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THE TWENTIETH-CENTURY ITALIAN SCHOOL OF ENGINEERING: BETWEEN NATURE AND TECHNIQUE

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In the 1950s and 1960s, Italian engineering garnered international attention with a number of highly original structural works. From World War II through the economic miracle period, there were many opportunities to build: the reconstruction of thousands of bridges destroyed during the conflict, the Autostrada del Sole north-south highway, the 1960 Rome Olympics, the centennial of the Unification of Italy celebrated in Turin in 1961, hangars for the first international airports, and skyscrapers in Milan and Rome. In this fervent period, a real School of structural engineering took shape, and soon garnered admiration around the world. In fact, the exhibition held in the summer of 1964 at the Museum of Modern Art in New York reserved a place of honor for Italy, generously displaying Pier Luigi Nervi's roofs, Riccardo Morandi's cable-stayed bridges, Silvano Zorzi's prestressed structures, and the gigantic arches of the Autosole highway, as well as the monumental dams Claudio Marcello built using his "hollow gravity" technique.

These feats of "Italian Style" engineering were the culmination of a long period of experimentation that had begun with the advent of reinforced concrete in the early twentieth century and continued uninterrupted through the difficult years of Fascist autarchical prohibitions and the war. The experiments went on without fanfare in the open-air laboratory of postwar reconstruction, and became a torrent in the euphoric boom years. Then, just after the economic miracle, the School suddenly waned. There were several reasons: the national economic crisis, worsened by the international energy crises of the 1970s; the increasing cost of labor after the strikes and protests of Italy's "hot autumn" (1969/70); changes at universities, which decupled the number of matriculants, and in the business world, with a shrinking number of family businesses. An attempt to resist the general homogenization with a series of "posthumous masterpieces" failed; the end was marked by one of the most beautiful bridges in the world, the bridge with the "nameless form" designed by Sergio Musmeci in Potenza. Then the School died out, like the fireflies in Pier Paolo Pasolini's 1975 "corsair writing," and was gradually forgotten, even by historiography. It is true that a few of its leading figures became famous: Nervi is still today one of the best-known structural designers in the world, and Morandi also enjoyed significant international popularity, long before the dramatic collapse of the bridge over the Polcevera river in Genoa in 2018. But the School was a collective adventure that involved two entire generations of scientists, architects, entrepreneurs and builders, and left its valuable heritage throughout Italy.

To bring this story out of the shadows of archives and into the light, the SIXXI research project was launched in 2012, financed by an ERC Advanced Grant and led by Sergio Poretti and Tullia Iori. For a complete bibliography of all the volumes published as the research progressed and a sample of the information available, readers can see the SIXXIdata database, which gathers tens of terabytes of archival documents. Thousands of drawings, calculation reports, letters, cost breakdowns, patents, business indexes, publicity videos, entire libraries, and magnificent construction-site photographs: delving into that "magical library" has made it possible over the past decade to immerse ourselves in the glorious history of twentieh-century Italian engineering, and thus to recognize its originality.[1]

At first glance, Italian structures do not present particularly innovative traits from the scientific or technological points of view. On the contrary, they fit perfectly into well-defined typological categories of modern structures, so at first, they appear familiar: appropriate, with no particularly local or vernacular elements. And yet, in this context, they are also highly recognizable, introducing their own unmistakable tone, and are distinguished by a specific architectural physiognomy. This balanced polarity between orthodoxy and national identity is the truly characterizing trait of the Italian School of engineering—its fingerprint, we might say.

So, as we explored the characteristics of a world-class engineering formulated by a country that was struggling to achieve complete modernity, two contrasting questions guided us through the labyrinth of the past: what foundations formed the basis of the conformity of Italian structures to the international context? And at the same time, what factors in the country's history generated its uniqueness?

Let's start by asking: was it always like this? Has Italian engineering always told a special story? In ancient times, certainly yes, but not in the nineteenth century.

In the nineteenth century, metal construction came to the fore: bridges and roofs in cast iron, and then in wrought iron, and towards the end of the century, steel. This type of construction was extraneous to us; we remained an agricultural land that had been skipped over by the first industrial revolution, with no iron mines and no coal. Compared to the rest of Europe, our iron and steel industry was irrelevant in the nineteenth century.

But in terms of structures, we were orthodox; we did what everyone was doing. Suspension bridges, trusses and reticular arches—types invented abroad, where they mainly served the development of railroads and consequently of industry. We imported them, copied them, built them by the thousands throughout the nineteenth century. But there was no "Italian way" of building suspension bridges (while there was an English way, with chains, and a French way, with wires); Alfredo Cottrau's wrought iron lattice trusses, and Jules Röthlisberger's truss arch bridges, which dotted Italy at the end of the nineteenth century, were repetitions of types that had already been successfully developed elsewhere.

But we did make an original contribution in that period, a theoretical one. It was the Italian approach to developing hyperstatic

1 1 This essay, which should have been written by Sergio Poretti (1944-2017) as well, is the result of research carried out within the sphere of the SIXXI – *Twentieth Century Structural Engineering: the Italian Contribution* project, ERC Advanced Grant 2011. For details, see the series of volumes *SIXXI. Storia dell'ingegneria strutturale in Italia*, specifically: *SIXXI* 1 (2014), *SIXXI* 2 (2015), *SIXXI* 3 (2015), *SIXXI* 4 (2017), *SIXXI* 5 (2020), edited by Tullia Iori and Sergio Poretti and published by Gangemi, and monographic issues of the magazine "Rassegna di architettura e urbanistica": from *La Scuola italiana di Ingegneria* (no. 148, January-April 2016) to the pioneering *Ingegneria italiana* (no. 121/122, January-August 2007).

structures, which we did not yet know how to calculate in the mid-nineteenth century; even a load distributed along a continuous beam with multiple supports generated stress that were still mysterious. Federico Menabrea first and Alberto Castigliano later contributed to solving the problem by proposing an "energy approach." Other theories from German spheres would eventually rise to the fore, but the Italian way was central to debate on the question for quite some time. Menabrea said: "When a system attains equilibrium under external forces, the elastic energy is a minimum." Menabrea presented the principle, and Castigliano demonstrated it scientifically. At the base of it was a philosophical position, a way of viewing reality and the role of the architect. To simplify: the laws of nature are determined by criteria of minimum effort and maximum effect; if we let nature do its work, equilibrium is achieved with minimal effort. Hence, the idea that nature knows how to find the ideal solution on its own and it would be better to let it do so conditioned the Italian School of engineering in one way or another.

With the advent of reinforced concrete, everything changed. The new technique spread rapidly at the start of the twentieth century, partly because we had plenty of cement and the raw materials to make it. Moreover, compared to iron, reinforced concrete was more compatible with the artisanal state of Italian construction. But even in the pioneering phase, bridges with arches cast *in-situ* by patent holders or, after the Great War, by the first builders to be liberated from paying royalties, remained orthodox with regard to international developments. François Hennebique himself was directly responsible for changing the course of the history of reinforced concrete, overhauling the design for the Risorgimento Bridge which Giovanni Antonio Porcheddu built over the Tiber in Rome; Eugenio Miozzi learned from Eugène Freyssinet how to perfect the "systematic cracking" technique for the bridges of Venice, and openly acknowledged his indebtedness. To begin to recognize characteristics of a specifically Italian identity, we must look to the experimentation of the autarchic period, and then, especially, the postwar period, when the School finally achieved maturity.
Spurred by restrictions on the use of certain materials imposed by Fascist propaganda after Italy became subject to international sanctions for the invasion of Ethiopia (in 1936 reinforced concrete was accused of being not Italian enough, and thus prohibited), experimentation began that would lead to the definitive physiognomy of our structures. The obligation was to save steel, which was reserved for the war industry and which no other country was authorized to sell us. We thus moved in two directions, which were once again common to experimentation taking place around the world, confirming our School's inclusion in the great family of modern engineering.
On one hand, the decision was made to diminish reinforcement, reducing weight and taking advantage of shape-based resistance: we became enthusiastic about thin vaults, which marked an international shift in structures in the mid-1920s, from Dischinger and Finsterwalder's Zeiss-Dywidag planetarium domes and cylindrical thin shells to Eduardo Torroja's hyperboloid canopy roofs and Bernard Lafaille's hypars. On the other, we were early adopters of prestressing, introduced in 1928 by Freyssinet, which led to more efficient use, and thus savings, of the two materials in play, concrete and steel.
In Italy, however, these two lines of thought became veritable ideologies, and their opposition is palpable in texts that sometimes ingenuously sought to support and endorse one over the other. In any case, this sort of virtuous competition is how maturity is achieved.

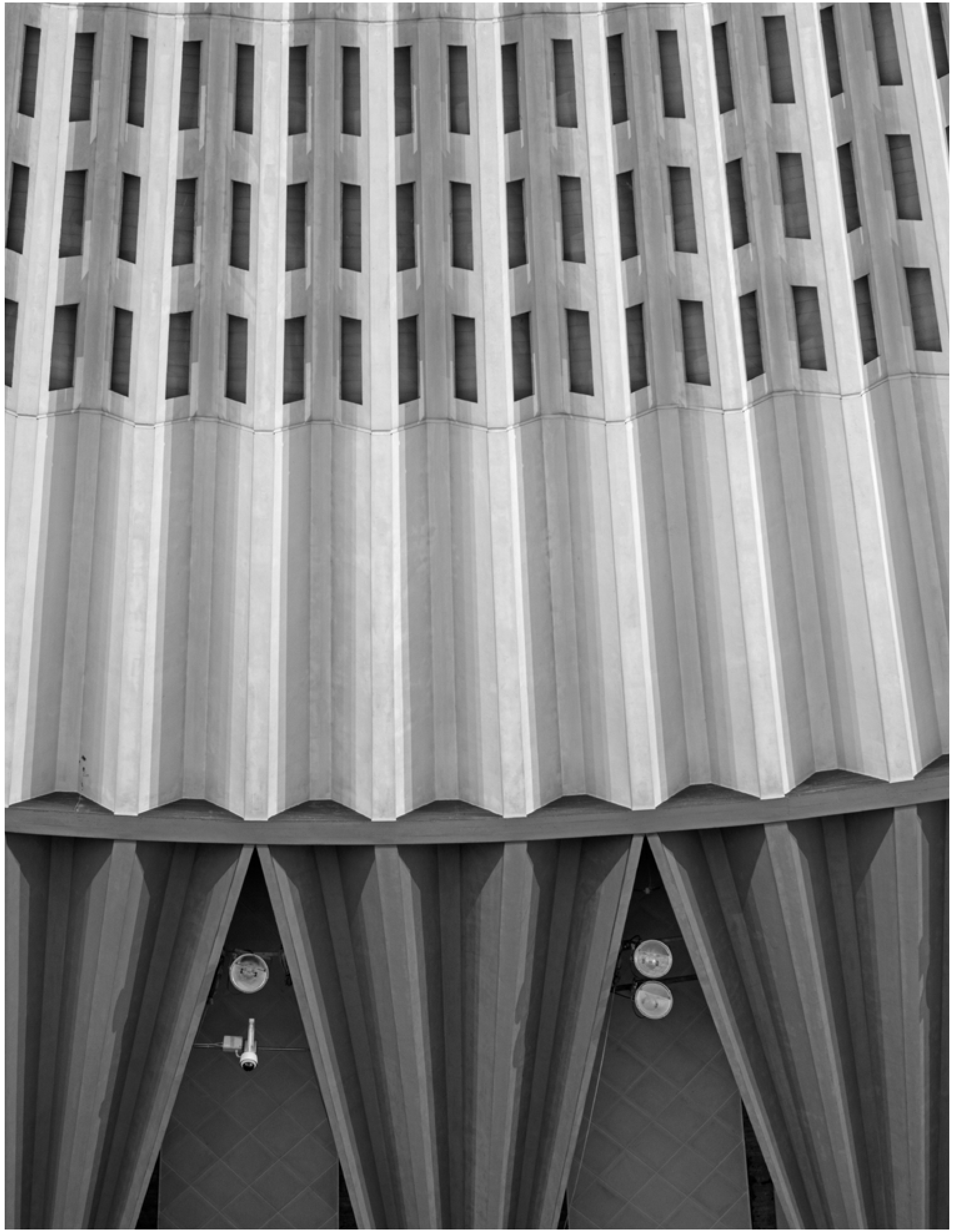
Two of the interpreters and guides along the way in this process were Arturo Danusso and Gustavo Colonnetti, professors of Theory of Structures at the Polytechnic schools of Milan and Turin, respectively, who influenced the entire School until the boom years (nearly the same age, they died a few months apart in 1968). With a shared passion for reinforced concrete, both were aware that the classical theory of elasticity, developed for iron and hastily adapted to the new material during the pioneering experimentation phases, was absolutely insufficient to justify its behavior.
Colonnetti was certain that it was possible to formulate a new mathematical theory that could predict the true functioning of structures, even beyond the elastic phase: the long-awaited, but never elaborated, "general theory of coactions." This faith in theory and thus in calculation was accompanied by the conviction that engineers must play an active role: in Colonnetti's view, structures had to be "trained" to respond to stress in the best possible way. And this could be done by impressing on bodies forces or coactions, precisely established through calculation and capable of correcting the natural state of equilibrium of the structures themselves. Colonnetti thus urged architects and engineers not to passively wait for a bridge or roof to find its own equilibrium, but to balance, compensate and equilibrate its forces, ensuring more favorable distribution of internal tensions. The most brilliant concrete application of this logic is prestressing: does it not mean, precisely, teaching concrete to resist forces of traction? That is, to do something that by nature it would not be able to do?
Danusso, on the other hand, referring back to Menabrea, maintained that it was not necessary to teach structures how to behave, but rather to allow them to spontaneously adapt to loads, making up for any gaps or design errors in the project. So, he had unconditional faith in the intrinsic resources of works. In Danusso's view, the engineer's job is to observe and interpret nature and facil-

← Riccardo Morandi, cover of the Alitalia hangar, Fiumicino, 1961-1964. Photo Sergio Poretti

itate its intervention, so complex and often hyperstatic solutions are good, although very difficult to theoretically predict through calculation. In his articles, he constantly mentioned the host of restrictions that theory must impose in order to reduce ordinary structures to calculation schemes, noting the consequent lack of validity. Skeptical of the possibility of mathematically predicting a structure's response via analytical calculations, he relied on a "stress calculating machine," i.e., a reduced-scale model on which to perform load tests in the laboratory. The model simulated, showed and anticipated the work, and, if correctly stimulated, would deform just like its real full-scale duplicate. In short, the model could come closer to nature than the calculation. Hence, in 1931 he founded a model testing laboratory at the Milan Polytechnic, and later, after the war, the famed ISMES, the Institute for Experimental Models and Structures. (On a parallel track, Colonnetti founded the Center for Study of elastic coaction states in Turin, which oversaw precompressed reinforced concrete constructions authorized in Italy beginning in 1950.)
Italian engineers of these generations were all either Danussians, like Nervi and Musmeci, or Colonnettians, like Morandi, Zorzi, and Giulio Krall. But all architects and engineers, including current ones, might ask themselves which side they are on: the side of "going with the flow" of natural behavior (as in form-finding experimentation, and in Mutsuro Sasaki's "Flux Structures") or correcting and enhancing it through technological means (as Santiago Calatrava, Peter Rice and Jürg Conzett, for example, have always done)?

In the postwar period, the two lines of thought, sketched out during the autarchy, gave rise in Italy to a structural engineering that stood apart in the international panorama. Our School was completely different from the Anglo-Saxon one, for example. The underlying reason was that Italian engineering developed in an environment that was literally dominated by humanistic culture and Catholicism, allied in combating the supremacy of the scientific and technological culture that was accompanying modernization in other countries. On the secular side, Benedetto Croce's neo-idealism was utterly hegemonic; there was no other country where a philosopher influenced the totality of cultural development as it did in ours. On the religious side, where Catholicism held sway, the key was the compatibility between faith and science. In this cultural climate, there was no recognition of the autonomy of the scientist, but rather an acknowledgement of the need to bring scientific knowledge under the *aegis* of a superior spiritual truth. This should not have facilitated the development of engineering; on a path towards modernity, the dominance of philosophical/literary and spiritual views should have been an obstacle. In the modernization of Anglo-Saxon countries, the situation was the diametric opposite: there, positivism was more prevalent than ever. In fact, the scientific approach extended to the humanities and social sciences. Engineers were considered stars, heroes—the builder of bridges was an exemplary model for all other disciplines.
The Italian engineer, however, was constantly subjected to a process of "humanization." The paradoxical thing was that the engineer, rather than defending himself, i.e., defending the autonomy of applied science from the dominion of humanistic culture, became one of the latter's most fervent supporters. Theoreticians were among the most dogged defenders of the superiority of the spiritual view, as we need only read a few lines of their most popular writings to understand. In 1943, Colonnetti wrote: "I think that the Apostle's adage *Adjutores Dei sumus*—we are collaborators with God—applies to scientists and technicians in a very special way. Devoting oneself to science or technology means agreeing to collaborate with God in the fulfilment of a divine design [...]. It means freely accepting a mission in which every activity, in the sphere of thought as well as that of action, in the dominion of ideas as in that of life, must be oriented towards this supreme purpose of collaboration with God for the realization of good; a supreme purpose that is neither weakened nor diminished by the fact that the field in which God wants us to practice is modest and limited."
Danusso, for his part, in the celebrated article *Le autotensioni* published in 1934, as well as in successive reworkings, recognized parallelisms between divine justice

→ Pier Luigi Nervi, dome of Palazzo dello Sport all'Eur (details), Rome, 1957-1960- Photo Sergio Poretti



and the plastic deformation of bridges: "Under the glare of a higher light, the effort of experimentation is ennobled, because it is first and foremost an encounter with nature, considered the great revealer of the harmonies and purposes that God has put in place to govern the world. They should be drawn from fully, profitably studying the material world, which might otherwise seem arid [...]. In particular, in constructions elastic deformability tends to distribute strains in harmony with resistant tendencies; and when in spite of that the strains in certain parts worsen, corrective plasticity comes into play to improve the situation [...]. So, the construction behaves like an orderly society, which is based on the distributive, integrated and perfect justness of charity."
In addition to its impact on theoreticians, humanistic culture also influenced engineers who designed large structures, who more secularly set above all else any mystical sort of understanding of correctness. It is no wonder that in this context, Nervi entitled his first article in the first 1947 issue of the magazine *Strutture* "Corretto costruire" [Correct construction], accompanying it with a conceptual map in which social values, human values, art, science and technology merged, and later gave a nearly identical title to his 1955 book *Costruire correttamente* [Constructing correctly]. The principle of the "structural minimum," which had always been present in the engineer's experimentation, goes beyond the specialistic bounds of science to take on a universally ethical value.

In the end, what practical consequences did the humanistic propensity have on the characteristics of built works? What differentiated the Italian School was above all their pronounced architectural value, and the consequences of the cultural climate are easily identified in the languages of these structures. The Italian "humanist" engineers were, first and foremost, history lovers. The dogma of modernity that imposes a break with the past did not prosper in our country. Nervi, like many of his colleagues, looked at the monuments of antiquity with sincere admiration. He thoroughly studied and consulted on the stabilization of the cupola of Santa Maria del Fiore in Florence, auscultating its increasingly labored breathing as a doctor would a patient's lungs. He had a true sense of devotion with regard to the artifices of grand cupolas, in masonry or concrete. After all, isn't his Palazzetto dello Sport a Pantheon in reinforced concrete, as Bruno Zevi defined it? The "Nervi system"—a means of construction based on ferrocement and structural prefabrication, with a large wooden model and a sequence of "grandmother, mother, daughter" matrixes thanks to which workers, beneath a covered loggia, molded small pieces to be put together like a gigantic three-dimensional puzzle—seems a direct imitation of the worksite of a Gothic cathedral. (We know from his grandchildren that Nervi kept Jean Gimpel's book *The Cathedral Builders* on his nightstand for a long time.) His nostalgia for the pre-scientific era when architecture and engineering were not yet distinct and separate from one another was shared by all of his colleagues.

And that was not all: the engineers of the boom years were trained in art and were particularly sensitive to avant-garde movements like Futurism. Futurism fed on engineering: it was based on positivism, scientism and technolatry. Antonio Sant'Elia's drawing are filled with endless skyscrapers, hovering streets and dams filled with energy. What engineering absorbed from Futurism, for its part, was a certain lyricism and visionary tendency. These themes are evident in Morandi, for example, who was an early Colonnettian: he was capable of stabilizing his bridges by adding strength in the form of tie rods or cables; compensating for thrust by using struts that constantly refuse vertical direction; setting up worksites where temporary prestressing brought about beneficial alterations in the functioning of entire pieces of the structure, which only reached their final positions after significant turning. Morandi even declared himself a Futurist in terms of his designs, with their very high antennas that seems to rival airplanes in perspective images. But above all, his works, with their jointed, hinged elements, look like automatons ready to spring forward with Boccionian velocity. Thus, the underground pavilion in Turin for Italia '61 seemed the perfect setting for an aerodance.

Coming out of the war and heading towards the miracle of the boom years, Italian engineers were in perfect harmony with the world of design. They designed structure as if they were landscape-scale pieces of furniture. The elective affinity with this sector of architectural culture was largely due to the co-habitation between engineers and designers in Swiss university internment camps, during the World War II exile of many Northern Italian students and young professors in Lausanne, in particular Colonnetti and his favorite apprentice Silvano Zorzi. Zorzi, a very young major player in the reconstruction and the boom years, was one of the few who tried to stop the decline during the crisis. He did so by transforming work sites, without capitulating to prefabrication. He invented, and imported from other worlds, machines with futuristic names: "self-launching formwork" or "little by little" balanced system allowed him to continue to shape his made-to-measure bridges, using an elegant, minimalist approach not unlike that of the great names in fashion. The affinity with design was also in part based on an "anthropological" resemblance; after all, a bridge is an object for everyday use, like a lamp, a bookcase, a bicycle or a coffee pot. And a bridge is much more similar to a table than to a house.

↓ Silvano Zorzi, Teccio viaduct for the highway Torino-Savona, 1973-1976. Photo Sergio Poretti

→ Sergio Musmeci, ceiling of the San Carlo church in Vicenza, Vicenza, 1959. Photo Sergio Poretti

History, art, design: these were the foundations of postwar Italian engineering. But in all honesty, it was not just the different humanistic climate that distinguished our structures in the international panorama. The Italian School also sprang from particularities with the production system that were lost when the crisis hit. In fact, the history of modern construction followed a unique path in Italy in the twentieth century. While industrialization was sweeping the rest of the world, Italy tiptoed quietly into modernity, without violent breaks with the past, and without industrial revolutions. It was a slow modernization, and the country seems frozen, suspended in a sort of chronic "protoindustrialization" for quite some time.
What were the repercussions of this for construction, and in particular the construction of large structures? In lagging yet successful Italy, the construction sector, in every phase of the period, had a specific task: to deal with unemployment. That meant that technical progress was slowed and at certain moments completely blocked. The construction site was the junction in the passage of manual labor from agriculture to industry. Hence, highway construction sites, which included hundreds of bridges, were filled not with equipment, but with men: they revolved around the worker and his potential to build "by hand" enormous artisanal objects, unique sculptures in the landscape. Philosophical humanism was thus joined by humanism in practice. This artisanal character, which favored unique, unrepeatable works, was the first to suffer the effects of the crisis: when the workers realized they had not enjoyed the benefits of the boom as others had, when they understood that these works were the fruit of their laboring without guarantees, without disability insurance, without vacation days, without a pension and without overtime, they began to go on strike. They demanded their sacrosanct rights, which would be recognized by the Workers' Statute of 1970, but which effectively led to the depopulation of work sites, and to the drastic reduction in manual labor, replaced by machines and above all by the use of conventional prefabrication.
This was what led to the sudden disappearance of the reinforced concrete arch, unquestionably a mainstay of the Autosole

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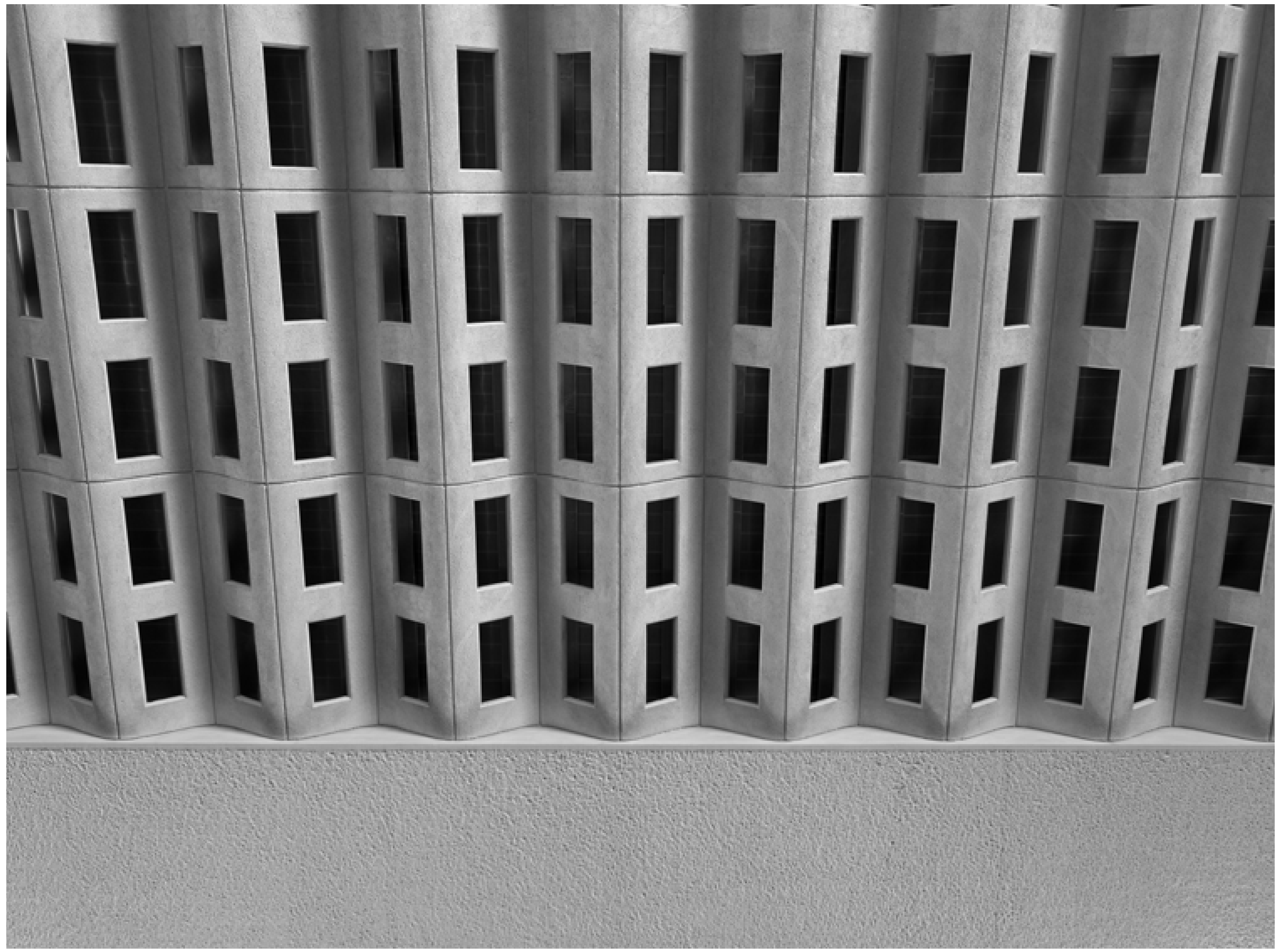
highway, but built with Innocenti tube scaffolding, which had to be assembled solely by hand, by acrobatic workers. Its place was taken by bridges with extremely tall pilings and rectilinear trusses, which can be put up without propping up with Zorzi's timid machines, or with beams, all exactly the same, produced in the workshop. And so, the smaller firms, those that could handle only one worksite at a time, and not too far from their operational center, succumbed to the crisis and were swallowed up by larger enterprises that no longer had names, but that had internal technical offices and were more inclined to invest in the means required to win tenders than in technological innovation and dedicated design professionals.

Another effect of the "humanism" that imbued Italian engineering in the boom years was the development of the figure of the designer of large structures, the creator. He was a multifaceted figure who opposed specialization in the field, personally combating it on various fronts. He was more than just a hybrid engineer-architect or architect-engineer.
This traditional interdisciplinarity was enhanced by another, special sort of flexibility: the capacity nimbly alternate between high culture and material culture, between theory and practice, between research and handiness, between laboratory and building site. A visionary figure, he vanished along with the fireflies when Italian universities were transformed from elite to mass institutions and the decision was made to teach the crowded classes only calculation rules and methods, omitting the element of innovative conception.

Exemplary creator-engineers of their time, a time of change during the short century, were Nervi, Morandi and Zorzi. And Musmeci, who died too young to see the era when his visions would come to fruition. At the beginning of the 1970s, he wrote that he wished for the advent of the computer to help him not in the banal phase of calculation verification, but in the truly useful one of conception: in his imagination, he skipped over an entire generation of software to arrive directly at the most recent genetic optimization algorithms in the sphere of artificial intelligence. And in practice, his bridge of the Basento anticipated by decades the form-finding engineering and parametric engineering of the new millennium. Musmeci predicted a new era—ours—in which engineering, like architecture, has lost its strictly functional role, but is instead called upon to amaze, to attract attention with new, complex forms that are repeatable yet astounding. The rigorous principles of maximum economy typical of engineers of previous generations, assimilated directly from Gothic construction sites, were replaced by new principles much closer to those of Baroque construction. Musmeci was the element of transition in this process: with his exceptional mathematical-scientific abilities and his pursuit of optimized but certainly not economic forms—which were in fact intended to astound—, he embodied the transition towards "Pop Structure" engineering, the engineering of Instagram.

This congenital impurity of influences sheds light on another characteristic of the Italian-born structural idiom that may be the most distinctive of all: its historical weightiness. Rarely have works of engineering, as opposed to architectural idioms, demonstrated such a capacity to reflect their historical context. Structural language usually limits itself to saying something about the universal value of scientific progress. But in this sense, the structural architectures created by Nervi, Morandi, Zorzi, Musmeci and the others constitute a striking exception. Their strict adherence to the tenet of sincerity notwithstanding, they also tell us a great deal about some sensational vicissitudes of Italy's singular modernization phase (especially in terms of the ways in which they were built). For this reason alone, engineering structures should hold a place of honor in a museum of all things Made in Italy, in the grand showcase of "Italian Style" products, alongside objects by the most famous industrial designers and clothing by our most sophisticated fashion designers.



← Pier Luigi Nervi, hall ceiling of the pontificial audiences in the Vatican (detail), Vatican City, 1964-1971. Photo Sergio Poretti