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PIER LUIGI NERVI: ART AND TECHNOLOGY IN BUILDING**

Guest Editors: J. F. Abel, G. Arun and M. A. Chiorino

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PIER LUIGI NERVI: ART AND TECHNOLOGY IN BUILDING

Special Double Issue on Pier Luigi Nervi: Preface by the Guest Editors	79
<i>J. F. Abel, G. Arun and M. A. Chiorino</i>	
PLN – Pier Luigi Nervi Project Association	87
<i>M. Nervi</i>	
Book Review: Pier Luigi Nervi: Architecture as Challenge	99
<i>Review by J. F. Abel</i>	
Reflections on Pier Luigi Nervi and his Works	101
<i>D. P. Billington</i>	
Carpenter's Parametrics: Economics, Efficiency & Form in Nervi's Concrete Designs	107
<i>T. Leslie</i>	
Pier Luigi Nervi: his Construction System for Shell and Spatial Structures	117
<i>T. Iori and S. Poretti</i>	
The Ribbed Floor Slab Systems of Pier Luigi Nervi	127
<i>A. B. Halpern, D. P. Billington and S. Adriaenssens</i>	
Pier Luigi Nervi's Columns: Flow of Lines and Forces	137
<i>P. Perugini and S. Andreani</i>	
Pier Luigi Nervi's Reduced Scale Models for HP Shells	149
<i>G. Neri</i>	
The Grid Structures of Nervi's first Hangars in Orvieto: Innovation in Context	159
<i>M. Sassone and E. Piccoli</i>	
Nervi's Cantilevering Stadium Roofs: Discipline of Economy Leads to Inspiration	169
<i>S. Adriaenssens and D. P. Billington</i>	
Force Lines Embodied In The Building: Palazzetto dello Sport	179
<i>I. Bucur-Horváth and R. V. Săplăcan</i>	
Norfolk Scope Arena: A US Dome with a Unique Configuration of Interior Ribs and Buttresses	189
<i>E. M. Segal and S. Adriaenssens</i>	
Pier Luigi Nervi, Felix Candela and the Kuwait Sports Centre Competition in 1969	199
<i>M. Mendoza and M. Cresciani</i>	
Presenting Nervi's Work through Scale Models: The NerViLab	211
<i>F. Romeo</i>	
Problems and Strategies for Conservation of Pier Luigi Nervi's Heritage	221
<i>C. Chiorino</i>	
Nervi and Candela: A Dialogue between Engineering and Architecture	233
<i>J. G. Oliva Salinas, A. Rodall Rodriguez and E. Valdez Olmedo</i>	
Mechanics and Architecture: Nervi's Creative Knowledge versus the Unsolved Contemporary Complexity	243
<i>G. Rega</i>	

COVER PHOTO: Turin Exhibition Center, Hall C, from paper by C. Chiorino

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CARPENTER'S PARAMETRICS: ECONOMICS, EFFICIENCY, AND FORM IN PIER LUIGI NERVI'S CONCRETE DESIGNS

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ABSTRACT

Pier Luigi Nervi's work is typically seen in terms of its performance and expression, but the role of fabrication and construction in his designs has rarely been fully acknowledged. Nervi practiced in a time of intense economic growth in Italy, but the national construction industry faced shortages of labor, steel, and skill as the country boomed. As a result, Nervi's projects often faced intense economic and schedule pressure, which forced him to use economical materials and efficient forming techniques. Rather than limiting expression, these constraints contributed to the resulting structures' visual appeal, as patterns and algorithms based in construction matched the forms and geometry of ideal structural shapes.

Keywords: reinforced concrete, Nervi, columns, piers

1. INTRODUCTION

"...it may be advisable to consider the efficiency of the two separate phases of any architectural achievement: the creative efficiency which decides the principal characteristics of the work, and the efficiency of its realization, which defines dimensions and structural characteristics in detail, and governs the economic and administrative relations with the contractor."

Pier Luigi Nervi [6]

The works of Italian engineer and *constructeur* Pier Luigi Nervi are often cited for their remarkably expressive approach to structural form. His designs and executed buildings for long-span programs such as sports arenas, exposition palaces, and even the Papal Audience Hall in the Vatican City all demonstrated a fidelity to static principles that is at once evident and engaging to even the most casual observer. Indeed, for Milan architect Ernesto Rogers, Nervi's work began in "scientific certainty," but "transcended" this deterministic basis through "intuition," arriving at a humane, experiential approach to structural design and engineering [9]. His structures thus occur at the intersection of Italy's tradition of monumental construction and the country's exceptionally robust climate of engineering innovation in the mid-twentieth century [3].

Such compelling connections between form and *structural* principles are, however, only the most apparent link in Nervi's work. As I have shown elsewhere, much of Nervi's effort went into understanding not only how form could instantiate structural principles, but also how those forms themselves could be fabricated. Here, Nervi faced severe limitations. Postwar Italy enjoyed the greatest economic growth in Europe, but it did so with very limited access to both material and labor. Indeed, the combination of migration to the United States in the 1950s, a growth rate of over 8%, and Marshall Plan funding meant that the country enjoyed full employment, and thus exceptionally high labor costs. The country's industrial capacity was still hampered by damage to factories and infrastructure from World War II's military campaigns and bombing runs, and thus Italy—and Nervi—faced the problems of constructing on a large scale for an explosive economy with fundamentally limited means.

Designing under these conditions meant a necessary focus, therefore, not only on form and performance, but also on the economics and pace of assembly and construction. It was not enough, in these conditions, to design a structure that minimized quantities of *materials* if, in doing so, the project required unrealistic quantities of *labor*. And the construction industry in Italy faced an additional

hurdle in that most of its labor force was under skilled compared with other countries; whereas England or the United States could build on paradigm-shifting developments in industrial production and material science brought on by the war effort, Italy had been entirely reliant on its Axis partners for its military technology, and had none of the surplus research and development infrastructure—or attendant, highly skilled labor—that existed elsewhere [2].

A country that demanded technically advanced skyscrapers, factories, assembly halls, and transport terminals without a similarly advanced construction industry, in the midst of expansionary pricing and a general tightening in the labor market, was inevitably reliant on extraordinary cleverness in its designers, and the constraints of the country's economic situation made heroes out of those who were able to match Italy's expansive needs with its limited resources. Nervi was uniquely suited for this task having been educated as a civil engineer but having spent his early career as a consultant for the concrete industry working closely with architects and builders. He was recognized early in his career for his fluency in both structural design *and* constructional efficiency, and throughout his career he operated as consulting engineer, lead designer, and even builder. His office maintained an active experimental yard south of Rome where hands-on experiments in full-sized concrete construction informed the firm's design work, and this engagement with actual fabrication and construction led to a number of innovations not only in concrete form, but also in technique, including several patents. Nervi thus understood design as a balancing of forces or, as I have suggested elsewhere, *causes*. In particular his work can be seen as the negotiation between the Aristotelean division of *final*, or functional, and *motive*, or constructional, causes. For Nervi, function was further divided into those criteria that enabled a structure to perform its desired circulatory and programmatic functions, and (equally important) criteria that revolved around safe, efficient structure. Both of these can be seen as *performance* based causes, but they were balanced in Nervi's philosophy and construction by an equally important emphasis on *material* causes:

...We owe [great structural architecture] to the simultaneous appearance of three factors. These factors, which are only

apparently independent, are: the refinement of theories of structural analysis, and the consequent possibility of investigating *a priori* the stability of even complicated static systems; the industrial and low-cost production of high-quality mechanical materials such as steel and concrete; and the emergence each year of new structures of increasing size, such as railway and air terminals, industrial buildings, stadia, large theatres, and very tall buildings [5, p.7].

Such thoughtful balancing of functional and material vectors permeated Nervi's work, informing everything from large-scale sectional and plan forms through roof patterns and details. One family of structural elements in particular—piers and columns whose shapes were tuned to integrate or to balance circulatory, structural, and fabrication issues—encapsulates the difficulties of designing under such economic pressure while demonstrating the fluency with which Nervi was able to deploy concrete in complex forms. An analysis of these piers' design and construction reveals his ability to coax such complex forms from fairly simple algorithms and on-site processes, suggesting an early precursor to contemporary experiments in parametric design and hinting that a major element in these structures' visual appeal lies precisely in such underlying rules and basic geometric premises. In this 'family' of piers and columns, Nervi balanced strict requirements for simple and rapid on-site labor with functional and structural performance to arrive at forms that, through their adherence to simple geometric and productive processes, are both intuitively comprehensible and sculpturally engaging.

2. EARLY EXPERIMENTS IN FUNCTIONALLY DRIVEN FORMAL TRANSFORMATIONS

Nervi's early work was highlighted by his design for Florence's Municipal Stadium (1928-1932) and a similar project for a larger stadium in Rio de Janeiro (1935). While the former has become well known for its cantilevered grandstand roof and dramatic spiral stairs, it also deserves recognition for its sectional solution, a reinforced concrete frame that is repeated around the perimeter of the stadium, offering a repeatable formwork module that was adapted to the stadium's slightly odd plan. This section provided consistent seating throughout

the two straight grandstands and at the widely radiused corners on the field's east side. On the west, main grandstand side, however, the program called for a 200-meter straightaway as part of a competition running track, and here Nervi changed the typical section to provide a shorter, simpler stand of seating. The march of concrete frames around the stadium guaranteed efficiency in formwork, which was likely re-used for multiple frames, but it also provided a visual continuity between concourses. Such a simple method of achieving economic construction in a large stadium also informed the project for Rio de Janeiro, where a single section based on ideal sight lines and a large, cantilevered upper deck was to be deployed throughout a vast, elliptical plan, accommodating 150,000 spectators with only minor alterations to the section throughout.

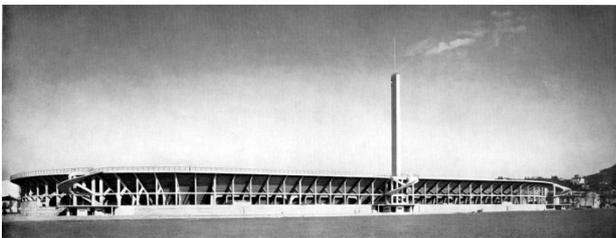


Figure 1. *Stadio Comunale, Florence. Pier Luigi Nervi, 1929-32. East grandstand showing consistent structural frames (from Nervi, *Costruire Correttamente*, plate 1) and Stadio Flaminio, Rome. Pier Luigi Nervi & Antonio Nervi, 1957-59; East Grandstand showing transforming structural frame (Photo by the author)*

In each of these stadia, the generic structural section came about as a result of functional vectors—primarily sight lines and stair slope—and this was then deployed relentlessly around a ground plan based on the dimensions of a playing field. Such a

strategy seems simple enough to hardly bear mention, but a later stadium by Nervi, the Stadio Flaminio in Rome (1958-59, Figure 1), shows a subtle variation on the march of repeated concrete frames that was able to more fluently match the stadium's plan and section to more localized functional requirements. In the two earlier stadia, the repeated use of generic sectional frames provided the same number of seats at each point in the stands. This provision ignored the rather obvious fact, however, that seats near the mid-field line are more desirable, whereas seats at the end zones are typically less so. The rigid conception of the structural frame thus did not allow the forms of these two designs to most efficiently disperse seating in the most desirable areas.

However, at the Flaminio, Nervi developed a structural section that could be extended based on the desirability of seating in different locations. The section consisted of two large vertical piers with a simple span between them—this segment remained consistent throughout the stadium—and cantilevered ends that extended up and down from this central portion. These latter elements were longer to accommodate more seats, in the desirable mid-field portions, and shorter, with correspondingly fewer seats, in the end zones. Along the main grandstand, the generic section was further extended to support a large, cantilevered roof. The section could thus be formed with re-used formwork in the center portion while the cantilevers were cast with individually shaped pieces. Importantly, however, these unique elements all shared certain important dimensions—their width, for instance, and the angle of the seating deck above—which enabled formwork to be quickly constructed on jigs that replicated these key dimensions—slope and width—while allowing the important variable dimensions—height and length. The result was not only a stadium form that was better tuned to the vagaries of seating preferences, but also one that visually communicated this principle via the exposed concrete frames. These elements not only support the variably scaled seating bowl above, they also provide a measurable element that highlights the greater or lesser reach of the upper rank of seats to the viewer. All of this came at a slight cost to constructional efficiency, in that the subtly different concrete elements each required additional effort to build the custom formwork. But this was balanced by a greater functional efficiency in having a greater percentage

of desirable seats, and by an admittedly intangible visual impact that was more nuanced than that of the Florence Stadium.

3. TRANSITIONAL FORMS – FANS & PIERS

Both the Florence Stadium and the Stadio Flaminio can be seen as functionally gradient structures, in which their form responds—in large blocks in the former case, in more nuanced curves in the latter—to varying requirements of seating over their lengths. In both of these cases, however, the gradation is handled by discrete elements—concrete structural frames—that can be understood as isolated moments in a system that appears to be a single smooth transition, analogous to film stills that when seen in sequence give the sensation of smooth motion. The transition, in each case, relies on individual elements that are essentially “frozen,” that is, shaped and calculated for a single moment within the functionally gradient shape. While efficient and effective, such a strategy was complemented in Nervi’s work by a more complex system of formwork that focused more on the actual gradient surfaces themselves and that created forms that were both more efficient and more expressive.

Nervi’s formwork relied on two strategies to achieve complex forms using simple materials: simple timber construction that used ruled geometry to achieve curved surfaces, and *ferrocemento*, or wire-reinforced light cement, to achieve regular, repetitive units. *Ferrocemento* in particular allowed a rudimentary mass-production of forms through the use of wood molds over which wire cages could be easily bent. These cages were then sprayed with aggregate-free cement, which cured into a thin, lightweight, yet strong shell. The resulting forms allowed a wealth of complex shapes on a small scale, which when replicated across the surface of a dome or vaulted roof created patterns that combined structural and constructional efficiency with recognizable and engaging patterns.

A tentative step toward this system can be found in the gathering “fans” that Nervi designed to condense loads from lightweight, folded plate roofs into piers that accommodated large circulating crowds. Such roofs formed an important element in Nervi’s research, beginning with his designs for aircraft hangars near Orvieto around 1940. These roofs were supported by narrow piers designed to maximize the available space for hangar doors, and

the transition from one system to another was handled by shaping the roofs’ lamella grids to bring diagonal members into either the piers themselves, or into a deep, trussed girder at the roof base. This arrangement handled the functional requirement of leaving large openings at ground level, but it did not provide a satisfying visual resolution to the transition between the light roof system and the heavy piers and foundations. A similar arrangement of folded, prefabricated roof ribs, large *in situ* piers, and a heavy concrete beam that formed the delineation between the two was used for a proposed rail station in Palermo in 1946, and in his 1947 design for a military swimming pool at Livorno.



Figure 2. Palazetto dello Sport, Rome, Pier Luigi Nervi & Annibale Vitellozzi, 1956-57; Detail of concrete fan between overhead ferrocemento pans and supporting, poured-in-place concrete piers (Photo by the author)

In the 1948-49 designs for a new Exposition Hall in Turin, however, Nervi took the transitional zone of the girder and stretched it to become a more statically efficient and a more expressive element. The roof of the main hall was built using lightweight *ferrocemento* pans, triangular in section, that when joined by *in situ* concrete ribs formed a monolithic, corrugated shell roof. At the springing points of the individual corrugations, Nervi designed a transitional element that matched the profile of three adjacent corrugations to that of a reinforced concrete pier below. The pier had to maximize circulation and exhibit space at its base, and was therefore rendered as a thin, blade-like element. To gather the compressive loads (and, importantly, the reinforcing bars) of the

corrugations, the transitional element thus became a fan-like shape in which the triangles of the prefabricated pans above were traced through a narrowing section until they disappeared into the width and depth of the pier below. Their complex geometry was achieved using the same *ferrocemento* material as the actual pans above, which provided a smooth finished surface and allowed the complex shape of the fan to be rendered in concrete by simply bending wire reinforcement over a timber mold. This process was also used to produce the diamond-shaped formwork pans of the Hall's "apse," although here concrete was poured over the entire surface of the dome to form a monolithic shell instead of the single-direction ribs in the main hall.

Similar gathering fans that, in Nervi's words, provided a static "passage from...continuous undulated structure to [a] discontinuous one formed by the supports" occur in the two indoor arenas for

the 1960 Olympics, the Palazzo dello Sport and the Palazetto dello Sport [4]. In both buildings, the long-span domical roofs were achieved with precast elements—corrugated *ferrocemento* similar to those of the Turin Hall's "nave" but placed on a rotational grid in the former, rotated lamellar pans similar to those of the Turin Hall's "apse" in the latter—whose constructional grid was necessarily quite fine. These numerous small elements had to have their individual loads gathered into large, discrete piers that again permitted large crowds to move around them at their bases. The resulting shapes were again triangular fans; the smaller *Palazetto* achieved this gradient form with simple downstand beams that were gathered into a shape matching the section of forked exterior piers (Figure 2), but the larger *Palazzo* demanded a three-dimensional form similar to that at Turin to blend both the depths and the widths of the roof corrugations with the rectangular section of the pier below.

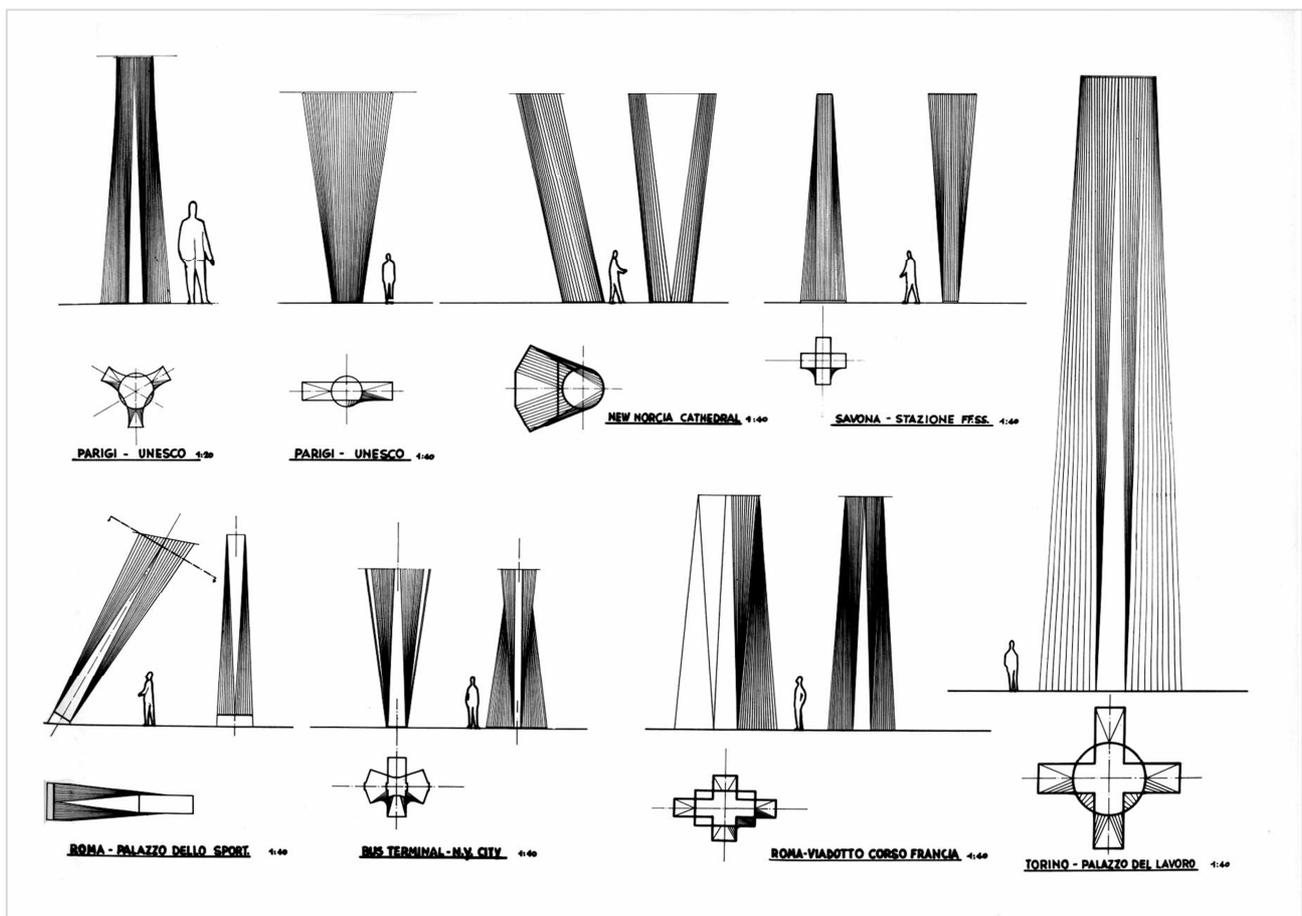


Figure 3. Comparative plans and elevations of transitional concrete piers in Nervi's work, 1953-1961. (from Nervi, *Aesthetics and Technology in Building*, 37.)

These fans show a developing understanding of functional gradation based not on the isolated, “stop-action” of individually constructed sections, but rather on understanding the *surface itself* as both a functionally responsive element *and* as a fabrication method. The labor involved in building an initial timber jig was considerable, but the continued re-use of such a jig to form multiple wire cages, and thus multiple cement fans of such a complex shape amortized this labor of many instances, and provided a shape that could be finely tuned to precisely match fabrication to function. Such a system was, of course, limited to mostly planar elements, and it relied on the more or less flat (or domical) reinforced concrete surface above to form a full structural link to both lightweight and heavyweight elements above and below. But it also provided an architectural element that quite clearly spoke to both the distinction between the light, tightly grained structure in the roof domes and the heavier, bearing elements below. This was important to Nervi, and indeed was a major influence in his fascination with what he termed the “plastic richness” of prefabrication:

...Another specific quality which results from these construction methods, which in many cases may surpass the technical and economical advantages [is] the possibility of creating great richness of form, delicate refinement of surfaces, and close rhythms, by the repetition of equal elements [4, p. 98].

4. CURVED SURFACES, STRAIGHT LINES: FUNCTIONALLY GRADIENT PIERS

Perhaps the most sophisticated of Nervi’s formwork experiments came with a family of structural piers that relied on simple timber boards to produce complex, curved concrete shapes (Figure 3). Beginning with his collaboration with Marcel Breuer on the Paris UNESCO building, Nervi applied his fluency in board forming to static and circulatory problems that were inherent in long-span public structures, matching constructive technique to pressing functional problems and producing, out of this crucible of tight economics, elements that remain striking examples of architectural expression.

Framed concrete structures require both stability and ductility; while beams, girders, and columns

must remain rigidly connected to one another, large networks of concrete elements also need built-in room for thermal expansion and small movements due to uneven loading. Concrete’s brittle nature demands some relief, or play, in larger buildings to ensure that stresses do not build up in monolithic structures to the point that they crack individual members. Thus, the engineer is faced with the need to provide stability in one axis and flexibility in another. Similarly, programs such as stadia and exhibition halls must balance the need for stability in a given direction with the need to maximize flow and visibility for large crowds. It is, therefore, not uncommon to arrive at a “program” for a column or pier that demands a particular cross sectional shape at the top—long in one direction, say, to provide robust lateral stability, but short in the other to allow flexibility—with a very different shape at the base—blade-like in the direction of greatest circulatory flow, for example.

At UNESCO, Nervi wrote that the piers on the ground level had to negotiate between a “transitional haunch of variable section” at their tops to equalize wind forces, and an ideal elliptical section at the ground that was “justified both by the technical need for a considerable resisting capacity in that direction and by the functional need to decrease its obstruction for circulation purposes [4, p. 29].” To do this, he developed a system of cast-in-place formwork whose makeup was quite simple, but whose surfaces themselves offered the transitional form that negotiated between the two ideal column sections at top and base:

The transition between each section is obtained by joining with straight lines the corresponding points of the two extreme sections; these lines are easily realized with the planks used for the formwork [4, p. 23].

Nervi’s famously terse prose style here belied the profound economies in such a system. By beginning with two sections, each tuned to perform its function, and simply connecting equally spaced points around each sections’ perimeter, Nervi defined a three-dimensional form that naturally transformed from one planform to the other. That the connecting lines were straight guaranteed that the straight lines of standard timber boards could define the form; by additionally calculating the sections to have equal perimeters, he could define the entire form with boards of equal width. These

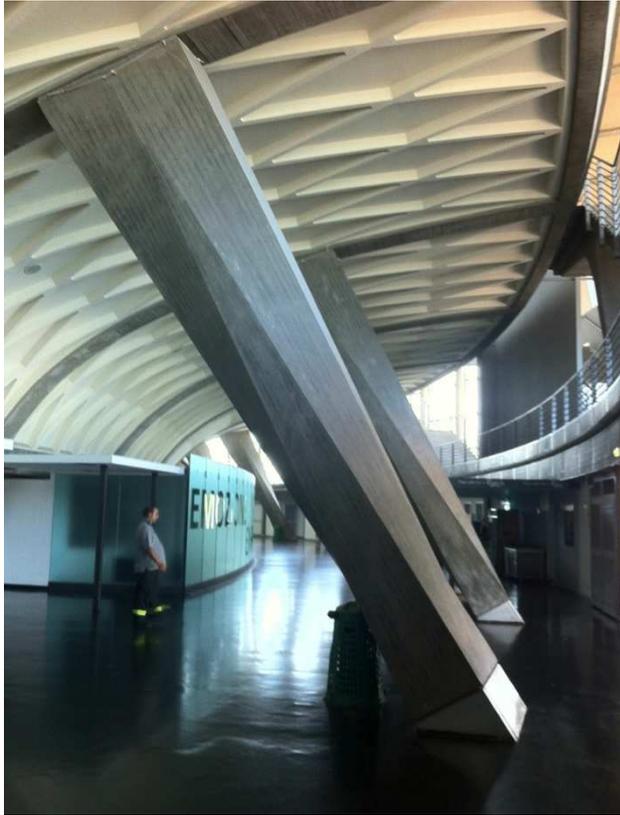


Figure 4. *Palazzo dello Sport, Rome, Pier Luigi Nervi and Marcello Piacentini, 1958-59; Detail showing formally transitional concrete piers (Photo by the author)*

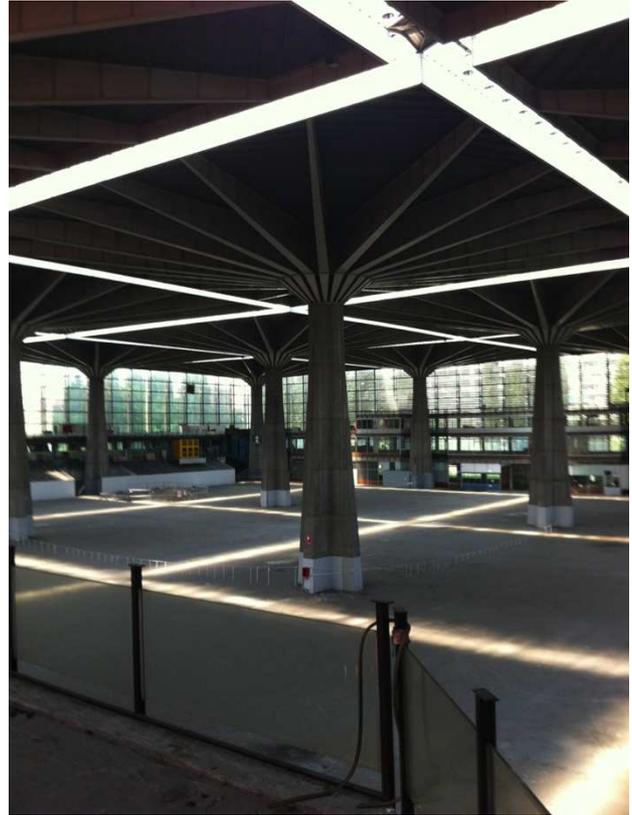


Figure 5. *Palazzo del Lavoro, Turin. Pier Luigi Nervi and Antonio Nervi, 1960-61; Interior view showing formally transitional piers and mushroom roof structure (Photo by the author)*

boards would match the straight connecting lines of a drawing at their edges, but would have to twist to negotiate between adjacent ruling lines. The results were rough hyperbolic paraboloid surfaces, shapes that are doubly curved and defined by two families of skew lines—in these cases, such lines are represented by the edges of each timber board. By making these formwork boards of relatively thin timber, such a twist could be easily induced with relatively light tools and labor on a job site, but as Nervi experimented with the technique he developed reusable armatures, spaced at equal divisions along the length of a pier, that were defined by measuring equal lengths along the ruling lines, connecting these points, and arriving at a transitional section. When this section was fabricated in metal or timber, it provided a collar into which the twisting board forms could be nailed, ensuring adherence to the ideally gradient surface.

Nervi deployed this technique throughout the rest of his career, for projects as diverse as the Savona Rail Station, the Palazzo dello Sport (Figure 4), and the gigantic Palazzo del Lavoro for the 1961 Turin Ex-

position (Figure 5). In each case, a pair of defining shapes—two rectangles set at 90° to one another at Savona, a stable cruciform base and circular top at the Palazzo del Lavoro, for instance—provided the setting out for drafted ruling lines connecting equal points along the two perimeters [4, p. 23]. Once these had been established, horizontal section cuts connected equally spaced points on the ruling lines, defining stabilizing armatures. On site, workers built formwork by twisting thin boards and nailing them into the armatures, after which these light timber shells could be hoisted into place and filled with concrete that would emerge as a sculptural expression of the transition from one functionally driven section to another.

The results of these geometrically-driven forms are universally compelling; the patterns formed by the straight but twisting formwork has typically been left untouched, and these lines reinforce the subtly changing and curving surfaces even as they add a profound visual linearity to each pier [4, p. 23]. It is difficult to understand fully these piers' geometry in one glance, and they are thus particularly

engaging as the eye is encouraged to linger on them as one walks past, seeing the forms unfold as one's viewing angle changes.

But it is important to note that these architecturally compelling forms arose from tremendous economic and schedule limitations. The case of the Palazzo del Lavoro piers is particularly instructive [1]. Nervi and his son, Antonio, won the competition in July, 1959 for an exposition structure of nearly half a million square feet, and a deadline of less than two years for design and construction. Their scheme, for a grid of sixteen concrete piers with mushroom-like cantilevered roofs above, was selected almost entirely on the basis that it could be efficiently sequenced; re-usable forms could be staged so that each of the sixteen columns could progress one after the other, balancing the cost of forms with the need to proceed rapidly. Once the geometry of the ideal column had been figured out, Nervi developed the formwork in six sections per pier, each of which represented a feasible weight to be lifted by site cranes, and a reasonable volume of concrete that could be poured in one day. "The results," according to Nervi, "were completely satisfying; the construction time for one column was reduce to ten or twelve days, and the surfaces turned out perfectly regular [4, p. 34]."

5. CONCLUSIONS

Such blending of static and constructive factors permeated Nervi's work, as did his full engagement and enthusiastic acceptance of stark limits in terms of budget, schedule, and constructional technique. Scarce resources, a lack of skilled labor, and unrealistically tight deadlines defined the bulk of Nervi's work during the time of Italy's explosive economy in the 1950s and early 1960s. The distillation of the functionally gradient pier is but one example of how the application of structural and constructional fluency at the drawing board *and* on the job site could turn these constraints into works of profound efficiency and clarity. Nervi often spoke about how extreme spans produced greater and greater fidelity to structurally pure shapes; the suspension bridge, for example, could be no other shape than a catenary curve, no matter what aesthetic desires might be brought to its detailing. The same proved to be true in the realm of constructive technique. As his budgets and schedules grew tighter, and as the gap between his clients' desires for larger and more elaborate arenas

and stadia and a regional construction industry that was profoundly lacking in the skills and techniques needed to meet these requirements, the design of these projects was necessarily focused on finding and expressing clever ways to bridge this gap. Simple drafting algorithms were matched by simple materials on the job site—ruling lines became strips of timber, in particular. Nervi's knowledge of how concrete could be formed and how this formwork could be built by only modestly skilled carpenters led to an orchestrated fabrication process in which simple actions of labor and assembly—building a metal jig, for instance, or twisting a single piece of timber formwork—gradually added to one another to create, out of simple materials and basic carpentry, components of exceptional efficiency and striking beauty.

In Nervi's view, it was important to connect the work of the engineer and the builder to the experience of the user, and to do this in ways that sprung from statically efficient forms and from the patterns of construction that were inherent in concrete forming. When faced with choices of geometry or fabrication, Nervi tended toward those solutions that clearly presented some visual or tactile connection to the statics or construction economics involved. Choices such as tapering piers or self-similar ceiling pan forms cannot, therefore, be strictly explained by their efficiency; instead, the importance of cognition on the part of the viewer played a considerable role in these elements' development. This, to Nervi, was a largely unexplainable phenomenon, but the understanding of a structure's rationale and its development paralleled, in his mind, the intuitive development of its formation on the part of the designers and fabricators:

I believe that even philosophers interested in esthetics find it difficult to explain the origin of our feelings towards forms which are dictated by the laws of statics or dynamics, since those laws are not intuitively understood, nor can they be explained by the experiences of our ancestors. But there is no doubt that any product of high efficiency is always esthetically satisfying. In the field of architecture, in which functional, statical, and economical needs are intimately mixed, truthfulness is an indispensable condition of good esthetic results [8, p. 27].

Such “truthfulness” — a distinctly Augustinian ideal — relied for Nervi on fidelity to “grammar and syntax,” or “the means of expression.” Much like literature, he described the rules of statics and construction as “allow[ing] one to say what is to be said in correct, *understandable*, and formally satisfying sentences [8, pp. 25-26]” [emphasis added]. While such correctness carries with it an undeniable tone of authority, this explanation suggests instead that adherence to such rules arose from a far more humanist goal of communicating the genesis and instantiation of a structure to an appreciative audience.

But this reliance on syntax also arose from profound constraints. While these structures are all powerfully evocative, their adherence to such “understandable” grammars stemmed from the difficult realities of Italian construction in the postwar boom. Timber formwork certainly left communicative patterns in concrete—but given the lack of skilled labor and shortages of steel in the country, Nervi had little choice but to use cheap, available boards and similarly available cement and gravel for his structures. Similarly, the adherence of his *ferrocemento* formwork to simple algorithms and materials was a response to labor and technical shortcomings and a sense of how the resulting constraints could be forged into coherent constructions. Without constraints, Nervi believed, the architect was at risk of becoming merely an “artist,” a noble profession in itself but one that lacked the readily legible grammars imposed on building design by often-determinant boundaries—budgets, functional needs, codes, and fabricational necessities. Acknowledgement of these constraints was, to Nervi’s eyes, a “necessary if not sufficient base” for architectural expression, and it was the particular role of the architect—as opposed to the engineer—to understand these limitations and to craft out of them an efficient, affordable response

that nevertheless provoked a genuine aesthetic experience in the minds of a structures’ audience [4, p. 8].

REFERENCES

- [1] **Chiorino, Cristiana**, “The Palazzo del Lavoro” in Olmo, Carlo and Cristiana Chiorino, *Pier Luigi Nervi: Architecture as Challenge* (Milan: Silvana Editoriale, 2010).
- [2] **Cohen, Jon and Federico, Giovanni**, *The Growth of the Italian Economy, 1820-1960* (Cambridge: Cambridge University Press, 2001)
- [3] **Iori, Tullia**, *Il Cemento Armato in Italia dalle Origini alla Seconda Guerra Mondiale*, (Rome: EdilStampa, 2001).
- [4] **Nervi, Pier Luigi**, *Aesthetics and Technology in Building*, (Cambridge: Harvard University Press, 1965).
- [5] **Nervi, Pier Luigi**, *Buildings, Projects, Structures, 1953-1963*. (New York: Praeger, 1963).
- [6] **Nervi, Pier Luigi**, *Costruire Correttamente*. (Milan, Hoepli, 1965).
- [7] **Nervi, Pier Luigi**, “L’evoluzione delle strutture in cemento armato [The Evolution of Reinforced Concrete Structures]” in Gustavo Colonnetti, *Scienza delle costruzioni*, vol. 3. (Turin, Einaudi, 1957).
- [8] **Nervi, Pier Luigi**, *Structures*. (New York: F. W. Dodge, 1956).
- [9] **Rogers, Ernesto N.**, “A Portrait of Pier Luigi Nervi” in *The Works of Pier Luigi Nervi* (New York: Praeger, 1957). x.