A 'poet in concrete': structure, fabrication and aesthetics in the work of Pier Luigi Nervi

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Synopsis

In this paper adapted from his 2019 James Sutherland History Lecture, Professor Thomas Leslie explores the aesthetic philosophy of Italian engineer Pier Luigi Nervi. Leslie shows how Nervi negotiated structural and fabricational 'truths' to create works that celebrated the constraints that he practised within, earning acclaim as a 'poet in concrete'.

The Italian engineer, builder and entrepreneur, Pier Luigi Nervi (1891–1979), constructed some of the most widely acknowledged and critically acclaimed works of structural design of the mid-20th century. His sports halls in Rome, which appeared on television screens worldwide during the 1960 Olympic Games, made him an international figure, one whose expertise was sought throughout the ensuing decade for his ability to combine engineering and architecture into forms and spaces of resonant, evocative beauty.

Magazines from *The New Yorker* to *Life* praised him as a 'poet in concrete', noting that the web-like patterns and elegant proportions of his long-span roofs seemed to defy gravity, transforming concrete from – in the words of one particularly enthusiastic critic – 'mere vile stuffing' into 'one of the most eloquent [materials] there is' through his 'Midas touch'[1].

MAXXI MUSEO NAZIONALE DELLE ARTI DEL XXI SECOLO, ROME. MAXXI ARCHITETTURA COLLECTION

Figure 1
Aircraft hangar for Italian Air Force, near Orvieto. Pier Luigi Nervi/ Nervi and Bartoli, 1935–38

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Figure 2
Aircraft hangar for Italian Air Force, Orbetello/Torre del Lago. Pier Luigi Nervi/Nervi and Bartoli, 1939–40

Such richly deserved praise for Nervi's work often marvelled that his designs were frequently achieved with modest budgets and tight programmes – but they rarely acknowledged that his prowess in distilling beautiful yet cost-effective solutions had been a necessary response to the stringent conditions of building during his early years.

Responding to constraints

Nervi graduated from the *Università di Bologna* just before the outbreak of World War I, serving in the aviation corps before going to work for one of his professors, Attilio Muggia[2]. This work, mostly for low-cost, concrete textile factories in and around Prato, on its own must have instilled a sense of fidelity to cost concerns, but this was more sharply honed after Nervi left to form his own concrete engineering and contracting practice in 1923.

Mussolini's rise to power the year before, and the country's gradual slide over the next five years into dictatorship, led to worsening economic conditions within Italy. After the country's invasion of Ethiopia in 1936 resulted in international condemnation and trade sanctions, the fascist's policy of total self-sufficiency strangled the country's construction industry; with no native sources of iron ore or coal, Italy suddenly had no access to steel and, after 2000 years of profligate timber consumption, builders' access to wood was similarly limited.

Nervi was not immediately affected by these changes, given his firm's emphasis on concrete, but as war in Europe loomed and steel became harder to obtain, even the quantities used for reinforcement became a serious issue. Nervi, initially indifferent to the regime and its growing calls for 'autarchic' construction using brick and stone, became a vocal critic, pointing out that even the exorbitant costs for reinforcing steel could, if deployed with extraordinary care and calculation[3], be amortised over the costs of a whole project to be competitive with these other materials. War brought multiple opportunities for him to prove this.

Designs for aircraft hangars

In 1935, Nervi won a military competition for two aircraft hangars at Orvieto. The Italian Air Force still flew fragile, fabric-clad biplanes, which required shelter against wind and rain. But the country's lack of steel and timber meant that traditional hangar designs couldn't be built economically.

Nervi proposed a working example of his anti-autarchic thesis, forming rectangular hangars out of thin-shell vaults, stiffened with deep ribs on a diamond-shaped, lamella plan, supported by 36 perimeter columns around the sides and back, but spanning two large openings across the front with a deep, horizontal truss to allow aircraft movements in and out (Figure 1).

The layering of structural techniques produced a remarkable material efficiency and, through model tests with engineer Arturo Danusso at the ISMES institute in Bergamo, Nervi established that the vaulted form and the lamella pattern would in fact work together to allow the vast span below.

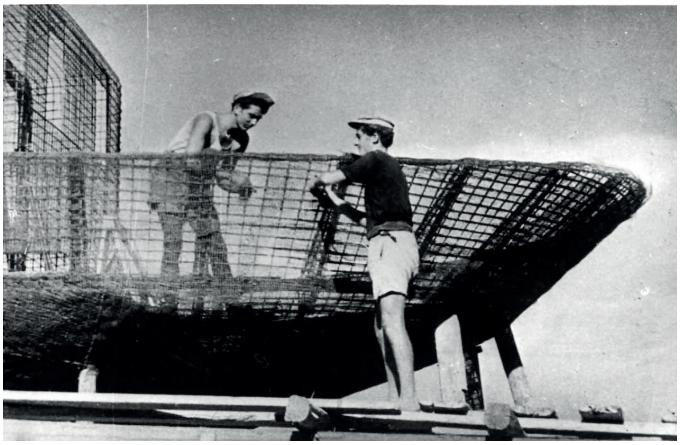
Such a complex form, while structurally impressive, proved difficult and expensive to construct. Nervi would later write that he realised there were two errors in his scheme. First, the intersecting ribs had required a vast quantity of scarce timber for formwork, along with the skilled carpentry necessary to build its intricate, curving shapes[4]. Second, while the lamella ribs had saved dead weight in the roof shell, the poured *in situ* roof was still phenomenally heavy, and its distillation into the point supports of the surrounding buttresses required a considerable amount of reinforcing steel in these areas[5].

While the hangars were hailed as engineering and architectural successes, Nervi was quietly self-critical, and he continued to think about how to reduce the costs of the formwork and reinforcing in the scheme.

In subsequent Air Force competitions for similar hangars, Nervi continued to propose the same basic scheme – a vaulted roof form with a lamella pattern of ribs set atop buttresses angled to absorb gravity loads and thrusts – but he developed a new system for *producing* those elements.

He experimented in his contractor's yard in Magliana with precasting segments of the ribs. This allowed him to produce their complex shapes quickly and with limited skilled labour, since their difficult geometries had to be built only once, for a mould, into which concrete could simply be poured again and again. But it also allowed him to fine-tune the ribs' configurations themselves, since the formwork could also be made more complex to produce more structurally efficient shapes. Understanding that each rib would work as both arch and beam, Nervi was able to design these as trusses, eliminating the dead weight of concrete around their neutral axes.

Photographs of these experiments show attempts to form these with Vierendeel trusses and with regular triangulated elements. It apparently proved easier to produce the latter, as his designs for hangars built at Orbetello and Torre del Lago were both based on these (Figure 2). This family of hangars employed lighter, demountable metal scaffolding that eliminated timber entirely and that could be



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re-used to support bay after bay of precast elements as they were placed.

Each element incorporated small amounts of reinforcing steel that extended beyond their ends in long loops; these were then locked to other elements by small pours of concrete at the truss elements' intersections. The savings in formwork were matched by savings in reinforcing; by removing more than half the weight of the ribs through the truss design, and by replacing the shell of the roof with purlins and asphalt shingles, Nervi was able to support this series of roofs on just six buttresses each[6].

As the first pair of these later hangars neared completion, Nervi made a telling choice. He had consistently documented progress on his job sites with simple black and white photography, but at Orbetello he hired Studio Vasari, Rome's premiere architectural photographers, to document the appearance of the incomplete – but stunningly graceful – hangar structures.

The resulting images, which became iconic in ensuing decades, show the hangars as more than simply pragmatic engineering; they are composed, studied, and architectural in that the photographers were clearly engaged by their rhythmic patterns of light and structure.

Nervi himself, when faced with questions of beauty in his work, would typically offer a shrugging disclaimer; yet here he apparently recognised that the enormous pressures brought to bear on his work had, somehow, distilled a visual and spatial experience that touched something beyond efficiency.

Experiments in ferrocement

Hulls for the Navy

The pressures faced by Nervi on the hangar projects were compounded by the charge given to him by the Italian Navy in the heat of World War II. Desperate for ships but lacking the steel needed to build them, the Navy sought radical approaches. Nervi proposed constructing hulls using a technique developed in France called, in Italian, *ferrocemento*.

This process involved bending layers of thin screens of metal mesh around jigs made of wood or bent rebar (Figure 3) and trowelling thin, aggregate-free concrete into the voids created by the overlapping mesh. When cured, the resulting forms were thin, durable and, because the small quantity of steel involved was distributed throughout,

Figure 3
Naval experiment in *ferrocemento*. Pier Luigi Nervi/Nervi and Bartoli, 1942–43

they were also flexible, able to take both impact and bending stresses.

This was ideal for marine service, but the process was also well-suited to the strictures of wartime autarchy; it required no formwork and a minimum of skilled labour. Most of the actual work could be done by anyone with a trowel, properly instructed, once the jigs had been set up.

Nervi produced four working hulls out of *ferrocemento*, a considerable achievement especially given that the Navy had provided him with a shipyard entirely lacking in machinery – or even electricity[7].

Turin exposition hall

The lessons of these handmade ships proved vital for Nervi's postwar career, much of which saw him exploit the hybrid structural properties and simple fabrication of *ferrocemento*. In 1947, he was hired by a somewhat panicked exposition authority in Turin, which had promised to host the annual *Salone Internazionale dell'Automobile* as a symbol of the country's rebuilding after the war. Turin, because it was the industrial centre of Italy's automotive industry, had been intensely bombarded, and its exposition facilities ruined.

Nervi promised to complete the job in the eight months remaining before the scheduled opening; to do this, he opened two *cantiere*, or working yards, on the site. One began by excavating and pouring foundations. While this work went on, a second yard began fabricating boat-like elements, of *ferrocemento*, that would form the structure's roof.

To span the 70m needed for the exposition, Nervi designed the roof with a shallow, two-hinged arch profile, set atop raked, poured *in situ* concrete buttresses. This profile, however, was executed in *ferrocemento* elements rather than heavy, time-consuming concrete; when placed together, they were designed to form a thin, corrugated

"THE PROFILE WAS EXECUTED IN FERROCEMENTO ELEMENTS RATHER THAN HEAVY, TIME-CONSUMING CONCRETE"

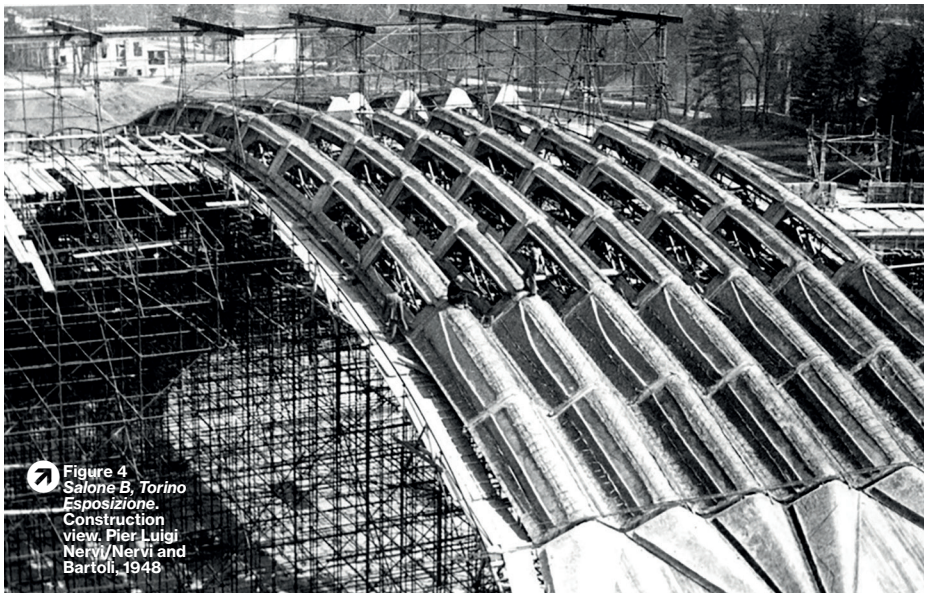

Figure 4
***Salone B, Torino Esposizione*. Construction view. Pier Luigi Nervi/Nervi and Bartoli, 1948**

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Figure 5
***Salone B, Torino Esposizione*. Interior view. Pier Luigi Nervi/Nervi and Bartoli, 1948**

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Figure 6
***Salone B, Torino Esposizione*. View of 'apse' at southeast end of main hall. Pier Luigi Nervi/Nervi and Bartoli, 1948**

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shell that achieved structural depth with only 3in. of material.

These, too, required no formwork. Instead, Nervi devised a travelling scaffold that allowed labourers to winch each element to the top of the structure and to slide it down greased rails into place where it could be grouted to its neighbours (Figure 4). Once a full arch of elements had been placed, his crews placed rebar in specially formed slots at the top and bottom of the corrugations, filling them with concrete that effectively locked the elements together into a monolithic roof[8,9]. A final detail – windows sliced out of each hull form around their neutral axes – introduced daylight on a regular module throughout the hall.

While the conception of the roof at Turin was based in the difficulties of scheduling, production, and span, the results – again – were spectacular (Figure 5), drawing praise not only from the world's engineering press, but also from architectural critics. Thomas Ennis of the *New York Times*, for one, described it as 'all space and light'[10].

As impressive as the main roof was, however, it was Nervi's application of *ferrocemento* to a different problem, a semi-circular 'apse' at the end of the hall demanded by the clients as an honorific space, that proved most stunning. Here, Nervi faced structural and fabricational challenges.

The shape of the apse demanded a half-dome, but this would come with difficult thrust issues around its raised base. To handle these, Nervi worked to make the roof as light as possible. But it also required a monolithic roof, and the schedule did not allow time for the complex timber formwork that would have been required to pour a traditional concrete shell. Instead, Nervi developed a system of formwork, made of *ferrocemento,* that could effectively tile the doubly curved surface into individual, diamond-shaped pans. These would replicate the structural behaviour of a two-way waffle slab, in that each pan created an individual 'coffer' or, if one looked at it another way, an interlocking system of ribs similar to those in the earlier hangars, but now wrapped around a spherical surface instead of simply extruded into a vault.

The result was an extraordinarily thin concrete shell, stiffened by a network of ribs formed by the *ferrocemento* pans, that could be assembled atop light metal scaffolding without timber formwork. Like the main roof, the apse was completed on time and it, too, drew raves for the web-like appearance of its graceful ribs[11] (Figure 6).

Rome Olympics

It was this latter system, of diamond-shaped *ferrocemento* pans, or what Nervi called *tavelloni*, that shaped some of his best-known work – the mushroom-shaped, gymnastic roof of the Kursaal restaurant in Ostia, the oval ceiling of the spa ballroom at Chianciano, and especially the *Palazzetto dello Sport*, the arena in Rome built as a demonstration project in 1957 to show the International Olympic Committee that Italy possessed the constructive prowess necessary to host the 1960 Olympic games.

The *Palazzetto* hosted boxing and basketball, among other sports, and its breathtaking span and gracefully ribbed ceiling were broadcast worldwide, earning Nervi a global reputation as a 'poet in concrete'. The space benefited from the decision to support the thin roof shell atop a ring of forked, reinforced concrete buttresses, bringing in light from under the dome and emphasising its uncanny sense of hovering over the seats below[12] (Figure 7).

The *Palazzetto* was one of several structures built by Nervi for the Games. Next door he led the reconstruction of the *Stadio Flaminio* in concrete, featuring a cantilevered roof of long, bill-shaped *ferrocemento* units and the *Via Corso*, a highway spur that brought traffic into the venues from the north. On the other side of Rome, the larger *Palazzo dello Sport* was set atop a hill overlooking the EUR district. With a thin, *ferrocemento* dome that was essentially a rotated version of the Turin hall's extruded, corrugated roof and raking concrete supports that boasted ruled surfaces formed by twisting timber formwork, the *Palazzo* also stunned the Games' audiences; among other events, the space saw Cassius Clay win the gold medal for boxing.

THOMAS LESLIE

Figure 7
***Palazzetto dello Sport*, Rome. Interior view. Pier Luigi Nervi/Nervi and Bartoli, 1957**

International acclaim

These projects led to international acclaim and demand for Nervi's time and thoughts on the role of structure in architecture; his work was seen as an exemplary approach to melding the traditional, humanist role of building design in Western culture with the profound changes ushered in by scientific and technological developments in the 20th century.

Clients and designers throughout the world – from the Vatican City to Sydney, Australia – sought his advice and expertise on projects ranging from the Cathedral of St Mary in San Francisco to record-breaking office towers in Montreal.

In Chicago, he was commissioned to design a civic memorial to Enrico Fermi on the site of the *émigré* Italian physicist's greatest accomplishment – the working atomic pile at the University of Chicago in Hyde Park. This project fell victim to political pressure from neighbourhood activists, but as much as any other project it showed the extent of Nervi's reputation for speaking the two languages of the arts and sciences[13].

Many of these projects suffered from Nervi's remove from their actual job sites; his techniques did not always translate to countries with differing economies or building traditions. But they were matched by a long list of honours and invitations to lecture. The most notable of these, the Charles Eliot Norton Lectures in Poetry, which Nervi delivered at Harvard in 1961–62, gave him an opportunity to develop his stated philosophy of design, alongside examples from his career of such poetic structures – his hangar projects and the Turin roof figured prominently in his illustrations.

Asked to step back from the rigours of the calculation pad and the job site, Nervi distilled his process into a neat formulation that recognised both the inherent 'truths' of statics and the contingencies of materials, economics, and architectural taste:

'[T]he objective data of ... technology and statics, suggest the solutions and forms; the aesthetic sensibility of the designer, who understands their intrinsic beauty and validity, welcomes the suggestion and models it, emphasizes it, proportions it in a personal manner which constitutes the artistic element in architecture[14].'

Poet in concrete

Given the deeply pragmatic nature of Nervi's approach, it seemed miraculous to contemporary critics that he should have been able to achieve the artistry in concrete that he did. Wresting beauty from the most unforgiving and unlikely of circumstances is an irresistibly heroic tale, and his status as a 'poet in concrete' was inevitably mentioned alongside accounts of his projects' thriftiness and efficiency.

His career, and the built artefacts that still, decades later, captivate us and hold our attention with their delicate patterns and awesome spans, provide ample evidence that the rigours of structure and construction can, in the best of circumstance, be forged into spaces and forms that are stunningly beautiful – literally poetic.

"NERVI'S WORK COMBINES THRILLING SPANS WITH INTRICATE MATHEMATICAL PATTERNING"

And yet, this should not be so surprising given the nature of poetry itself. Its whole point, after all, is to condense moments of beauty into concise, allusive forms that resonate beyond their meaning or their economy of breath and print alone. To close, I want to suggest that the claim of Nervi as a 'poet' may well be more insightful than it at first appears.

'Rigor of beauty is the quest,' noted American poet William Carlos Williams in his 1946–58 epic, *Paterson*, a phrase I have borrowed as a title to my study of Nervi's processes and one that suggests that, rather than an exultant leap, the poet's quest is one of diligence[15].

The challenge of poetry is not simply conveying an emotion; it is, rather to do so within the constraints of accepted rhythms, meters and schemes, systems of rules that force choices about words, phrases and pacing – 'the expression of feelings and ideas,' according to one definition, 'given intensity by the use of distinctive style and rhythm'. The discipline imposed by these conventions and rules distils, by necessity, emotional content into poetic efficiency.

To the listener or reader, the tension between the content of a piece and the rhythms and patterns into which it is refined reward attention and compel thought. Our response has to be one of stereoscopic

focus on both the overall impression and the finer-grained details, a tension that we seem cognitively inclined to seek out and enjoy.

Nervi's work combines thrilling spans with intricate mathematical patterning. His domes, especially the *Palazetto dello Sport* in Rome, captivate us by showing us all at once the vast *size* of their structural achievement, and the finely wrought *scale* of the human labour that produced it. His breathtaking spans were distilled by another set of constraints and rules – those of the job site – and imprinted by those patterns and rhythms. Our minds are caught between the vastness of the overall aspiration and the effort of the individual cell, or, perhaps, between that of the *cantiere* and that of the labourers themselves.

Whenever I have led tours of the *Palazetto*, I have been struck both by how immediate the impression of the space is, upon entering, and how difficult it is to coax visitors away from its breathtaking but endlessly engaging space. The initial response is pure, breathtaking emotion, complemented by the rewarding depth of its rich patterning that compels lingering and continued attention.

Seeing Nervi's work as *poetic*, in this sense of resonating between content and form, expression and constraint, ambition and labour, suggests perhaps why his work seems so much more engaging than other, similar spans executed without his fluency in the grammars of construction and fabrication. In his short-lived role as architectural critic for *Casabella*, Nervi took designers lacking such fluency to task – in particular Eero Saarinen and Jørn Utzon[16].

Saarinen's TWA terminal in New York, he felt, was 'a structure that makes no sense,' and 'a waste of money'. Even more damning, Utzon's Sydney Opera House was, for him, an 'anti-structure'. 'When the problem is large, man must make himself small and follow the road of technology,' Nervi wrote. 'Beauty as an end is not the criterion for structure. Beauty comes from itself.'

Such an intimate awareness of the jobsite's economics is also lacking, for example, in much celebrated contemporary work – structurally gymnastic architecture that fails to achieve the deep resonance of Nervi's. Many of today's dramatic, often biomorphic, forms – the heirs of Saarinen and Utzon – are also lacking the fine grain, the rules and the productive constraints that make visible the human processes of assembly; these gymnastic forms are intentionally scale-less, lacking the discipline or rigour imposed by the demands of economy and fabrication.

Such projects are dramatic and captivating; they are literally *sensational* in that they arrest our attention and thrill us with often sublime leaps of span and forms that often seem magically, precariously balanced. They are, as Augustine suggested, structures that provide delight *of* the senses; photogenic, utterly Instagrammable, visually entertaining.

The pleasures of Nervi's projects are deeper. They are structures that provide, again in Augustine's words, delight *through* the senses, experiences that connect us to principles of physics embodied in structural form and to those of materials, fabrication and labour that occur in the field[17].

We cannot take in these two complementary experiences through our senses alone; our minds must be engaged to understand them in conjunction with one another. Nervi's fluency in these two languages – of static shape and of constructive grammar – are very much like the poet's fluency in the distinct realms of metaphor and rhythm. When content and form are combined through the hard work of design or writing into a distilled piece of structural or linguistic poetry, we cannot help but be drawn into the rich interplay between the two, into the beauty that comes only from a commitment to finding meaning within the oft-competing constraints of our individual disciplines.

At their best, poetry and engineering both extend us as well, imparting knowledge – either explicitly or intuitively – about the world beyond us. Nervi's best work does exactly this; gives us tangible evidence of the principles of physics *and* of the capabilities we have to form raw matter into conformance with those principles, lifting, as Shelley said only poetry can do, the veil from the hidden beauty of the world.

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