Architecture of Structural Membrane in Chile

Form Follows Structural Stress in the Search of Lightness

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Abstract. The present paper deals with the theoretical and technical reflection on basic structural principles that allow the generation and controlling of architectural complexity of double curvature surfaces. Despite the difficulties in designing and building such complex forms, Chile has several examples that were developed and built during the first half of the twentieth century. All of them were developed with local building technologies which studied the implementation of experimental and simple materials with innovative mounting techniques. All of them explored new structural concepts generating great interest of architectural spaces for religious cult, housing and civil works. The research objective of this work deals with the recognition and analysis with contemporary modelling and simulation tools that can reveal the type of relationship that occurs between the initial conception of the architectural shape and membranous structural surfaces. Their curvature and sleekness generated innovative structural spaces that contain an architectural envelope with clear and revealing expression of the acting forces.

Keywords: Membranes; shells; structural geometry; digital design simulation; structural simulation.

Introduction

Nowadays the digital technology has provided the access to generating complex architectural forms, with different methodologies, however, often, in this simulated creative processes we found that some of the real world conditions are absent; such gravity force, and these should be the first considerations, when approaching to the physical realization of the projects. Some architects like Frank Gehry, illustrate the accomplishment of formal freedom that the digital tools provide. However the construction of these complex architectural objects is based mainly in the traditional crossing of beams, or linear structural elements, hidden behind a non structural skin. Referring to this, authors like Martin Bechthold expose the following critic: (…) “Visible Surfaces in these free forms generally do not play any structural roll. The structure depends mainly on flexion efforts, the less effective method for load transmission. Curvatures present in free shapes, rarely allow to develop membrane efforts” (…), which will be seen further on this paper.
Frank Gehry’s graph shows the constructive system of one wall of the Guggenheim Museum in Bilbao, which is based in the crossing of linear structural pieces covered by a non-structural skin. The antique structural concepts of laminar work are in general ignored by contemporary architects, considering that there are some notable constructions and not so known, these works are usually called shells or structural skins. These have been developed in Chile as well as on the rest of the world, during the first half of the nineteenth century. These works show developments in the architectonic search for quality spaces, material optimization together with structural efficiency.

In the world we found constructions where the structural condition generates quality spaces, relating engineering to architecture, in an also creative way, establishing some interdisciplinary bridges. The architecture of structural membrane presents variety of possibilities, such as tensed membranes, collaborative nets, and rigid membranes; on this last category is that the work of this paper is focused.

In Chile we found constructed works of this type for several years, but we rarely stop to watch its real beauty. These are considered as rare cases or singular experiments, which have been constructed exploring diverse material techniques and present characteristics of great interest. (Figure 1)

In general the works if these type present complex curved surfaces, which generate spatial relations and constructive relations without precedents in architecture at the time, a fluid spatiality that allows the use of free plan as a result. In this innovative vision, a complex integration between wall and ceiling is created, where the structural function between vertical and horizontal pieces, differs from the concept of roof as something independent from walls. By dissolving the concept of wall and roof and creating only one surface that takes care of their role, we get a structural skin.

It is very important to mention that the exercise of revising the recent history in relation to the matters that this paper presents, does not intend to be a nostalgic review, but instead, seeking the potential application of these forgotten works of innovation. By this, it is expected to wake a slept topic in relation to Chilean architectonic patrimony and to develop a reflection about the contribution this could mean for future architectural projects.

**Objectives**

The general objective of this investigation consists on rediscovering some forgotten built structures in Chile, which date from the first half of the nineteenth century, and lie under the concept of structural curved surfaces, or structural membrane. This study is done by means of a theoretical analysis, and through this, to make an architectural contribution to researchers on the subject.
It is the main goal to develop an operative language that supports the theoretical discussion on how form follows tension, and the benefits that this may bring to architectural projects, by establishing the shared logic between architectural shape and resistant form.

**Methodologies**

The structural concepts applied on these architectures, and the way in which they intervene on the design stage of the building, will be revised through digital tools, that allow simulating structural behaviors with an intuitive focus, and a simple graphic language on its representation.

As a first step, digital models are built based on the abstracted geometries of each building chose for the study. For this matter, they were simulated with a continuous and isotropic material, so that the structural behavior scheme could be abstracted, in order to make general observations about the structural type and its relations to architectural space.

(Figure 2)

Understanding the complexity that implies the precise analysis of any digital model, the present study searches to make a general analysis through the vision of an architect that seeks discovering the logic of structural form. So the focus of the study is qualitative, and searches to evidence the critical tensioned zones of some structures, however, it doesn’t seek to determine tension calculations or to asses fatigue. It is an intuitive work made to help architects to understand some basic conceptual engineering criteria that should be applied by the designers when defining the complex shapes of the studied architecture.

To make visible the invisibility of resistance phenomena helped make tangible this unknown field of static fundaments. This shall help us architects to enrich our projects, creating designs with greater liberty, by using forms that are activated by forces.

**Study of resistance phenomena on structural curved membranes.**

As a first step a simulation is made on a surface that is deformed gradually by a curvature, and to these
deformations is applied the same load, than to the original surface. This shows that the structural phenomena applied in the study cases is based on giving a resistance condition to a membrane with minimal thickness by deforming them with structural curvatures or folds. This establishes a relation on reaching the maximum resistance with less material by using deformation, on the search for lightness.

By watching the graphic results of the exercise, it can be approved that the plane shell, in relation to the curved shells, doesn't react in the same way to the forces. The plane membrane should have a much taller section, and a bigger amount of mass, in order to avoid deformation. So curvature seems to allow mass reduction and favor efficient structural behavior.

**Study Cases**

The study cases are located in Chile; these buildings arise during the intellectual context in which arises modern architecture. This invites some architects to explore the plastic possibilities of new Technologies and materials, such as reinforced cement and steel. In Chile, since 1945 the Compañía de Aceros del Pacífico started producing steel, which gave an extraordinary opportunity to start building with this material. On the other hand, we have the unstable sismic condition of Chile. The sismic territory of Chile, demands great structural considerations on building, but also it encourages innovating on structural matters.

The buildings revised next are a selection of a larger group of works and projects that explore rigid membranes considering structural criteria during the design process.

**Chillan Cathedral, Chile:**

The earthquake of 1939 in Chillán not only surprised the inhabitants of the city for the level of destruction, but also because of the great renovation this meant for the city when the reconstruction began. In this context, is that Hernán Larrain's Cathedral took place, as one of the buildings of the reconstruction plan. (Figure 4)

The innovative forms of Chillan's Cathedral remind us of the huge hangars built in 1919 in Orly, by Eugienne Freyssinet. The hangars of Orly were constructed with membranes of reinforced cement, and its scale defies the bear of their own weight and the
loads of wind. To help with these matters the shape of the membrane is curved and folded into a continuity of nerves.

These structural principals, developed originally in industrial buildings, were taken by Larraín to worship buildings, reading the possibility of filtering the light through the cement structure to create a space qualified by this light as a space for cult. The geometry of the cathedral is composed by a truncated conoid curved sheet and of reinforcement nerves between elliptic support arches. This shows another way of enlightening mass, and at the same time provides rigidity.

The search for lightness on this case is based on the exploration of the concept of the arch, but through the use of small section curved surfaces, combined in an expressive development of light.

**German School’s Church, Los Angeles, Chile. 1954:**

The church is made of steel; as it was mentioned before in this paper, Compañía de Aceros del Pacífico fomented the innovation in construction with this material, providing quality certification. (Figure 7 and 8)

The geometrical construction based on ruled surfaces offers multiple spatial possibilities as for the chance they offer of reducing the number of points by which the structure touches the ground, this allows to liberate internal space, offering considerable big collective spaces. This building in particular defies its lecture from orthogonal projections, meaning that its generative logic is three dimensional rather than planar.

**Villa President Antonio Ríos:**

The villa President José Antonio Ríos is a housing Project built in Santiago on 1958 thanks to the design of Guillermo Geisse, Francisco Hurtado and Sergio Rojo, it has been considered as an important modern architectural piece in Chile. The villa presents a double building that is sustained by a pillar, composed by hyperbolic paraboloids.

It is on the base of the building that this study focuses, on the concept of centralized buildings which settle in pairs to avoid torsion and have a structure called hyperbolic paraboloids umbrella. The original ideas of Felix Candela were interpreted in Chile, but taken to the limit of its architectonic expression. This shape has been explored beyond the original idea in search of other possibilities.

The structural system establishes composed platforms, by four paraboloids united by nerves that
lead the forces to the central masts.

**Candelaria Chapel, San Pedro de Concepción, Chile:**
This chapel corresponds to a series of sacred buildings that were designed by the Universidad Católica de Valparaíso, to rebuild the destroyed spaces for cult after the 1960 earthquake. The designers were Arturo Baeza and Sergio Rojo.
The surfaces relate the line with the curve through a series of ellipses. This building is made out of wood and it differs from the other study cases by introducing the use of prefabrication. The surface was first planned to be made with linear wood, but because of the impermeability needs, the architects had to develop the

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**Figure 7**
The building combine a series of Hyperbolic Paraboloids that support themselves mutually on their rectilinear edges, acting like beams. There are auto-support perimeter walls.

**Figure 8**
The structure is based on woven surfaces, made out of a grid of round sectioned steel bars, tensioned by welded steel diagonals. This surface acts like a stereo metric curved membrane which lean son reticulated beams.

**Figure 9**
Rules Geometry allows studying the system of hyperboles and parables as if the material was continuous, and simulate possible simplified behaviors. On the graphs we can appreciate that the surface concentrates the critical loads on two areas; on the highest support points, and on the longer perimeter sides.
outside skin with curved wood, which gives the building its great appearance. The plates were brought completely built to the construction site, where they were just mounted. (Figure 11)

On the effort graph we can appreciate that without considering the quality of the membrane construction, the most deformed and tensioned areas are on the perimeter edge and on the top ridges. This is exactly where the structure collapsed during the 80’s.

This structural system is then defined by individual pieces, connected between them with weak unions, which mean that this building was not working as a membrane.

**Synthesis and Conclusions**

The selection of buildings shown in this paper allows understanding generally the genesis of its proposals in terms of structural geometries and constructive logic. It is interesting to compare the revised buildings, together with other Chilean works that were left out for a matter of extension, in front of some of the great buildings that were made following these structural concepts in Europe. (Figure 11)

Our national buildings have the value of being made from the modesty of means, with a professional expertise that has generated a knowledge and experimentation on the structural phenomena from another perception of resisting form. Even if the study cases do not correspond to homogeneous membranes, through the digital tools it was possible to simulate the construction of those shapes under admissible tensions and an isotropic behavior.

In this sense, and in despite of having very different characteristics between the revised buildings, there can be distinguished two groups, on one side we have the double curved shell systems, as hyperbolic paraboloids; and another group of arched sheets or membranes, that make cylindrical short vaults. Two approximations to the generation of
these types of buildings can be distinguished.

The geometrical construction of the volume, where different design and shape control resources appear: The application of mathematical functions that define geometrical surface generators; Surfaces generated by the relative movement between geometrical elements; Physical tension experiments, from which the architectural and geometric form can be extracted. In order to realize these formal explorations advanced geometric concepts have to be studied, besides than a complex geometrical thought.

The physical construction of the surfaces, where appear two simultaneous searches: The search for material lightness through the diminished section of the elements, and the election of materials of great structural efficiency, as reinforced cement, or steel. However it is of relevance to mention that the behavior of the Candelaria Chapel that did as a matter of fact collapse, was the same on the simulations than on the reality, despite that on the simulation the material that gave form to the shape was isotropic and continuous, and in real life this project was made out of diagonal layers of nailed wood, which shows great structural discontinuity. This coincidence means that the constructive quality of the skin is not enough to sustain itself, shape is also important.

Finally as a general observation, these types of buildings are an evidence of a stage of growth and maturity in the schools of architecture due to the mathematic and geometric rigor, and from there the capability of facing the concept of architectural plastic.

The Chilean Works belong to a small group of professionals related between each other, through some specific architectonic influences, especially through the way of thinking the architectural shape in relation to engineering, through shared logics of the disciplines, such as analytic geometry and descriptive geometry.

References


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