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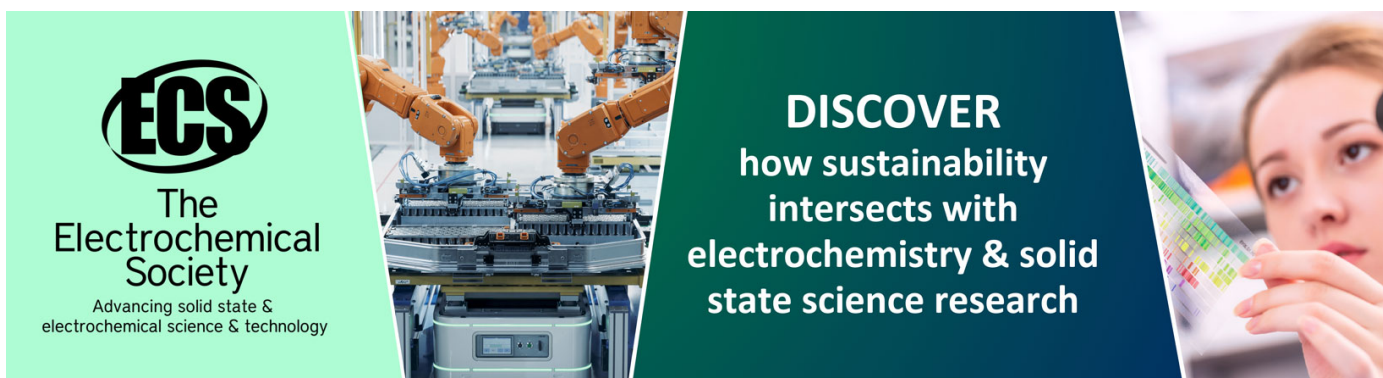
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Physics in the structure and form of the architectural project. Museum of Contemporary Art Niterói, Brazil

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Abstract. This article analyzed the formal, functional, and structural aspects of the Museum of Contemporary Art Niterói in Brazil, by identifying the criteria associated with architecture and physics; this is to establish the importance of the analysis of the architectural project to obtain the basic skills of the architect. A mixed methodological framework was used, the quantitative phase was developed from a questionnaire under a non-probabilistic sample allowed to recognize the formal, structural, and functional aspects of the work under study, the qualitative phase used an interview that established the value represented by the recognition of the application of physics in architecture. As a relevant finding, it is highlighted a basic understanding of the physical elements applied to architecture, specifically in the case of Museum of Contemporary Art Niterói, Brazil, and that they recognize the importance of the analysis of architectural works as a pedagogical tool that favors obtaining the basic skills of the architect.

1. Introduction

Oscar Niemeyer as an architect and engineer, was characterized by being one of the main exponents of modernism, who recognized and materialized Carioca's architecture using free, sinuous, and sensual forms that, gave a new language to architecture in Brazil [1]. His proposal focused on considering the architectural project, in which aspects such as form, function and structure gave rise to the creation of imposing urban landmarks, widely recognized worldwide today [2].

His architectural works consider continuity as their fundamental basis of the organizing principles of design. This, because their projects are made up of different elements that combine a single set, which allows the identification of different volumetric bodies [3]. For this reason, language becomes an important element that links form, function and structure; that reflects compositional elements such as rhythm, hierarchy, symmetry, simplicity, elasticity, scale, movement and purity [4] In this project, Oscar Niemeyer, from an architectural-organic language, and based on the basic principles of physics, manages to generate a structure based on a pyramid supported by a central support on a water mirror that provides lightness to the project, which has a ramp that allows access to the interior of the volume and provides a 360-degree view that is integrated into the landscape where it is located [5,6].

In this research, they were posed as problematizing questions: What are the aspects associated with physics that can be identified in the Museum of Contemporary Art (MAC) Niterói, Brazil? Do you think that aspects such as: Form-Function, aesthetics-morphology and structure-tectonics can be enhanced in architectural projects through the joint work between physics and architecture? And what is the



importance of analyzing architectural projects in the training of future architecture professionals? This research allowed us to recognize the important role of physics in architecture because the Niterói-MAC shows the importance of the structure in the functional component of the architectural work. In addition, this research allowed to recognize the importance of the analysis of the architectural project within the teaching of architecture, because it favors the identification of processes associated with form, function, structure and materiality; from which students can strengthen learning outcomes.

2. Method

This research was framed in the line of work of science, technology, engineering, arts, and mathematics, adopting a mixed approach [7] composed of two phases: The first, corresponding to a questionnaire under a non-probabilistic sample - intentional developed by 26 people, the (53.8%) corresponded to the female gender, (80.8%) to students and (19.2%) to graduates of the Architecture program of the Universidad Francisco de Paula Santander, Colombia.

The second phase corresponded to a qualitative phase where a semi-structured interview was implemented with three informants selected from the richness of the answers given in the first phase (quantitative phase); the data were collected from a primary source and processed descriptively, after applying the instruments. The questionnaire had four items, the first three with multiple-choice and single-response questions, which measured the level of knowledge of the informants about the physical concepts present in the project; the fourth was developed to obtain an open response on the importance of linking physical concepts for the design and construction of architectural projects.

The interview instrument raises three topics with the aim of knowing the perception and understanding of the formal, spatial, urban, and structural aspects of the architectural project under study; in both cases, the design of the instruments was carried out from the knowledge of the researchers according to their academic training. For the validation process, the criteria of experts were used, made up of two architects in the disciplinary field and a teacher in the area of physics. Likewise, a philologist was linked, who guaranteed the validity from the cultural sensitivity.

3. Results and discussion

The Niterói-MAC was designed and built by Oscar Niemeyer in 1991 with the aim of increasing the number of visitors to the city of Niterói, Brazil. Its architectural value lies in its formal-functional aspect (program-museum) and in its urban contribution (integration with the urban landscape) [8]. Niemeyer made the most of the site, achieving exceptional architectural work on a narrow piece of land, bordered by the Atlantic Ocean in Guanabara Bay [9]. The architectural volume was generated from a sinuous line that joins the exterior with the interior (museum program) of the project, based on a circular plan with a single central support that evokes lightness and flower shape [10].

The museum rises 16 meters above ground level and is supported by a 2.7-meter diameter cylinder. In the formal aspect it stands out that in addition to continuity, this concrete volume complies with design ordering principles such as: monotonous rhythm, associated with the repetition of elements at constant intervals; axuality, referring to the use of several axes articulated by a single center, and symmetry; because position, shape, and size are intertwined with respect to the center of the volume and its other components [6-9].

The structure of the museum was developed in reinforced concrete, the main transmission of loads to the ground of this architectural work is carried out through the central cylinder (support) in accordance with the law of static balance, which postulates that a body remains at rest or in movement but with constant speed until it undergoes the intervention of an external force. In the museum, the skin does not fulfill a structural function, while the inverted dome that shapes the museum enclosure, favors the transmission of loads and the structural functioning of the building; within the design criteria, physics affects the structure and shape of the architectural project because the design of the central support and the cantilever achieve a visual lightness that counteracts the materiality and scale of the project [11].

The contribution of physics to the structure and shape of the museum corresponds mainly to the implementation of a post-tensioned reinforcement with posterior transverse beams and wall beams; as

can be seen in Figure 1, for Niemeyer, the shape of the flower (formal aspect) responds to a structural need. The museum is conceptually configured from three parts: the underground part, the main body; and central support (structure), developing the structural load support, the monolithic structure, and the central structure (Figure 1(a)). These three parts are associated with axially, symmetry and rhythm (Figure 1(b), Figure 1(c), and Figure 1(d), respectively), forming a complete structure, starting from a hollow cylinder of 9 meters in diameter and 1 meter thick that rises 5 meters above ground level, and contains a deck that supports the main body, giving general support to the project [12].

Niemeyer through his structural calculation obtains large spans, the optimization of the structure of this project is related to an interlacing of upper beams that form a star, which generates relative deformations, practically zero; that reduce flexion and traction [11].

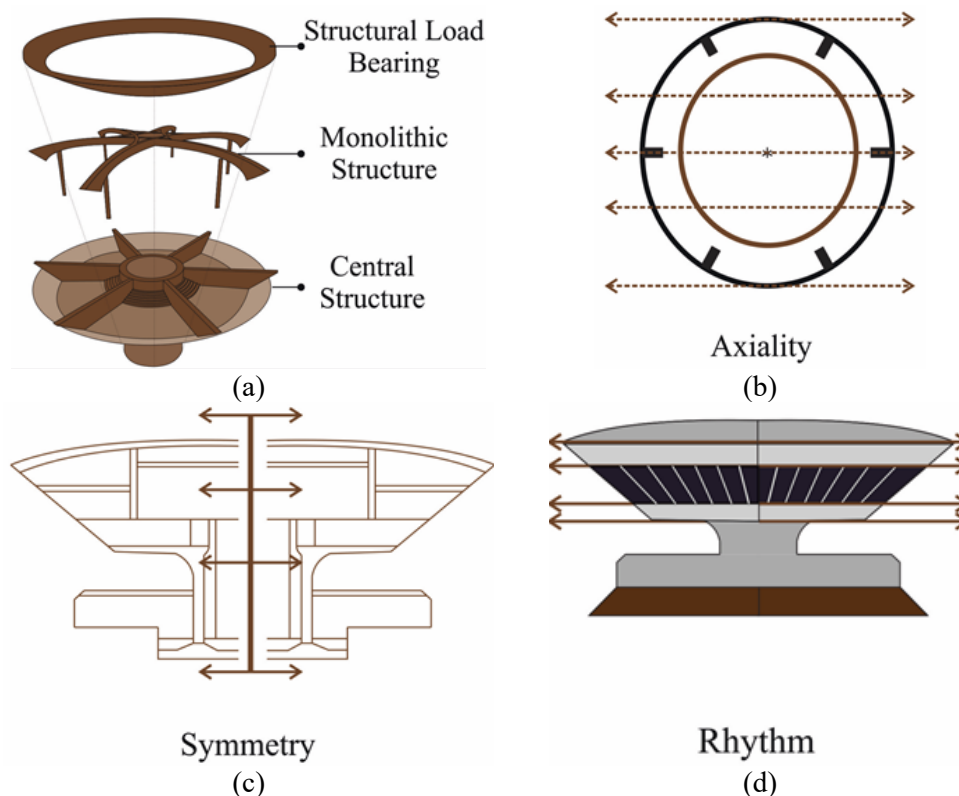


Figure 1. Formal-structural aspects and design ordering principles of the Niterói-MAC, (a) structural composition, (b) articulation of axles by a single center, (c) main body symmetry (position, shape, and size), (d) monotonous rhythm.

The Niterói-MAC is a clear example where the architectural project is favored using the basic concepts of physics, because its application strengthened the structure and the form, allowing the generation of an architectural volume that meets the design criteria (form-function), and marks a milestone in the understanding of the architectural project from physics, the latter understood as a design resource.

This research considered it important to recognize the perception and understanding of the physical concepts present in the project under study, their association with the structural component, and the importance and usefulness of carrying out work analysis as a fundamental part of the architect's training, of students and graduates of the Universidad Francisco de Paula Santander, Colombia, Architecture program. The demographic profile of the informants was determined to correspond to 53.8% women, 11.5% of them graduated from the architecture program and 42.3% in the training process. Men were represented with 46.2% of the sample, 38.5% as students and 7.7% as graduates of the program.

3.1. Quantitative phase

The results obtained from the group of informants in which the object of study is reported below, using cross tables in order to compare their opinions based on their professional profile. The objective of this comparison was to validate the premise of whether the graduate considers and values the importance of physics in the analysis and design of architectural works. This according to what was established by United Nations Educational, Scientific and Cultural Organization (UNESCO) in the 1998 Paris conference where it was specified that the relevance of an academic program is related to the satisfaction of the needs and expectations demanded by society, through the development of skills, competencies and skills that promote critical, creative, and independent analysis [13], accompanied by basic architectural competencies, which allow us to recognize the importance of structure in projects [11].

The first item of the survey allows us to select Newton's law most related to the structural approach of the museum. In Table 1 it can be observed that in the two profiles of informants there is a duality of opinions. 34.6% (mainly graduates) think that the law of inertia is the one that has the greatest influence on the structure of the museum, as opposed to 50% (mainly students) who believe that the law of static equilibrium is the protagonist in this project; this duality may be because Newton's statics establishes the foundations of classical mechanics with the only condition of setting all accelerations equal to zero [14]. It is necessary to bear in mind that statics studies the equilibrium of bodies both at rest and in motion, but with constant speed; while dynamics studies accelerated bodies, which at some point can experience a dynamic equilibrium with the introduction of inertial forces [15].

Table 1. Comparison of response based on the informant's profile for item 1.

Answer options	Informant profile		Total
	Graduate	Student	
Newton's first law or law of inertia	40.0%	33.3%	34.6%
Newton's second law or fundamental law of dynamics	20.0%	9.5%	11.5%
Newton's third law or principle of action and reaction	0.0%	4.8%	3.8%
Law of mechanical equilibrium of bodies	40.0%	52.4%	50.0%
Total	100.0%	100.0%	100.0%

In the second item, from the urban component, the informants were asked if the Niterói-MAC has characteristics that make it stand out or be an iconic work. Table 2 shows that approximately 81% of the informants determined that it is a modernist work of an organic nature in which a visual counterbalance is made with the Cerro de Corcovado, the Cristo Redentor and the Pan de Azúcar in Rio of Janeiro's city, Brazil. This museum generates an open square of 2500 square meters, located on a water mirror that evokes a direct connection with the sea; developed from principles such as rhythm, which favors its structure, position, shape, and size; achieving a direct implantation and integration with the landscape.

Table 2. Comparison of response based on the informant's profile for item 2.

Answer options	Informant profile		Total
	Graduate	Student	
Being an organic modernist architectural work (...)	80.0%	81.0%	80.8%
Be a contemporary work of a classic order (...)	20.0%	9.5%	11.5%
Consider yourself a modernist structure with circular lines (...)	0.0%	9.5%	7.7%
Total	100.0%	100.0%	100.0%

The third item asked about the ordering principles that are part of the formal-spatial component of the museum (see Table 3), identifying that 84.6% suggest that symmetry, axiality and rhythm are the principles that are present in this architectural project, it is noted that graduates agree on this option, as opposed to 19% of students who chose the principle of addition, retraction, and procedure.

Finally, with to the importance of knowing, understanding and mastering concepts of physics when designing architectural works (see Table 4), it was possible to identify that there are predominant coincidences in both groups of informants in which the relevance of physics is recognized when moment

of designing a work, since it must be guaranteed that it is safe in its structure and at the same time harmonious with the environment. In other words, the formal, aesthetic, and structural must be articulated with the functional.

Table 3. Comparison of response based on the informant's profile for item 3.

Answer options	Informant profile		Total
	Graduate	Student	
Addition, retraction, and procedure	0.0%	19.0%	15.4%
Symmetry, axiality and rhythm	100.0%	81.0%	84.6%
Porosity, pattern, and orthogonality	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%

Table 4. Comparison of response based on the informant's profile for item 4.

Answer options	Informant profile	
	Graduate	Student
Respecting the laws of Physics helps to understand the structure of any work on which it must be guaranteed that it is safe	100.0%	86.0%
It is necessary to know them as well as to guarantee the harmony of the work with the environment in which it is immersed	0.0%	14.0%
Total	100.0%	100.0%

3.2. Qualitative phase

After the quantitative exploration of the perceptions of the informants, three of them were selected, based on their fluency and quality of argumentation, to carry out a semi-structured interview. This instrument is composed of three main questions and results are presented below. Each informant was identified with a code composed of the letter I followed by the number in the order in which they conducted the interview, then I1 represents the first interviewee of the group of three.

P1. What is the importance of analyzing architectural works in training as future architecture professionals? It is observed that I3 recognizes that this activity generates knowledge, since it allows to analyze the aspects, characteristics or elements that have been functional in architectural projects, in contrast to those that have not fulfilled their purpose. This activity is understood as a permanent reflection process on the professional's field of action. I1 argues that architecture must be in constant evolution, so studying these works from an architectural and structural point of view guarantees a constant update in terms of avant-garde mechanisms, materials and/or techniques. This opinion coincides with what was expressed by I2 who emphasizes that the importance of the relationship between the design of the architectural project and the space it occupies, is determined by a coherent, structured, and logical process, which broadens the perspective when designing.

P2. What are the aspects associated with physics that can be identified within the Niterói-MAC? The I3 affirms that "the morphology of this architectural work resembles the shape of a tree, and how the loads are distributed to achieve great heights and have weight in the upper part", so this person is seeing the work as a platform in equilibrium supported by a column in which it stands out that "it is convenient to visualize the shoe as being subjected to an upward force transmitted by the ground and to a downward reaction supplied by the column" so it can be said that this person sees the shoe like a cantilever beam. This analogy of a tree is also presented by I2, who complements his argument by including the action of "gravity is the most influential aspect in the Niterói-MAC, since at first glance it seems that the building is floating, Oscar Niemeyer intelligently takes advantage of his design gravity, which for other people can be an obstacle, he uses it as an advantage since, like a tree, the structure rests on a central body that goes to the foundation, anchoring itself to the ground like the roots of a tree".

Finally, the I1 goes further and expresses its argument supported by some physical laws, thus “it seems to me that it took into account two laws when carrying out the structural design of the museum, one of them is the law of action-reaction, where the soil where the museum is located is adapted so that it can withstand and react to the magnitude of the project's weight and at the same time have stability in the face of external factors such as the wind, thus being able to go against Newton's law of inertia”. Niemeyer designed a sixteen-meter-high radial structure, with a fifty-meter diameter roof and almost 2000 square meters of surface that is supported by a single 9-meter diameter cylindrical central support anchored in a giant two-meter-high footing. This complex structure that appears to float in the air was designed to support a weight equivalent to 400 kg/m² and winds of up to 200 km/hour; where the frames of the beams and pillars form a kind of table that is supported by a set of radial beams.

P3. Do you think that aspects such as: form-function, aesthetics-morphology, and structure-tectonics, can be strengthened in architectural works through the joint work between physics and architecture? Why? In this questioning, everyone agrees that it is necessary in the process of training architects to consider training in physics topics, since as I1 says “know the behavior of weights, the force of gravity, entropy, inertia, concepts basic such as force, vector, moment, effort, resistance, stiffness, load, tension, elasticity, deformation, leads us to understand how a shear force, a tensile stress, compression stress, tangential stress is produced, among others”, by what “having these notions of physics gives us freedom to make bold and innovative designs, since we know the limits and what would be impossible or possible to do by identifying the critical points of our architectural designs”. I2 recognizes that a project could have shortcomings when considering it if the physical concepts are still unknown at the structural level at the time of their design. It recognizes the need to “must in all work articulate the aesthetic as well as the structural, only in this way can iconic and safe works be generated”.

4. Conclusions

This research allowed to corroborate the relationship that exists between architecture and physics, the foregoing by recognizing that its application favors the structural and formal design of the architectural project. In the case of the Museum of Contemporary Art Niterói, Brazil, the structure was conceived as a fundamental pillar of its project stage; therefore, the structural load support, the central support and the monolithic structure are directly associated with the ordering design criteria: Axiality, symmetry and rhythm. This shows that the joint work between physics and architecture allows generating a balance within the composition of the project that encourages impact and in the case of the Museum of Contemporary Art Niterói, Brazil, a successful interrelation with the urban landscape, organized based on the form, the function, materiality, structure, and scale.

The methodological framework of this research favored the recognition of the perception presented by students and graduates of the Architecture program of the Universidad Francisco de Paula Santander, Colombia, about the importance of the analysis of architectural projects in the professional training of the architect. This becomes relevant, when understanding that within the basic competences of the architect are the understanding of the formal, material, functional and structural aspects of the architectural project. Therefore, the learning results obtained from the analysis of architectural projects allow the student to identify elements, techniques, characteristics of the project from architecture and physics; thus, favoring the generation of processes of analysis, reflection, argumentation, and criticism, which will favor the understanding of architecture and professional practice.

Finally, it was evidenced that students and graduates of the Architecture program of the Universidad Francisco de Paula Santander, Colombia, manifest a basic knowledge of the physical elements applied to architecture, specifically in the case of the Museum of Contemporary Art Niterói, Brazil, in the which recognized the formal, spatial, urban, and structural aspects, that characterize it. However, to enhance the application and understanding of the basic concepts of physics in architecture, it is recommended that, based on the subjects associated with the project (workshop), historical technological component (structures, histories), exercises aimed at the analysis of architectural projects as a pedagogical tool.

References

- [1] Bullaro L 2014 Moderno y tropical: la reinterpretación de los principios lecorbuserianos en las primeras obras de Oscar Niemeyer *Dearq* **15** 38
- [2] González Escobar L F 2013 Oscar Niemeyer el legado de un gran arquitecto *Revista Universidad de Antioquia* **311** 90
- [3] Chávez Giraldo J F 2017 Niemeyer: el espacio convertido en invención *Arquitectura y Urbanismo* **38(3)** 87
- [4] Zubaran L C, Silva da Silveira L A, Catafesto L A 2002 *Entrevista com o arquiteto Oscar Niemeyer* (Canoas: Ulbra)
- [5] Neiva S 2008 Museu de Arte Contemporânea de Niterói: leveza moldada em concreto *Arquitectura Revista* **4(1)** 66
- [6] Philippou S 2013 El modernismo radical de Oscar Niemeyer *Arquitectura y Urbanismo* **34(2)** 5
- [7] Cascanate J 2011 *Métodos Mixtos de Investigación. Guía de Estudio* (San José: Universidad Estatal a Distancia)
- [8] Dudeque M C 2009 *O Lugar na Obra de Oscar Niemeyer* (São Paulo: Universidad de Sao Paolo)
- [9] Segre R 2007 Oscar Niemeyer un joven centenario *Arquitectura y Urbanismo* **28(2)** 10
- [10] Chavez M 2018 *Edificios de Moda: Pasarelas en Arquitecturas Singulares* (Madrid: Universidad Politécnica de Madrid)
- [11] Soler V 2015 *Análisis de la Estructura del Museo de Arte Contemporáneo de Niterói (O Niemeyer)* (Valencia: Universidad Politécnica de Valencia)
- [12] Zeballos M 2014 *Calculo Estructural del Museo de Arte Contemporáneo Niterói bajo las Normas Peruanas* (Arequipa: Universidad Católica de Santa María)
- [13] Díaz L F 2001 Evaluación de carreras universitarias *Ciencias Sociales* **4(94)** 61
- [14] Vaccaro D S 2008 La tensión entre estática y dinámica desde la antigüedad hasta el renacimiento *Scientiae Studia* **6** 509
- [15] McKelvey J P, Grotch H, Everest S F 1980 *Física para Ciencias e Ingeniería* (México: Harla)