"The Influence of Reinforced Concrete and Technical and Scientific Progress on the Architecture of Today and Tomorrow"

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From the Paper by Pier Luigi Nervi entitled " The Influence of Reinforced Concrete and Technical and Scientific Progress on the Architecture of Today and Tomorrow."

(*Owing to indisposition, Professor Nervi was unable to present this paper in person*)

IN the last fifty years the slow, age-long evolution of the art of building has undergone a sudden change, which has given us, in the space of a few decades, buildings and other structures which bear no resemblance to anything previously created by mankind. This is a remarkable phenomenon and its causes, the way it has been produced and its foreseeable future developments deserve to be examined as closely as possible.

While attempting to correlate the causes which, in less than a century, have produced such a profound transformation in the art of building, it would, I think, be well to bear in mind the two-fold character of a work of architecture : it has a physical existence, dependent on materials and technical necessity, and an emotional content in which dimensions and materials play little part and which becomes more difficult to define the nearer the building is to the domain of art.

We have only to make a very short comparison between the past (that is to say all building from pre-historic times to halfway through the last century) and the world of building today, together with what is foreseeable of that of tomorrow, to realise what a radical change has come about in building techniques and materials. As a result of the irresistible pressure of economic factors and of the rapid evolution of industrial production, acting in a chain of causes and results, whose point of departure is very hard to determine or explain, stone, bricks and timber have come to be supplemented, if not largely replaced, by steel, concrete, light alloys and plastics.

All the same, however unmistakable the architectural difference may be between a cast-iron column and a corresponding marble column, or between a facade with a steel frame and aluminium panels and one in brick, it is easy to see that the most complete transformation in architectural language and thought has been brought about by the new and daring structural forms made possible by the application of structural analysis and constructional techniques, which may be called Building Science.

Building Science—We have, all of us here, made Building Science the foundation of our studies and we accept it, not only as a sure guide, but almost as implied by the very existence of designing and building. But when we reflect that this system of theory was born about a hundred years ago and that until then every work of architecture, even the Gothic cathedrals, the great domes, the great masonry bridges and the vaults of the great galleries of the Renaissance palaces, were designed, proportioned and built by virtue of intuition and experience, apart from feeling unlimited admiration for the courage and intellectual acuteness of those distant predecessors of ours, we see in a clearer light how radically the conditions of building today differ from those of every century before our own. Restriction to a few simple structural forms, which bit by bit architects of genius had discovered and which, though slowly changing, remained valid for tens and even hundreds of years until a new breath of genius permitted the rise of new forms, has given way, thanks to Building Science, to the possibility of allowing the imagination a free run and of thinking out new structural forms, of testing the conditions of internal equilibrium and of deciding with more than the necessary precision, the dimensions required to resist stress.

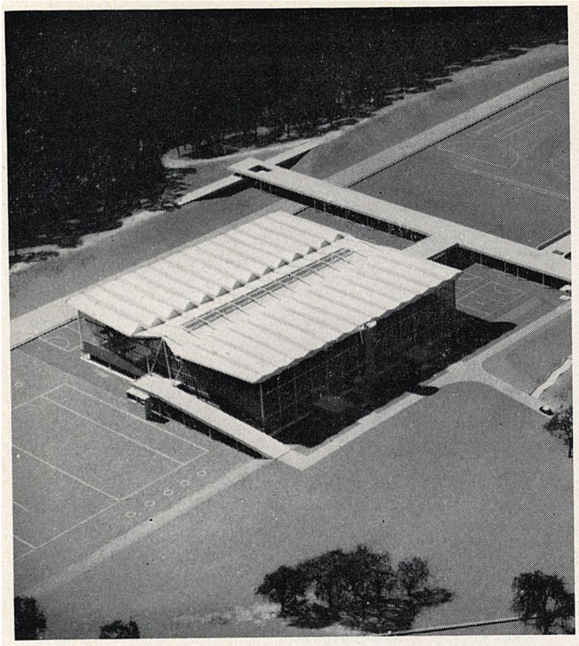
Finally one must take into account the violent intervention of economic limits and considerations in the whole vast field of building. It is certainly hard for us to estimate the economic conditions of building in the past, but it is clear that for the grandiose palaces of the powerful, and even more for the great churches and for the most representative buildings, the cost of the work must have had limits and conditions of expenditure very different from those of today. Today cheapness, or rather the economic return of building activity, is of fundamental importance for the balance and social development of nations. It is the strict duty of every architect to study economical building; one has only to remember that if building costs could be reduced by an appreciable fraction and if, as a result, at an equal total cost the numbers or the size of buildings could be increased by that much, many of the problems which embarrass the less fortunate nations would be considerably eased.

To this consideration, in itself already more than sufficient to justify the revolutionary changes of the last hundred years in the vocabulary of the architectural language, have been added the new demands arising from the progressive technical and social developments of our times. The use of new and increasingly efficient materials and the possibility of qualitative and quantitative tests devised by Building Science have made possible the realisation in vital and expressive architecture of the unprecedented structural forms demanded by railway stations, airports, seaports, enormous bridges, very high buildings and huge factories. It was therefore inevitable that this combination of factors should lead to the complete transformation in the exterior aspect of a great many modern works of architecture, so much so that, in the light of these elementary observations, the dispute which developed in the first decades of this century between the upholders of the old forms, grouped in Italy in the so-called " arch and column architecture," and the champions of a new architecture grouped in various tendencies such as futurism and functionalism, seems now quite pointless.

Reinforced Concrete—The richness in form of architecture's new vocabulary increases every day, not only because of the increase in the number and variety of the building materials made available by the manufacturing industries, but, more important, because of progress in building methods.

To take reinforced concrete structures as an example, it is easy to see how, from their beginnings up to the present day, as a result of perfected building procedures, their appearance and architectural possibilities have radically changed. At first reinforced concrete was considered purely from the technical point of view. Once it had fulfilled the structural function entrusted to it, it was hurriedly covered up with masonry and marble facings; it was accepted as a brutal necessity, but to be hidden as soon as it had served its purpose.

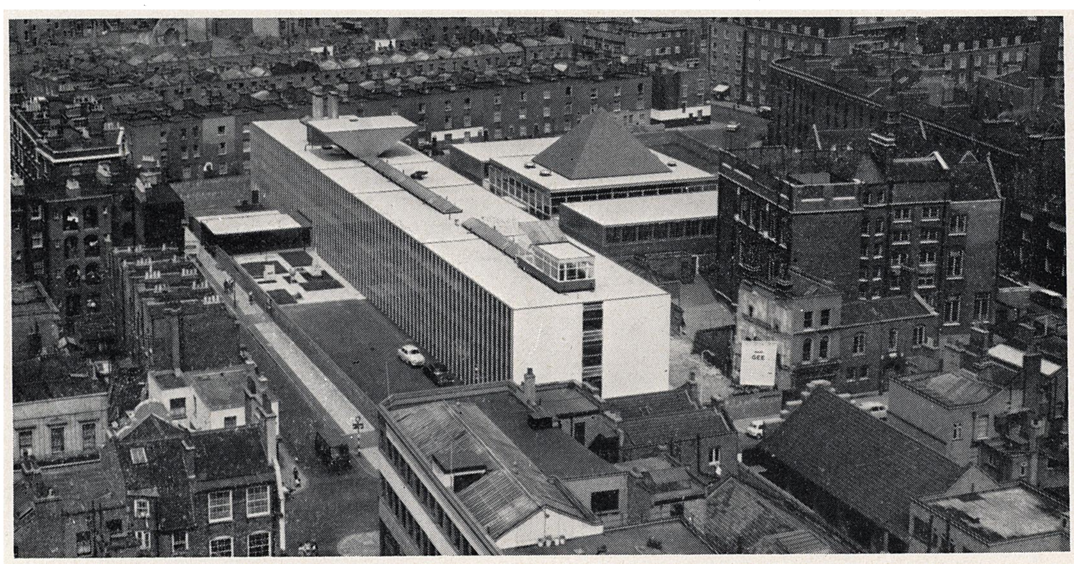
If, at the start of the century, someone had wanted to put up exposed concrete walls like those of the exterior of the UNESCO conference building in Paris, apart from the hostility to the acceptance of such a revolutionary conception which would have been encountered at that time on all sides (from clients, local authorities and public opinion), he would have found it even harder to overcome the many small difficulties of execution, whose resolution one by one in the continual refinement of building technique has allowed us to obtain a satisfactory result today.



OFFICIAL ARCHITECTURE ON SHOW ON THE SOUTH BANK

About a dozen examples of official architecture from the United Kingdom were among the buildings illustrated in the Architecture of Technology Exhibition. They included the three works illustrated here—the Crystal Palace Sports Hall by Hubert Bennett (in succession to Sir Leslie Martin); the Rutherford School in Marylebone, designed for the L.C.C. by Leonard Manasseh and Partners; and flats at Leeds designed by the late R. A. H. Livett and constructed by the Reema system for multi-storey housing.

Other official work illustrated in the exhibition included the L.C.C. flats at Roehampton and on the Cleveland Estate in Stepney; the Tile Cross Secondary Modern School in Warwickshire, designed by the late G. R. Barnsley in association with Architects' Co-partnership; the Two Saints' School in Southwark, designed for the L.C.C. by Chamberlin, Powell and Bon; the Southampton University Women's Hall of Residence by Sir Basil Spence; Gatwick Airport by Yorke, Rosenberg and Mardall; and Berkeley Nuclear Power Station.



The perfecting of the various stages of construction, and in particular that of the formwork, has allowed the use of new structural forms characteristic of concrete. Particularly expressive among these are columns of varying section generated by straight lines which present a great richness of possible forms and are capable of expressing a pure structural logic.

How can we doubt the decisive contribution made to architecture by building materials and techniques when we consider that sections of such a kind as to have the architectural importance and the aesthetic expressivity of the columns and capitals of the past could not be built at a reasonable cost using any material other than reinforced concrete?

It seems to me that a few examples like these would show clearly the wealth of forms which architecture has acquired by coming into possession of a material which is highly resistant and has the disconcerting property of starting off plastic and being able to take the shape of whatever mould it is poured into.

In the field of flat structures the use of a certain type of mobile formwork, which I had the opportunity of studying about fifteen years ago, has permitted an appreciable advance in the direction of a freer and more aesthetic disposition of structural ribs. The preparation of these forms is relatively easy and, if the building is large enough in area, they allow an appreciable saving in expense independent of the saving made possible by the fact that the perfection of the ceiling surfaces allows the elimination of the plaster finish.

The process is naturally capable of further improvements and, most important, of extension to large dimensions. My use of it so far has been limited to the repetition in series, even over very large areas, of spans of the order of ten metres by ten metres with a rib depth (and a consequent lowering of the shuttering when removed) of less than a metre.

In this case too—as in all delicate operations—one meets with unforeseen problems, from deciding the quality and method of application of the oil used to prevent the concrete from sticking to the formwork, the design of the mobile scaffolding, the profile of the ribs and the dimensions of the repeating bay, to the programme of placing and the consideration of how each span is to be linked to the next one.

It is therefore superfluous to emphasise the fact that work of this type demands a certain experience, not only in the creator and designer, but also in the office technicians and, above all, in the foremen and skilled operatives on the site.

Ferro-Cemento—In the continuous research which I have pursued for more than thirty years, with the aim of freeing concrete structures from the formal and structural slavery of wooden formwork, I have found two other methods of construction particularly efficacious: that of building slender structures of cement mortar with a widely spread reinforcement built up of multiple layers of wire netting and rods of small diameter; and that of structural prefabrication.

The first process, which I have called (not very appropriately) "ferro-cemento," allows the reduction to a minimum and even the complete elimination of formwork, either in timber or in other materials. In fact, when a high quality mortar of cement and sand is spread by hand on a steel reinforcement completed by well placed layers of wire netting, it is held perfectly in place by the netting and can be given its finish at once. Using this process I have constructed ships, a large sphere designed by the architect Libera for an exhibition, and the undulating sections, fifteen metres in span, of the projecting part of the canopy at the Stadio Flaminio at Rome.

The system has many possibilities; its essence is that, with an unlimited freedom of form, it allows the transformation of any cage of rods and wire netting into a concrete structure. From the structural point of view, when the combination of fabric and rods is such as to give an evenly distributed metal content of about 300-400 kg. per cubic metre of cement mortar, you obtain a very resistant material which is practically waterproof and will not crack. In the field of thin vaults it allows a freedom and variety of architectural interpretation which would be quite out of the question with any other system of construction whatsoever.

Prefabrication—Prefabrication, however, still seems to me the building process richest in structural and architectural possibilities. It falls into two main categories; prefabrication of whole load-bearing units, and the sub-division of a building into relatively small sections which can be prefabricated and then joined together to form a structural and architectural unity.

The first category includes structures composed of beams placed side by side, relying on each other and yet remaining individually capable of bearing the share of the load entrusted to them. The process is especially suitable for flat roofs and for the decks of bridges but, in fact, in most cases it has no special architectural significance. In effect, the advantages of prefabrication are limited to the possibility of varying the section of the beams with far greater freedom than that allowed by timber formwork, and therefore it allows delicate refinements of shape to be obtained.

However, as the dimensions of buildings to be prefabricated are increased, the weights involved rapidly become such as to demand the use of very, if not prohibitively, expensive mechanical site equipment. For blocks of flats prefabrication seems to be possible and economically profitable only if applied under special conditions, not often met with, where there is perfect uniformity in a sizable number of buildings, and the conformation of the ground allows the use of mechanical means of transport and lifting. Besides, it seems unlikely that the aesthetic uniformity arising from it would often give a pleasing architectural result.

On the other hand the second category of prefabrication, for which I would like to propose the name of "structural prefabrication," offers an unlimited wealth of shapes and architectural features besides its economic advantages and relative ease of construction. As I have already indicated, its essence is that it produces a structurally and architecturally unified building by the skilful joining of prefabricated sections. The process displays all its richness in the construction of vaulted roofs, either for the various sorts of dome already part of architectural tradition, or for the larger and more varied ones of the near future.

The most significant aesthetic result of the process seems to me to be the effect of the repetition of identical sections, which, being mass-produced, can be designed with a complete freedom of form and made with absolute accuracy, and by the enrichment due to the necessity of joining or completing the individual sections with other sections which, if designed with sufficient care, contribute to the final architectural result.

To use this process too—and perhaps even more, to use those already discussed—the designer needs a complete mastery of building technique in its smallest details, and the building organisation needs personnel experienced in these operations among both the office technicians and the workmen on the site. A sensible proportion between the weights of the sections, their dimensions and the mechanical equipment to place them in position, the choice of the techniques to be used on the site to obtain the indispensable exactness of execution—all these are equally necessary to obtain a good result.

Among the real qualities of the system, its intrinsic economy and rapidity of execution seem to me particularly important; in this respect we have only to consider the fact that, while work is proceeding on the foundations of a building, the prefabrication of all the sections which are precast on site can be begun, and this method has all the advantages of mass-production.

Prestressed Concrete—Among the methods of construction which contribute most to enrich the architectural possibilities of reinforced concrete, we must finally remember prestressed concrete. The slenderness of supports and the elegance which can be obtained by using this process cannot be equalled in the whole field of building. The future is full of promise for this technique.

I think these few remarks should suffice to make clear the very close relations between structure and building methods in reinforced concrete and the architectural conception and result.

To plan convincing work in concrete without a sufficiently exact knowledge of the very rich building possibilities of this technique is an absurdity comparable to that of the man who, feeling capable of a musical phrase, imagines himself a real composer, although he knows nothing of instrumental technique or of the theories of counterpoint.

The designer of the near future will be obliged to take building technique more and more into consideration and this development, which has scarcely begun today, will constitute the essential difference between the mental attitude of the architect of fifty years ago, a simple designer of decorative forms, and the architect of tomorrow who, in his true role as master builder, will restore to the title of architect all the loftiness and nobility it has had from the most distant past.

Steel, Alloys, Plastics, etc.—If, on account of my own particular professional interest, I have been led to talk at some length on the subject of concrete techniques, it is easy to see that steel, light alloys, plastics and their building possibilities and techniques are, with equally decisive importance, the causes and results of unprecedented architectural conceptions, whose timid beginnings today will certainly be followed by a splendid flowering in the near future.

With the change-over to building in steel the dimensions of the essential elements of the traditional masonry architecture of the past undergo an even more clear-cut and decisive transformation than that produced by the change-over to building in concrete. For example, a building may be 30 to 40 metres high in masonry, 100 to 150 in reinforced concrete and 300 or more in steel. Is not a building's height an essential part of its architectural effect ?

But, as I have already pointed out in connection with reinforced concrete, the appearance of buildings is determined not only by the material used and its mechanical characteristics, but also by the techniques applied to the particular material. There is a substantial difference of appearance between riveted and welded steel structures, between the profiles of steel sections and those of light alloys obtained by extrusion, and this difference has inevitable repercussions on the expressiveness of works of architecture in which they are used.

In the field of wooden structures it will be enough to remark that the new adhesives which permit the perfect joining of planks of wood to form artificial beams stronger than the original tree-trunk permit new structural and architectural solutions which have little in common with the creations of the past, magnificent though they are.

Finally, using plastics we can have weatherproof sheets of perfect surface in brilliant colours.

What a promising vision it is! Residential areas built with aluminium framework and panels in laminated plastic, clean, attractive, well protected from heat and cold by the very high insulation qualities of the synthetic resin foam with which the walls and roofs will be finished.

New and unlimited horizons are open to the building of the future, but the first necessary condition for the fulfilment of these happy promises is that architects should take a passionate interest in details of technique and construction, so as better to be able to use the already enormous possibilities of the building materials and systems of today, and to prepare themselves for the full exploitation of those which industry and technology will make available in the near future.

Technical Progress—Nevertheless, however decisive the results of the new building materials and techniques may be in the evolution of the vocabulary of architecture, it may be said that the influence of technical progress in general—and of technical progress in building in particular—on the most intimate substance of architectural thought, is perhaps still deeper even if less evident.

In these last decades we have seen the dimensions and the structural importance of a great number of buildings growing at an ever-accelerating rhythm. We already have buildings 200 or 300 metres high, domes or vaulted roofs of 100 metres span or more, bridges with arches of more than 200 metres and suspension bridges of 1,500 metres; we will soon certainly have much bigger ones. Even the number of these works of great structural daring will continually increase, because it is determined by economic and social reasons in strict relation with the progressive development of modern civilisation.

Now it must be remembered that each of these works is dominated—and the bigger its dimensions the more strictly is it dominated—by structural necessities which are, in their turn, the consequence of natural laws completely independent of man's will or aesthetic feelings. The profile of an arch bridge of 200 metres or more must follow accurately the line of thrust of permanent loads. Any attempt to depart from it to an appreciable extent would make the work impossible to carry out. The catenary curve of a big suspension bridge is fixed and unalterable in time and place; a dome of 100 metres or more, or a vault of equivalent size, must obey structural laws which cannot be disobeyed without intolerable increases in cost and waste of material.

If an architect today wished to build a dome, more than 100 metres across, the shape of the Taj Mahal, he would very soon find such an architectural formalism impossibly expensive and would quickly be led back to structurally better shapes. And if we bear in mind that even for less daring buildings the most convenient solutions are those based on simple structures, it is easy to see that pressure in favour of structurally better solutions will become continually more decisive.

Finally, if we add that in other fields, especially that of high speed on land or water or in the air, the shapes of our creations tend, in the constant search for maximum efficiency, to approach an ideal form in perfect harmony with the laws which govern dynamic equilibrium and resistance to movement, it is easy to see that every day we come into contact with things whose forms are determined by natural factors which we can only press into service, but cannot interfere with or modify. Unless we foresee in the near or more distant future a voluntary abandonment of science and a return to the empiricism of the past (an event which really seems unlikely and even less to be hoped for), it becomes plain that the number and expressive efficiency of these creations in perfect accord with the laws of physics will continually increase.