Some Reflections on Architecture and Construction

Eladio Dieste

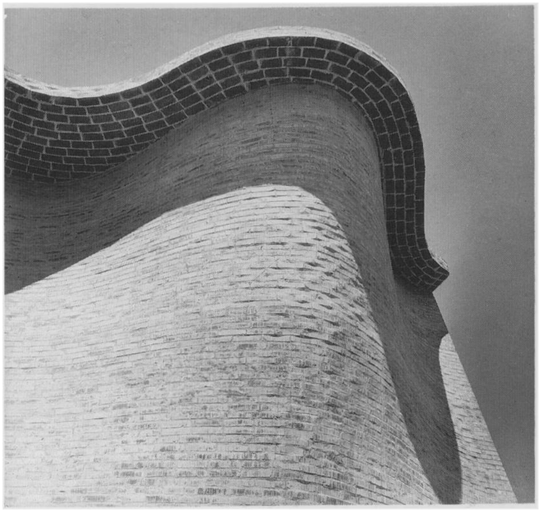
The following is a somewhat free meditation on themes of importance to me, reflections with a certain provisional order. I began to work on structures in 1942. It was then that I began to reflect on the way we build, the origins of the methods we use, and the philosophy at the base of our activity.

To relate these reflections, I feel it necessary to outline the evolution of construction methods since the Industrial Revolution. In analyzing this evolution I have been struck by an apparent discontinuity, precisely at the time of the Industrial Revolution, of a millennial tradition. Until the end of the eighteenth-century construction was carried out with methods that evolved from those used in the High Middle Ages and the Renaissance. The expressive traditions of these periods conceived of the integration of construction and architecture in essentially the same way. But suddenly, between the eighteenth and nineteenth-centuries, it became possible to use iron as a construction material (first cast iron, then various types of steel), and very quickly this material began to be manufactured in pieces of prismatic wholes that were then assembled to form the structure of buildings. It is by now a commonplace to point out the importance of this conceptual shift, which allowed us to think of the structure of a building as a skeleton partially free of its walls, and which made architectural space independent from construction method in a way unknown until that time.

With great speed, iron invaded and revolutionized our methods of construction. This change, however, was not occasioned by economic considerations. Sometimes, and it was certainly the case here, it is initially more costly to utilize a new method or material. The change is brought about, though, because man fortunately possesses the generosity that enables him to embark upon projects for which he feels a solid and intimate suitability. Structures that could never have been attempted with the methods of the past, and that were quite suited to the typical programmatic concerns of the industrial era, i.e., warehouses, factories, and transportation terminals, became possible with iron. Indeed, such large-scale iron buildings are the most representative architecture of the last century.

But, although there is a wealth of scholarship on this period, there is an aspect of this revolution that I have not seen investigated, perhaps because it is a strictly structural issue, and that I believe is as important to the evolution of architecture as the so called "freeing" of the ground plan from the building structure.

1 Church of Atlantida, Eladio Dieste, Atlantida, Uruguay, 1961, view of south wall.



2 Church of Atlantida, detail of west wall at eave.

Iron: The Technological and Theoretical Predominance of the Plane

The technical revolution was accompanied by great advances in the science of construction. The very process of assembly of iron components made it possible to decompose the building, without omitting anything essential, into trussed planes that were easy for engineers to calculate. Though lacking the subtleties of the theories of elasticity and superior stability, engineers could determine the stresses and sections of all parts of a structure by employing the great principles of statics, very simply applicable to any system of planes, and an only rudimentary understanding of material resistance. This theoretical clarity drove engineers to reduce everything to diagrammatic planes. When working with planes, they could move with agility.

The technological dominance of the plane had a tremendous influence on the evolution of construction and consequently of architecture. The rational mastery of construction problems created a self-confidence that prompted the most lucid and bold minds to enthusiastically explore the possibilities of iron. Prior to this revolution, traditional methods of construction were developed not through analysis but rather through secular adjustments, not calculated but intuited, tried, and sometimes corrected through spectacular failure. The perfection that was achieved is occasionally disconcerting. [1]

The technical revolution provided builders with methods that could be calculated and constructed with confidence, without guessing. Time-consuming, uncertain processes were replaced by efficient rapid analysis. Only an intoxication of certainty can explain the ensuing abandonment of such an enormous amount of accumulated knowledge of traditional construction. At the time of the Industrial Revolution, that tradition, though lacking the vitality of its great creative moments, remained intact as a reservoir of possibilities. Perhaps the apparent unwieldiness of those traditional methods in the face of the new "planning" mentality might explain why it was neglected by those minds capable of founding a whole new tradition, men like Eiffel, who were not only genial as engineers but also as artists who constructed buildings and bridges of great beauty.

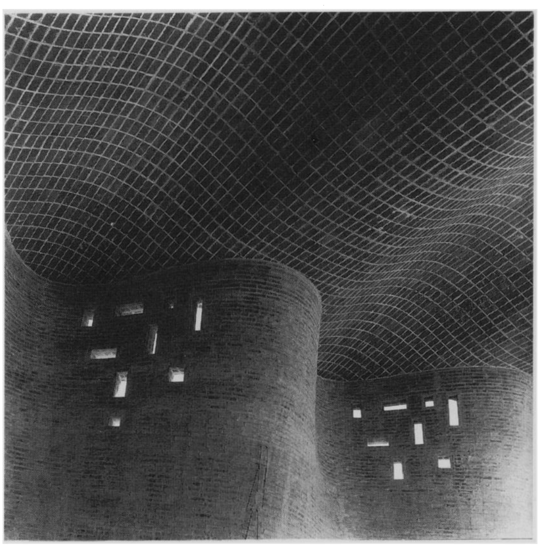
As I've said, the structures derived from iron typical of the nineteenth-century were planar structures. Even today most construction is made with trussed planes. These are the structures analyzed by the science of construction and the only structures that we study with any depth in our schools of architecture and engineering. Ancient structures like Hagia Sofia or a Gothic cathedral are not planar. They are systems that must be understood three-dimensionally and are much more difficult to both conceptualize and analyze. Even for an experienced builder, it would be difficult to simply calculate the stresses on the different parts of such a structure.

The rational clarity of the trussed plane also had a tremendous effect on the compositional aspects of architecture. The plane's crispness had a peculiar expressive charge that coincided with formal investigations at the root of the modern movement, and the plane vibrates with an almost religious tension in the works of many modern masters. Still today architects seem to work with more comfort when composing planes even when the plane's surface, limiting space in a preconceived way, is not the most appropriate solution. We all have seen those buildings in which the ceiling, for example, is structurally tortured to prevent it from leaving the flat surface of the plane. Undoubtedly, the fact that a planar building is easier to express graphically is influential.[2] But I believe that the essential thing is the work, not the plans. And if the plans prove unable to help us express something that we consider valid, this is no reason to abandon our idea.

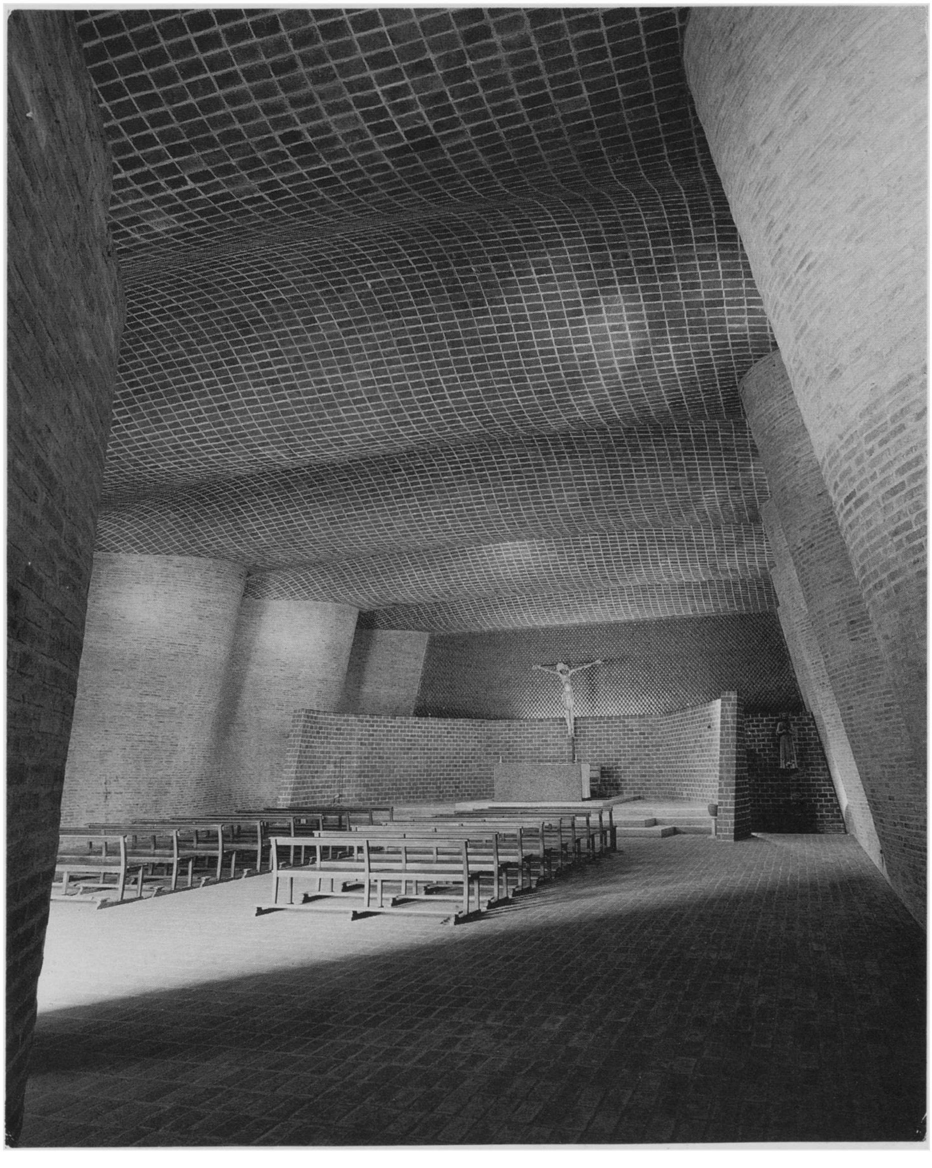
1 I remember having seen an analysis of a flying buttress from Notre Dame in Paris that studied the lines of pressure corresponding to their own weight combined with the effects of wind, snow, and temperature. Those lines of forces, in every case, run through the central nucleus of the structure, so that the flying buttress is always entirely in compression with no extra mass in its section. Those medieval builders seemed to intuit the theories and work methods that were formulated seven or eight centuries later. I should mention, however, that this level of precision and correctness is not apparent everywhere. The vaults, for example, are much more massive than statically necessary. But the example of the flying buttress allows us to see the degree of refinement that could be achieved by the secular process of adjustment to which I allude.

2 I remember once asking a friend what he thought of the work of Gaudí. His response was unequivocal: "All that has nothing to do with us. Besides, I wouldn't know how to draw one of Gaudí's buildings, and how would one, today, build a structure without plans, sections, and elevations?" My friend, though obviously not interested in Gaudí as an artist, also represented, I think, a certain mentality that places a disproportionate importance on the graphic representation that we require for our construction work today. (This was 25 years ago when Gaudí's work had not been properly evaluated. I did not know of his architecture but the painter Torres Garcia had spoken of him with enthusiasm.)

3 *Church of Atlantida, under construction.*



4 *Church of Atlantida, detail of interior fenestration at ceiling.*



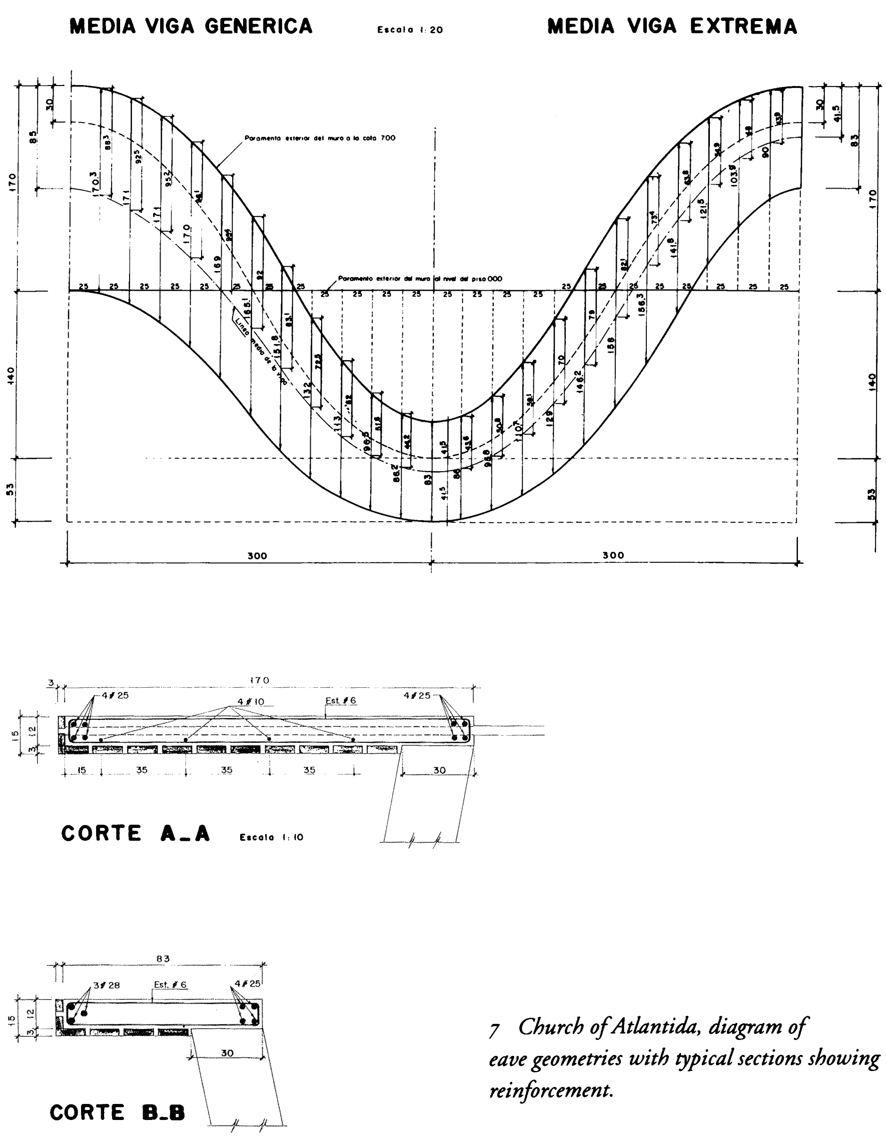
5 *Church of Atlantida, general view of nave.*

6 Church of Atlantida, wall under construction.

Today we seem to give more thought to the drawings than to the work itself, thinking of the work schematically, through its graphic representation. Current methods of construction and even our professional training teach us to build projects, not works. It is our natural tendency to do what we know best, and it is only through sustained effort that we can free ourselves from what Sert called the "tyranny of the drawing board." All of the great works of the past were built with extremely simple plans. The organization of labor was very different then, and I know from experience how difficult it is to execute conceptions that cannot be clearly rendered in graphic terms. But very frequently the results justify the extra work required even from the most utilitarian point of view. The laminary structures of double curvature that I will discuss later, for example, cannot be clearly rendered graphically but are very economical and very easily built.

If the great advantage of the trussed plane is its primary clarity and ease of analysis, its disadvantages are often preponderant. It is the most elemental kind of structure and often a simplistic solution that does not distribute loads in the most efficient way. All of the medieval art of stone vaults and cupolas is not only chronologically posterior to the conception of the plane but presupposes great refinements in the understanding of complex structures and in the techniques to build them. Above and beyond that, the clarity, rationality, and speed of the process of design and construction prevent the work from gradually acquiring a personality of its own. Surprise and discovery become less likely.[3]

3 In this as in everything else, there is no advance or increase that does not carry a risk. As a current example, few things today are as prodigious as computers. Many of the calculation problems to which I will refer have almost disappeared because there is no system of differential equations, no matter how complex, that can resist analysis by a powerful computer. But, as has been noted, the machine cannot answer for itself and will never give us anything more than what we put into it. The creation of form will continue to be the result of the mind's labor. The great risk of computation is that laziness and the mechanical work of programming the machine will distance us from the substance of the real. We will tend to simplify and impoverish our thought in order to adjust it to systems that function without our continuous input. For example, it is easy to program the calculation of the classical structural skeleton, but it requires much more effort to substitute that system with one that might prove more convenient, such as diaphragms. All of this admonishment is not meant to support the reactionary and unintelligent rejection of the astounding media that progress has put at our disposal. I am not advocating "Luddism" for architects and engineers. I simply point out the dangers of an attitude that uses progress to sterilize the force of progress, diminishing rather than enlarging man. We may again face the danger that what we build, rather than being richer and more truly rational, will ultimately be an impoverishing simplification of what we had already done better with more primitive methods.



7 Church of Atlantida, diagram of eave geometries with typical sections showing reinforcement.

Concrete Laminary Structures: Calculations, Models, Imaginations

In the second half of the ninteenth-century, as the technological revolution continued, the discovery of reinforced concrete developed very quickly from its humble beginnings into one of the most vital methods of construction.[4] Initially, reinforced concrete was also utilized in planar systems of slabs, beams, and pillars not only in those instances in which it was an appropriate solution, but also in situations in which it was clearly an absurd choice. Slowly, it became obvious that this was not the most rational use of the material, but it was difficult to change our ways of conceptualizing structures because of our previous training. As soon as new uses and solutions were imagined, their execution sank into a sea of doubts. We were always faced with the limits of what we could calculate; and for an engineer, to conceive of something meant to be able to calculate it.[5]

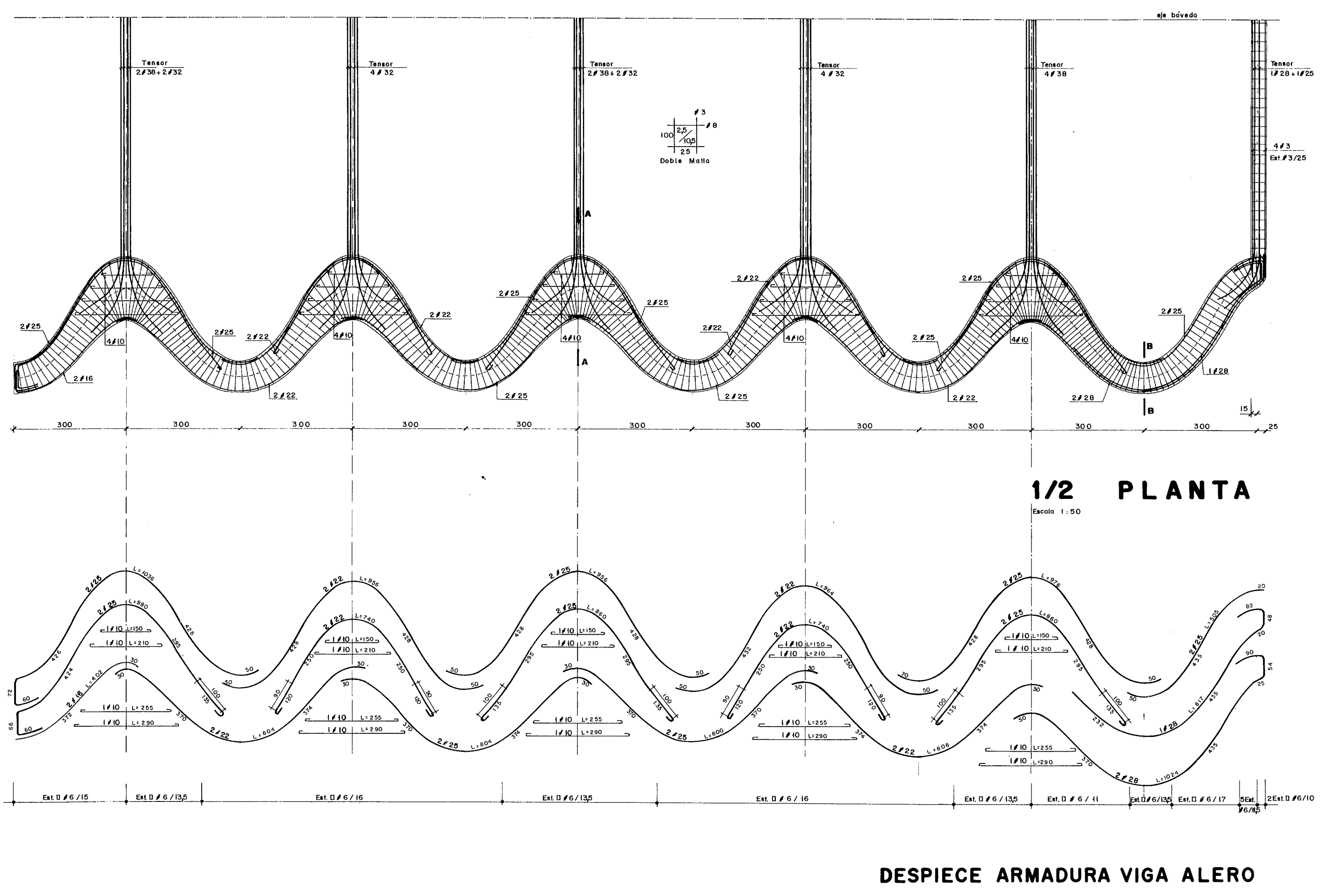
4 What I say about reinforced concrete is equally applicable to reinforced ceramics, the techniques of which I will describe later.

5 Sometimes when I am speaking about laminary structures to students of architecture or engineering, I realize how difficult it is to do it without falling into recipes. Still, today, the time we devote to the study of structural surfaces is insufficient. It is true that there is no structure that cannot be analyzed, but the more complex a form is the more analysis and hard work it requires.

Almost all that is written about laminary structures is the work of builders who first conceived of a solution and only after the whole process was completed, with testing in situ, began systematizing their analytical and constructive experience into theories that were valid only for specific structures. Work and studies through models are always possible, but in general they don't yield more than a qualitative orientation. To specify quantitative stresses requires a continuing survey of the problem in order to arrive at the necessary precision. Besides, models are more expensive and time-consuming than computation, and are useful only at a final stage in the design of very complex structures. In my own practice I have used models very seldom. But I can say that I have proceeded gradually in my work and that the smaller structures have served as models for the larger ones.

Even with the most modern tools, the ideation and fabrication of structures that are both rational and expressive will always be very time-consuming and will require an enormous amount of work. I have come to think that the most sensible thing to do would be to create repertories of studied forms that could be used to compose in many

8 Church of Atlantida, diagram of reinforcement at connection of roof vault and wall.

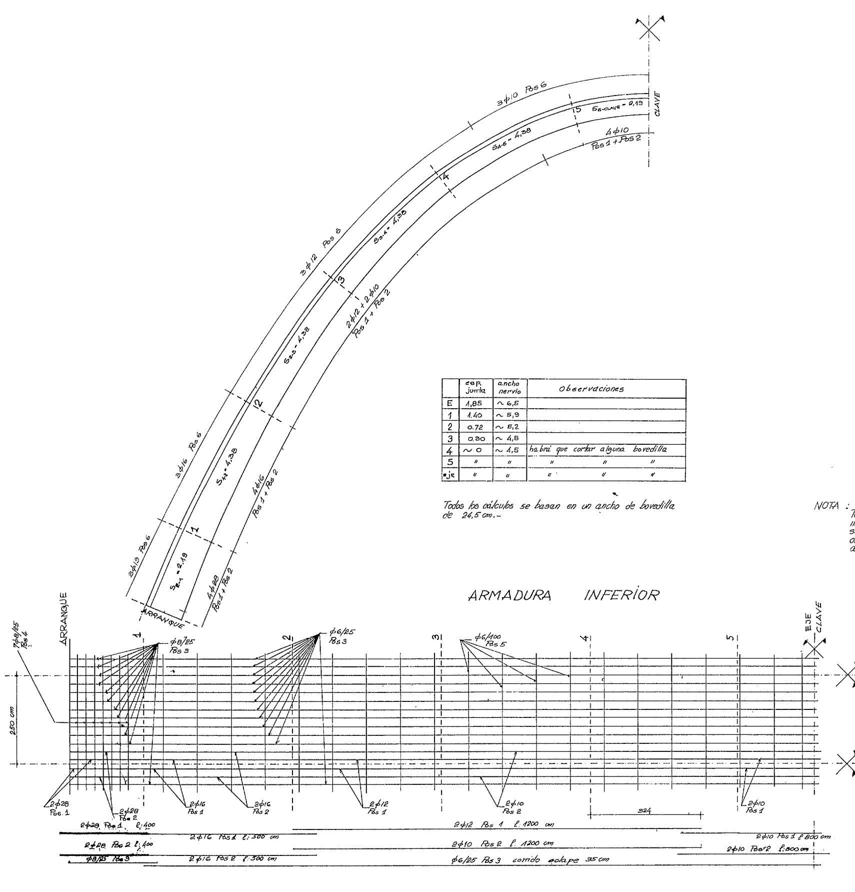


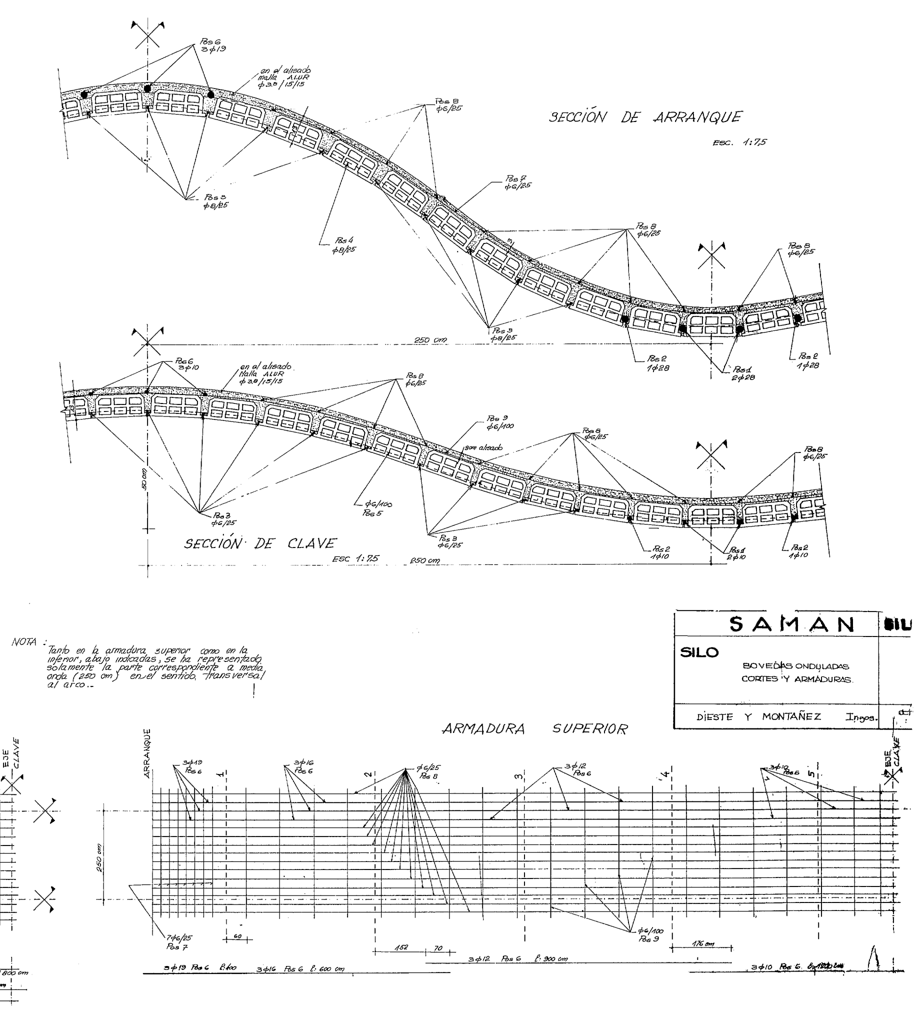
different ways. Is this not a perfectly rational justification for what we call "style"? The creation of styles, in antiquity, referred to a process of study and refinement that included both proportional dimensioning and constructive techniques.

The construction of rich and complex forms, however, cannot be the product of a routine. They require a love for quality in work and an attention to detail that is not common among businessmen. And anyone with enough experience in the field knows that generally the designer and the technician have little direct intervention in the work once construction begins. They limit themselves to administrative control, demanding financial performance and scheduled completion. It can be said without exaggeration that in many cases the work is built by the foreman. But the complex structures of which I speak require not only conception and calculation, they also require our input at the site during execution, and a greater personal commitment on the part of the contractor. They force him to be a builder, not merely a businessman.

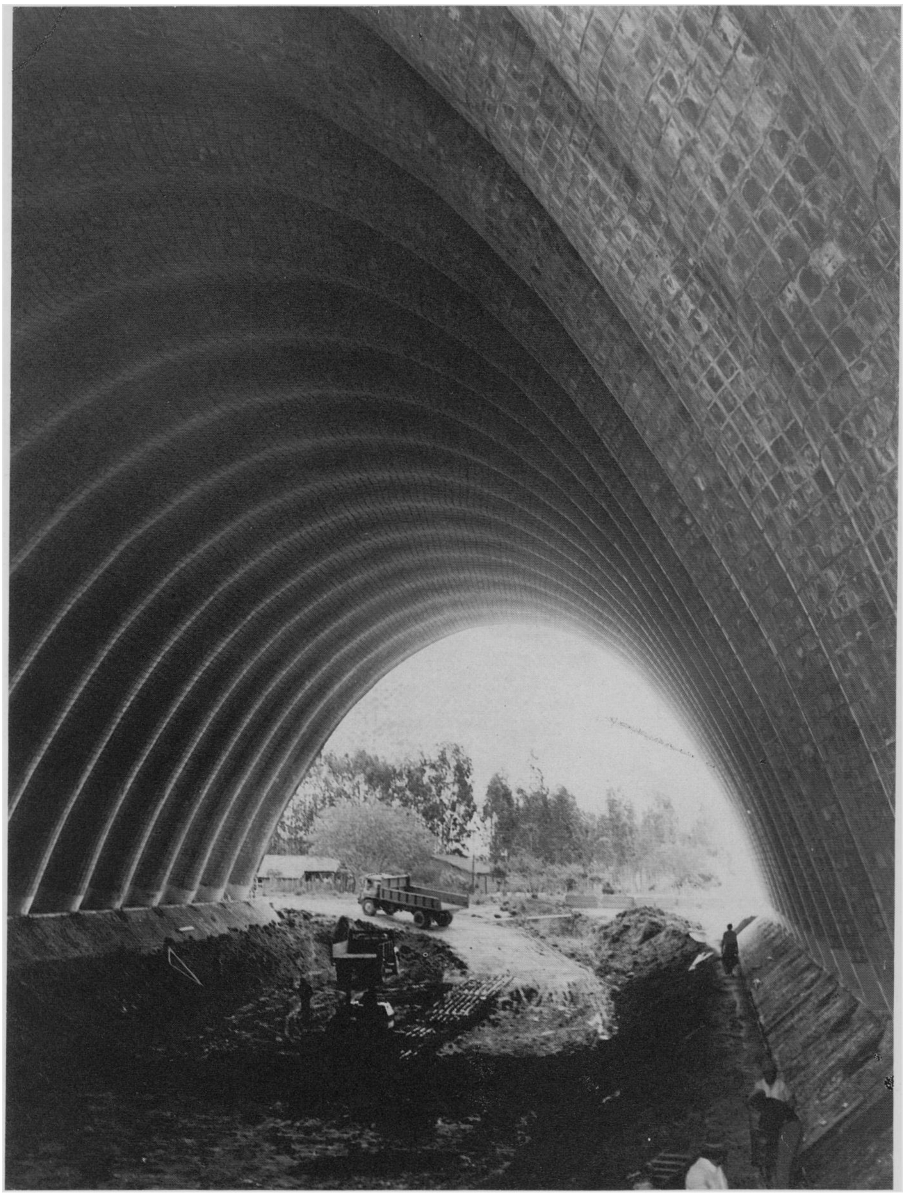
It is well known that the economic imperative can be an obstacle. As soon as an innovative building solution is proposed, the associated cost estimates begin to climb. But we must keep in mind that the only costs that are known with certainty are the costs of what has already been mastered and repeated many times; one must not trust cost estimates to establish the projected economies of a truly new solution. In this case, the most reliable thing to do is to visualize the process of execution and break it down into smaller units, the difficulty and cost of which are clearer. But ultimately, when the proposed methods are very new, it will be only the power of the imagination, the ability to "see" the work through its various stages, that will be our guarantee of viability and efficiency.

9 Horizontal silo, Eladio Dieste, Vergara, Uruguay, 1974, horizontal sections of vault at spring and crown.





10 Horizontal silo, view of interior under construction.

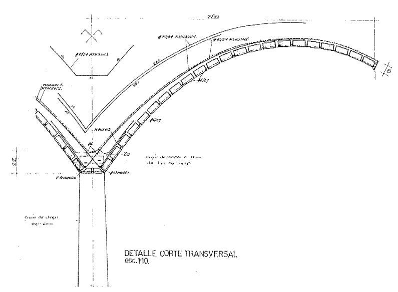


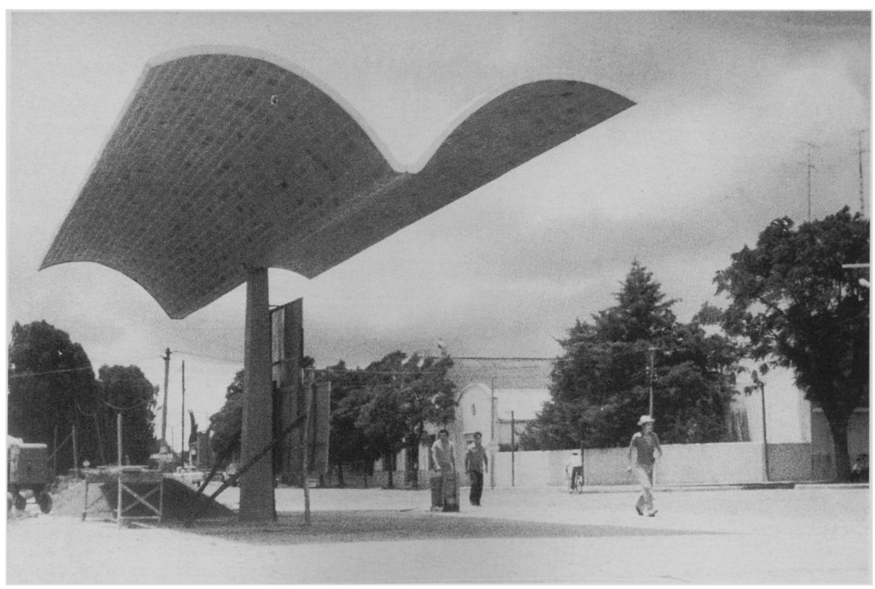
Rationality and Expressiveness

After this first glance at the problems we have posed, it seems natural to return to think them through in the light of something that seems evident to me. In many cases structures have the ability to move us and attract us because they are mysteriously expressive. Our excitement is primarily due to the fact that we perceive these structures not only with our eyes but with our spirit, and they display a more exact adaptation to the laws that control matter in equilibrium. This adjustment is not only rational in the sense that we usually assign to this word. We limit the meaning of this word because we do not have a complete and perfect knowledge of the materials or the methods of calculation that would allow us to determine the stresses in these structures. Giving form to a work, consciously or unconsciously, is like leaping into a void, and we want that jump to be more a flight than a fall. This is why it is more accurate to speak of an art of building than of a science of building. But we must remember that there is no art without science, and that it will take much rational effort to acquire the ability to take that jump.

The need to clarify other primary aspects of architecture seems to have made us forget an elemental thing: architecture is also construction. A work has not been well-conceived unless thought has been given to how it will be constructed. The methods of construction have in themselves extraordinary inspirational and expressive value. Every type of structure is intimately linked to certain building methods, and these methods can be read in the finished product. It is not enough to resolve functional problems and give them spatial form. We must also *build* those spaces so that their expression will be conditioned by the methods and materials that we use to construct them. Spatial conception, form, and materials must constitute a whole; they must be unified in the creative process after having dwelled in the architect's mind. Construction will always be indiscernible from architecture. It is its flesh and bones.

For our architecture to be truly *built* we must understand our materials and their possibilities. It is not enough to use brick because we like its texture or because it is a material full of reminiscences. Because, although these qualities are not worthy of our rejection, the material possesses many more qualities, and the risks of these kinds of reductions are greater today than ever before. Modern technology has apparently given us the possibility of doing anything, and we can use any building material as a stage designer uses cardboard. The economic risks that this practice entails are not immediately visible, but the long-term consequences could be disastrous. Before elaborating upon this I should provide a brief description of the main techniques we have developed.

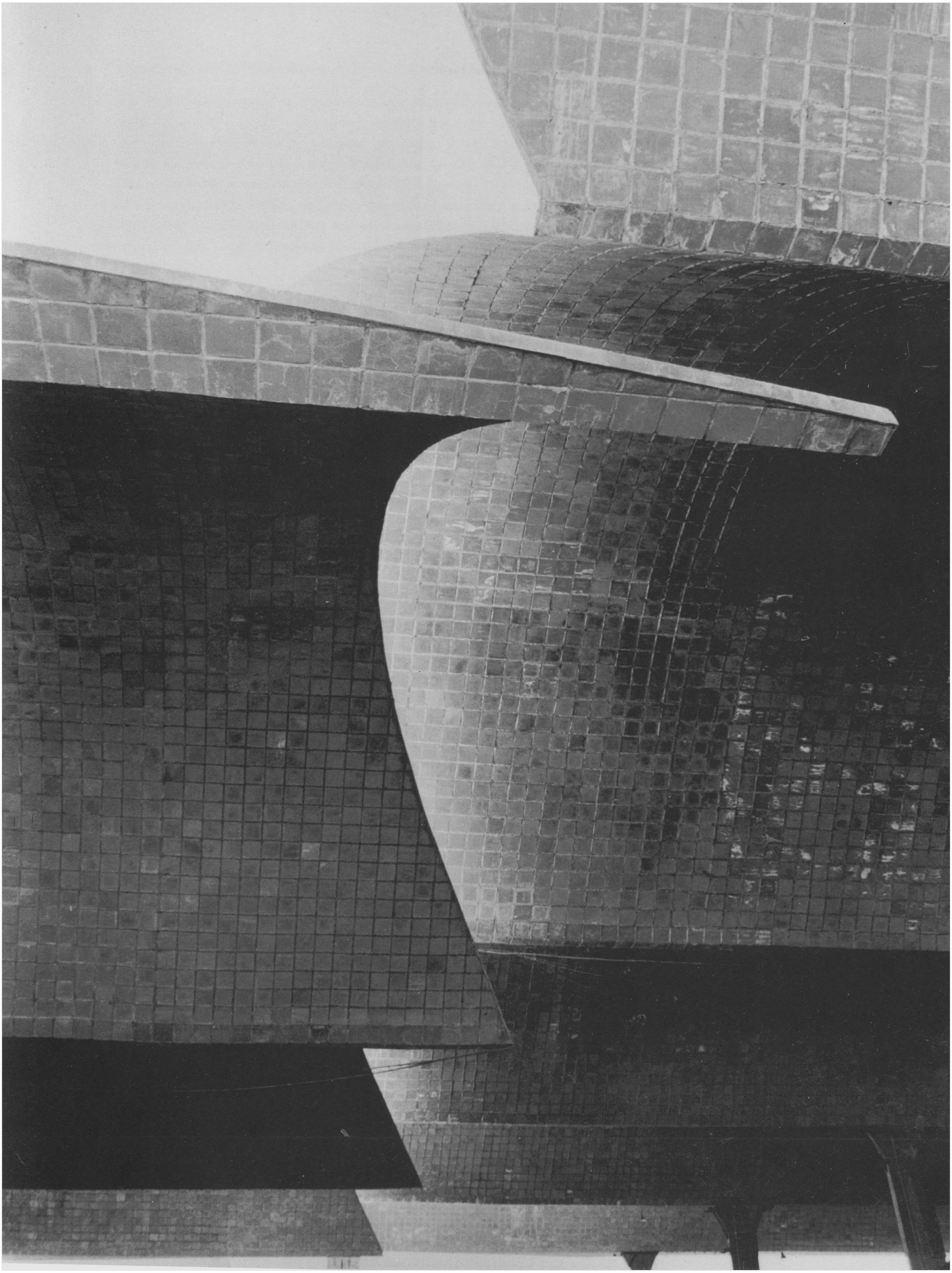




11 Section of a cantilevered shell.

12 Cantilevered shell under construction.

13 Massaro industrial complex, Eladio Dieste, Uruguay, detail of vaulting.



Brick and Ceramic Structures: Double Curvature and Self-Carrying Vaults

It is now more than forty years since my colleagues and I began to build brick structures. As is often the case, the process of using ceramic pieces as filler in cement and plaster was not a clear or rational one. More was intuited than was consciously understood. But little by little we pinned down our intuitions until we were able to master the techniques we use currently. This required us to design and build the necessary equipment to make those techniques economically viable, and to develop methods of calculation derived from the systems we were attempting to conceptualize, even though these models of calculation often forced us to veer from the paths of the structural theories we had been taught.

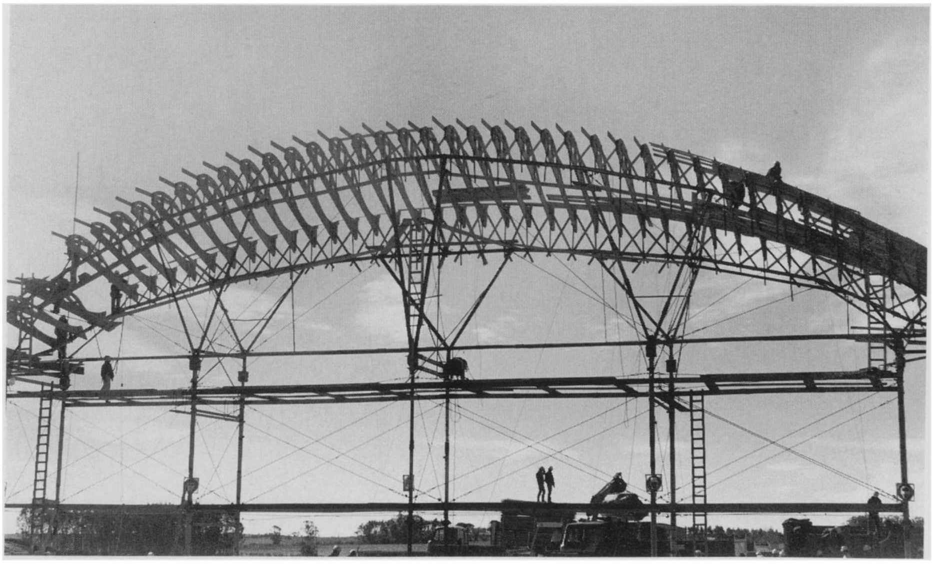
After working on these methods for these decades, we are convinced that we have come upon rational and economical techniques for construction in brick, offering a final product of high esthetic quality. What is less widely known is that brick can resist some stresses better than some of the best concrete, and that concrete and mortar cannot equal baked earth in lightness. We have been able to produce structures that because of their light weight would be impossible in reinforced concrete.

The building methods that I am describing and that can be seen in the accompanying photographs and drawings allow a building speed similar to that of prefabrication, requiring less equipment and a similar workforce. The simplicity of the necessary equipment and the fact that we are using the smallest and oldest of prefabricated elements often leads people to believe that we are employing arts and crafts methods, associated with a vague connotation of underdevelopment and failure to apply what science has put within the reach of technology. This is not true.

Using simple molds with a basic part of steel, and mechanical devices for moving them easily horizontally and vertically, we have produced shells of double curvature to which the variable longitudinal undulations give the necessary rigidity to face flexion and elastic instability. All of the cross sections are catenary curves, and, given its light weight, the shell is under very small stresses. The molds are first lined with hollow ceramic tiles with reinforcing bars placed in the joints between each block, and bonded with a mortar of sand and portland cement. It is finished with a polish coat of mortar and a light reinforcing mesh. When the form is filled with the pieces of ceramic, the joints of which have shrunken, the result is a shell that is hardened in 95 percent of its area. The joints have also acquired a consistency that is greater than that achieved by simply pouring the mortar into a mold, because the bricks remove part of the humidity of the system, producing a sort of "void mortar." Thus, we were able to guess that it is not necessary to wait for the mortar to harden before stripping the vaults of their forms. In having its reinforcing prepared properly, the shell gains the consistency and capacity to resist bending forces of any consequence because of the cohesion provided by the gravity-generated compression. Our experience has confirmed this prediction: we have successfully unmolded vaults of 50-meter spans only fourteen hours after completing them. If well designed, the vaults can resist, even as their forms are stripped, flexions produced by the equivalent of a 200 kph crosswind. The transverse sections of our self-carrying vaults are also catenaries, so that they do not require the heavy tympani of classical self-carrying vaults. Instead, the thrusts are absorbed along the vaults' edges by horizontal tile beams and, where convenient, prestressed cables. This allows us to quickly form and unform a single vault, reusing the "mobile" molds for the next shell.

Through the course of the last four decades it has been our experience that these techniques have proved an economical and rational substitute for prefabricated concrete and steel systems. We have produced large spans with a high building speed and a relatively small workforce. I should probably mention that we have built such works for crudely economic reasons, because they were either cheaper for the client or because for a similar price the only alternative was a far inferior product. Even in the most "artistic" applications, like the churches that we have built, the costs have been absurdly low.

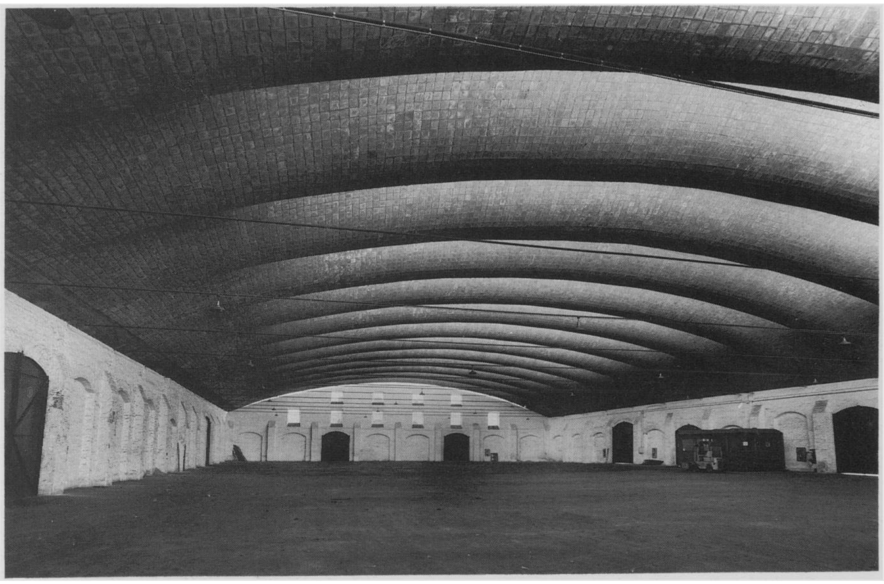
14 and 15 Formwork for vaults.



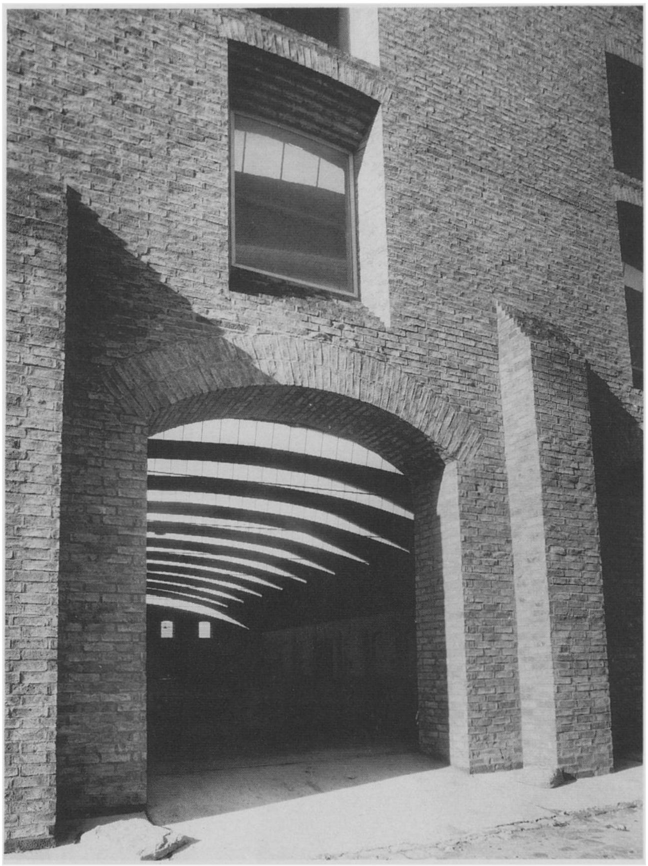
Industrial Society and the Paths of Man

Once I was told that the structures I designed would not be viable in a mechanized society of the future in which everything would be mass-produced by giant industrial complexes. In this light, to study forms that require high skills from the workers and close attention from the technician would betray a sentimental attitude that is opposed to progress. Of course, one would first have to define progress and, therefore, define the goals of a society and of individuals. If we do not clarify these goals we cannot know whether we are progressing toward them. It is very likely that we will have a future civilization in which almost everything will be made by large organizations and the use of the machine will be even more extensive than it is today. But organizations and machines need to be nourished. Someone will have to think through the prototypes and processes. Beyond that, it seems risky to me to assume that the paths of today will be those of the future. The errors of our present civilization are becoming so evident that we might now be on the verge of changes as fundamental as those brought by the Industrial Revolution. The type of person who romanticizes the mechanized civilization of the future tends not to be a doer; his attitude is the product of a somewhat infantile bewilderment in the face of the strength and efficiency of today's most powerful nations.

If the goal of progress is the production of a convivial environment for man, then the results have thus far not been very satisfactory. The industrialized nations of today are those that produced the revolution of the scientific interpretation of reality, and then applied that interpretation to different techniques. The so-called Industrial Revolution has, without a doubt, been very positive in many respects. It has shown man a way to use his own power to transform the world and make it his home. But the inequity of the ensuing processes has produced an imbalance and a resulting destructive furor that has spread throughout the world. To know this inequity, one doesn't need to study history or read Dickens, one only need eyes with which to look around. I worked for a month in a small industrial city in the northeast of France and will never forget the sadness of these so-called modern cities, lines of "economical" stalls that provide the unfortunate many with only animal comfort, and that give no sign of having been constructed with human dignity in mind. The countryside in spring is beautiful, but that sky crossed by tattered clouds, the cherry and lilac blossoms, were nowhere to be found

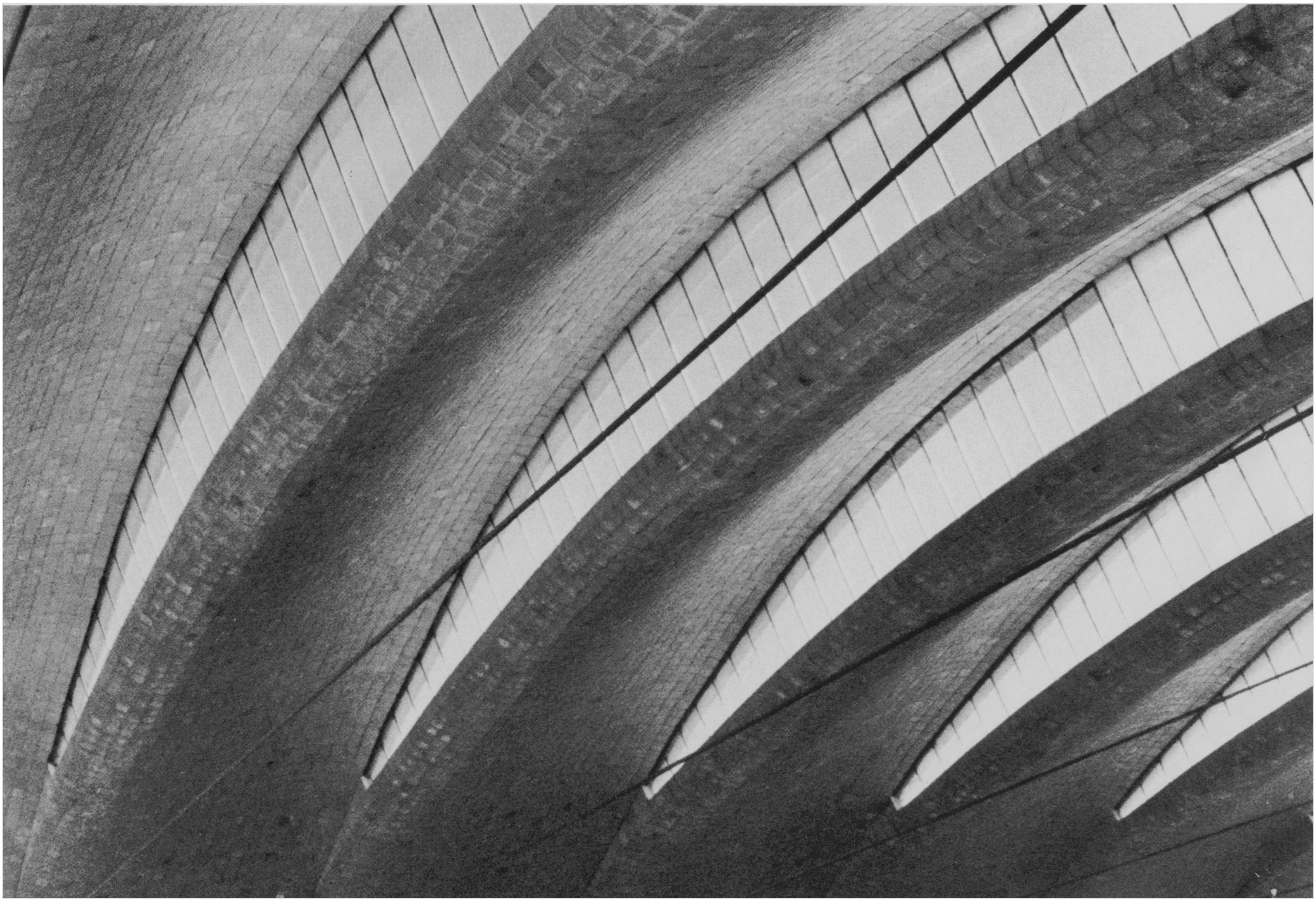


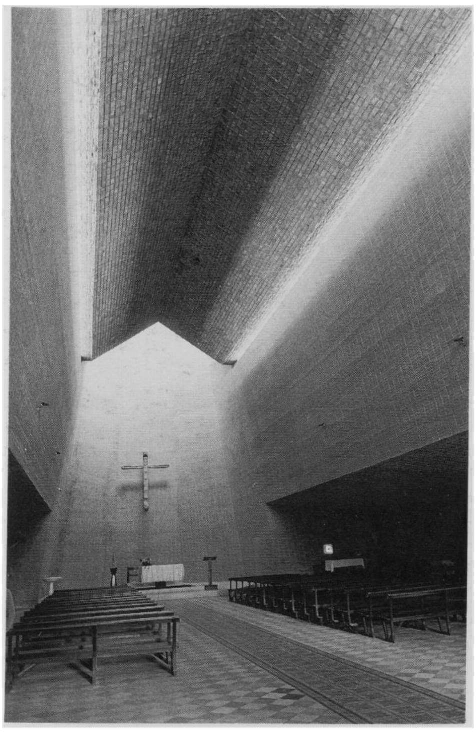
16 Warehouse renovation, Eladio Dieste, Montevideo, Uruguay, original façade with new vaulted ceiling beyond.



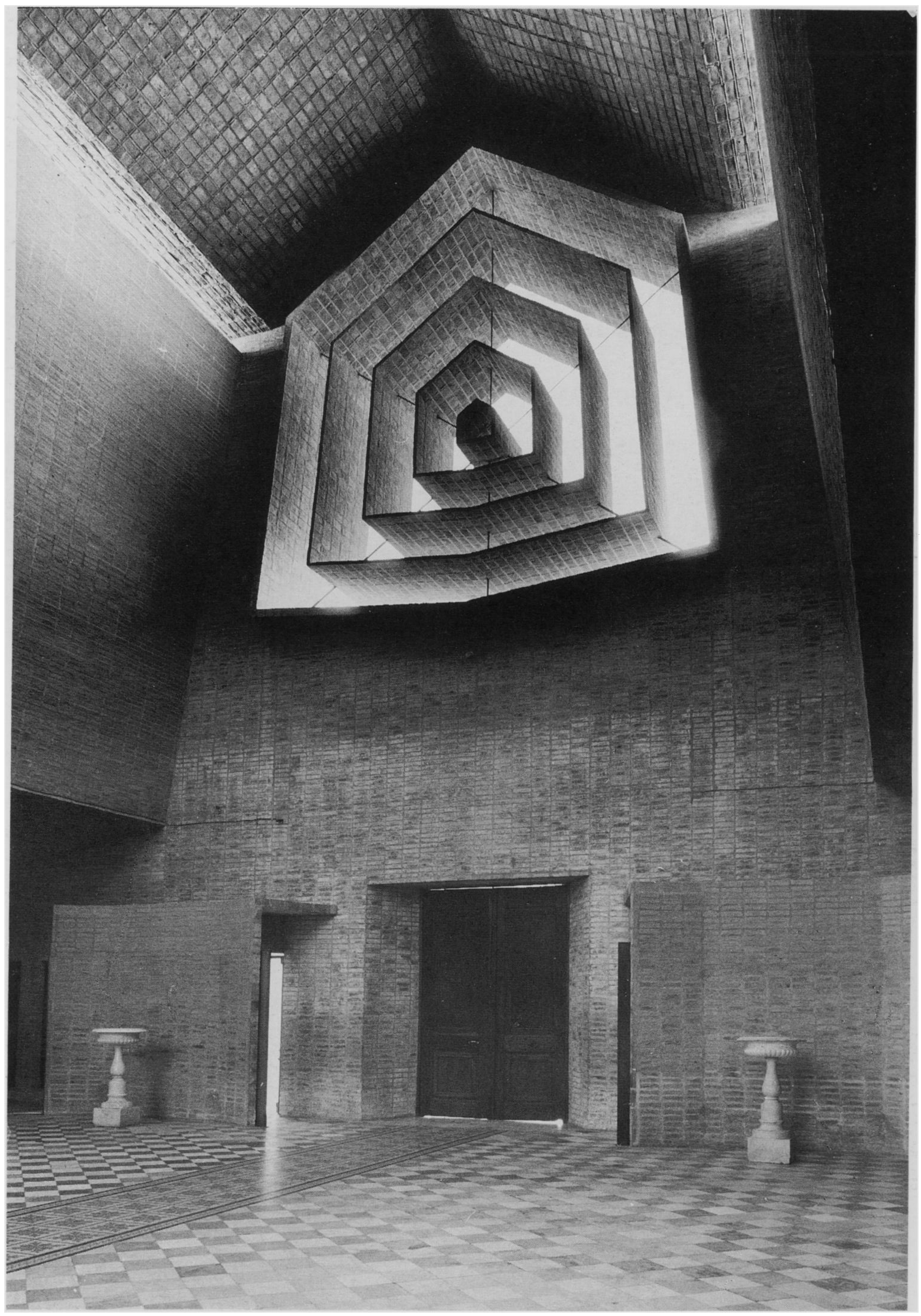
17 Warehouse, interior with new ceiling.

18 Warehouse, detail of clerestory lights.



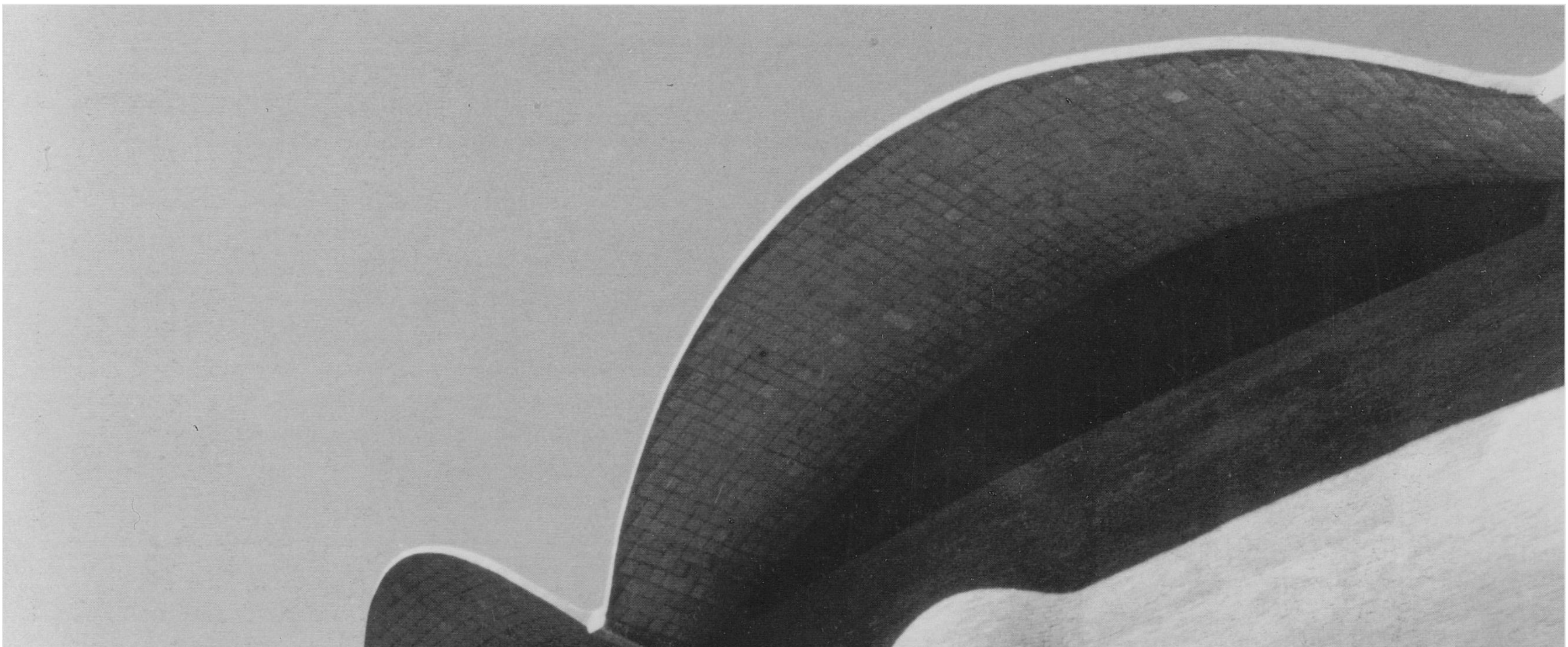


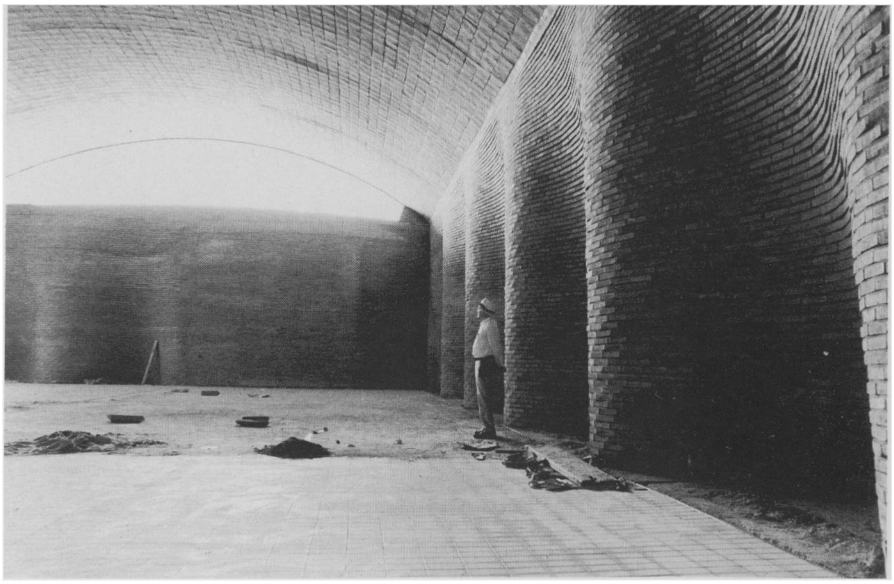
19 Church of Durazno, Eladio Dieste, Durazno, Uruguay, general view of nave.



20 Church of Durazno, detail of rosette window.

21 Market building, Eladio Dieste, Montevideo, Uruguay, exterior wall.





22 Market building, interior.

among the houses of the urban poor. Once I saw from the train the cathedral of Amiens. It hit me with enormous intensity. It seemed like a spider of astronomical proportions, something from another world, a mute but eloquent witness from a world in which man expressed himself in space. Around it, everything else seemed made for ants.

I find few things as depressing as the building boom in Europe. The cities reconstructed after two wars are hideous. They reveal just how much our civilization has forgotten our architecture. The reconstruction was meant not to correct the shortcomings of the previous centuries but simply and brutally to make money. The reconstructed zones are boring, mechanical monstrosities without imagination or grace, produced at a time in which the available technology would have permitted the construction of a city with spatial richness not even dreamed of in the Middle Ages. Those who built the old cities, the builders and also the inhabitants, must have thought of man when they made them. Those who reconstructed the destroyed cities, in the best instances, thought of circulation, building codes, orientation, ventilation, and other admirable abstractions that omitted the essential protagonist of the space: man. The new city is not a city but, rather, a place where cars may circulate with greater ease, where the inhabitants sleep and bathe but still feel uncomfortable because their city lacks anything that relates to their emotions. The result is eye-shattering.

Architecture is perhaps the most important of all arts because it is inescapable; we must live with it. Like all other forms of art, architecture helps us contemplate our infinite and rationally ungraspable universe. But there must be prose *and* poetry, popular dances *and* Bach cantatas. Not all of the architecture that we build must aspire to the role of art. But the buildings in which we attain such lofty goals will have an exemplary virtue in the city. Such architecture is poetry. Not everyone is capable of building it but everyone needs it. And so we now see the economic risks of simplification and reduction. One might very well question the validity of a search for a true and rational expression of the laws of matter in equilibrium. And if asked whether it is not enough to produce simple, "economical" constructions, I would not hesitate to answer, "No, it is not enough." Unnecessary simplification is the work of the financial economy of money and its management. If we want our buildings to have the power of the great architectural inventions of the past, then we must strive for a greater economy than the financial, an economy long forgotten by the practical gentlemen who manage us and squander things of real worth with careless financial speculation.

I recall a brief story that takes place at an aristocratic spa in the north of Norway. The supplies for the spa arrive daily from the south by train. One day the establishment finds itself without its supply of meat. The manager, hearing that a peasant in the area has a calf, attempts to buy it from him. But the peasant explains that he cannot sell the calf because it is not yet ready for slaughter. So the manager offers to pay as if it were. Still the peasant refuses to move from his position, suggesting that the manager return in the spring, at which time he can buy the calf at a fair price. "It would be different," the peasant concludes the discussion by saying, "if you had nothing else to eat."

The clash of these two disparate views, that of the apparently practical and that of the deeply practical, provide the moral reasons for our work. The resistant virtues of the structures we seek depend on their form; it is through the structures' form that they are stable, not because of an awkward accumulation of material. There is nothing more noble and elegant from an intellectual viewpoint than this: to resist through form.

23 Market building, exterior wall.