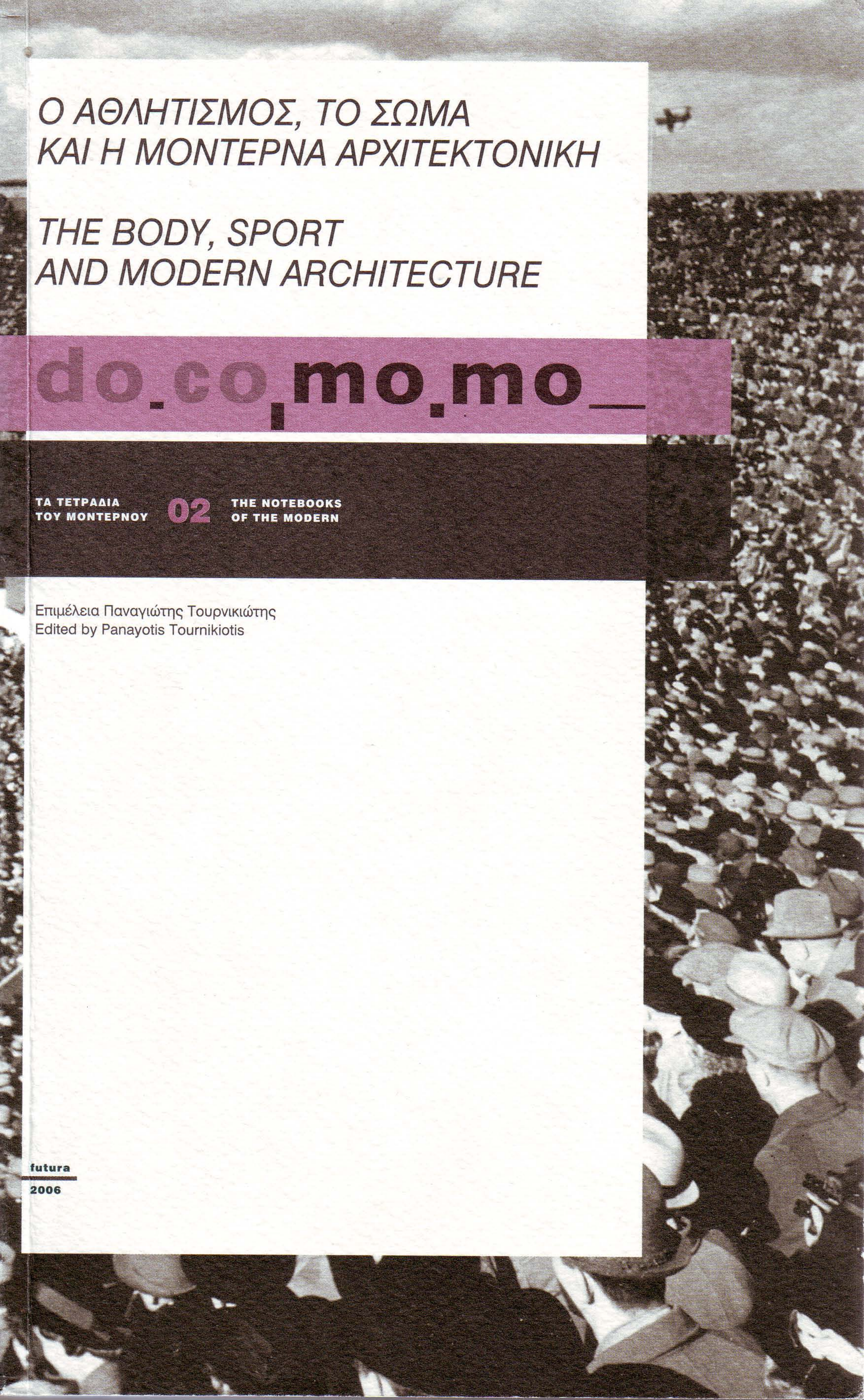


Ο ΑΘΛΗΤΙΣΜΟΣ, ΤΟ ΣΩΜΑ ΚΑΙ Η ΜΟΝΤΕΡΝΑ ΑΡΧΙΤΕΚΤΟΝΙΚΗ

THE BODY, SPORT AND MODERN ARCHITECTURE

do_co_mo_mo_

ΤΑ ΤΕΤΡΑΔΙΑ ΤΟΥ ΜΟΝΤΕΡΝΟΥ **02** THE NOTEBOOKS OF THE MODERN

Επιμέλεια Παναγιώτης Τουρνικιώτης
Edited by Panayotis Tournikiotis

futura
2006

PIER LUIGI NERVI'S WORKS FOR THE 1960 ROME OLYMPICS

TULLIA IORI AND SERGIO PORETTI

Pier Luigi Nervi designed and constructed four structures for the 1960 Rome Olympic games: three sports facilities and a viaduct serving the Athlete's residential quarter, the *Villaggio Olimpico*. These are considered some of his most famous international works.

The Palazzetto dello Sport (Small Sports Palace; 1956-57; with Annibale Vitellozzi) in the Flaminio area of Rome is characterized by its sixty-meter diameter dome, which is held up - or better, held down - by 36 radial Y-shaped struts whose divergent upper arms develop the rim 'decoration'. The externally smooth dome only reveals its large rhomboidal ribbing internally.

The Palazzo dello Sport (Sports Palace; 1956-59; with Marcello Piacentini) in the EUR area is also dome-shaped, but with a hundred-meter diameter. The internal surface is characterized by minute pleated V-shaped "waves". Externally, the dome is concealed by a high glass cylinder, which only partially reveals the structure of the perimetral stands.

The Stadio Flaminio (Flaminio Stadium; 1956-59; with Antonio Nervi) is characterized by the numerous moulded frames, upholding the slim ridged canopy covering the grandstand, which vary in width along the oversail and completely flatten out along the rim.

The Corso Francia Viaduct (1958-60), also in the Flaminio area, is characterized by varying width pillars - the sections change from rectangular to cross-shaped and the transitional surface from one to the other in a hyper surface, formed by straight lines - and by the V-shaped beams, precast and prestressed.

The works erected for the 1960 Olympic games represented a crucial milestone in Pier Luigi Nervi's career. They are the best examples of his experimentation on statics, construction and architecture, and guaranteed his international fame.

However, the objective of this paper is not to illustrate the architectural or typological features of these works, which are already well known.

The true aim is to showcase those features that made Nervi's works clearly unique and understand the reasons, which made his distinctive method of reinforced concrete construction bloom in post-war Italy.

Nervi was sixty-nine years old when he completed these four structures. He only took four years (from the end of 1956 to the early months of 1960) to erect them. Moreover, he wasn't solely focused on the projects. Nervi's own construction company, the Soc. An. Ingg. Nervi & Bartoli (practically a family-run business) staffed all four building sites. Nonetheless, the works were executed with great speed and all four structures were completed in 12 to 18 months. All of these works clearly display Nervi's imprint and global paternity from the design to the construction.

How did he accomplish this? What came to be known as the "Nervi System" was the result of a twenty-year-long intense and complex experimentation on statics and construction aspects. The deserved results are showcased by the four Roman structures.

During the twenty years preceding the Olympics, Nervi had devised a new building material, *ferrocemento*, and a unique construction process, structural prefabrication, which allowed him to face the simultaneous construction of four such imposing projects. Therefore, in order to investigate the genesis of the Olympic works, it is necessary to step back in time to the late 1930s.

The Invention of ferrocemento and Structural Prefabrication

The stimulus to experiment was brought about by the particular economic situation, Autarchy, which reigned in Italy at the time. Mussolini was preparing for war and wanted Italy to become economically independent from other European countries. Self-sufficiency, however, was particularly complicated due to the dearth of raw materials present on the national territory. The construction industry, therefore, was the first to feel the consequences. Steel was among the materials, normally imported from abroad, which was suddenly rationed. (In any case, steel was reserved for military needs.)

Reinforced concrete, which requires steel for the reinforcement, suddenly became an anti-autarchic and anti-national construction material. Notwithstanding the fact that reinforced concrete was the most widespreadly used material in both small and large-scale construction work, in 1939 its use was banned.

So what could designers and constructors using reinforced concrete do (and Pier Luigi Nervi was one of the most important figures in both categories)? Hoping for better times, they began experimenting alternative solutions.

In the ordinary building industry, experimentation concentrated on the substitution of steel reinforcement with other materials found throughout Italy, such as aluminum, wood, bamboo, etc.

In large-scale constructions, instead, attempts were made to minimize the use of steel by optimizing the performance of other materials, while hopes focused on the discovery of a more efficient manner for the use of steel and concrete. Pier Luigi Nervi conducted such experiments (as well as, for example, Riccardo Morandi, who at this time began to discover the potential of prestressed concrete).

Nervi carried out a detailed analysis of every single construction cost. He became an expert in calculating the incidence of every steel rod, every bag of cement, every wooden plank, every liter of petrol used for transportation on the global cost of erecting a structure. This allowed him to evaluate the most economical structural solution for every detail in the construction plan. (This meticulous analysis excluded two parameters, the cost of labor and design, both of which were considered to hardly amount to anything.)

Nervi's analysis led him to focus on two fundamental points.

The first was that in order to save on steel it was fundamental to reduce the use of cement: thin layers of densely reinforced concrete are more efficient – and therefore more inexpensive – than larger bodies of concrete with less reinforcement.

The second was that reducing the use of wooden casting moulds for directly erecting elements proved to be the most important cutback.

These simple reflections gave rise to two parallel activities. First, Nervi began experimenting with slender concrete slabs densely reinforced with steel; secondly, he started an important experimental building yard in which he significantly reduced the need for wood, which was becoming exceedingly scarce, by making use of prefabricated on-site concrete elements.

The experiments conducted on the densely reinforced concrete slabs were hardly scientific. They were very artisanal and conducted in chance labs, often in his house. (There even are accounts that state that Nervi conserved these experiments on his balcony). Nervi was only able to rely on load tests much later, when they were carried out in the Milan Polytechnic laboratory headed by Arturo Danusso.

How were these slabs, which Nervi first referred to as being "evenly reinforced" and then "*ferrocemento* slab", made?

Nervi superimposed various layers of metal netting formed by small diameter (1 mm. or less) steel wire. He then pressed mortar made of cement and sand (but no gravel) into the metallic mesh using a trowel or float This operation was conducted on one side of the mesh until the cement emerged from the other side after having saturated it. Naturally, the operation also depended on the plasticity of the mortar, which had to be accurately prepared. Both horizontal and vertical slabs could be made in this manner and they did not require wooden moulds to shape the mortar until it hardened.

The extreme subdivision and the uniform distribution of the reinforcement in the concrete created a material that was different from ordinary reinforced concrete. The new material, called *ferrocemento*, is a homogeneous, isotropic, elastic material and resists both traction and compression.

Nervi patented his invention in April 1943, when Italy was still at war. In July 1943, when the Fascist regime collapsed and the Nazi forces occupied Rome, Nervi refused to collaborate and closed his building company. (Rome would not be liberated until June 1944.)

In the meantime, Nervi continued to experiment with what he called "structural prefabrication". This technique, which involved the use of prefabricated elements, allowed him to dramatically reduce the use of wood from his building sites.

The opportunity to employ his new construction methods was provided by the construction of the famous series of airplane hangars for the Italian Air-Force: six identical hangars were created in pairs in Orvieto, Orbetello, and Torre del Lago between 1939 and 1942.

Nervi adopted the same structural plan he had employed in Orvieto in 1939, but abandoned the complex and expensive wooden moulds that he had needed to erect the great ribbed vault. How was this done? Nervi divided the ribs into as few small and identical elements as possible. These individual elements were prepared in series in moulds that could be reused dozens of times. The elements were then lifted into place by using a light scaffolding system and joined with concrete pour. Once the work was completed, there was no trace of this fragmentation and the resulting structure proved to be statically monolithic.

In November 1939, this procedure was protected by a patent. Nervi was aware that he had devised a system that could be applied to any type of construction. All it required was an efficient de-composition of the structure into a few types of elements that could then be pre-fabricated.

Thus, by the end of the war, Nervi possessed a new material, *ferrocemento,* and a new building technique, structural prefabrication.

Ferrocemento is a light material composed of layers of steel mesh grouted together with cement (which can still be found in natural deposits throughout Italy) and sand. An unspecialized laborer can easily prepare it with very simple equipment (trowel, float, etc.). It was cheap and perfect for post-World-War-II Italy.

Structural prefabrication is an artisanal technique that requires accurate planning, but can easily be implemented on a traditional building site as it does not require specialized labor. What Nervi invented was not factory-made serial construction elements, but the application to individual building of serial elements pre-fabricated directly on the building site. Notwithstanding the pompous name, prefabrication, this really is an age-old technique applied on the basis of available means and materials. Just as in the past, columns, capitals, metopes, triglyphs and ashlars were carved on the building site and then erected into their permanent position; Nervi's construction elements were constructed on the site and then erected into position. It was a perfect technique for building yards in post-war Italy without either specialized labor or machinery.

The Nervi System

In the period between the liberation of Rome and the Olympic games, Nervi had many opportunities to test his inventions. First, separately with the famous Magliana hangar and then together in a series of minor experimental construction jobs. However, the best prospect to test both together was provided by the construction of Hall B of the Turin Fair.

During the extremely rapid construction of this building (begun in September 1948 and completed in April 1949), Nervi was able to perfect all the construction processes that he would use in the future and which came to be known as the "Nervi System".

The four structures simultaneously constructed for the Olympic games provided the opportunity for the definitive fine-tuning of the Nervi System. Their analysis, in fact, allows us to understand the system itself, and how *ferrocemento* and pre-fabrication were combined.

In designing these facilities, Nervi opted for rather traditional architectural solutions and showed a clear preference for symmetrical curved forms. However, Nervi's domes and vaults are clearly discernible from classical examples on account of their complex surfaces. Nervi created extremely detailed ridged, wavy, pleated and ribbed surface areas. His structures are enriched by a minute superficial design that is not found in any other contemporaneous reinforced concrete structures. The surface depths are often no thicker than 3 centimeters, but the complexity of the movement prevents one from perceiving its slenderness, which can only be discovered by consulting the executive plans.

Why did Nervi adopt such complicated surfaces that had been abandoned by others due to the construction and calculation problems they entailed? Why were these complex superficial combinations reserved for symmetrical and even circular structures?

The answer lies in the peculiarity of Nervi's building sites.
Nervi's concept of structural prefabrication meant that structures had to be de-composed and the separate elements had to be prepared ahead of time.

So, every element had to be small and light enough to be lifted and easily set into place. The slenderness of each section was functional not only in terms of weight, but also helped streamline material costs and the minute superficial design depended on the scale of the prefabricated elements. Each piece had to have a shape, which would allow it to be rigid enough to resist the handling and erecting stress. Finally, each piece had to be replicable as many times as possible. This meant that only translation and revolution surface designs were feasible.

How was structural prefabrication adapted to the structures erected for the Olympic games? What was the de-composition principle adopted?

The spherical vault of the *Palazzetto dello Sport* is composed of a total of 1,620 elements, but only 19 different types of them (12 rhomboidal elements of varying shapes and 1 anomalous piece for the apex were repeated 108 times, while the 6 elements for the edge were repeated 36 times). The spherical vault of the *Palazzo dello Sport*, instead, is formed by 1,008 elements of only 9 different types (6 V-shaped ashlars forming 144 identical waves and 3 for the 48 fan-shaped elements). The *Stadio Flaminio* canopy and grandstand stands are even simpler in conception: a single identical piece was repeated dozens of times. The same holds true for the floor system of the Viaduct.

The elements were prepared directly at the site and stacked, while the parts that needed to be cast-in-place were created. (Naturally, there still were plenty of these: from the foundations to the pillars). Subsequently, the elements were set into place by using scaffolding. The double purpose of reestablishing the monolithic nature of the whole and completing the resisting system was obtained with cast-in-place ribs. One of the most interesting aspects of the Nervi System is the skillful combination of prefabrication and casting.

What element types were adopted to de-compose the complex structures? In which parts was *ferrocemento* used?

The complexity of the surface, the minute design of the ribbing, the thick pleating of the domes and floors was obtained, albeit with different results, by employing only two different types of 'special' elements made with *ferrocemento*, the 'wave elements' and the 'rhomboidal elements', which Nervi had invented at the Turin site.

The 'wave elements', patented in August 1948, were meant to give prefabricated sections a geometrical design that would guarantee an elevated moment of inertia with a minimum use of material. The use of *ferrocemento* made this technique economical. It was just a matter of bending the wire mesh with a brick mould and then filling the mesh with mortar as usual. The result was a light (about 1500 kg every 4 meters) construction element no thicker than a few centimeters, and resistant to transport due to its elevated moment of inertia. The 'wave elements' are closed at either end by non-deformable headers and their rigidity is ensured by two or three internal diaphragms, which keep the slender walls (often lightened by wide apertures) from deforming. When the elements are mounted on the falsework, their shaping allows the casting of concrete ribs both along the top and the bottom of the wave. The reinforced ribs are connected to the precast element via the reinforcing rods left protruding from the element itself.

The "wave elements" used in the dome of the *Palazzo dello Sport* are made up of V-shaped elements that vary between 4 and 5 meters and have large side apertures with perforated diaphragms to allow the passage of the lighting system and other installations. The V-shape motif is also repeated in the beams that form the road bed of the Corso Francia Viaduct. These, however, are 16 m. long and partially pre-compressed.

In the canopy covering the grandstand at the *Stadio Flaminio*, the 15 m oversail was obtained by juxtaposing variable geometric waves along it. In this case, the casting is limited to the ridge of the wave and joins the prefabricated elements to the previously erected structure.

The other special element, the "rhomboidal element", was patented in May 1950.

The idea sprouted from the need for a thin curved surface stiffened by ribs, which is very complicated to cast. Nervi solved this problem by inventing a special type of formwork, a precast 'shape-element', no wider than a few centimeters, which would not be dismantled, but became an integral part of the completed structure.

'Shape-elements' must be geometrically exact parts of the surface to be created. This can easily be done by creating a surface model replicating the exact surface to be erected. The wooden model is used to prepare the moulds in cement, plaster or wood, which are then used to make the entire series of 'shape-elements'. Naturally, this technique is economically sound only if the same moulds can be utilized for hundreds of pieces.

The shape-elements are shaped so that once they are set on the scaffolding; they generate a channel (closed underneath) in which the stiffening rib can be casted. A thin slab can also be poured in place over the whole surface.

Precast "rhomboidal elements" were employed to create the entire dome of the *Palazzetto dello Sport*. The 12 types of elements all have the same thickness (2.5 cm). They were prefabricated in series by using a mould created with a model. Once these elements were mounted on the scaffolding, only resting on 2 points, the reinforcement was placed in the channels and the cast was executed. The reinforcement also extends to the extrados of the dome where a 3 cm thick layer of concrete was cast.

The same technique was also used for the intrados of the ring gallery in the

Palazzo dello Sport. Here, too, a model was used to prepare the moulds in 6 different measures used to prefabricate the required 240 elements.

This still leaves us curious regarding a central point: How did Nervi's dome function statically? Do the thin *ferrocemento* elements support the load or is this accomplished by the more consistent cast ribbing? Do the waves and rhomboidal elements serve a structural function or did they only serve as casting moulds? In his papers, Nervi declared that they served both purposes: the domes attain stability both as membranes and as a series of rib-arches. Certainly these structures are deeply hyperstatic and it is practically impossible to comprehend exactly how the dome settled considering that its elements were created at different times and underwent different shrinking, aging and stress processes during their erection.

Reconstruction Monuments

The analysis of the Olympic works confirms the originality of Pier Luigi Nervi's experimentation. Their originality lies especially in the unique technique, which was employed to construct them.

At the time, in fact, many engineers around the world were examining the issue of thin shell concrete structures following the pre-war experiments conducted by Dischinger, Finsterwalder, Torroja, Freyssinet, Aimond and Lafaille. Other works under scrutiny included those by Felix Candela and Heinz Isler, who became famous at the end of the 1950s. They also employed thin sections and took advantage of resistance through shape.

However, Nervi's domes and vaults were not only the result of a new invention in reinforced concrete construction, but also profoundly related to post-war Italy.

Italy lagged far behind in the technological advances that had been achieved in construction work. During the phases that led from Autarchy to war, and the long and difficult years of the post-war reconstruction, the Italian construction industry remained unaltered. It was both technologically and industrially behind, had no specialized labor or machinery, and was controlled by small, improvised firms.

Nervi's works certainly reflect this condition in the poverty of means and the artisanal nature of the building sites. Nonetheless, his works remain masterpieces of structural engineering and their sophisticated and bold solutions became the symbol of Italy's rebirth. They were true monuments to the reconstruction effort.

Nervi was certain that his system demonstrated that the full potential of reinforced concrete still had to be discovered. He believed that his work would usher in a new phase of reinforced concrete construction. However, as we now know, the exact opposite took place. The use of thin shell concrete structures was progressively abandoned and *ferrocemento* - an economic miracle - remained exclusively associated to Nervi.

Thus, Nervi's work did not trigger further experimentation, but rather closed the age of the great reinforced concrete structures. Why?

First and foremost, the inexpensive nature of *ferrocemento* and artisanal prefabrication was brought to an end by the growing costs of labor and materials. However, what became even more anachronistic was the idea that a single person could control the entire construction process. The great designer and site director was the last heir of a long dynasty of Italian constructors that from Antonelli and Vittone all the way back to Brunelleschi had created many masterpieces.

This particular placement in the history of engineering does not in any way diminish the great influence that Nervi's works had on the architectural culture and production of the twentieth century. Nervi's influence affected architectural experimentation in general, rather than the evolution of great structures. (In fact, Nervi has always fascinated architects more so than engineers.)

Thus, Nervi's works for the 1960 Rome Olympic games decisively influenced the development of structural expressionism, which characterized the architectural languages of Italy in the years to come.

References

P.L. Nervi, *Nuove strutture*, Milano, Ed. di Comunità, 1963.

P.L. Nervi, *Aesthetics and Technology in Building*, Charles Eliot Norton Lectures, 1961-1962, Cambridge, Mass., Harvard University Press, 1965.

P.L. Nervi, *Costruire correttamente. Caratteristiche e possibilità delle strutture cementizie armate*, Milano, Hoepli, 1965.

A. Pica, *Pier Luigi Nervi*, Roma, Editalia, [1969].

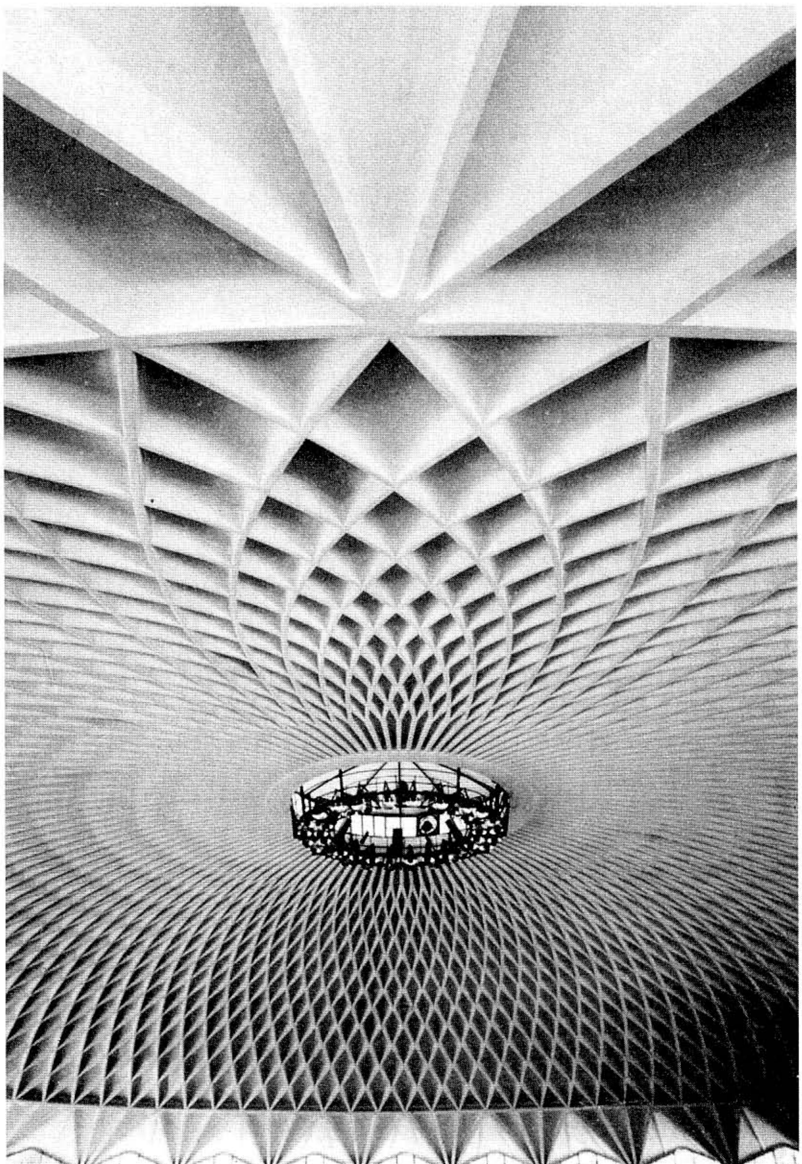
P. Desideri, P.L. Nervi jr, G. Positano, *Pier Luigi Nervi*, Bologna, Zanichelli, 1979.

Εικ.1: Το Palazzetto dello Sport, Ρώμη (1956-57), αεροφωτογραφία.

Fig.1: Small Sports Palace, Rome (1956-57), aerial view.

Εικ.2: Το Palazzetto dello Sport, ο θόλος από το εσωτερικό.

Fig.2: Small Sports Palace, the dome from the interior.

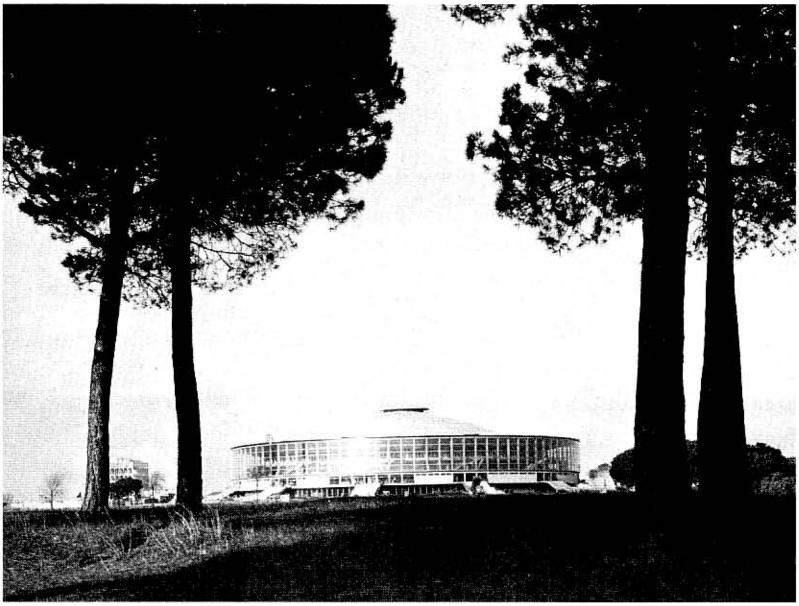


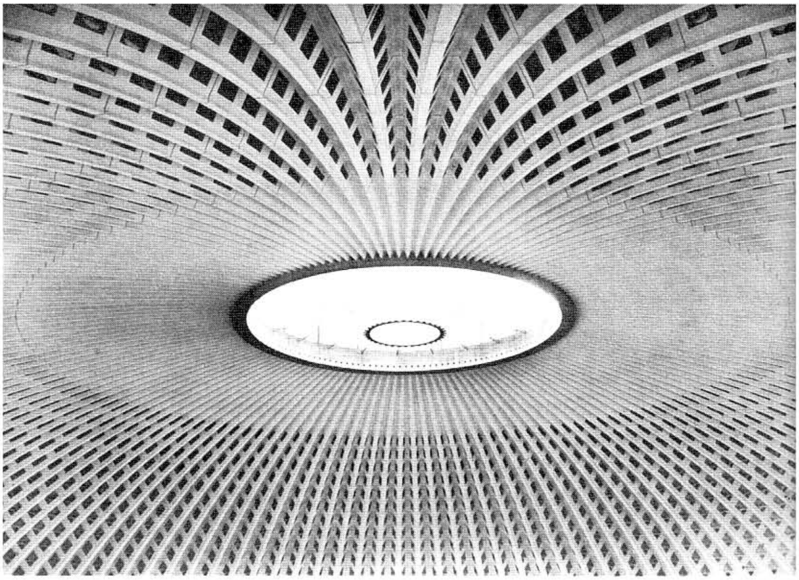
Εικ.3: Το Palazzo dello Sport, Ρώμη (1956-59).

Εικ.4: Το Palazzo dello Sport, ο θόλος από το εσωτερικό.

Fig.3: Sports Palace, Rome (1956-59).

Fig.4: Sports Palace, the dome from the interior.





Εικ.5: Το Στάδιο Flaminio, Ρώμη (1956-59), η στεγασμένη εξέδρα.

Εικ.6: Η Γέφυρα Corso Francia, Ρώμη (1958-60).

Fig.5: Flaminio Stadium, Rome (1956-59), the covered grandstand.

Fig.6: The Corso Francia Viaduct, Rome (1958-60).

Εικ.7: Το Palazzetto dello Sport, άποψη από τη διαδικασία κατασκευής του θόλου.

Εικ.8: Το Palazzo dello Sport, τοποθέτηση ενός στοιχείου διατομής V στο θόλο.

Fig.7: Small Sports Palace, view during construction of the dome.

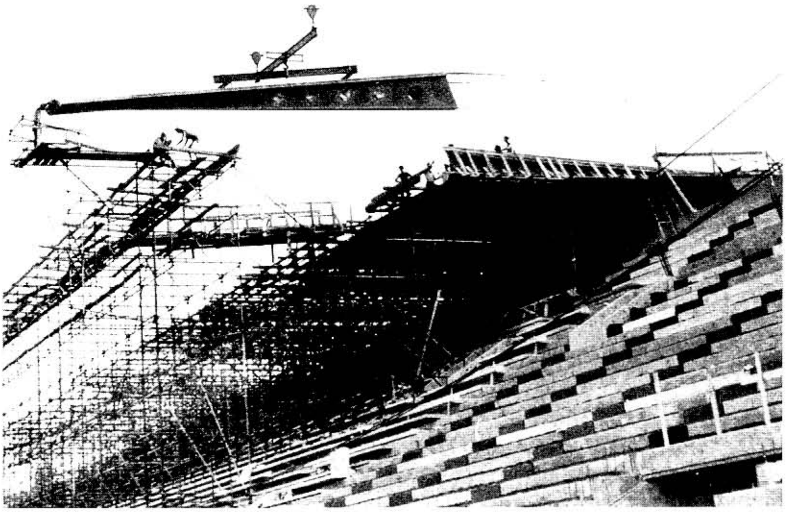
Fig.8: Sports Palace, placement of a V-shaped element for the dome.

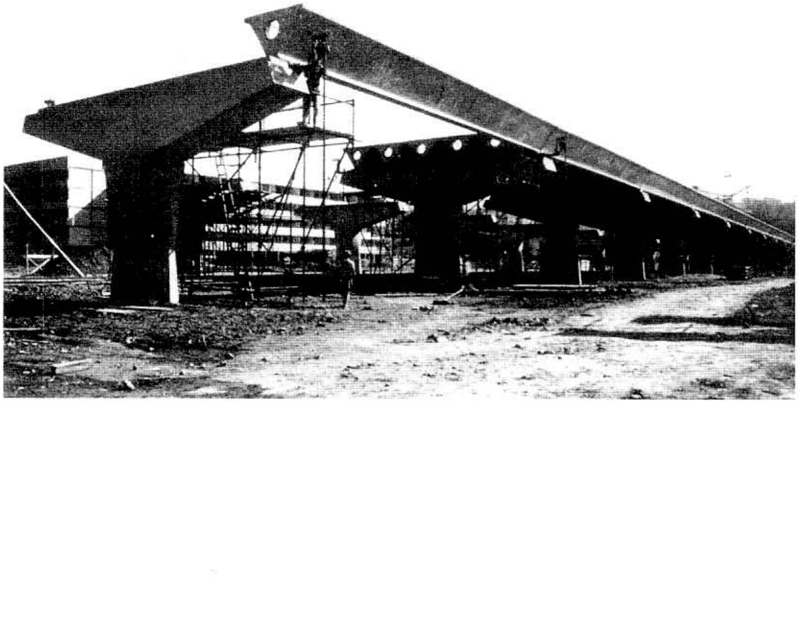
Εικ.9: Το Στάδιο Flaminio, τοποθέτηση ενός στοιχείου του στέγαστρου.

Εικ.10: Η Γέφυρα Corso Francia, η τοποθέτηση μιας δοκού πάνω σε υποστυλώματα.

Fig.9: Flaminio Stadium, placement of one of the canopy elements.

Fig.10: The Corso Francia Viaduct, the positioning of a beam on a support.





Εικ.11: Pier Luigi Nervi, Ιταλική πατέντα αρ. 445781, 26η Αυγούστου 1948: το «κυματιστό» στοιχείο.

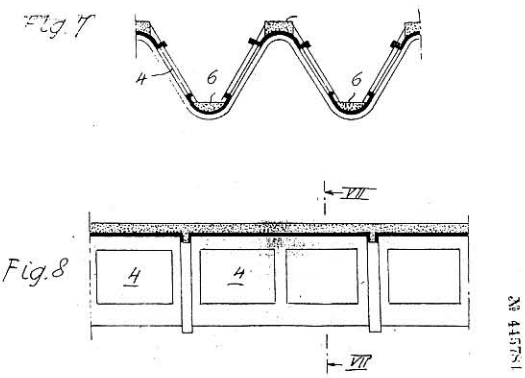
Εικ.12: Pier Luigi Nervi, Ιταλική πατέντα αρ. 465636, 19η Μαΐου 1950, το «ρομβοειδές» στοιχείο.

Εικ.13: Palazzetto dello Sport, «ρομβοειδή στοιχεία» στοιβαγμένα.

Fig.11: Pier Luigi Nervi, Italian patent n. 445781, August 26th 1948: the "wave element".

Fig. 2: Pier Luigi Nervi, Italian Patent n. 465636, May 19th 1950: the "rhomboidal element".

Fig.13: Small Sports Palace: piled "rhomboidal element".



N. 465636