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Affonso Eduardo Reidy and the Aterro Do Flamengo Pavilions. Structural Concrete Shells During Modern Revisionism

Sergio Garcia-Gasco Lominchar // Universitat Politècnica de Valencia

Abstract

This article focuses on the research of the last three works built by Affonso Eduardo Reidy, designed in 1962 for the urban project of Aterro do Flamengo, in Rio de Janeiro.

The conception of the Coreto and the Morro da Viuva and Flamengo Pavilions is based in the logic of concrete shells and folded plates. This structural system, despite being used since the end of the XIXth century by engineers, was ignored by Modern Architects until the second half of XXth century. The reason for that can probably be found in its formal and expressive connotations, and their assimilation in the Modern Movement occurred only after some conceptual changes produced within the revisionist context of the 50s and 60s. While the combination of forms can be infinite, most of the architects intended to optimize the structure in terms of material saving, logical construction or easier calculation. In order to do so, they studied natural shapes to find the most efficient variables.

Through these three modest buildings designed by Reidy, this article will try to analyze not only the key points of this assimilation, but also the intrinsic qualities of the structural system, based on the variations and the flexibility of the same geometric principle.

Keywords

concrete shells; folded plates; structural system; Reidy

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1. The ambivalent nature of concrete shells and folded plates: structure and envelope.

The music stand (also called "Coreto") and the two pavilions built for the Aterro do Flamengo Park by Affonso Eduardo Reidy, in Rio de Janeiro, are three small buildings that remain imperceptible within the architect's rich architectural legacy. However, its chronological position at the end of his professional career makes them specially interesting. Not only for synthesizing some important features of Reidy´s work, but also for showing new strategies that, even appearing in previous works, can be better seen in these three buildings. Reidy's premature death in 1964 didn´t allow the possibility of continuing this research, remaining halted in the pavilions.

The construction of geometric concrete forms to increase the structural stability is a common strategy used in all three works. Their shapes are defined by the principles of this system, resulting in a prominent variety of solutions. Even though they belong to the same structural family, the differences are also remarkable: continuous folds of concrete plates define the Coreto and the Morro da Viuva Pavilion. However, while the Coreto (fig. 1) shows a delicate and open composition, based on an umbrella structural typology, the external appearance of Morro da Viuva Pavilion (fig. 2) is circular and hermetic, an abstract volume based on the radial deformation of the same folded unit. The Flamengo Pavilion Playground (fig. 3) can be considered a different variation of the system: geometries are based in curves and not in folds. Specifically, all components are curved in just one direction. In addition, the building is composed by different units resting one on each other and not as a continuous concrete element.

Figure 1.
Coreto Music Stand

Figure 2.
Morro da Viuva Playground Pavilion

The complex geometry of the pavilions reveals Reidy's intention to experiment with different solutions and reach a variety of architectural forms. This strategy is also related with other concepts that were highly valued by Reidy, like economy, prefabrication and structural expressivity. However, comparing to the structural concept, other parameters look secondary or not considered. This fact can be easily seen in several inconsistencies in the architectural solution in relation with the program required.

The mushroom typology is a well-known approach in 1962 and a widespread typology used by Modern architects. It normally works by addition, as a combination of several units to compose a bigger structure. This propriety to be combined, applied in most of the projects composed by umbrellas, contrasts with an isolated unit in the Aterro Park. This fact, together with the ambiguous resolution of the program, highlights somehow the intention of the architect to experiment with a structural prototype, rather than designing a correct music stand: the central column remove

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visibility and make difficult the distribution of the band components. The roof, with four segments oriented to four opposite sides, doesn´t seem to be the best solution for an acoustic shell. At the same time, from a structural point of view, the use of folded plates shows a variation that totally differs from other similar structures. Candela´s hypars, probably the most known mushrooms, are based in the membrane theory: the roof works as a thin and continues surface with no hierarchies. Comparing to Candela, Baronni´s umbrellas are based in linear structural ribs to support the roof. From this point of view, the Coreto's approach is closer to an umbrella, with the particularity of implementing the triangular folded logic to establish the structural hierarchy.

The Morro da Viuva pavilion is also based in triangular folded elements, but the logic of the structure is comparable with a dome. The regular external appearance doesn´t show the extreme deformation of each segment in the roof. The reason for that is the oval shape of the top compressive ring. Starting with the same shape in the perimeter, each segment deforms differently to adapt to the geometry of the ring, getting a wide range of variations from a single element. The opaque configuration of the folded shell creates a difficult relation with the environment and makes again wondering if this was the best structural strategy to solve the required playground program.

Figure 3.
Flamengo Playground Pavilion

Even having exactly the same program as Morro da Viuva, the Flamengo Pavilion seems to be the opposite: an open and centrifugal configuration, visually connected with the Park. The structure, based on a beam mounted on two supports is composed by prefab elements that work as almost independent units in a perfect balance. The fact of being fragmented instead of continuous surfaces, reveals the intrinsic variability and the open results provided by the combination of the same ele-

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ments. As the concept of repetition of the umbrellas, this feature is related with other movements appearing in the 60´s against Rationalism. The dynamism and flexibility of Structuralism, based on combinations of the same elements that may compound different results, emphasize the importance of the relation between components. This quality draws the attention to the roof of the Pavilion, showing the archetypical vaults of Modernity upside down, an intentional manifest that changes dramatically the perception of the building and put forward the fact that these elements are not vaults anymore, but beams.

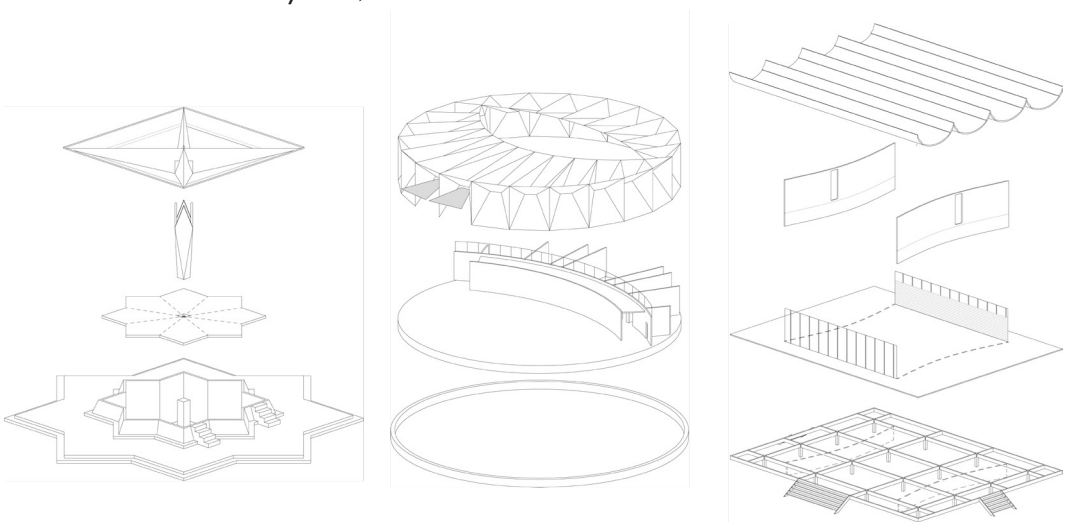

Figure 4.
Axonometric view of the pavilions.

The construction of self-supporting concrete shells has been used in architecture since its origins[1]. Shapes were defined by their structural behavior and the properties of opus caementicium (assuming mainly compressive stresses). These limitations would be solved after the technological development of reinforced concrete in the 20th century, making it possible to obtain other types of shapes with more complex geometries due to the combination of steel and concrete, and thus being able to withstand compressive axial forces combined with meaningful bending moments with thinner cross-sections.

1 Mass concrete domes, vaults, arches or slurry walls already used these principles in Roman times. The Pantheon in Rome, built around 125 A.D., is the biggest non-reinforced concrete dome in history (Croci 2006).

The studies of biological theories around the idea of form and natural evolution in 19th century established the necessary links to influence the structural studies and calculation methods in 20th century. Carmen Jordá (2015) highlights D'Arcy Thompson, and the book On growth and form, as one of the most important texts. The author established consistent rules for biological forms and relations between mathematics and nature, defending the variability of the same shapes in all biological forms based on the same logarithmical spiral.

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These principles, applied to the structural behavior of concrete shell elements, became an infinite source of variations. Even so, the most common forms due to the easier calculation and construction process are grouped in two: folded forms, based on flat surfaces, or curved forms based on ruled surfaces (fig. 4). Among curved forms, Gaussian surfaces, due to its simplicity and geometric logic represent the majority of the forms developed: domes, cones, hyperboloids and hyperbolic paraboloids. Most engineers also applied the principles of catenary on these surfaces, meaning that the form responds mainly to axial stresses (membrane theory), achieving a combination of simplicity of both calculation and construction process. Folded plates work as a combination of different flat concrete surfaces that becomes a bigger element, taking advantage of the spatiality of the form and differing from curved shells in the fact that they don´t benefit from the curvature properties and the membrane behavior, resulting in a more complex calculation.

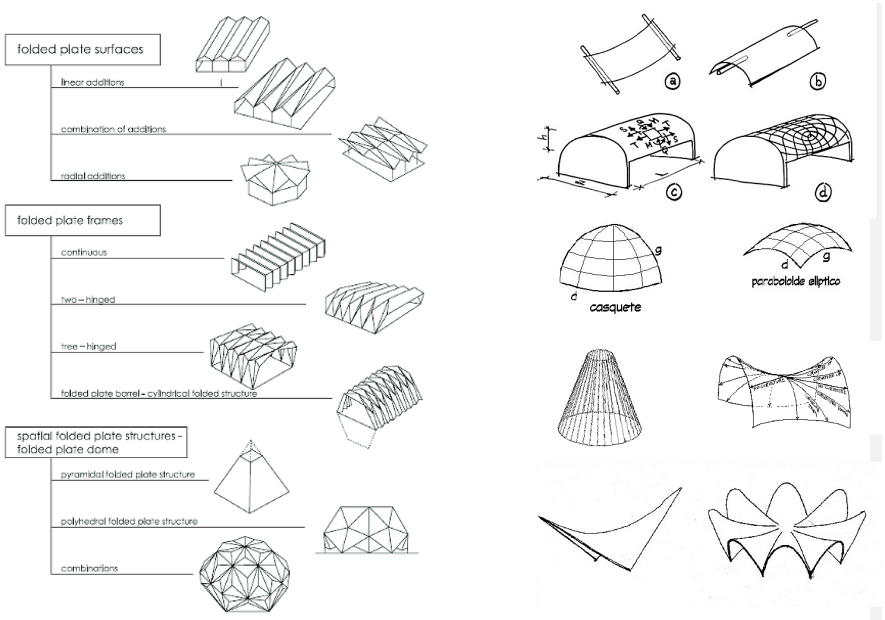

Figure 5.
Examples of reinforced concrete shells classified in folded forms and curved forms

The 1930s mark the beginning of the most remarkable concrete shells structures, establishing their acme between the 50s and 70s (García 2013). Mainly used for infrastructures, engineers like Eugène Freyssinet, Pier Luigi Nervi or Eduardo Torroja, among many others, designed all kind of buildings based on the geometric form as the principle of the structural optimization. Most of the works were public, in many cases covering large areas for specific programs. To do so, they developed calculation methods which made possible big spans using shells that may have a thickness of just 5 cm. Freyssinet's hangars in Orly in 1923 (fig. 6), Torroja´s Fronton of Recoletos in 1935 (fig. 7), Candela´s structural hyperbolic paraboloids (fig. 8) or the UNESCO Auditorium (fig. 9) by Pier Luigi Nervi between 1953 and 1958, are revolutionary structures built with this technology which covered huge areas with reduced material.

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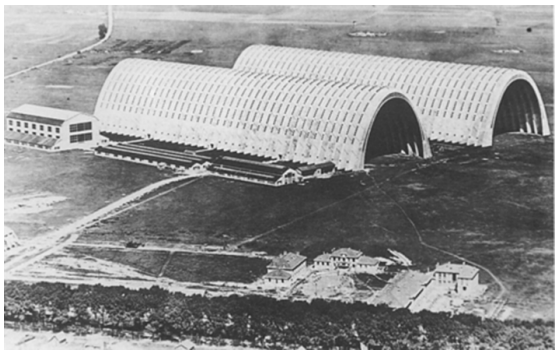

Figure 6.
Hangars in Orly by Eugéne Freyssinet

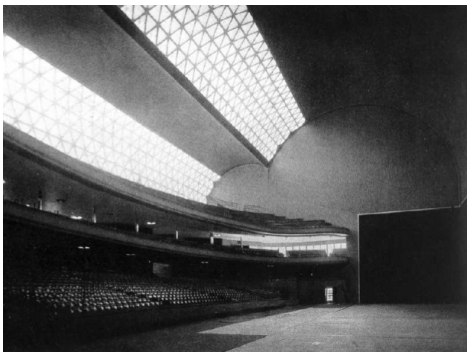

Figure 7.
Fronton of Recoletos by Eduardo Torroja

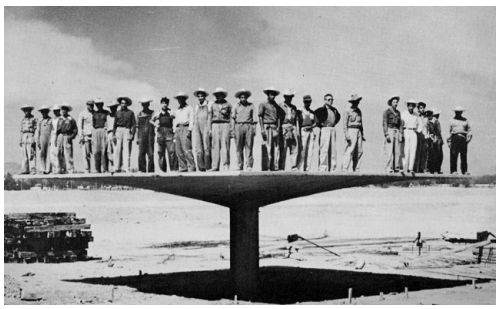

Figure 8.
Hyperbolic paraboloid by Felix Candela

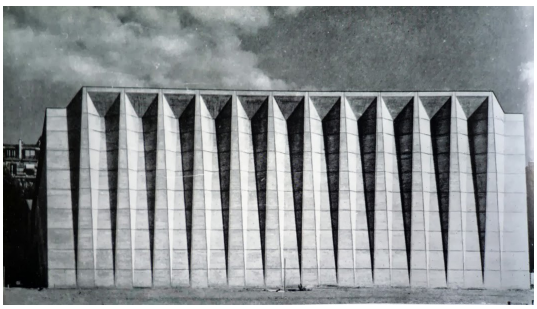

Figure 9.
UNESCO Auditorium by Pier Luigi Nervi

In an international context, in 1962 -year of the Aterro´s construction- the use of folded or curved elements was widespread. Therefore, Aterro Pavilions are not rare and isolated components in their context, but the consequence of contemporary and globalized approaches to new architecture strategies. In Brazil, concrete shells like vaults were common and used as structural element among many of Modern Architects since the 30s. Actually, Reidy projected several vaulted slabs in previous projects. However, all of them were configured only as roof elements, or just as complementary elements within a larger volumetric composition. Somehow, the potential of the system remained still unexplored until the Aterro Pavilions.

Probably, within all parameters that defined Reidy's architectural approach, the building techniques are the ones he put more emphasis on, as they allowed him to explore the potential of the structural form and its expressivity in the volumetric composition.

As Roberto Conduru abridges:

> In summary, Reidy's architecture is a research of the dialectic between the load bearing element and the building enclosure in their formal configuration. Starting from pure volumes in which the structure is embedded in the enclosure, the architect first differentiated the structural elements, then broke with the volumetric purity, after this brought the structural elements to the perimeter of the volumes and, finally, he returned to pure volumes, although preserving the distinction between structural components and enclosure. (Conduru, 2005).

In his last three works, this relationship seems to reach its limit, achieving a more extreme stage. In the Aterro there is a total fusion between volume and structure in a single element, so there is no distinction between structure and envelope. In addition, Reidy seems to bring to a more advanced stage different aspects previously experienced in other projects: the structure gets more sophisticated and complex than other concrete shells in the past. Also, there is a clear interest in optimizing the structural resources, designing elements as slender and thin as possible, in some cases 4 cm

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thick. Finally, even if Reidy used exposed concrete in the past, this time it is used as a global material, solving not only structure, but floor, walls and roof. Reidy took the role of the structure to the limit, conditioning the whole compositional and expressive aspects (Conduru 2005).

2. Conceptualization of the structure as an autonomous component. A necessary step for concrete shells

Which are the intrinsic peculiarities of concrete shells structures?

Generally speaking, there are three features that define them versus other structural systems:

- Structure and envelope as the same element,
- Formal expressivity generated by the combination of geometric forms.
- In case of concrete being exposed, the structure also defines the expressivity of the architectural surface.

The use of self-structural concrete shells and folded plates is strongly related with the idea of the structure becoming the generator of the architectural form, acquiring its expressivity through the logic of the structural geometry. Concrete shells changed the Modern paradigm of form when the architects leave the result of the architectural volume to this principle, loosening its control or putting in a second place other variables for the sake of structural optimization. This new parameter, shielded on scientific principles, let Modern Architects to break free with the static International Style standards in order to introduce, for the first time, a formal variable not controlled by composition.

Putting aside the concrete vaults previously named, during the first stage of Modern Movement it was unconceivable, except in rare circumstances, the use of such expressive elements. This fact highlights an obvious aspect to understand the way concrete shells were introduced: their conceptualization can only become part of Modernity after some changes that validate the intrinsic qualities of the system. The narrative, experiences, and contexts that let this particular type of structure to be validated are not simple and would need a different article. It is even based on certain aspects that in many cases would be contradictory with the International Style, needing a gradual process of assimilation.

As Iñaki Ábalos explains:

> Despite the radicalism in the postulates of Modern Movement and the abstraction of its architecture in relation to the context, there are formulations that could not be correctly stated by their contradiction with the bases of the movement. Some of the most representative architects, such as Le Corbusier, Bruno Taut or Mies Van der Rohe, among others, established links between the picturesque aesthetics and Modern ideology that escaped from the postulates that they established (2005, p.115).

Ábalos unmasks the "picturesque" elements in Le Corbusier's work. The author explains how, while many of them were "latent" from his early theoretical postulates, gradually and "almost secretly" they took over his way of designing to conquer all the scales of architecture in its final stage. Among

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the most representative elements of the picturesque elements are three major questions that would be characteristic of Le Corbusier's latest work: the importance of the context, or *Genius Locci,* the *Promenade Architectural* and the use of exposed concrete. Moreover, Ábalos shows two different stages in the architect's postulates: a first, positivist stage, with a total fulfillment in the social and technological development on the basis of a scientific nature, against a late stage, after World War II, where nature becomes related with subjective perceptions. Le Corbusier would free himself from the rationality of his first stage and evolve to a period characterized by a sensitivity towards to scale, monumentality, architectural perception, structural expression and materiality. This transformation, established in these two stages, helps to understand how concrete shells could eventually be assimilated at the end of Modernism.

Even if Le Corbusier's work is not representative of concrete shells architecture (he developed several of them, but they are more related with formal and expressive shapes than efficient structural elements), changes introduced in his architecture helped indirectly to the assimilation this alternative way of projecting. Le Corbusier personal relation with A. E. Reidy and the influence in Reidy´s works can help to establish a parallelism between changes that Le Corbusier's architecture produced into Modern architectural and the way these changes ended in the Pavilion's concept. In a strategic and simplified way, we can highlight in Le Corbusier's works the steps that allow the assimilation of expressionist parameters compatible with concrete shells.

3. First condition: the structure as an external formal element.

With the conceptualization of the Dom-Ino System (1914-17) the Swiss architect synthesizes an architectural approach strongly discussed during the XIXth century, setting a new relation between the two main elements of architecture: the structure and the building's enclosure. This new concept established the mechanism for the structural rationalization as an independent element.

> One of the greatest achievements of the modern construction technique is the free structure, that means, independent of the walls of the building. The free structure allows the standardization of structural elements and flexibility in terms of the use of spaces, so that in any time its internal divisions can be modified without prejudice to the good conditions of stability and appearance of the building (Reidy 1935).

Once conceptualized, the enclosure-structure disaggregation initiated with the Dom-Ino System will give way to a more important role of the structure as a generator of the architectural form, mainly in those projects where the program needed open spaces and bigger spans.

The turning point in this evolution is the Soviets Palace in 1931 (fig. 10). This project was composed of two large auditoriums that required a structural resolution never done before. Given the size of the structure and the impossibility of keeping the beams inside, they are moved outside to avoid internal constrains. The result is a set of volumes composed by radial structures with a strong expressivity, becoming the first significant exoskeleton projected by the Swiss architect.

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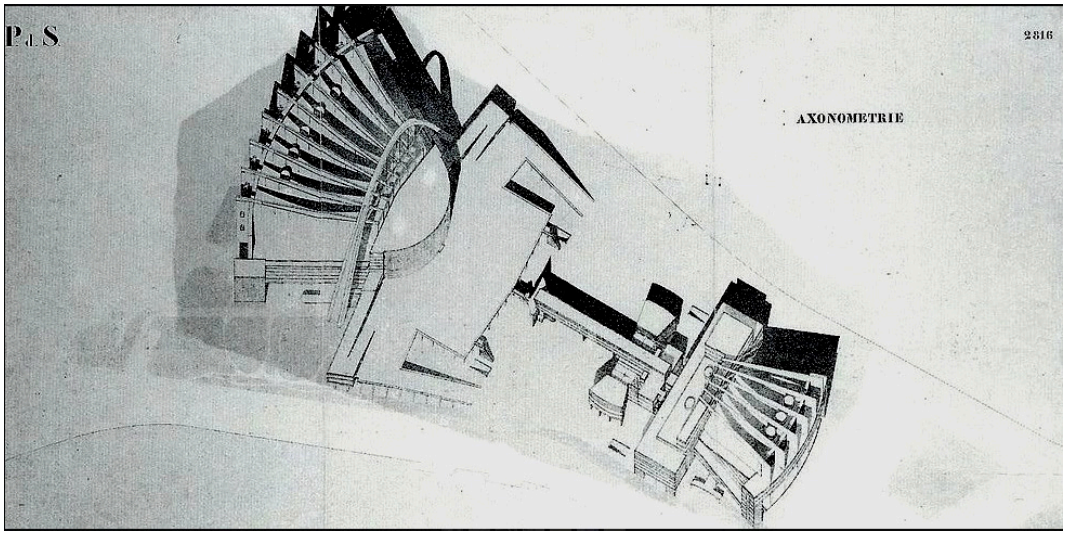

Figure 10.
Axonometric view of the Soviet Palace by Le Corbusier

As Julio Collares highlights:

> This primitive exoskeleton demonstrates the implicit potential of the transparency contained in these structures that collaborate in the porosity of the composition. In this way, a vocabulary of great significance is added in the Modern semantics (2003, p.51).

In the project developed for the University of Brazil in 1936 (fig. 11), Le Corbusier strengthens the structural strategy adopted in Moscow. This building leaves an important lesson among the members of the Brazilian team, composed of Lucio Costa, A.E.Redy, Oscar Niemeyer, F. Saldanha, J. M. Moreira, A. Bruhns and P. R. Fragoso.

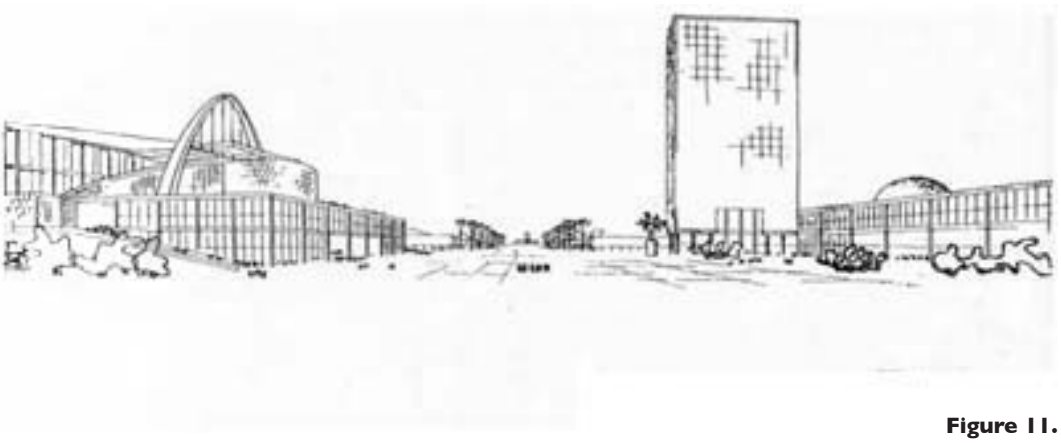

Figure 11.
University of Brazil view

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> The Auditorium with its acoustic ceiling suspended in the exposed structure, expressive, almost dramatic as the old cathedrals (Costa 1995, p.183).

This exchange, really significant in Brazilian modernity, establishes the germ of the semantic tools that will be used in large part of modern Brazilian projects.

> The new technique demands the revision of traditional formal values. What characterizes and, in a way, directs the radical transformation of all the old construction processes is the independent skeleton (Costa 1995, p.112).

As an inaugural milestone, the church of San Francisco de Asís in Pampulha, built from 1941 to 1943 by Niemeyer (fig.12), opens an architectural stage for the Brazilian architecture. It is the first project developed as a concrete shell. Another simultaneous project, the Municipal Theater of Belo Horizonte in 1941, also by Niemeyer (fig. 13), already establishes a totally exposed structural language, with constructive approaches of clear correspondence with the auditorium of Le Corbusier. However, in terms of not built projects, Reidy anticipates Niemeyer when he plans his first exoskeleton and concrete shell building in 1939, the Headquarters of the General Department of Transportation and offices of Rio de Janeiro (fig. 14), where he uses vaulted structural roofs for the office body, while projects external concrete frames to hold the garage roof.

The exoskeleton buildings, where the concrete shells are integrated, will lay down the guidelines of the tectonic tendency of Brazilian Modernity after these projects.

Figure 12.
Church of San Francisco de Asís in Pampulha by Oscar Niemeyer

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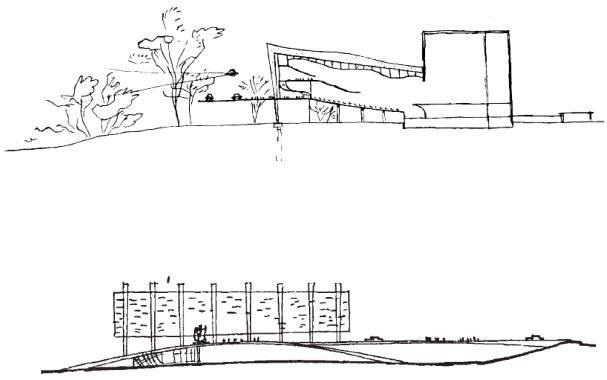

Figure 13.
Drawings of the Municipal Theater of Belo Department of Horizonte by Oscar Niemeyer

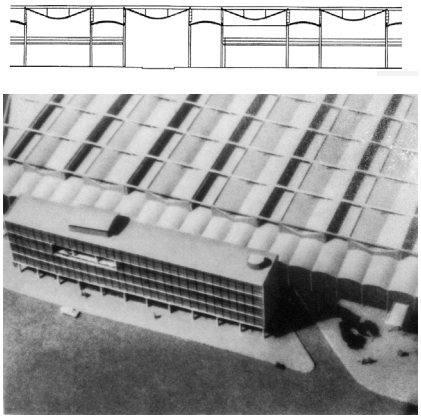

Figure 13.
Headquarters of the General ransportation and offices in Rio de Janeiro by Reidy

4. Second condition: exposed concrete as matter for expressivity

The expressivity of concrete as exposed material will come through the influence of another project by Le Corbusier: the Unité d´Habitation (1947) in Marseille. Although Le Corbusier doesn´t have all the merit for the general use of exposed concrete in modern buildings, it can be said that at least he was its major disseminator, as a consequence of his influence throughout Modern Movement.

In an interview in 1962, Le Corbusier recognizes the personal way of using exposed concrete in the Unité and its subsequent works: "I take advantage of these resources (of concrete), why not? I have fun, it interests me" (Charensol, Mallet cited in Sbriglio 2013). The expression "I have fun, it interests me" reflects the subjective nature of exposed concrete in Le Corbusier's work. It reveals a sensibility that approaches the artistic side of the architect. The expressiveness of his concrete wants to transmit sensations that have nothing to do with its structural function. Therefore, his main motivation would be the exploration of the material as an artistic element, providing the building with a new plastic component previously limited by its own postulates. With the Unité, Le Corbusier definitely leaves the positivist parameters, moving away from the lightness and abstraction of his previous stage to focus in the expressivity of the structural components (Frampton 1985).

> The crucial innovation of the Unité was not the heroic state, nor in its originalities in sectional organization, nor its sociological pretensions. It was, more than anything else, the fact that Le Corbusier abandoned the pre-war fiction stating that reinforced concrete was the precise "machine-age" material (Banham 1967, p.16).

The impact caused by the Unité among modern Brazilian architects is evidenced, again, in the words of their intellectual leader, Lucio Costa:

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> That was an impact. I was unarmed, I didn´t know what to say. We were thinking and demanding to the engineers to reduce the diameter of the columns and suddenly these huge piloti came with all that mass [...] When they were making the Jaoul houses [...] I was shocked, I said it was absurd, using concrete as mass, a prehistoric thing, such a primitive way, when in reality reinforced concrete subtends an intellectual speculation, taking advantage of the structure, the possibilities of the structure, the economy, and never using concrete as mass [...] We weren't prepared for that […] (1995, p.150).

5. Conclusion

Concrete shells and folded plates constitute a way of understanding architecture based on the observation of geometric and natural shapes. The variability of the system shows a strong flexibility and provides with infinite possible solutions. However, only some of the variations can be considered the most efficient under parameters of structural optimization, material waste or construction strategy. These combinations can only be defined through mathematical relations linking architectural form with biological structural behaviours. This new method gave the tools to Modern Architects to explore new architectural solutions, breaking the standards of International Style.

The path defined from the understanding of the structure as an internal element to its total prominence out of the building's enclosure was a necessary intellectual process for the proliferation of concrete shells and folded plates. Through this process Modern Architects assimilated the formal possibilities of the structure, first moving it to the exterior, then exploiting its expressivity through the study of different variations on the same principle. Concrete shells and folded plates, perhaps the last of the structural tools used by the Modern Architects, are also those which allow going further in the strategy of joining structure and enclosure, being at the same time the best expression of concrete qualities as a continuous, superficial, structural element.

The last three works of Affonso Eduardo Reidy constitute a meaningful shift in the role that structure had played in previous projects. In the Aterro´s Pavilions the structure became the building itself. The result is a variety of solutions highly efficient in terms of structural behavior, but shows a lack of balance between structure and other architectural parameters that highlights the fact of being projected as prototypes where Reidy had the opportunity to implement different thoughts on variability and flexibility of the structural system.

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Figures 1, 2, and 3: Coreto, Morro da Viuva and Flamengo Pavilions. Author´s pictures

Figure 4: Axonometric views of the pavilions. Author´s document

Figure 5. Examples of reinforced concrete shells classified in folded forms and curved forms; ENGEL, H., 1970, Sistemas de Estructuras., Blume, Madrid.

Figure 6. Hangars in Orly by Eugéne Freyssinet ; SAINT, A., 1991, Some thoughts about the architectural use of concrete. Architectural Association School of Architecture. AA Files, No. 22. pp 3-16.

Figure 7 and 8; Fronton of Recoletos by Eduardo Torroja and Hyperbolic paraboloid by Felix Candela ; CASINELLO, P; SCHLAICH, M; TORROJA, J.A., 2010, "Félix Candela. En memoria (1910-1997). Del cascarón de hormigón a las estructuras ligeras del s. XXI", Informes de la Construcción, Editorial CSIC, Vol. 62. 519, 5-26,

Figure 9. UNESCO Auditorium by Pier Luigi Nervi, Acropole Journal N° 189

Figure 10: Axonometric view of the Soviet Palace by Le Corbusier, Fundation Le Corbusier: http://fondationlecorbusier.fr/

Figure 11: University of Brazil view ; BONDUKI, N (ed), 2000. Affonso Eduardo Reidy. Ed Blau / Instituto Lina Bo Bardi.

Figure 12: Church of San Francisco de Asís in Pampulha by Oscar Niemeyer. Author's picture

Figure 13: Drawings of the Municipal Theater of Belo Horizonte. Oscar Niemeyer. COLLARES, J., 2003. Exoesqueletos no Modernismo Brasileiro nas décadas de 40 e 50, Universidade General do Rio Grande do Sul, Porto Alegre.

Figure 14: Headquarters of the General Department of Trasportation and offices in Rio de Janeiro: BONDUKI, N (ed), 2000. Affonso Eduardo Reidy. Ed Blau / Instituto Lina Bo Bardi.