural solutions, due to the difficulties of its construction.

Furthermore, the objective of avoiding the costs of traditional formwork also involved an original way of making the blocks on the ground at the site. The technique was the one that had become usual since the time of the construction of the semi-dome of the Salone B in Turin. It was based, above all, on the material invented by Nervi, *ferrocemento*, that genetic mutation of reinforced concrete that reformulates and inverts the proportions between the concrete and the steel reinforcement. A perfectly elastic, ductile, exceptionally strong material, patented in 1943 and gradually perfected over the years to adapt to increasingly complex structural needs.

In particular, the blocks were obtained by creating a light weave of rods and dense layers of overlaid screen, on which - using a counterform - the concrete, only with sand, was applied with a trowel, until a thickness of 2.5 cm was reached.

This laborious manual operation was made extraordinarily economical by an ingenious "generational" solution that permitted production of about 30 blocks per day, with the certainty that each piece would fit exactly in the final assembly.

The first step was the preparation of a wooden template that reproduced, in actual size, a segment of the spherical cap. On this profile, laid on the ground and finished with plaster, the axes were traced by hand and the 13 triangular or rhomboidal forms were constructed in masonry. On each masonry form a block prototype was made in ferrocemento. In theory, this last operation could be repeated 108 times for each form, to obtain all the pieces required: but this would have called for uncomfortable work, outdoors, with the workers operating in a tight space, using a support that would be deformed over time, as it was not sufficiently durable.

Nervi preferred to organize the sequence in a number of passages: reversing the first block sample, which was called the "grandmother", a small number of "mothers" were made, i.e. forms perfectly identical to the masonry profiles. On these "mothers", working in the shelter of a shed, multiple teams then made dozens and dozens of "daughters", also identical to the "grandmothers", which would effectively be used in the construction (the generational terminology was part of the jargon that was really used on the worksite).

Even the outermost band of the dome, the one connected to the trestles was made with the same technique: three different blocks to compose the fan, and three for the "festoon", whose famous profile, however, was the result of a formal correction obtained thanks to a special, sinuous prefabricated element that modified the interrupted triangular pattern suggested in the initial drawings.

At the end of December 1956, the 1620 prefabricated pieces were ready, stacked in perfect order near the completed ring of trestles. The blocks were rested, one after the other, on the light scaffolding of pipes. Then, once the mosaic had been assembled, in the canals created by placing the blocks side by side the reinforcement was inserted, followed by poured concrete to complete the work. The blocks, with a good finish on the visible inner surface thanks to the use of a smooth counterform, were engulfed by the poured concrete, functioning like formwork. In the end, the dome appeared like a monolithic moulded block: no one would be able to intuit the sequence of breakdown and recomposition revealed by the drawings or the worksite photographs.

The procedures of assembly of the pieces and pouring took just 30 days, helped by a mild

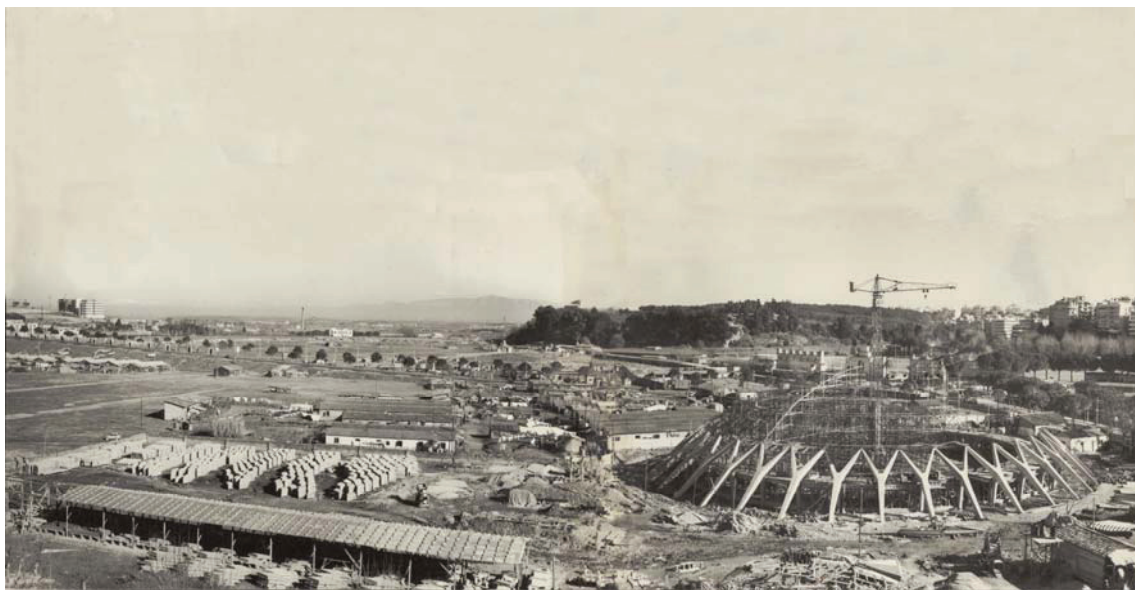


Figure 5. Palazzetto dello Sport in Rome. On the left, the prefabrication yard; on the right, the building site (Maxxi Architecture Archives Centre, Rome)

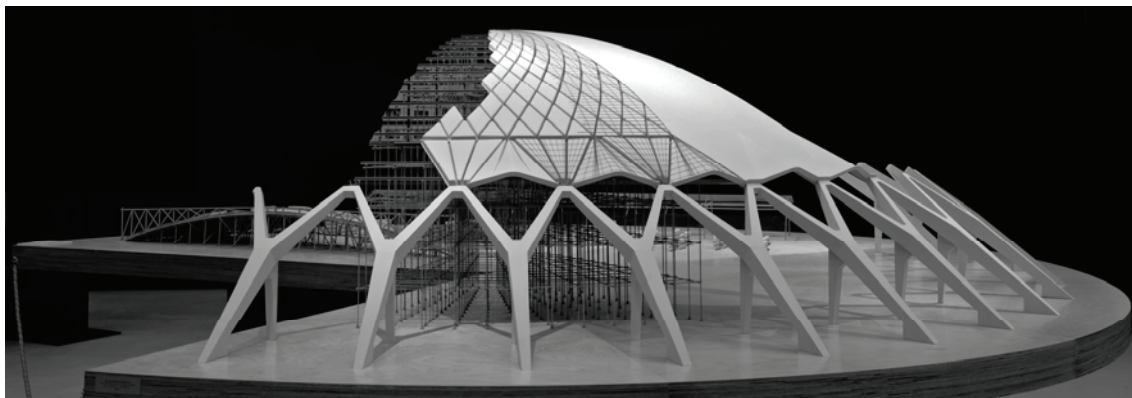


Figure 6. A model-game of the Palazzetto dello Sport designed by the authors in occasion of the Exhibition *Pier Luigi Nervi. Architettura come sfida. Roma. Ingegno e costruzione*, MAXXI, Rome, 2010.

winter, after the year of the famous snowstorm. So on 24 February the dome was finished, and it was already time for the first visits for ecstatic participants.

2.2 *The fame of a prototype*

Much remained to be done, but the work involved simple masonry partitions, painting, physical plant. Only the insulation and protection of the dome against the weather caused some concern, because the solution initially suggested and tested yellowed too fast. On the slender insulating layer of mixed vermiculite, a coat of glue and sand formed the base for attachment of layers of vetroflex and waterproofing asphalt: then everything was coated with bituminous gray paint, which would inevitably require repeated maintenance.

Halfway through September the documents for completion of the work were signed.

Load trials were performed in the next few days, and on 1 October a solemn opening ceremony was held, with a band, a blessing, refreshments and a commemorative medal. Two days later, Nervi himself guided a visit of journalists, experts and foreign delegates. Finally, the Italy-Czechoslovakia basketball match was the first event held at the Palazzetto.

Zevi, through detailed comparisons with the archetype of the Pantheon, underscored -in spite of the classical character- the originality, maturity and timeliness of the structural language of Nervi (Zevi 1957). Giuseppe Vaccaro added some compliments regarding the very lofty qualities of one of the greatest builders of the day, and on the "chastity" of the structure "that enhances its intrinsic virtues" (Vaccaro 1958). Nervi boasted that he had not only been able to match the estimate, but even to complete the work for 10 million less (based on the final expenditure, including the technical systems, which reached 265 million lire) (Nervi 1958).

Paradoxically, the secretary general of Coni, Bruno Zauli, a few months later, complained precisely about the excessive thrift, which turned out to not be suitable for Olympic pomp and splendor (Zauli 1958).

While the Italian design culture paid little attention to the masterpiece, on an international level, the specialized press was much less reluctant to cover the work: architecture magazines in all languages fought to use the limited number of worksite photographs made available, and the accompanying technical descriptions. The same images were used to illustrate the articles on the many international prizes - from the Royal Gold Medal of RIBA to the similar honor bestowed by the AIA - won by Nervi, as a result of the success of his construction System.

2.3 *4 masterpieces in 4 years*

The XVII Olympic Games commenced on 25 August 1960: the original Made in Italy structures that framed the event were realized by Pier Luigi Nervi, not only as a designer, but also as a builder.

The Ingg. Nervi & Bartoli enterprise, founded in 1932, employed, in addition his cousin Giovanni Bartoli, Nervi's recently graduated sons, in particular the engineer Mario and successively Vittorio, an architect; while Antonio, the eldest, also an architect, assisted him in the design office, with its staff of approximately ten people and a handful of external consultants.

The four construction sites of the Palazzetto, the Stadium, the Palazzo and the Viaduct were temporally overlapped with one another, and the first were completed while the projects for the others were still being developed. What is more, they were anything but ordinary building sites: in fact, the results represent some of the most important masterpieces of 20th century Italian engineering and, in particular, the golden age that coincided with the economic boom.

Each of the building sites was completed rigorously on time and on budget, without any accidents or harm to labourers.

4 masterpieces in 4 years: an undertaking made possible by the ethical approach of Nervi system.

3 CONCLUSIONS

The distinctive features of the Nervi system are based on a main trait: absolute fidelity to the "minimum principle" according to its classical Galilei's interpretation of 'uniform resistance'. More specifically: the belief that the potential of reinforced concrete can make the most out of that principle. As Nervi said:

"Adaptability to any form and the capacity to resist all three major stresses make reinforced concrete the most revolutionary material in the history of the construction industry" (Nervi 1945). More: *"The possibility to create cast stones of any form, which being more resistant to stress are better than the natural ones, is somewhat magic"* (Nervi 1945).

However, that is not enough. It has to be completed by the firm belief that the "Economy principle", a principle that in modern engineering represents extreme rationality, ensures also 'beauty'.

In other words, the belief that by respecting the principles of ethics, esthetical principles are reached. The monolithic structures of the domes with their rich and thick drawing actually highlight the balanced distribution of forces so that it appears as a "revealed truth". It is the structural honesty postulate, enhanced, in Nervi's case, by the construction honesty postulate. This way the artefact gets closer to Nature.

However, on such a (critical) issue Nervi has something to say:

"The distribution of forces within a hyperstatic system [...] is a perfect model of justice and distribution of economy, of which we can only vaguely grasp its mysterious and divine wisdom." (Nervi 1945)

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