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Architecture and structure: reading and dissection of the Oca building at Ibirapuera Park

Abstract

This article establishes associations between the structure and the architecture designs of the Oca building, through graphic sources surveys unknown until the investigation beginning. The research started from a survey on some structures designed by the engineer José Carlos de Figueiredo Ferraz (1918-1994), whose part of the collection was destroyed by fire. Many of his significant structural design works are known, as the buildings MASP, FAUUSP USP's Faculty of History and Geography, and SESC Pompéia. The Oca building, designed in the early 1950s by Oscar Niemeyer and his team, with structural calculations done by engineer José Carlos de Figueiredo Ferraz, the shell of the building was the first designed by the architect and became a widely used in his later works. This research rescued part of the design drawings, which made it possible to relate architecture and structure. The method used several parallel and hybrid phases: a search for iconographic material and documents in public and private archives, which represent a dissection of the structure of this case study. The text is constructed by an introduction about the Oca Project in Ibirapuera Park, its development, observations about its possible etymologies, its form and relations with the structure. The results shown reveal the advances in the Brazilian architecture and engineering manifested in the 1950s.

Keywords

Architectural design. Structural design. Oscar Niemeyer. José Carlos Figueiredo Ferraz. Oca Ibirapuera.

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ARQUITETURA E ESTRUTURA: LEITURA E DISSECAÇÃO DO EDIFÍCIO DA OCA DO PARQUE IBIRAPUERA

Resumo

Com o objetivo de estabelecer relações entre o projeto de arquitetura e estrutura, este artigo revela uma investigação sobre o edifício da Oca, a partir de levantamentos de fontes gráficas até o início da investigação desconhecida. O trabalho se iniciou a partir de uma pesquisa sobre algumas estruturas projetadas pelo engenheiro José Carlos de Figueiredo Ferraz (1918-1994), cuja parte do acervo foi destruída devido a um incêndio. Muitos de seus trabalhos significativos de projeto de estrutura são conhecidos, como os edifícios MASP, FAUUSP, Faculdade de História e Geografia, ambas da USP, SESC Pompéia. A OCA, projetada por Oscar Niemeyer e equipe com o cálculo estrutural do Engenheiro José Carlos de Figueiredo Ferraz, no início dos anos 1950, foi a primeira das calotas construída nas obras do arquiteto e tornou-se muito utilizada em trabalhos posteriores. A pesquisa resgatou parte dos desenhos de projeto, o que tornou possível uma leitura das relações entre arquitetura e estrutura. O método empregou várias etapas paralelas e híbridas, envolvendo: busca de material iconográfico e documentos em arquivos e análises e redesenhos que expõem uma dissecação da estrutura do objeto de estudo. O texto se constrói por uma introdução sobre o Projeto da Oca no Parque Ibirapuera, seu desenvolvimento, observações sobre suas possíveis etimologias, sua forma e relações com a estrutura. Os resultados expostos revelam os avanços da arquitetura e engenharia brasileira manifestos nos anos 1950.

Palavras-chave

Projeto arquitetônico. Projeto estrutural. Oscar Niemeyer. José Carlos Figueiredo Ferraz. Oca Ibirapuera.

Introduction

The distinguished OCA Building was designed by Oscar Niemeyer (1907-2012) and his team[1] between 1951 and 1953, as one of the five constructions within a complex to be built to commemorate the 400th anniversary of the city of São Paulo, at Ibirapuera Park.

First referred to as the *Pavilhão das Artes* [Arts Pavilion] or Lucas Nogueira Garcez Pavilion, the building accommodated the *Museu da Aeronáutica* [Aeronautics Museum] and the *Museu do Folclore (Folklore Museum)* for many years (Cavalcanti, 2017, p. 169). Today, it regained its original function as an exhibition hall, after being remodeled to match its original plan, in a design executed by the studio MMBB and architect Paulo Mendes da Rocha (1928 -).

The studies focusing the plans and construction of the Ibirapuera Park show its significance as a manifestation of the city of São Paulo pursuing the affirmation of its urban, industrial, population and cultural development (Cury, 2018), which occurred in the 1950s.

Ibirapuera Park proposition and meaning for the city of São Paulo in the fifties can be understood from Arruda's book (2001). The definition of its area and its design history and debate can be seen in a book by Barone (2018) and in Gurian's master thesis (2014) entitled *"Marquise do Ibirapuera: suporte para uso indeterminado"*. (Ibirapuera Marquee: a support for undetermined use).

Indeed, the pavilions in the Park – erected even over some opposition – became a manifestation of "the world's fastest-growing city" and, according to Barone, expressed:

> *Having overcome several bureaucratic barriers emanating from the authorities, it was irresistible to celebrate São Paulo's economic strength via its cultural sovereignty. It became unanimous. From the success of the 1954 endeavor, it was more important to erase the remainders of the conflicts and to exalt the modernity of the city in all fields, now with a complex of buildings in a park that combined nature, leisure, and culture in the largest and most powerful city in the world.* (Barone, 2009, no page)

Andrade's work (2014) shows that from the late 1920s until 1948 others studies had been considered for the Ibirapuera floodplain. After having resumed and criticized these plans in 1951, Architect Cristiano Stockler das Neves (1889-1982) presented a new design with a still classical-academic configuration with an accentuated monumental character.

After negotiations with Cristiano Stockler das Neves (1889-1982), the entrepreneur and president of The Fourth Centennial of São Paulo, Ciccillo Matarazzo (1898-1977) decided to redirect the studies to new guidelines aimed at the configuration of a park of modern expression, calling São Paulo architects connected to the new affiliations for this initiative.

[1] The team was formed by Oscar Niemeyer, Zenon Lotufo, Eduardo Kneese de Mello and associated architects, Gauss Estelita, and Carlos Lemos.

On September 20, 1951, Ciccillo Matarazzo formally invited architects Rino Levi, Oswald Bratke, Eduardo Kneese de Melo, Ícaro de Castro Mello, Roberto Cerqueira Cezar, Carlos Brasil Lodi, Carlos Alberto Gomes Cardim Filho, and Alfredo Giglio to constitute the planning team responsible for all celebrations. The last two names were, respectively the municipal directors of the Urbanism Department and the Architecture Department. (Andrade, 2004.)

The team work was also discontinued, as there were no well-defined understandings that were being developed with the IAB (Institute of Architects of Brazil) and, very soon, the team members requested removal.

After this deadlock, Ciccillo Matarazzo invited Oscar Niemeyer to undertake the design. In his view, he was convinced the work of the Rio de Janeiro architect would be closer to a modern concept more consistent with the message the park was meant to express.

After the definition of the new team coordinated by Niemeyer, the group developed a few location and construction studies, which were presented in two versions (Figures 1A and 1B). The first study showed a complex of six basic buildings, connected by a long marquee which, in addition to establishing the links and routes among the buildings, was in constant dialogue with the site and the shape of the lakes defined for the area.

This first version already showed the construction of a large hemispherical calotte that was to shelter part of the cultural brief of the Park (auditorium, exhibition hall, planetarium) (Figure 1C). Módulo magazine, in March 1955, published all the construction proposals for Ibirapuera Park, with all the planned buildings, which, eventually, in a second phase, had their number reduced and their shapes simplified for financial reasons. (Bruna, 2017).

The oca building and its development

First Moments

The OCA, initially known as the Palace of Arts [*Palácio das Artes],* was described in Acrópole magazine, Issue no.161, as relevant within the group of buildings proposed for the Park: "The really extraordinary part from the architectural point of view is its covering, dome or cupola, and we say dome because the building itself is a huge dome". (Acrópole, 1954, p. 493).)

Although the internal destination would be altered (as it indeed was), this building's spatial and volumetric solution – from the first version presented in the "The Fourth Centennial of São Paulo" document – appeared as a huge dome whose brief included an auditorium, a planetarium, and exhibition areas. (Figure 1C)

The second version of the design appeared when the use of the building as planetarium was canceled and its use as the Palace of Arts was well-defined. Also, due to financial restraints this version had its dimensions reduced and the

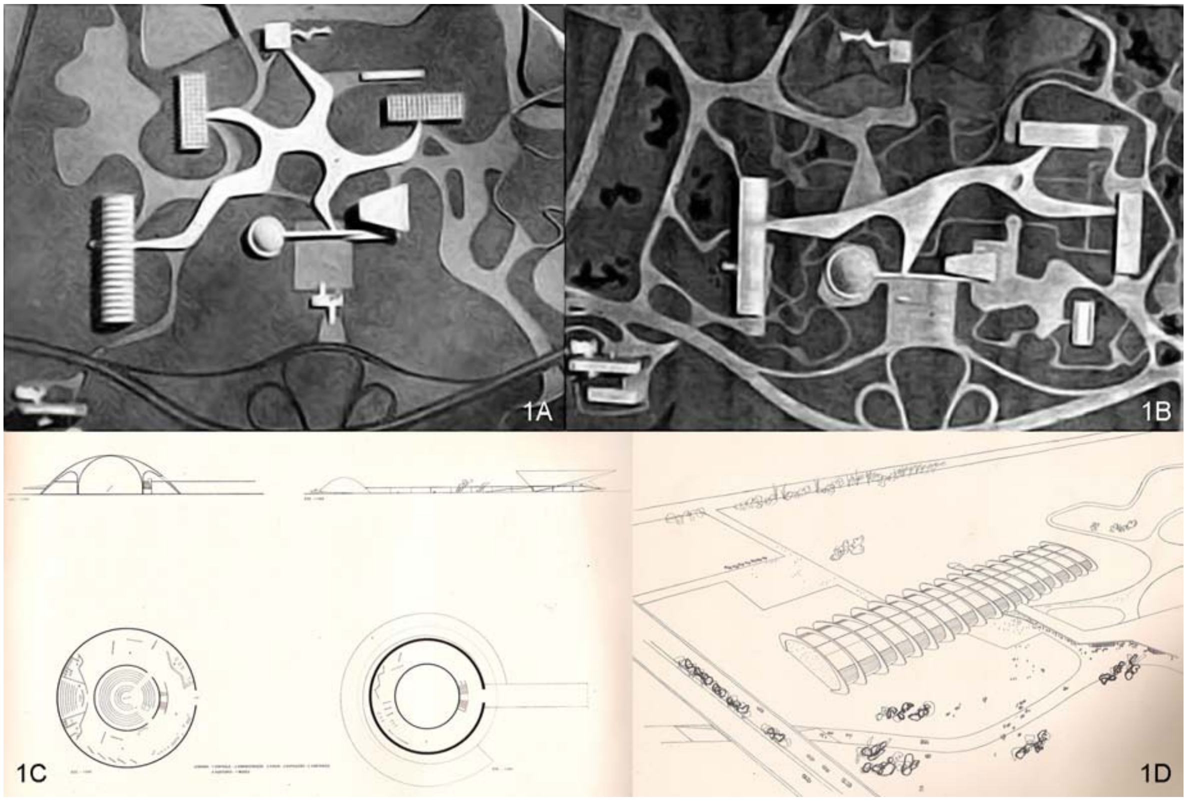


Figure 1

1A – Niemeyers' team. Version 1.
Source: Papadaki (1954).

1B – Niemeyers' team. Version 2.
Source: Papadaki (1954).

1C – Palace of Arts, 1st version.
Source: Schematic Design for the IV Centennial Exhibit (1952).

1D – Palace of Industries, version 1.
Source: Schematic Design for the IV Centennial Exhibit (1952).

formal constructive schemes adopted by the team were simplified. By then, the team was condensed to the architects Oscar Niemeyer, Hélio Uchoa, Eduardo Kneese de Melo and Zenon Lotufo.

In the new location plan, the number of buildings was reduced and their structural solutions altered. In the first version, they had been conceived as exoskeletons, whose porticoes referred to undulating arches (Figure 1D)– as Niemeyer had already done in the design of the testing lab for the Aeronautics Technological Institute (Instituto Tecnológico da Aeronáutica – ITA) (1947) and in the *Duchen Factory* (1951), as we can see in the structural solution (Figure 2A) of the first version presented for the design of the Palace of Industries *(Palácio das Indústrias)*, currently the Biennial Pavillion. This arrangement could refer to both Niemeyer's architectural vocabulary at the time and the participation of engineer Joaquim Cardozo (1897-1978), a personality to be highlighted, in the first versions. Despite not being a member of the team, he ended up authoring the presentation text for the design (Schematic Design of the Fourth Centennial of São Paulo Exhibition,1952).

What can be observed, in this shift from the first to the second version of the Park, is a cleaning up of the buildings' shapes, which turned out to be defined by more regular solids (prisms), and after the elimination of the theater, the marquee remained, although similarly reduced to access the other buildings, still preserving the "organic" character of the composition.

The exclusion of the inner planetarium led to a revision of the Palace of Arts (Figure 1D) program, adjusted to fulfill display functions with a single internal auditorium. Yet, its hemispherical shape was preserved, even with the removal of the ramp pathway that surrounded the entire building and connected it to the theater (also eliminated at that point) access levels, and to the marquee.

Possible etymologies and recognizable derivations

The dome or cupola is one of the most recognizable architecture typologies. Defined by the rotation of an arch, usually generating a hemisphere or pointed arch, it has the property of using much of the compression forces that develop along its surface, and for this reason is a thinner and lighter structure.

Its use has made it one of the typological elements of architecture, just like the ancient circular temples, in which the external form derived from their structural conception. In the case of domes, they may be incorporated into other parts of the building, as happens with the most significant example: The Pantheon of Agrippa or the Pantheon of Rome. (Figure 2B)

The dome's force of expression is linked to the possibilities of having large spans which allow a wide centrality and meeting space. Its structural ability develops from leading the forces on the covering by means of compressive loads on its surface (shell). The loads are collected by elements arranged at its end, usually the sidewalls or pendentives. (Koch, 2009: 133)

Adopting large cupolas is related to the sense of meeting point and, in the case of the Roman temple, to the image of the cosmos for the worship of all gods.

On the Roman Pantheon's shell (Figure 2B), the forces follow the shape of the surface and the latter thickness increases as the loads increase; to reduce the added weight, its inner part is executed with low relief patterns on the inner side (like those of a hive); they work as a vertical and horizontal ribbed grid.

The most recognizable buildings using cupolas generally place them in a central position resting on columns, walls or transferring loads to pendentives or

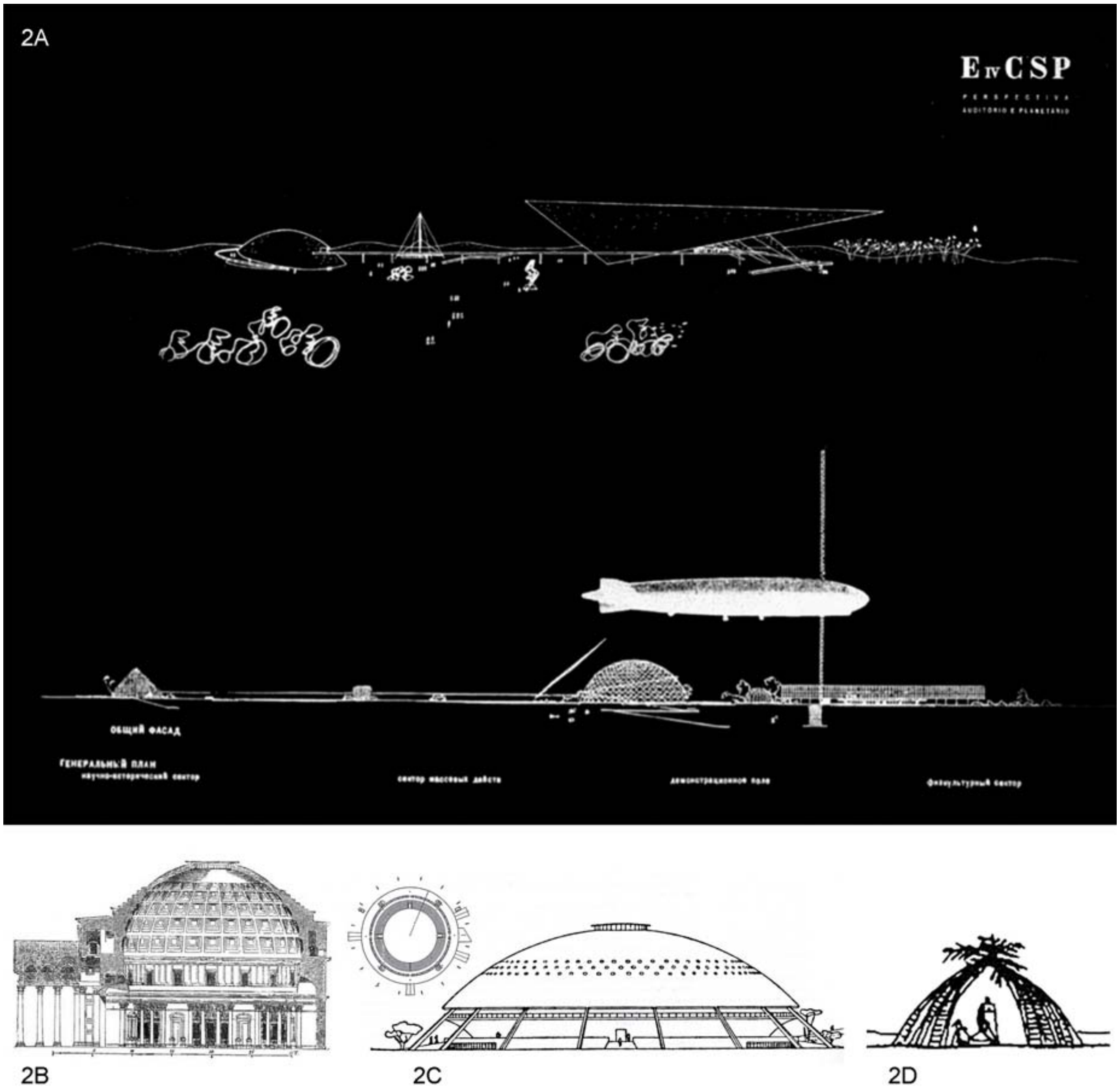


Figure 2

2A – View of the buildings at Ibirapuera Park – version 1 (1951) - Oscar Niemeyer and team; View of the design for the Proletariat Palace of Culture (1930) - arch. Ivan Leonidov; Composition from Gurian.
Sources: Schematic Design – IV Centennial Exhibit and Sovremennaia Arkhitektura Nº5 (1930).

2B – Pantheon section.
Source: Brockhaus and Efron Encyclopedic Dictionary (1890-1907).

2C – National Stadium Gymnastics Arena - RJ (1941) Oscar Niemeyer.
Source: Marco do Vale (2000).

2D – Oca by Oscar Niemeyer.
Source: Drawing by the authors from image in J.C. Miguel.

secondary cupolas, as in the Hagia Sophia Basilica, built in the capital of the Byzantine empire, Constantinople (today Istanbul) between the years of 532 and 537.

The OCA's etymology can also lead to several recollections: it reinvents the dome or cupola, and revisits the indigenous hut (Figure 2D), which is portrayed in a drawing by Niemeyer on Miguel (2002).

It can also refer to some of the avant-garde Russian proposals, such as the design for the Proletariat Palace of Culture (1931), designed by the Vesnin brothers – Leonid Vesnin (1880-1933), Victor Vesnin (1882-1950) and Alexander Vesnin (1883-1959) – as well as numerous proposals by Ivan Leonidov (1902-1959), as the design for the same palace (1930).

Dialogues between architects crossed countries borders and, somehow, were noticed by the most insightful designers. Gurian's master thesis (2014) presents one of these possible connections between the design for the Ibirapuera Park and Leonidov's above-mentioned work. (Figure 2A)

Niemeyer's undeclared reference to the works of Leonidov and other avant-garde Russian architects may be observed in the repertoire he amassed, as well as in his proximity to the Communist Party from the time of his twenties (Zappa, 2007), as well as his own relationship in his architectonic dialogues with Le Corbusier (Queiroz, 2017).

To check out these findings, Professor Hernández Correa, PhD architect from the ETSAM, mentions an event with the Swiss-French architect in the 1930s, when he was getting ready to present a design in a competition for the Soviets Palace:

> *Leonidov admired Le Corbusier and Corbusier admired Leonidov. It is said the Frenchman arrived in Moscow to enter the ignominious competition for the Soviets Palace and asked if Leonidov was participating. They answered he was not. Then, he rubbed his hands and said: So, I've already won! (Hernández Correa, 2011, no p.)* (Free translation by the authors from the Spanish)

Another reference on how Le Corbusier recognized Leonidov's work can be found in the book *Pioneers of Soviet Architecture* (1987): "Le Corbusier used to call him 'the poet and the hope of Russian Constructivist Architecture" .(Khan Magomedov, 1987, p. 233)

But, before the Oca Pavilion design, from the structural point of view, we must identify some of the major pioneers in the development of reinforced concrete shells: Pier Luigi Nervi, Eduardo Torroja Miret, and Felix Candela.

Pier Luigi Nervi (1891-1979) as a member of the army engineering corps and a group called "Society for Concrete Construction", after the World War I and, in 1926, he designed the covering shell of the Augusteo Cinema-Theater in Naples (Nervi, Pier Luigi, 2018).

The engineer Eduardo Torroja Miret (1899-1961) who used to design with roads, ports and canals, was a designer, professor and researcher, with a leading role in the major advances of pre-stressed concrete in the first half of the twentieth century. His investigations helped formulate norms for the material. The

Algeciras Market, in Cádiz, Spain, was built in 1934 and it consists of a thin shell of pre-stressed concrete with a minimum thickness of 9 centimeters and 47.62 m in diameter.

Felix Candela (1910-1997) was Eduardo Torroja's student and graduated from the *Escuela Superior de Arquitectura* de Madrid. He immigrated to México in 1939, where he developed several reinforced concrete shells. He built the Cosmic Rays Pavillion, at the campus of the National University of México (UNAM), in 1951, as an experiment which contributed with the formation and dissemination of the concrete shells. (Ledesma, 2008).

Nervi, Torroja Miret and Candela were avant-garde in the construction of reinforced concrete shells and, certainly, nourished the world know-how on the activity. Both Niemeyer and Figueiredo Ferraz should have known these international experiences, given that Figueiredo Ferraz had been a great researcher on pre-stressed concrete since the 1950s, and Niemeyer had already designed (Figure 2C) the Rio de Janeiro National Stadium Gymnastics Arena, in 1941. Yet, the OCA shell, both in shape and structure, is different and unique – and this finding demonstrates the pioneering spirit of this work, which brought together two exponents in the areas of architecture and civil engineering.

This Gymnastics Arena is a dome that uses columns to raise it to a level above the terrain. In their continuity the columns also work as the shell structuring ribs. Without its support columns, or pendentives, the cupola or dome suggests the architect adopted guiding principles such as Eugène Freyssinet's (1879-1962) in the Orly Airport hangars (1923), and in the *Pampulha* Church (1940), designs in which the shells emerge directly from the ground.

The oca design (palace of arts)

The shell or the hemispherical shape that characterizes the building has been there since Niemeyer's first sketches. Regardless of all the adjustments the complex went through over time, despite all the changes to the other buildings and the brief originally intended for the old Palace of Arts, its circular-shaped base and semi-spherical form were maintained. There was only one change: the ramp that would surround it and give access to the theater was eliminated.

This shell-shaped form used in the Ibirapuera design – understood as a dome or calotte – will develop into a striking feature in several future compositions of the architect, among them the National Congress in Brasília (1958), the headquarters of the French Communist Party in Paris (1965), the Honestino Guimarães National Museum, in Brasília (1999), and in the Principality of Asturias Cultural Center, in Avilés (1999-2006), Spain.

Its geometry refers to the hemispherical format, although, for Niemeyer this figure gets thinner in its endings by means of tangent surfaces (cone trunks) to come up or rest on the plane of the base into which it is inserted.

As for this tangency, it is impossible to find out if there were any suggestions for the structural solution. In another situation, it is said that calculation engineer Joaquim Cardoso and Niemeyer had once a conversation, in the early morning

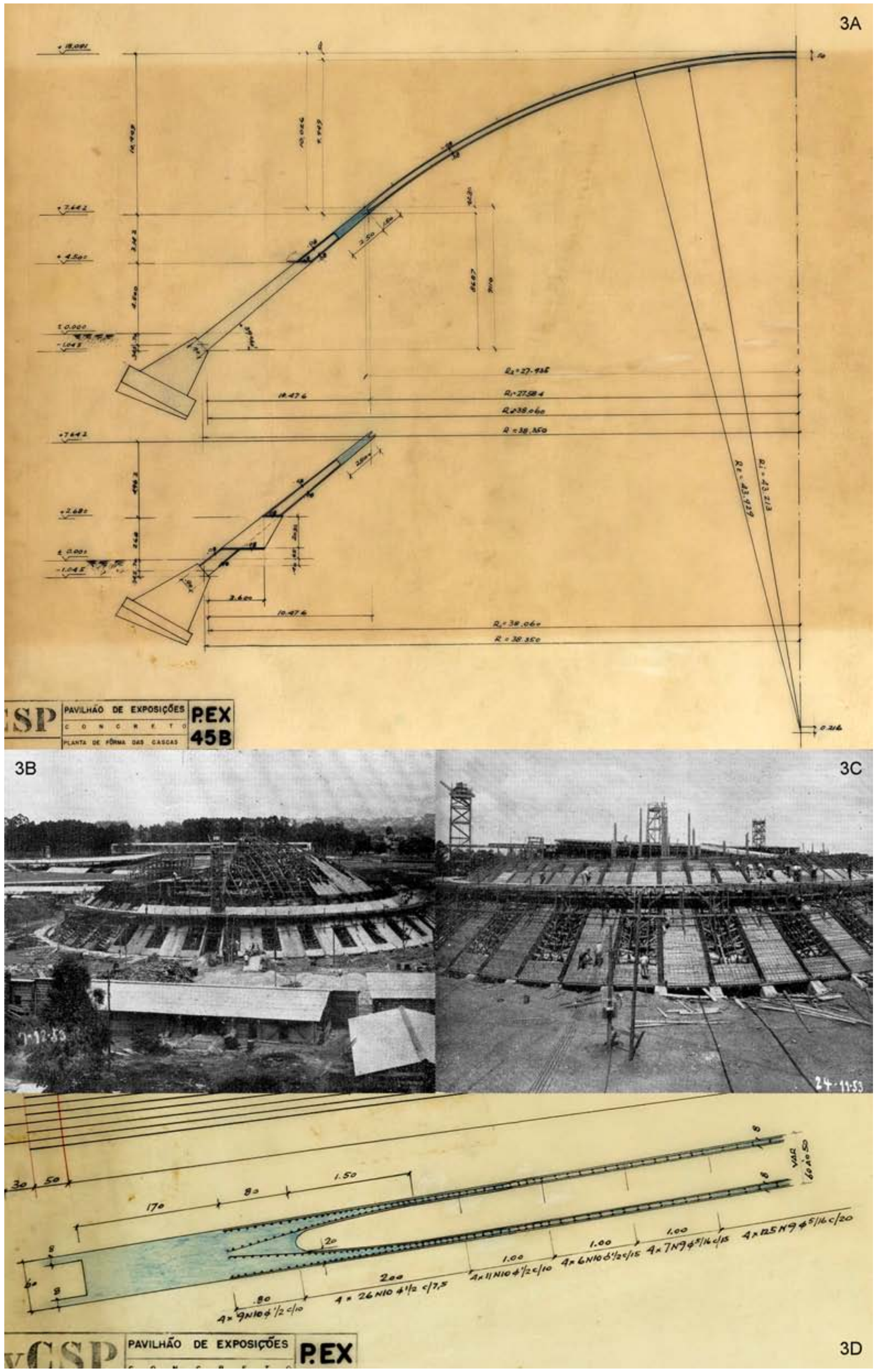


Figure 3

3A – Section of the shell structure.
Source: Figueiredo Ferraz / Municipal Archive.

3B e 3C – Photos of the OCA construction.
Source: Acrópole Magazine, nº 191 (1954).

3D – Detail of the strap and the beginning of the shell.
Source: Figueiredo Ferraz/ Municipal Archive.

hours, about placing the calotte of the Chamber of Deputies, in Brasília, on the upper level of the building, as reported in a statement by Niemeyer recorded in Utuari (2006):

> *Joaquim Cardozo: "My dear architect, I figured it out"!*
> *Niemeyer: "Come on, what have you figured it out, at this early dawn time?"*
> *Joaquim Cardoso: "I found out the tangent that will give the impression that the cupola you designed is landing lightly over the slab"* (Utuari, 2006: 8)

The OCA design is about a 76-cm diameter shell (Figure 3A). Its structure is a reinforced concrete spherical cupola, with a ring-shaped underground that functions as a strap to receive the stresses of the ground-floor pavement slab. Inside the dome there are three different-shaped slabs, resting on an independent column structure.

In the structural design obtained, the dome showed two shells: the outer radius covers 43.133 m and the inner radius covers 49.929 m, measured from the bottom. The total height of the surface with respect to the ground level is 18.01 m. The tangential feature is produced at 7.64 m from the ground. It is also possible to clearly verify the strap on the photo obtained during the concrete filling of the lower part of the dome. (Figures 3B, 3C, and 3D).

The floor plans for the three levels of the internal slabs have geometric shapes, derived from the subdivision of circular figures. These shapes decrease gradually as they rise with respect to the level of the ground floor. Starting with the ground floor slab, which rests beyond the pillars, on the circular ring of the retaining wall that constitutes the underground, the other slabs rest on a set of pillars that decrease in number on each floor. Although the internal slabs extend from the ground floor up to the shell, they do not bond with it and are treated as independent structures, as showed in the photographs. (Figures 4B and 4C).

In general terms, the building design is mixed up with its structure and can be fully understood from the general architectural drawings. (Figure 4A)

From the documents found, one cannot reflect on the dialogues between architect and engineer. However, some observations are verifiable, such as the need to avoid that the shell structure, both internally and externally, manifests as a pure clean geometrical calotte, a naked dome, without the visible presence of ribs.

This "smooth" or no apparent rib solution is made up by means of a paired shell with an external dimension between 50 cm and 60 cm, and variable internal gap according to detail next to the concrete strap, arranged to support the dome surface loads, both the sloping compression loads and the necessary horizontal traction efforts performing a ring-shaped strapping. (Figure 3D)

On the half section-half elevation structure drawing, one can notice the radius of the curvature and the levels of the slabs, some voids, different ceiling heights, and the internal ramp route.

The "smooth" shell, whose uniform composition does not allow to distinguish its components when giving a vision of homogeneous space, accomplishes the feat of suggesting a kind of cosmos or infinity backdrop to the place. The slabs and their internal shapes and voids characterize and establish a spatial *yin and yang* that is revealed to visitors who transit through an elliptical path when reaching and traversing the levels of the OCA internal slabs (Figure 5).

4A

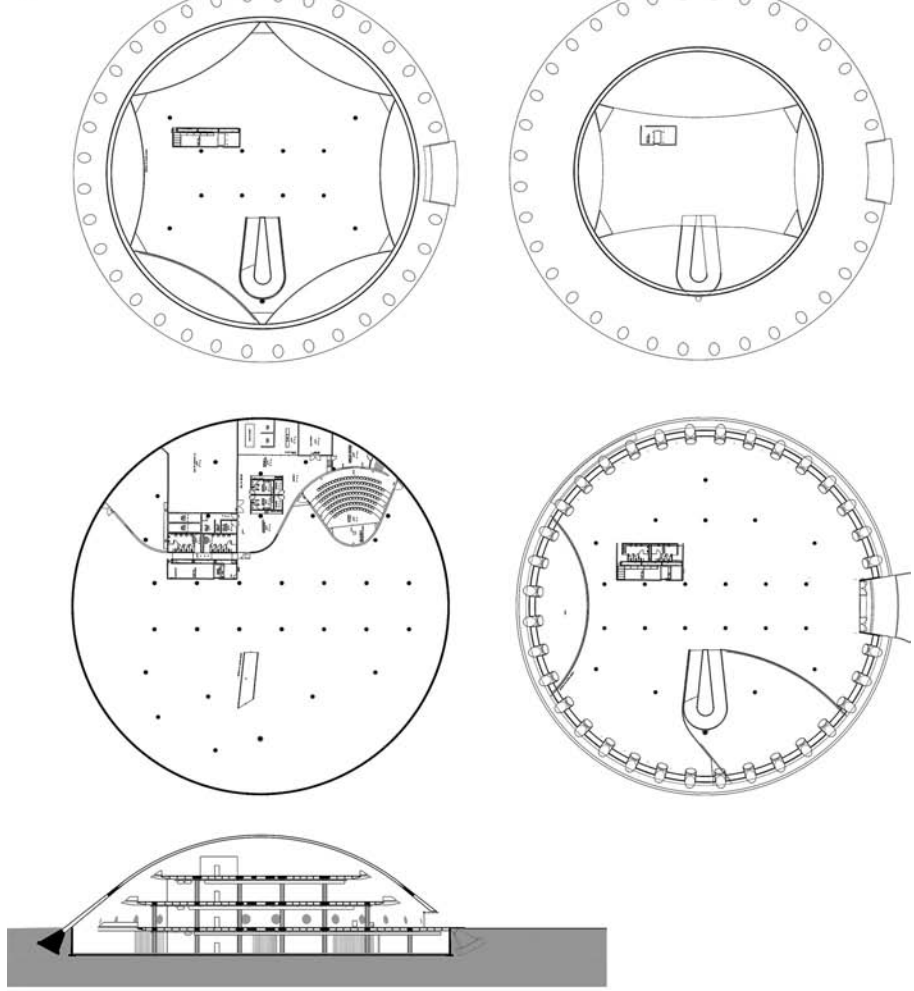


Figure 4

4A OCA floor plans and section (no scale). Source: MMBB Archive (1999).

4B Mismatched internal slabs of the shell. Photographs: Rafael Schimidt (2011).

Figure 5
5A 5B 5C 5D. Internal paths of the building, yin and yang space, and belonging to the cosmos.
Photographs: Rafael Schimidt (2011).

The most well-known cupolas such as those of churches and temples contain the notion of a sky or cosmos, environments that have tried to consider the connection between men and God or gods, in a broader sense, the harmony between the cosmos and the human microcosm, as studied by Lester (2014) in his work on the development of Leonardo da Vinci's drawing of the Vitruvian Man.

The Pantheon (from the Latin *Pantheon* and from the Greek *pántheion*, a temple dedicated to all the gods) establishes the view of the cupola as the home of all the gods. In the Middle Ages, the geometry of the internal space of the cathedrals established that: "the construction of a cathedral, which was in turn God's kingdom on Earth, was designed to reproduce the structure of the universe through its geometry, to be understood as a physical model of this cosmos" (Sinson, 1991, p. 48).

Evidently, the cupola or dome have always been connected to large meeting places with different interpretations, but always linked to the meaning of the word cupola. One of them refers to the design and construction of the Santa Maria del Fiore (1420-1436), in Florence, which reveals an advanced constructive technique linked to a meaning understood as:

> *…a structure not only self-bearing, but also prospective or representative, with its ribs that converge to a point. This point represents the infinite and, therefore, the architectural structure is the very structure of space).* (Argan.1999, p. 135).

Argan (2011) interprets the topping of the dome oculus by a lantern, years after its conclusion, just like a small classic temple of central floor plan, as an overlay of types. In this superposition of a classic element on the prodigy of Brunelleschi's modern ingenuity, he recognizes the establishment of a meaning.

> *…as for Alberti, he would hardly have defined the dome as raised above the skies, had he not known, through the model and drawings, the lantern, the element that effectively makes the transition from the physical to the empirical sky, or rather the symbolic sky ... The conjunction of the dome, a technical miracle, with recovered classicism, a historical miracle, is precisely the conjunction between modern Florence and ancient Rome…* (Argan, 2011, p.138)

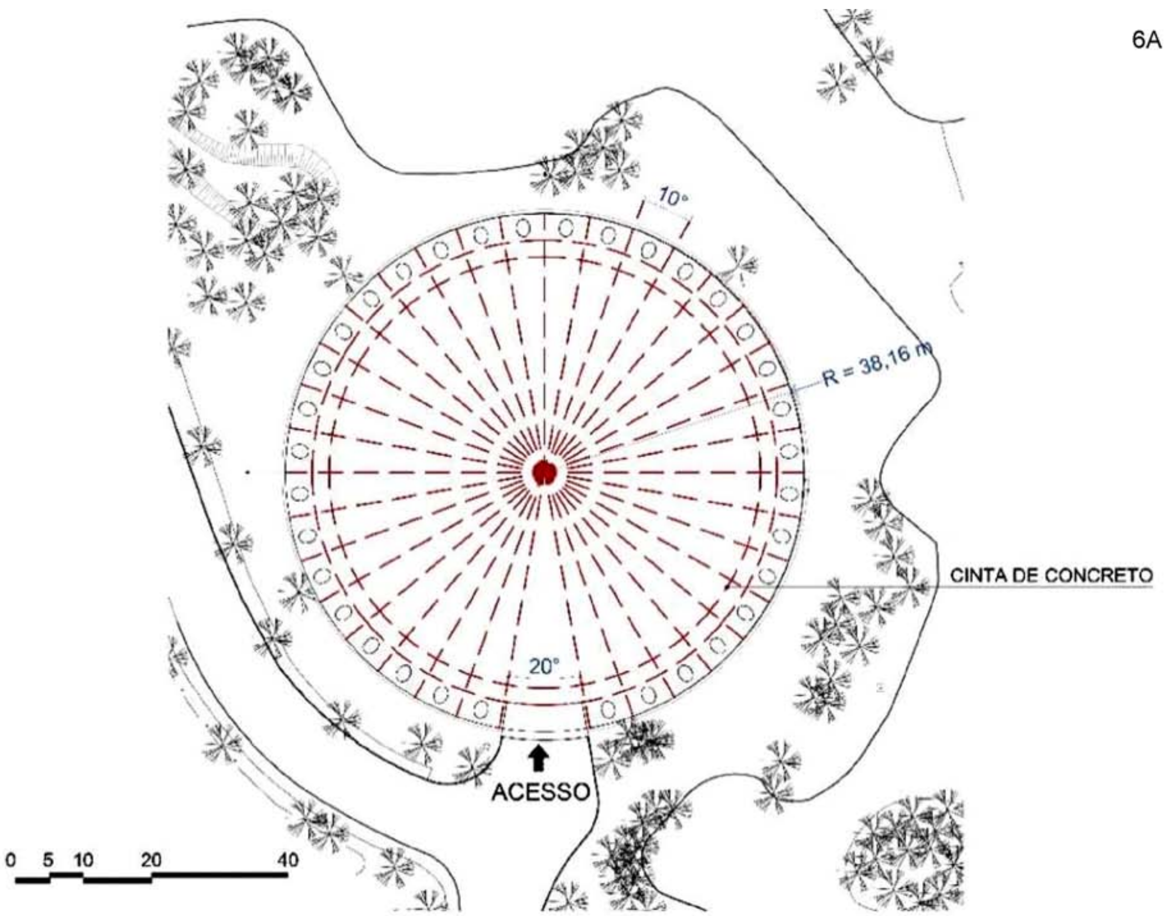
The sixteenth-century churches can have their space understood, as in the example of the design for the *Madonna Del Monte Church* (Rome, 1580), about which Brandão (2001) comments:

> *The interior space of the church, where the longevity of the congregation nave prevails, is expressed in the exterior plastic aspect that highlight the central area of the facade. At the end of the walk along the nave, the dome dominates the church and becomes the purpose of the movement. Its size, much more than the fifteenth-century churches, is an expression of a persuasive discourse.* (Brandão, 2001, p. 141)

The OCA dome is neither the target nor the end of a path. The dome without pendentives, born out of the ground, is unabridged and has no external protuberances or external appendages on the façade. Its path is not directed by linearity, on the contrary, it is elliptical. As there is no oculus, lantern or rib, it does not imply a point in infinity or one above the sky, but it refers to a confined space. It does not lead to an ascension-like illusion, but to a sort of heaven still confined. Its lower level leads to both cosmic and earth. While wandering, the observer is not persuaded to follow only one direction, but can be part of more than one (Figures 5C and 5D).

Contrasting with most of the calotte-shaped coverings on a construction top, only seen at a distance or from bellow by passersby, at the OCA this observer enters its space. That is OCA's major meaning: men penetrating the cosmos, a sense of belonging to the environment; even better, a kind of impertinence, such as Prometheus's when stealing fire from the gods. Men who enter the universe, perhaps to make the visit with others, and what has become the Portuguese expression known as "*cupola meeting*" or "summit" (Figures 5A and 5B).

From a bird's eye view, the dome is structured by dividing the circle into 36 sectors, each with a 10-degree angle. Two sectors are used for the access, allowing an opening to accommodate the building entrance. The remaining 34 sectors are intended alternately for the placement of cylindrical tube-shaped windows that line the outer surface and stand out inside the building. (Figure 6A)



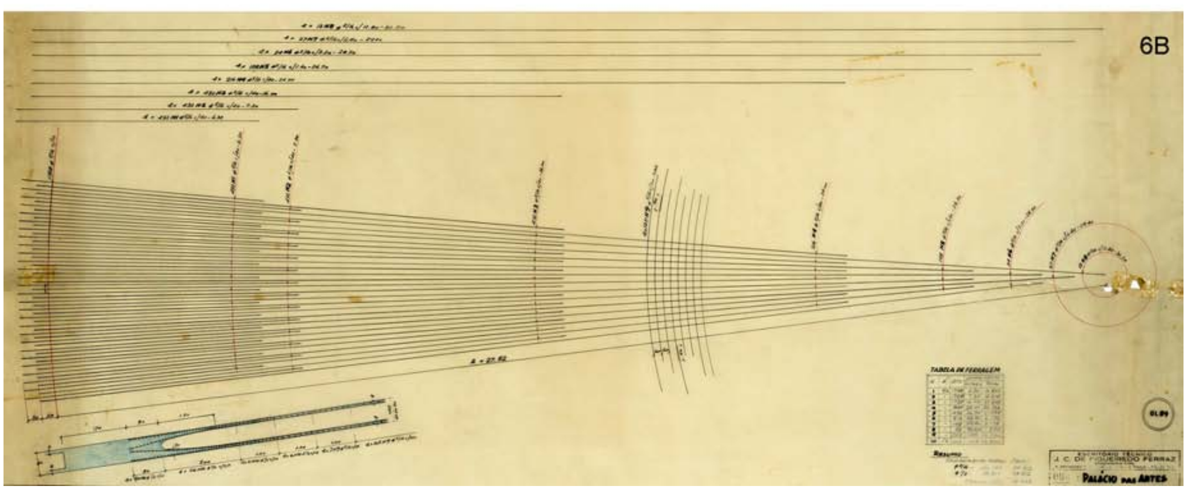


Figure 6

6A – Geometry of the OCA sectors.
Source: Drawings by the authors (2018).

6B – Rebar of one of the shell sectors
Source: Figueiredo Ferraz/ Municipal Archive.

[2] Career guidance lecture delivered to young people interested in studying architecture. At the time, an architecture student Rafael Perrone, one of the authors of this article, attended this lecture and was an instructor of Architectural Language in a preparatory course for the university.

The ring-shaped strap placed at the tangency point of the hemispherical cupola is designed as a 60 cm X 250 cm conical ring, acting as a support for the calotte forces, the horizontal stress strapping, and the transition to the pyramidal trunk-shaped pillars that lead the forces to the footings that work as direct foundations. Its positioning, at 4.50 m from ground level, generates the lintel for the entrance door and assists in accommodating the pipes used as modinature of the window frames.

Each sector of the covering is reinforced in its two layers by radially arranged rebars that progressively increase in number as stresses increase. The rebars are arranged to control the spacing of radial steel wires and bands of intermediate rebars in the form of straps that act to hold stresses on the shell surface. (Figure 6B)

If the cosmos manifests in the cupola, the way people wander inside it, appreciate artwork on exhibit, or visually dialogue with those observing one another, the roaming is the subject of a ramp in which visualization is also achieved through some mandatory turns proposed by the routes of the eye in multiple rotating directions. This itinerant look combined with the high-ceiling variations stimulate the perception of a multidimensional spherical space.

The slabs have different formats, all of them derived from parts of the circumference, forming figures generated by geometrical operations based on creating mandalas or rosettes. In these waffle slabs, the pillars, whose number is reduced at each level, are set back in relation to the edges which, in turn, have their height reduced near the edges generating an impression of lightness, as if floating in space. (Figure 4). The independence between slabs and the shell, including the foundations, makes the parts work independently, allowing for expansion and movement between them.

A curiosity worth remembering. In 1969, during a lecture at the [2] Anglo Latino Preparatory School, Engineer Figueiredo Ferraz was lecturing about some aspects of the relationship between architecture and structure in the case of OCA. He revealed that when he learned that the architect team had adopted ceramic tile finish for all the Ibirapuera Park buildings, he warned them not to use this finish at OCA, because its shell would undergo expansion and contractions due to sunlight and temperature changes.

However, the team did adopt the ceramic tile finish, as the photographs published in *Acropole* magazine issue 161 show (Figure 7D), taking into account the drawings containing the architects' specifications for the covering lining and their strategy to create small joints between the panes of the ceramic tiles (Figures 7C and 7D). In fact, time proved the engineer's recommendation correct: the tiles began to come off and ended up being removed, as one can see in the building today. For a long time, the double-surface cover made it possible to use embedded lighting fixtures inside the slabs.

Together with the blueprints collected during the investigation, the researchers found out an undated drawing that recorded an air conditioning system to be installed inside the OCA. This project would also use the voids between the shells and some of those existing in the waffle slabs. In the same drawing there is a simplified interpretation of the slanted pillars that support the dome to

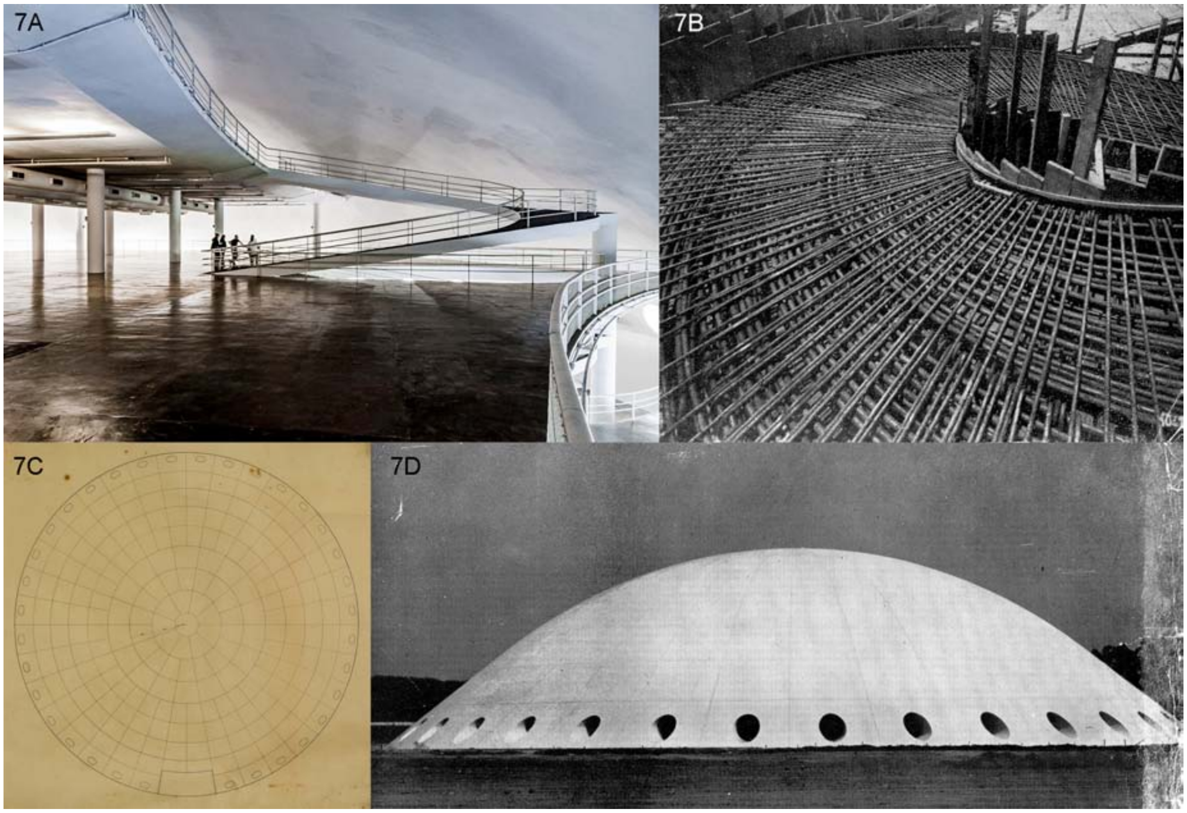


Figure 7

7A The ramp and the edges of the slabs.
Source: Rafael Schimidt (2011).

7B Ramp rebar.
Source: Acrópole magazine, n. 191 (1954).

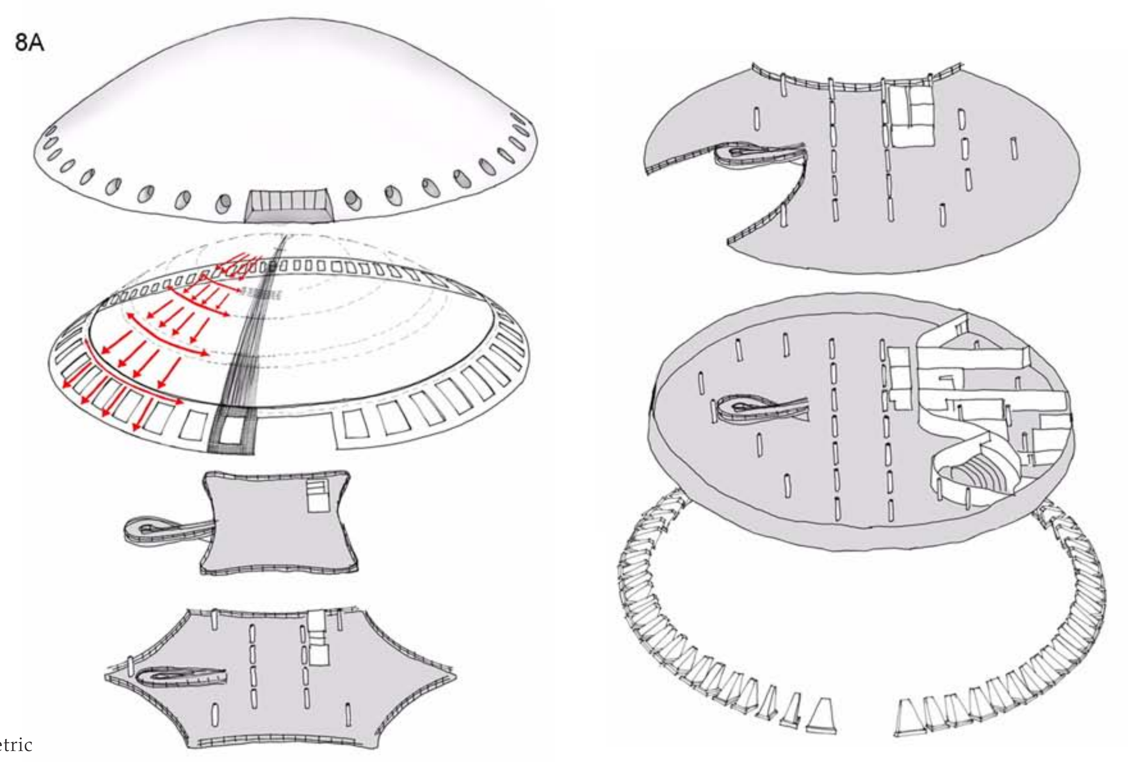
7C Expansion joints drawing for the tile coating.
Source: Municipal Archive.

7D The OCA coating with its expansion joints.
Source: Acrópole magazine, n. 191 (1954).

discharge the loads to the ground. In the drawings showing the relationship between the pillars and the ring-shaped fastening straps, one notices the format of the pillars that constitute the openings of the windows and those that structure the aperture for the entrance door.

Ducts measuring 45 cm x 30 cm for the passage of the electrical installation were provided on the fastening straps above the windows. These ducts allowed the placement of recessed lighting fixtures and other installations in the gaps between the shells.

General traffic is conducted via a narrow, horseshoe-shaped ramp that extends to all floors. The original design has a vertical component that considered a staircase next to a ventilation pipe for the placement of washrooms (there is no indication of this ventilation duct). During the last remodeling an elevator was installed in this area.



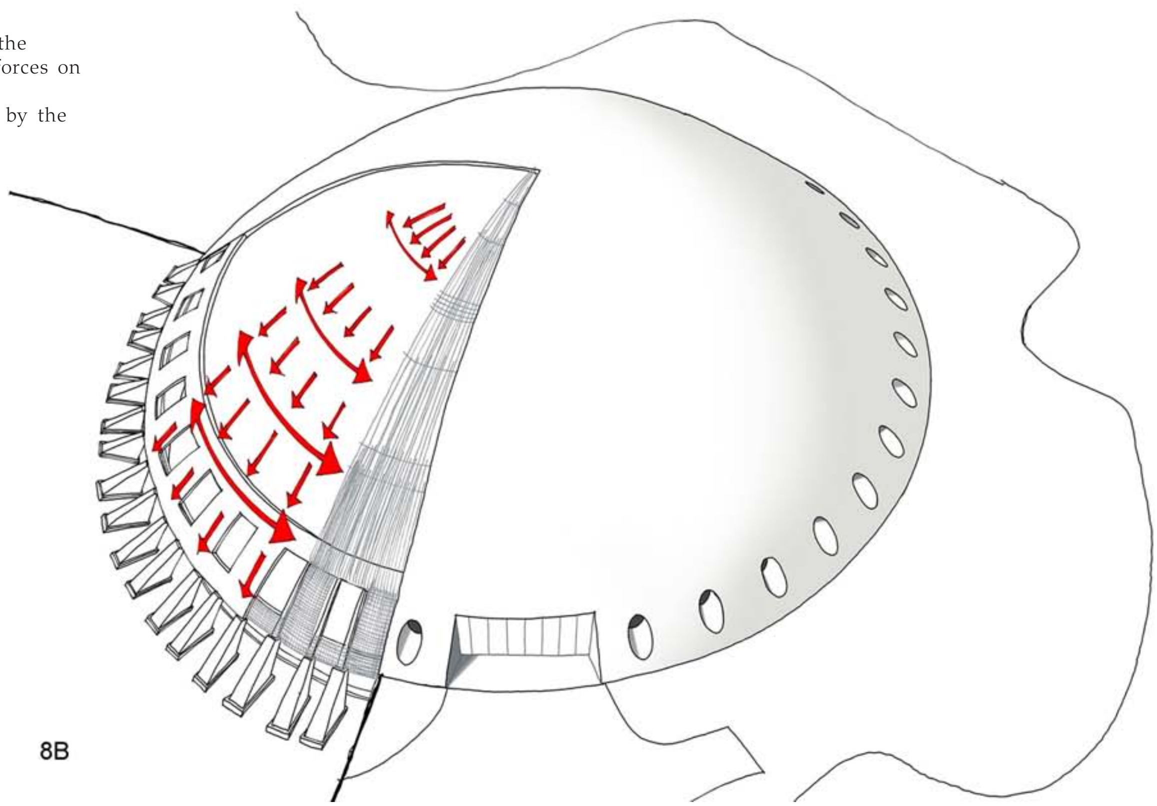


Figure 8
8A – OCA axonometric perspective.
Source: Drawing by the authors. (2018).
8B – Scheme of the direction of the forces on the shell.
Source: Drawing by the authors. (2018).

The ramp is structured by a solid reinforced concrete slab, whose rebar was not found in this study, but can be recognized in the photographs. (Figure 7B) The ramp rests on one of the pillars by means of a corbel; other support points are on the slabs, a place where the surfaces are combined to amplify the spatial continuity. (Figure 7A)

The integration between the whole structure and the architecture is designed in an exploded axonometric perspective and allows the researcher to visualize how the parts are connected, and the respective gaps generated by the voids created.

The independence between the slabs and the shell, and even the foundations, makes the parts work autonomously allowing for expansions and movements between them. To understand the direction of the forces on the shell, a drawing was made showing their routes by means of red lines with arrows. (Figure 8B)

Final remarks

In the early 1950s, when there were no major calculation resources to develop the thin structure of the shell and the solutions adopted to configure all the elements of the structure, Engineer Figueiredo Ferraz with his skills was able to provide the architectonic qualities desired by Niemeyer and his team.

Figueiredo Ferraz graduated as an engineer in 1940 and, after only 11 years working as with calculations, he coped with a big challenge: the OCA project. It is known that Niemeyer always worked with excellent calculation engineers, such as Otto Baumgart, Joaquim Cardozo, Bruno Contarini, José Carlos Sussekind. In the case of the OCA, the paperwork research did not allow us to describe the dialogue process between structure and architecture, but it let us verify the appropriate structural solution applied to the building design.

In the period it was proposed, the structural solution represented a huge contribution to complete a low curvature calotte, a fact that can be demonstrated through a statement Joaquim Cardozo made in the 1960s, and Macedo and Sobreira (2006) quoted: it says that some mathematical knowledge would not have been consolidated in 1952, period of the professional structural project. Here is what Joaquim Cardozo said:

> *(...) I was faced with a case of very low spherical shell and, perusing the little literature I had on the subject, I became aware of an essay by I. Vorovich, published in the comptes rendus of the Soviet Union Academy of Sciences, mathematics section, a work in which the problem is no longer expressed with the simplicity of a system of linear equations of partial derivatives* (Cardozo, 1960, apud. Macedo e Sobreira, 2009, p.140).

Although Bruand considered the solution of the dome with smoother curvature, and its tangency at the base of the cone trunk,"very low in relation to its diameter" (Bruand, 1981, p.166), perhaps by comparing the domes in his continent which had been constructed with techniques without reinforced concrete and with a more pointed design, that solution ended up establishing one of the most employed structures in Niemeyer's arsenal. Or perhaps, exactly in the use of the much desired tangent that brings the stress of the shell to the ground (or, in the case of the Chamber of Deputies in Brasília that turns it skyward and lands it gently on the top of the building). Niemeyer returned to these solutions in later works. The circulation scheme was also critized by Bruand:

> *... The impressively light ramps of the Palácio das Artes were more debatable from the rational and psychological point of view, for the reason that the environment produced was not at all suitable to the building's destination; it had been built as a brilliant example of pure architecture, where plastic concerns outweighed all other considerations.* (Bruand, 1981, p.158)

The Palace of Arts, known as the OCA, had a troubled life. Designed to host artwork exhibitions, it housed the Aeronautics Museum for a long time while was relegated to abandonment and ignorance of its potential. In 1999, it was restored by the architectural studio MMBB and the architect Paulo Mendes da Rocha. They retained the building's structural characteristics, improved its circulation, eliminated the recessed lighting fixtures, revealed the dome through indirect lighting, and finally provided the first air conditioning system.

The dynamics of its space places visitors inside the dome dimensioned by Figueiredo Ferraz. This incursion into circular routes within the dome is perhaps its greatest merit, which was not to fit into an academic program an art exhibition space with rowed rooms. After many years, the expressions and materiality of the arts have changed, but OCA's availability has allowed its various occupations.

Figueiredo Ferraz's contributions as an engineer are consistent with Niemeyer's statements:

> *When calculation engineers update their professional knowledge, when they are aware of all the advances in the construction technique, when they abandon the rules and limiting norms to speculate only on the problems posed by reinforced concrete, because they have discovered that this is the best way to evolve; when they know not only the profession, but also the visual arts and true architecture - which, by the way, is rare -, finally, when they can get enthusiastic not only about the technical problem to solve, but also about the artistic and creative sense of the work with which they collaborate, then their association with the architect becomes fruitful and positive.* (Oscar Niemeyer-apud Rebello e Leite, 2002)

"Oscar Niemeyer has always shown in his works interest in his creative process showing that architecture and structure are born together; they are not distinct elements of a construction." (Inojosa, 2010, p. 49)

The OCA, its architecture and its structure, is a product of this recognition.

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