

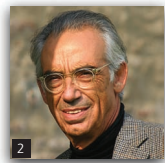
Conserving Pier Luigi Nervi's ferroconcrete

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The recent restorations conducted on the *La Giuseppa* motorboat (1972) and the warehouse in the Magliana district (1944) have revealed some secrets of ferroconcrete, the material developed by Pier Luigi Nervi between the Thirties and the late Fifties. Ferroconcrete was a composite material consisting of layers of wire mesh embedded with dense concrete incorporating fine aggregates. The new compound, protected by two subsequent patents between 1943 and 1944, perfected while working on the construction of some fishing boats, showed homogenous properties and allowed construction of complex, thin surfaces without the use of any wood formwork. The first application of the new material to building work was a warehouse in Rome: made entirely of ferroconcrete, including the roof, 3 cm in thickness, it was shaped in waves. Currently used as a car park, the building was subjected to extensive conservation works in the early months of 2013, following the success of the intervention method used for the *La Giuseppa* ferroconcrete motorboat. The study is part of the EU-funded research Sixxi – Structural Engineering in the Twentieth Century: the Italian contribution, ERC Advanced Grant 2011. Italcementi has provided the financial and technical support to the restoration.

1. Introduction

All Pier Luigi Nervi's works were closely related to the cultural and social upheavals both in Italy and worldwide, which changed considerably during his long working life (from 1913, when he graduated, to 1979): from World War I through the Fascist era to the post-Second World War reconstruction period, and on to the booming years of economic miracle up to the following financial and energy crisis. For this reason, upon reviewing his works, it seems to us that Pier Luigi Nervi lived not one but three lives: in the first life he was a modern architect talented in reinforced concrete construction, in the second an ingenious creator of a new construction method, and in the last an international star-architect. Three equally intense lives that coexisted, overlapped and interacted but remained independent of each other (Poretti, 2008).

With regard to conservation challenges, the most interesting period of his career is the 'second life'. That was the time between the end of the Thirties and the first half of the Sixties when he was a tireless experimenter and a busy constructor. In those years, he invented the so-called Nervi System, a completely new way of designing and constructing reinforced concrete structures, and then applied it to the breathtaking masterpieces of his maturity.

2. The invention of the Nervi System

The starting point of Nervi's second life coincides with the last years of fascist regime before World War II. In 1935, Italy invaded Ethiopia and the League of Nations imposed heavy sanctions: no state was allowed to sell strategic materials to Italy, particularly metals. The fascist regime profited from this opportunity to promote 'autarchy', that is, an economic self-sufficiency, which was in actual fact already intrinsic to the corporatist economic policy it had been implementing for years. At that critical time, the country's own modest steel production was mandatorily and exclusively used for armaments. The construction market was obliged to relinquish rebars and, consequently, reinforced concrete. In 1937, the material was accused of not being 'Italian' enough, and its use was first restricted to certain specific types of buildings (tall or anti-seismic buildings) and then, in 1939, banned (Iori, 2009a).

While the debate over autarchy was raging, Nervi went back to explore the unknown potentialities of reinforced concrete. His company, the legendary Nervi & Bartoli, turned into an actual laboratory where experimental research on new construction solutions was carried out.

In Nervi's opinion, reinforced concrete was not a codified building technique, rather a construction strategy that could still

be improved, enhanced or integrated by other inventions since it was in the early stage of its development (Poretti, 2010).

It was in the war years that the Nervi System was improved. The new construction process to make structures with concrete and reinforcement was based on two inventions.

The first one was called *prefabbricazione strutturale* (structural prefabrication) by Nervi himself and was patented in 1939 when the 'second series' of airplane hangars for the Italian Air Force was built (overall, six sheds located in Orbetello, Orvieto, and Torre del Lago; the 'first series' was built in Orvieto in 1936). Both series featured arches meeting at right angles, but while, in the first hangars, they had been cast in situ, in the second they were broken down in small, lightweight pieces, prefabricated on the construction site and then lifted and assembled into place, thereby restoring a monolithic structure. The pieces were prepared on the ground using elementary reusable formworks.

The second invention was *ferrocemento* (ferroconcrete), a composite material consisting of a genetic variant of reinforced concrete that was developed through subsequent patents between 1943 and the end of the war. Nervi inverted the standard proportion of the two main components of reinforced concrete: he prepared a package of layered steel meshes, which he then covered with a conglomerate of high-strength cement and sand, spreading it with a trowel from one side until the steel felt was saturated with mix so that it came out from the other side, where it was finally smoothed off (Figure 1). The resulting slab was very thin, normally 2 or 3 cm (the metal mesh had to be a few millimetres thinner than the slab once it was finished). Ferroconcrete is practically homogenous, lightweight, extraordinarily easy to shape into almost any form and exceptionally economical (above all because it did not require formworks). The structural behaviour of the material is exceptional: isotropic, very stiff and highly elastic.

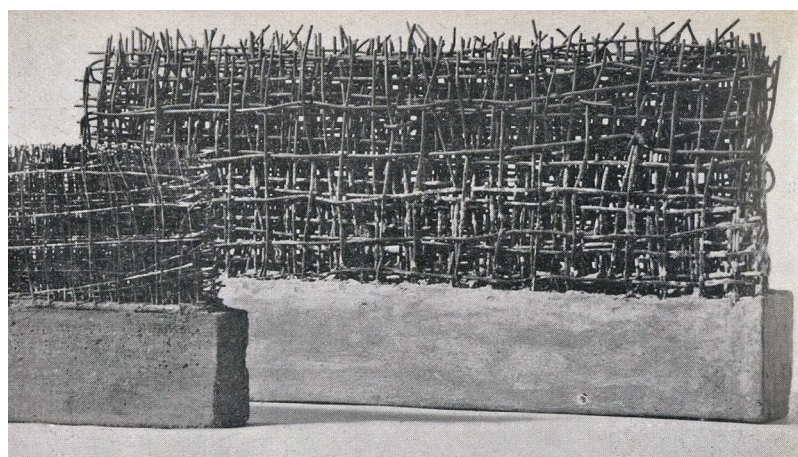


Figure 1. First version of P. L. Nervi's ferroconcrete, according to the Italian Patent 406296, April 1943 (Nervi, 1943)

Tests conducted in Milan Polytechnic Laboratory in 1949 proved that under loads, a ferroconcrete slab could elongate, without crackings, five times more than un-reinforced concrete, and it could preserve its waterproofing for elongations up to the yield strength of steel (Nervi, 1950).

Moreover, Nervi demonstrated that for any given span, his material, having such reduced thickness, would require much less steel than ordinary reinforced concrete. Of course, in order to be useful in construction, ferroconcrete had to be formed into appropriate shapes (wavy or pleated, for example) to make it 'shape-resistant' (Iori and Poretti, 2010).

Nervi patented his invention in April 1943 (Nervi, 1943). Soon after, things started to get complicated. After the collapse of the fascist regime, Italy was subjected to the post-armistice invasion of the Nazi forces, during which Nervi wisely decided to shut down his company and to retire into his house. His ferroconcrete slabs were stored on his balcony, which gave him the opportunity of testing their weather resistance. Rome was liberated in June 1944. A few months later, he was ready to create ferroconcrete prototypes, actually some fishing boats. The first application of the new material to building construction was a warehouse at the Magliana Nervi & Bartoli place in Rome: made entirely of ferroconcrete, including the roof, 3 cm thick, it was designed in waves, getting the most out of the inherent shape-resistant solution (Figures 2 and 3).

In fact, also in this pioneering use, ferroconcrete was strongly simplified. The multiple layers of steel mesh were soon discarded. In the Magliana warehouse's curly slabs, the steel inner weave was prepared with few 8 mm dia. vertical bars and couples of 6 mm dia. shaped horizontal bars (20 cm spaced): within these rebars, multiple square wood strips made the composition more stable and helped to support only two layers of mesh (weight: 1 kg/m²), one for each side.

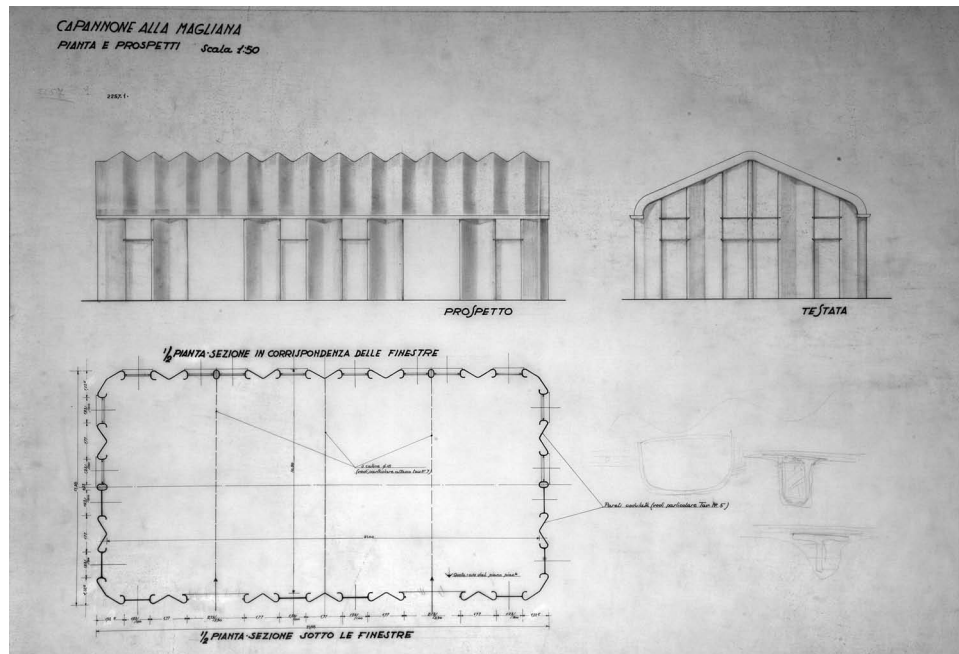


Figure 2. Plan and elevations of the Magliana warehouse, sd 1944 (reproduced by agreement of CSAC, Parma)



Figure 3. The Magliana warehouse under construction, 1945 (reproduced by agreement of Centro Archivi Maxxi, Rome)

The new version of the material was protected by a new patent, taken out in September 1944 (Figure 4).

In the application, Nervi claimed also the construction technique, so he explained how he built the Magliana warehouse (Figures 5 and 6). First, he predisposed wood studs that formed the temporary supports of the building (wood studs would eventually

be eliminated once the work was finished). Then he prepared the inner weave, tying rebars and wood with annealed steel wire so as to give the whole a certain robustness. To bend the rebars into the proper curvature, workers used a wooden model, which also served to pre-assemble vertical and horizontal bars (Figure 7). After disposing the ‘carcass’ on the studs, steel meshes were added gradually, directly on site.

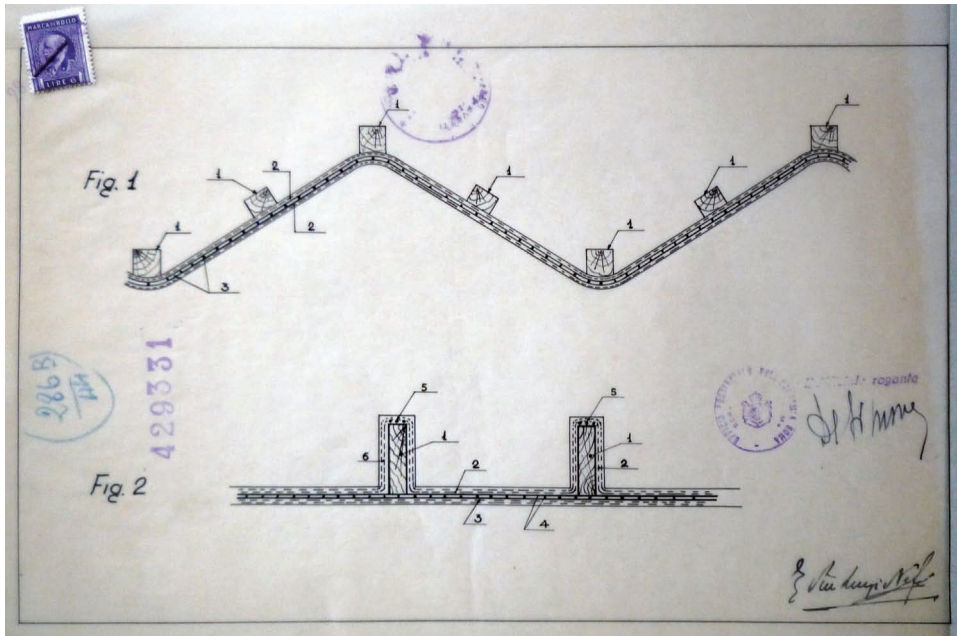


Figure 4. P. L. Nervi's ferroconcrete according to the Italian Patent 429331, September 1944 (reproduced by kind permission of Archivio centrale dello Stato, Rome)

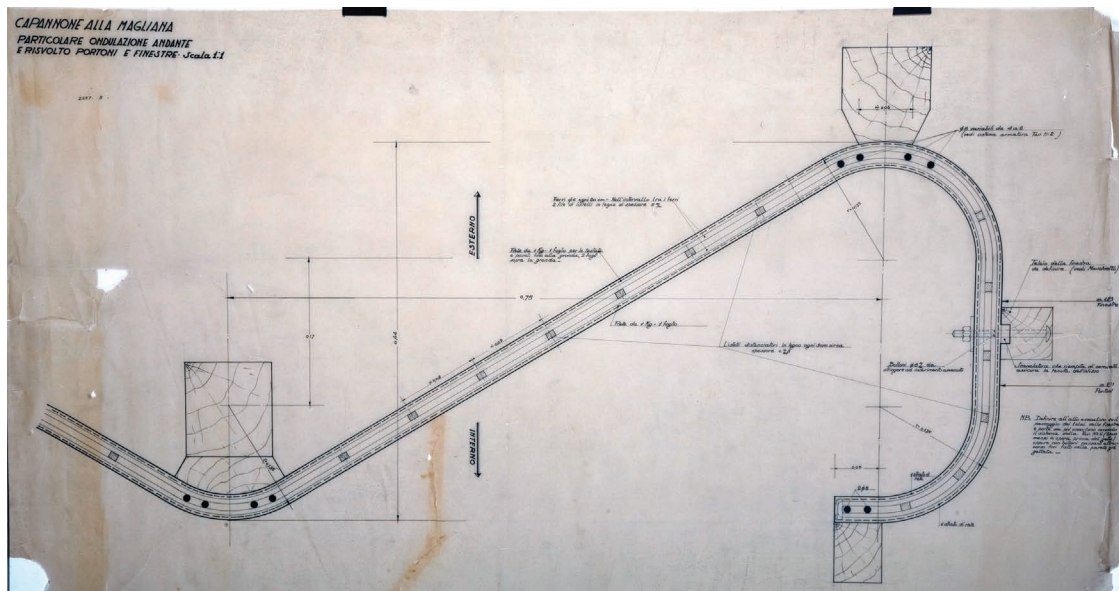


Figure 5. Detail of the ferroconcrete wall of the Magliana warehouse, sd 1944 (reproduced by agreement of CSAC, Parma)

Why wood? Wood is cheaper and, in the immediate post-war, it was easier to find than the rebars. But wood did not bend easily, so workers could not use it for curves but only for flat surfaces. Wood had no static function in ferroconcrete, being regularly interrupted, but served to provide rigidity to the weave so that the two mesh layers could be held together properly. Indeed, if the

weave was rigid, it better captured the cement and sand mortar. Thus, the mortar is pushed (with the desired plasticity) by trowel, through the weave, 'so that the execution of the operation on one side of the slab implies that the concrete flows back to the other, filling completely the thickness. [...] The operation is carried out on one side, but the other is monitored to ensure uniform

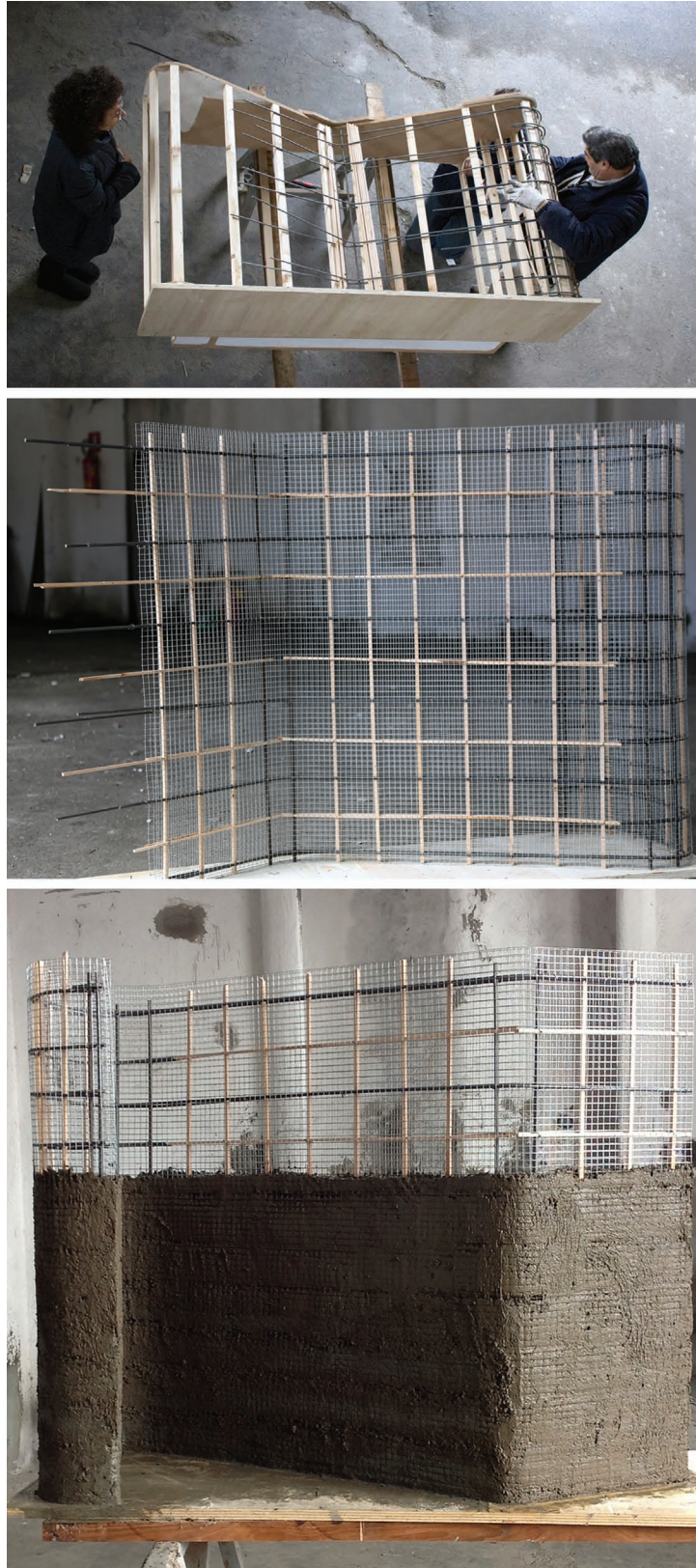


Figure 6. Reproducing 1:1 scale model of ferroconcrete wall of the Magliana warehouse, step by step, 2013, © Sixxi



Figure 7. Workers building the Magliana warehouse walls, 1944–1945 (reproduced by agreement of Centro Archivi Maxxi, Rome).

distribution of the mortar. During this first stage of the procedure, the outer faces of the slab, especially the one towards which the mortar is pushed, cannot be perfectly regular; as soon as the mortar begins to set and harden, surfaces should be treated with the trowel thus obtaining the desired smoothness. The structure doesn't need additional coatings' (Greco, 2008; Nervi, 1944).

On May 1945, when Nervi's first book, *Scienza o Arte del Costruire?* (Nervi, 1945), was printed, the warehouse was almost complete (a picture in the book showed three quarters of the building). Six pages were also devoted to ferroconcrete, which in a few years would allow Nervi to become one of the most famous engineers in the world. In the next book, *El Lenguaje Arquitectónico* (published in 1951 in Buenos Aires), Nervi stated with reference to the 'galpón para nuestro depósito de Roma': 'The construction has achieved excellent technical results, although its cost is approximately slightly higher than a traditional shed' (Nervi, 1951).

Nevertheless, on-site manufacturing of the entire building was long, demanding and difficult. To fix problems while putting dense concrete on the mesh required several attempts. The Magliana warehouse was the first and only building entirely conceived in this way. Thereafter, prefabrication of ferroconcrete smaller pieces was preferred for the roof and ordinary reinforced concrete for vertical structures.

3. The development of the Nervi System

Except for the Fair's Central Pavilion in Milan (now destroyed) and some other small 'sculptures' (such as the springboard for the Kursaal bath house or the so-called 'Sphere' for the EA53 Exhibition), Nervi hardly used ferroconcrete as in the Magliana warehouse. Therefore, ferroconcrete would only be used to

prepare small elements to compose gigantic structures as if they were puzzles. The all-on-site solution was saved only for the boats, definitely with a simpler shape.

The core of the Nervi System became the combination of ferroconcrete and structural prefabrication. The Nervi System was both economical and rapid. Economical because it eliminated the wooden, costly and difficult to reuse formwork required to pour reinforced concrete, and also because it reduced the material costs by limiting thickness of the load-bearing elements (and hence diminishing dead loads). Rapid because it divided the construction yard into two stand-alone sectors where workers could 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, in which the pieces necessary to complete the structure were prepared. The pieces were small, lightweight and easy to move from the storage area to the building site, which were always adjacent.

Nervi tested his inventions on various minor works in the years leading from post-war reconstruction to the economic boom. The best chance he had to test ferroconcrete and structural prefabrication together was the construction of the exhibition halls at the Turin Expo (hall B and hall C). During the very rapid building process (1947–1949), Nervi was able to fine tune the method he would use in his future works: the so-called 'Nervi System'.

At the end of the development process, the construction of the Palazzetto dello Sport for the Rome 1960 Olympic Games (1956–1957) was the best example of the application of the Nervi System in a 'mature' manner (Iori, 2009b; Iori and Poretti, 2012).

The dome was made up of 1620 small, rhomboidal *tavelloni* (ferroconcrete special elements). Overall, 13 different types of *tavelloni*, once assembled in place, would create the dome as if it were a huge mosaic. Each element was small enough to be made by hand and moved by two workers. That was the key issue.

What made that painstaking manual process so extraordinarily cost-effective was an ingenious ‘generational’ solution that allowed production of around 30 *tavelloni* per day with the certainty that each of them would fit exactly in the final assembly.

First of all, a wooden template had to be made that would replicate a dome section. Then the template would be finished off with chalk; then, after drawing the axes, 13 different masonry moulds would be made. Each mould would then be used to make a ferroconcrete prototype element.

To produce the prefabricated elements, a square grid of 6 mm dia. bars (15 cm spaced) supporting only one layer of mesh (weight: 0.6 kg/m²) was used, over which a 2.5 cm-thick layer of dense concrete incorporating fine sand was applied (Figures 8 and 9).

To replicate 108 times each of the 13 prototypes, Nervi planned a precise sequence of steps: by turning the first *tavellone*, called ‘grandmother’, upside down, he would obtain a small number of ‘mothers’, that is, moulds that would be a perfect match of the masonry ones; the mothers would then be brought under a shed where several workers’ teams would use them to produce tens of

‘daughters’, that would be eventually used in the construction process (the generational terminology belonged to the real site jargon).

The wooden template was finally conceived at the end of August 1956. In late December, thousands of prefabricated elements were ready, stacked in perfect order near the completed ring of 36 trestles. Starting in January 1957, the *tavelloni* were rested, one next to the other, on the sparse scaffolding of pipes. Then, once the mosaic had been assembled, reinforcement bars were inserted in the flights formed by placing the elements side by side. The *tavelloni*, with a good surface finish on the visible inner side obtained with the use of smooth counterforms, were engulfed by the poured concrete, functioning like disposable formworks (Figure 10). 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 piece assembly and pouring took just 30 d. So, on February 1957, the dome was finished. An insulating layer of 5 cm of vermiculite mix was spread on the concrete, followed by glass fibre tissue and asphalt for waterproofing: the entire structure was then painted with bitumen paint.

The signature feature of Nervi’s vaults, domes, and ceilings lies essentially in the folded, ribbed, undulated version of the surfaces, which is the distinctive feature of Nervi’s architecture, which can, therefore, be seen more clearly from the inside. Paradoxically,

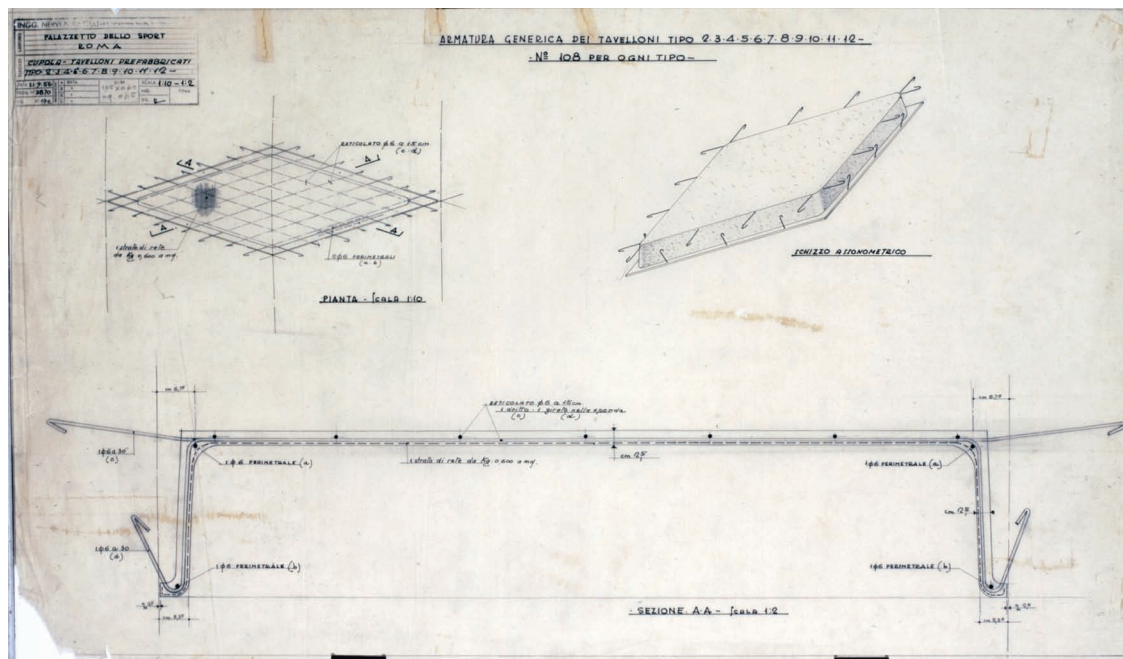


Figure 8. Detail of the ferroconcrete *tavellone* for the dome of the Palazzetto dello sport, 1956 (reproduced by agreement of CSAC, Parma)



Figure 9. Workers creating one of the 1620 inner steel weaves of the ferroconcrete *tavellone* for the dome of the Palazzetto dello Sport, 1956 (reproduced by agreement of Centro Archivi Maxxi, Rome)

however, the exceptional nature of Nervi's works (and hence their Italianness) lies in their being complex structures made by using a simple and plain method invented by Nervi himself, which is closely related to the year-long technological underdevelopment the Italian building sector would experience from the reconstruction years to the first half of the Sixties. Nervi's sophisticated and bold works became the symbols of Italy's rebirth and of valued 'made in Italy' products (Iori and Poretti, 2013).

4. Restoring Nervi's ferroconcrete

Thinking of the development process outlined below, Nervi's material and construction system was unique of its kind. Moreover, he refined his original material over time so much that the first ferroconcrete made in 1945 had little in common with the material he would employ around the late Fifties. Its preparation and static properties evolved over time: as a matter of fact, the kind he used for building boats or the Magliana warehouse



Figure 10. The Palazzetto dello Sport under construction, 1957 (reproduced by agreement of Coni Historical Archive, Rome)

was a structural load-bearing material; instead, the kind employed in the construction of the Palazzetto dello Sport was a simpler material, suitable to build disposable formworks that would resist together with the other cast-in-situ concrete parts of the dome. The structural properties of ferroconcrete were unchanged, but eventually, Nervi preferred a mixed system combining small, easy-to-make, prefabricated elements and more traditional cast-in-situ components.

Hence, restoring ferroconcrete is an experimental operation. However, the conventional repairing procedures used for standard reinforced concrete are of no help at all. Some special constraints have to be respected, including the following: to strictly keep the minimum thickness between 1.4 and 3 cm; to preserve a very dense, steel reinforcement covered with a thin layer of concrete, in the order of a few millimetres; to use hand-crafted, rigorously handmade procedure.

The Sixxi research team, which operates out of Università di Roma Tor Vergata under the authors' supervision, has had two opportunities of restoring ferroconcrete. On both occasions, they have worked in partnership with Italcementi, Italy's leading cement manufacturer, a firm that is always ready to experiment with materials.

The first restoration works involved the fishing boat called *La Giuseppa* that Pier Luigi Nervi built with his son Antonio in 1972. Nervi's family had used the boat during the summer for 6 years, mostly for cruising along the Amalfi coast; then in 2002, they donated it to Università di Roma Tor Vergata. With the help of Prof. Claudio Greco (Greco, 2008), *La Giuseppa* is now displayed to the public in front of the Civil Engineering building. The boat was also part of the exhibition 'Pier Luigi Nervi. Architecture as challenge. Rome: genius and construction' (Iori and Poretti, 2010) that took place from December 15, 2010, to March 20, 2011, at the Maxxi – National Museum of XXI Century Arts. Then it was taken to the Food and Agriculture Organization of the United Nations (FAO) headquarters at the Circo Massimo in Rome where it was displayed until September (Figure 11).

In view of such an outstanding tour, careful and accurate restoration works were carried out on the boat. Its ferroconcrete body is only 1.4 cm thick. In such a case, therefore, the conventional techniques that had been developed and validated for standard concrete could not be used or did not offer any methodological ideas. However, the project represented a unique opportunity to perform a direct material analysis and to experiment with an executive procedure that would be extremely helpful for the unavoidable next step: to restore Nervi's most prestigious works, beginning with the huge Olympic domes.

La Giuseppa is the only remaining evidence of the numerous boats Nervi designed from the immediate post-war period to the early Seventies (Figures 12–14). The complex forms and

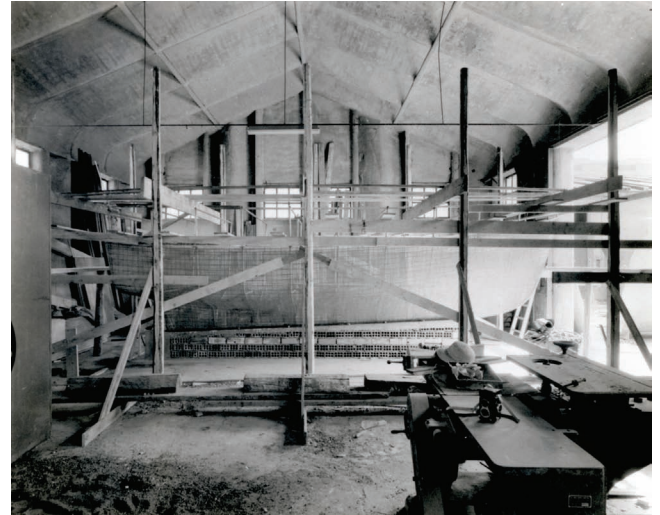


Figure 11. The FAO ferroconcrete motorboat under construction inside the Magliana warehouse, 1970 (reproduced by agreement of Centro Archivi Maxxi, Rome)

lightweightness of a boat hull had seemed to Nervi the most natural application for ferroconcrete. Being ductile, elastic and resistant, it prevents hull cracks and assures compactness and water tightness. Furthermore, the properties of the pozzolana cement mixture protect the wire mesh even in a marine environment, notwithstanding the thinness of the concrete layer. Also, its pliability makes it ideal to mould any shape without timber formworks, which makes the construction of a boat body particularly cost-effective.

Right after the end of the war, using the hand-crafted technique that he had developed, Nervi built a motorboat, then the *Irene* motorsailer, several pontoons, the *Santa Rita* fishing boat and, finally, the beautiful *Nennele* cruising ketch designed in 1948. The excellent performances of his pioneering boats confirmed the validity of his technique. However, he gave up boat designing because of the little enthusiasm with which naval builders, faithful to tradition, responded and also of the increasing success he scored in other building sectors.

In March 1967, despite an overwhelming amount of commitments, Nervi was given the opportunity of working again on his beloved ferroconcrete boats. In fact, FAO commissioned him the design of two fishing boats in order to promote fishing as a helpful instrument for combating famine. The boats were to be used on man-made lake Nasser in Egypt, which was being created at that time as a result of the construction of the Aswan dam.

The project provided for the construction of two prototypes in Rome, the development of a construction instruction manual and subsequent training of local manpower to make similar boats that were very suitable for developing countries. Nervi contributed to the project for free. In September 1970, the vessels (7.5 and 10 m



Figure 12. The *La Giuseppa* motorboat being restored in Università di Roma Tor Vergata Laboratory, 2010, © Sixxi



Figure 14. The *La Giuseppa* motorboat during the conclusive restoration works at the Maxxi Museum, Rome, 2011, © Sixxi

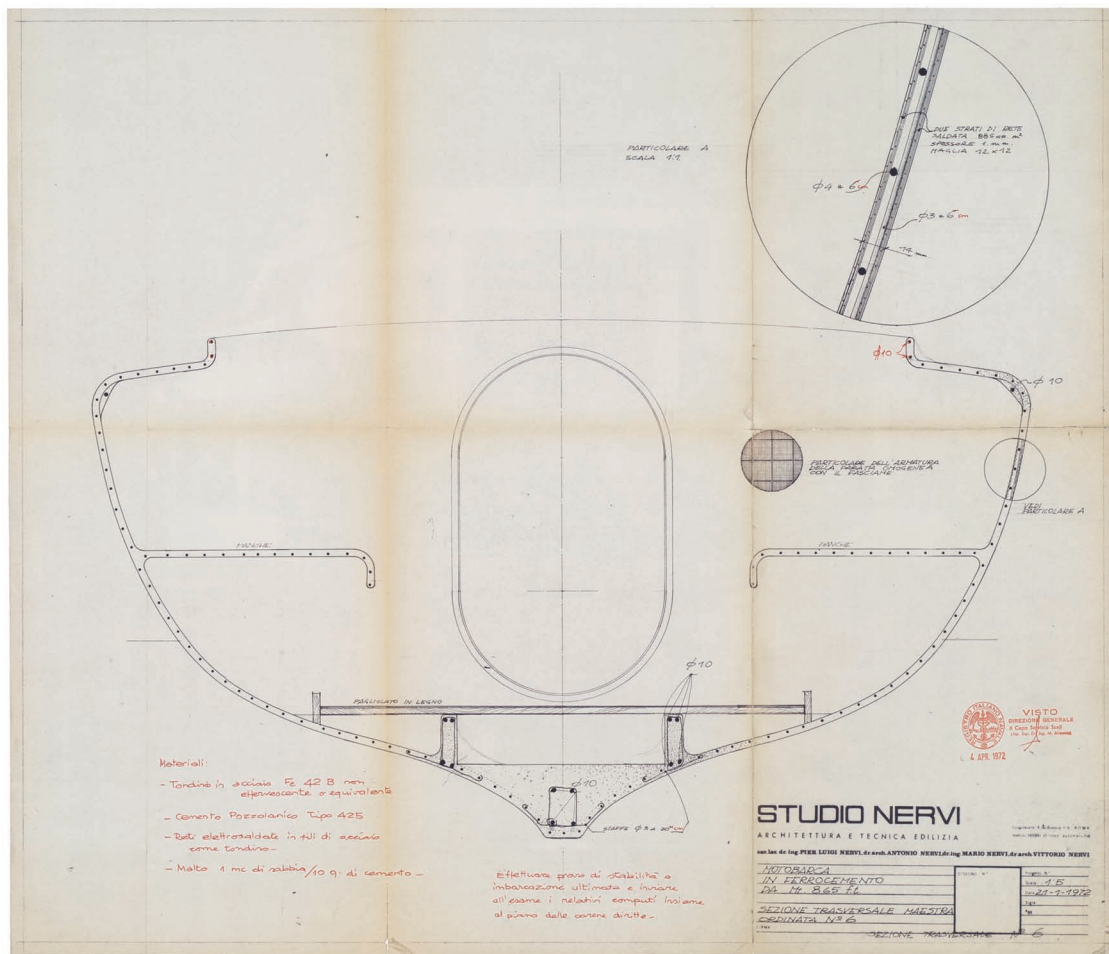


Figure 13. A section of the *La Giuseppa* motorboat. Note the 1.4 cm thickness of the ferroconcrete hull (reproduced by agreement of Centro Archivi Maxxi, Rome)

long, respectively) were launched from the port of Fiumicino (Figure 15). The FAO humanitarian program had no further developments. However, it gave Nervi the opportunity to work again on the production of ferroconcrete vessels starting with the construction of his boat (that was to remain the only example of this further anachronistic attempt). All boats designed by Nervi have nowadays gone astray, either no longer used, destroyed or abandoned somewhere. The family private boat pulled off the water in 1979 is, therefore, the only evidence of Nervi's continuous and stimulating experimentation.

On the occasion of the boat transportation to Università di Roma Tor Vergata, the shipyard that had stored the vessel for so many years carried out a simple cleaning operation. At that time, it was decided that one side would be finished with a traditional marine coating, the other would be left untreated in its natural state. The boat, like an actual sculpture, was placed for some years on the university campus grounds, exposed to weathering.

At the time the restoration works began in summer 2010, there were several significant signs of deterioration, including loosed concrete and mesh corrosion. Apparently, the treated side of the boat was better preserved. However, the removal of the coating layer revealed even worse defects caused by an inappropriate execution of the previous intervention (in particular, as a result of material and colour incompatibility of the resins used).

First of all, the old varnish and loosed concrete were washed away with pressure water jets. Resins, being more adhesive, were more difficult to remove and required the use of light sandblasting with very fine media. The mesh unveiled after cleaning was brushed and then treated with a protective coating.

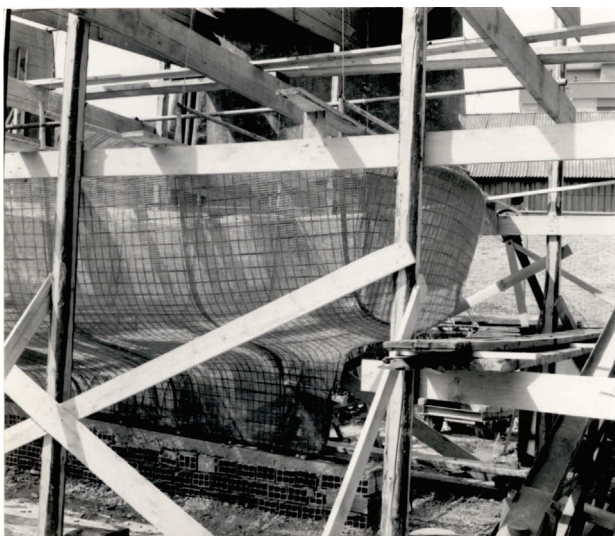


Figure 15. The FAO ferroconcrete motorboat under construction, 1970 (reproduced by agreement of Centro Archivi Maxxi, Rome)

At this stage, a cement-based product was applied that had been developed specifically for the boat restoration by Ctg Italcementi laboratories in Bergamo. The requirements the material had to meet were the following: to be cement based to assure compatibility with the original material; to have grain size as close to the original one as possible; to be exactly of the same colour as the very aged, original material; to be thixotropic for smooth hand placement, using the same techniques as the ones applied to the realization of the original ferroconcrete; to be applicable in very thin layers, in the order of few millimetres, not to alter the geometrical peculiarities of the material and structure (which, it should be borne in mind, does not exceed 15 mm in thickness); to protect the structure over time, assuring adequate durability of ferroconcrete and unvarying chromatic qualities and smoothness of the surface being treated. In this respect, a catalyst, namely, TX Active, was added to the material in order to reduce air pollutants and hence assure a self-cleaning surface.

The material was prepared by Italcementi laboratories as premixed packed in canisters. Because of the product reduced workability time, it was premixed with little quantities of water and soon applied with a trowel. This part of the works was performed by Sa.Gi (Rome). The material had to be applied very carefully in order to favour the double, even reverse curves of the hull, thereby maintaining thickness at a constant and almost imperceptible level.

The application of the product has given a significant contribution to the historical and constructive study of the material. As a result, the ferroconcrete original production sequence could be traced from the manual operations, which would otherwise have been difficult to figure out based on file records. For instance, the greater roughness of the inner side of the hull has shown that the concrete had been applied from the outside towards the inside up to saturation of the wire mesh pack.

The intervention consisted of two clearly distinct phases. Cleaning and restoration of the right side were carried out at the Università di Roma Tor Vergata Material and Structure Laboratory (Last), with the crucial help and supervision of Prof. Alberto Meda and Engineer Angelo Caratelli (Iori and Meda, 2012). The works on the left side of the boat were performed during the Maxxi exhibition, thereby becoming a minor expo and educational event within the monograph on Pier Luigi Nervi.

In the wake of the boat restoration requested by the Sixxi team, in 2013, Italcementi decided to support also the restoration of the Magliana warehouse's ferroconcrete.

After Nervi's death, the Nervi & Bartoli building business went bankrupt: their lands and the small warehouse were sold at auction and purchased by a private individual. The warehouse is currently used as a garage. Some 20 years ago, the city administration decided to expropriate the building and pull it down to turn the area into a public parking lot, but fortunately, Antonio's daughter,

Irene Nervi (herself an architect), was able to rescue it. Recently, the building has been entered in the list of monuments requiring attention by the city administration's superintendence. A little success, even though it is simply a list of places regarded as of cultural significance, which does not guarantee any protection. Several reuse and reconversion projects have been submitted over

time, including the proposal to turn the warehouse into a museum, but in the meantime, it remains a parking lot, abused by the owner. The partial restoration works have been an opportunity to report on the poor conservation status of the building and to request the intervention of the city administration and the ministry. So far, all attempts have been unsuccessful (Figures 16 and 17).



Figure 16. The Magliana warehouse walls before the restoration works, 2012, © Sixxi



Figure 17. The Magliana warehouse roof before the restoration works, 2012, © Sixxi



Figure 18. Preserving the Magliana warehouse ferroconcrete wall, 2013, © Sixxi



Figure 19. Preserving the Magliana warehouse ferroconcrete roof, 2013, © Sixxi



Figure 20. The Magliana warehouse after the ferroconcrete restoration works, 2013, © Sixxi

The ferroconcrete's restoration works were carried out in 2013. Italcementi financed the whole project and prepared the special product required for the intervention that was performed by Sa.Gi. Before starting, a laboratory test was made on a sample of the original material, to establish the aggregate type used in the ferroconcrete. The test established the maximum diameter (1.2 mm) and minimum diameter (0.07 mm) of the inert materials and an almost linear distribution between the two values; the petrographic examination showed the presence of both natural sand and crushed stone and well-filled voids. The new aggregate type and grading was almost identical to the original. Tests didn't give us information on water/cement and aggregate/cement ratios of the original ferroconcrete: the authors had to try and try again in the field to find the right ones (Figures 18 and 19).

Ctg laboratories developed a special non-shrinking cement, the next stage of the Effix product used for restoring the boat, to repair parts that had deteriorated over time due to water infiltration. Being an experimental building, no waterproofing was used on the roof for many years and the waterproofing applied later was locally in bad condition; on the walls, no coating was applied. This new material was also used to rebuild those parts that had been destroyed by accidental impacts from vehicles. In some very damaged portions, the steel mesh layers were integrated, but there was never the need to supplement rebars or wood strips, perfectly preserved inside the few millimetres of concrete. The same procedures that had been followed for the boat restoration were applied. A complete and detailed documentary was filmed during the works. The authors, with the Sixxi team, promoted, guided and coordinated the whole restoration process (Figure 20).

5. Conclusions

The restoration of the *La Giuseppa* motorboat and the Magliana warehouse gave the opportunity for an intensive cooperation experience that saw the transversal involvement of different and complementary expertise: from construction history to material

research and construction techniques. Furthermore, synergies developed between the university and business world, always desirable but difficult to leverage. The active collaboration of Italcementi's research laboratories turned out to be very helpful: having been made aware of the exceptional value of Nervi's works, they were encouraged to design ad hoc products since the materials already available on the market were absolutely inappropriate. So a simultaneously conventional and innovative material was created that was able to assure ferroconcrete the necessary respect but also to improve its performance by increasing durability and keeping the colour constant.

The interventions have been the first contribution to investigating ferroconcrete restoration and have represented the starting point to develop ad hoc guidelines for the preservation of Pier Luigi Nervi's most challenging ferroconcrete domes and vaults.

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