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THE DESIGN AND APPLICATION OF LANTERNS IN TENT STRUCTURES

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Summary This work describes the design and construction of lanterns and their application in tent structures by looking at four projects in chronological order that have been developed by the Structures Laboratory of the Faculty of Architecture at the Universidad Nacional Autónoma de México (UNAM) over the last decade. Through these projects this paper deals with the functional and aesthetic aspects of lanterns, their usefulness in assembly and disassembly of tent structures and the materials used in their construction.

1 INTRODUCTION

Throughout the history of architecture light has been an essential element in the construction of dwelling space. Definitions of architecture like that of Le Corbusier "*...architecture is the masterly, correct and magnificent play of masses brought together in light...*" or the work of Mexican architect, Luis Barragán, make this clear.

Within textile architecture, light plays a very important role, both in terms of function and appearance. The translucence and opaqueness of plastic membranes fulfils the users' need for light in order to allow them to carry out diverse activities in a certain space. Furthermore, light evokes different feelings in the user through the various atmospheres it creates in the interior.

However, in certain cases additional elements are required to provide greater richness and complement the lighting capacity of the membrane and aid installation of the membrane itself. The Structures Laboratory team of the Faculty of Architecture at the UNAM has incorporated these components, which we may identify with the term "*lanterns*", in various projects for tent structures. In this context, the term "lantern" is used to refer to "a structure on top of a dome or roof having openings or windows to admit light" [1].

1 LANTERN DESIGN

In order to present the variables involved in the design and construction of a *lantern*, the two basic components that it includes should be described: firstly, a structure that ensures stiffness and works as a element for fitting the membrane, as well as the fittings for lifting it to the structure of the entire system, and secondly a transparent or translucent surface over the top of the structure that allows the passage of light. The design process involves the specification of the materials for the structure, such as steel or aluminium with welded or bolted fittings, and for the translucent surface, for which tempered glass, acrylic or polycarbonate panels with UV protection may be used. Any of latter materials, used for constructing the translucent surface, may be finished with two-dimensional shapes that are sandblasted or with the application of self-adhesive plastic film to control solar incidence and generate lighting effects inside the covered space.

The geometric configuration of the *lantern* may vary greatly. For the design of the structure, the shapes found on the plane of a fixed circle of radius or similar curves, such as elliptic curves, are the most appropriate, given that the stresses are more evenly spread over what may be described as a traction ring. Fixed double or triple curves, which can be modelled with NURBS curves (*freeforms*), are a good option providing that they comply with strict criteria in relation to the structural behaviour of the membrane.

As regards the translucent layer, the geometry of the surface must be regarded as a developable surface in the event of making flat panels as in the case of glass. In this regard, the use of acrylic or polycarbonate in the design makes it possible to consider using thermoforming for the construction of the lanterns. Using thermoforming the lanterns can be made with surfaces with synclastic or anticlastic curves in one piece or various pieces, depending on the scale required.

For the structural analysis, in the same way as for other components such as poles, arches or cables, the loads transmitted by the membrane to the lantern must be taken into account, considering dead load, pre-traction and the loads produced by the wind or snow (in regions where this is necessary). It is worth noting that providing for the logistics of installation during the design phase is extremely important. This should include providing for the load and stress conditions to which the structure will be subjected during assembly in to order to design the necessary fixtures.

2 PALACIO DE MINERIA.

Various factors make the roof for the central courtyard of the Palacio de Mineria building an icon of textile architecture in Mexico. The first is the importance of the neoclassical building, constructed by Manuel Tolsa in the nineteenth century. The second is the scale of the roof, which covers an area of approximately 1000 m^2. The final factor is the function that the roof performs, providing shade and protecting from the rain and thus enabling diverse events organised in the space each year, such as the international book fair, conferences, concerts, exhibitions and even fashion shows. The functionality of the structure, together with its lightness and flexibility enhance this historic building with its foundations in the former Mexico Valley basin.

Right from the preliminary design phase of the tent structure, which was constructed in 2002, there were plans to include a lantern that would create overhead lighting in the courtyard, as well as forming the point in which the eight sections that make up the main cover of the structure would join. In addition, the *lantern* was designed to aid the assembly and disassembly of the roof, given that one of the principles on which the roof was based was that it could be removed, i.e. it had to be possible to assemble and disassemble it within a certain length of time in order to leave the courtyard of the building as it was originally designed. This condition, driven by the design team in order to protect the building, was based on the regulations set by the Mexican Institute of Anthropology and History (INAH), the organisation responsible for the protection and conservation of architectural heritage dating back to the period prior to the twentieth century in Mexico.

Figure 1: Interior view of the tent structure over the central courtyard of the Palacio de Minería building.

The structure of the *lantern* rises 23 m above the floor level of the courtyard, has a diameter of 2.5 m and was designed in structural steel with standard profiles with an electroplating finish created using hot immersion. The translucent surface was constructed with eight acrylic sections that follow the geometry of the cross section of a sphere with a height of 0.70 m. The traction ring is stiffened with two sets of two perpendicular cables, in order to avoid any deformation during the installation process. In this position, there are two articulated sheaves around which the cable that is used to lift the membrane towards the two cable poles passes. There are a further two sheaves at the highest point, which direct the cable towards the two independent electric hand winches, from the east to west side of the building. During the installation process, temporary structures were placed in position to protect the balustrade of the building.

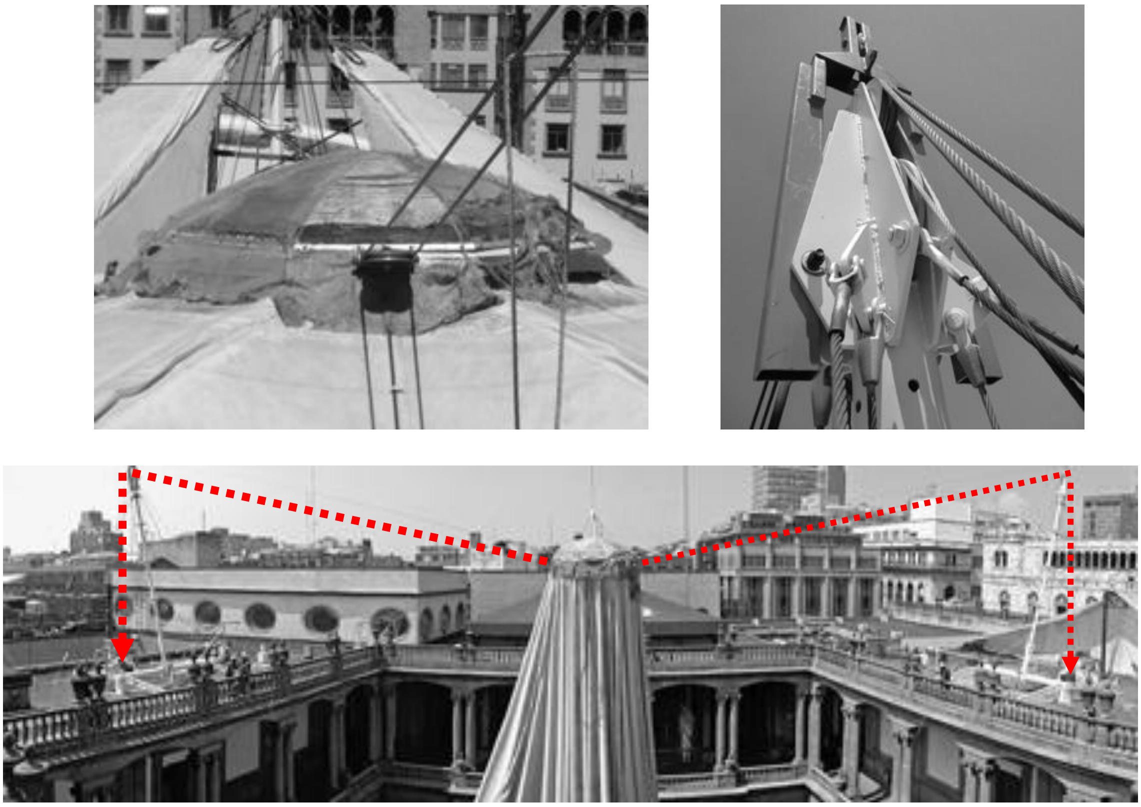

Figure 2: Lantern and lifting system

Over the course of nine years of use, it was not necessary to remove the structure. However, at the end of this period, the building authorities decided to change the membrane of the roof without changing the original design, given that, although the structure was still in good mechanical condition, its appearance had been strongly affected by the level of pollution in Mexico City and to the lack of regular maintenance. In 2011, with the technology now available on the Mexican market, the design has been improved. For the lantern, in particular, the dimensions have been maintained. The improvements to the design essentially consisted in the replacement of the lifting sheave with two fixed cables with a parallel electrically controlled disassembly and assembly system, which ensures even lifting, and the replacement of the translucent surface with a thermoformed acrylic surface made up of four sections. The specification for the latter was originally solid polycarbonate. However, conditions for thermoforming this material are very precise as regards the level of humidity in the environment and the initial test for its manufacture was negative. Hence the specification was changed to highly impact-resistant acrylic.

Lastly, with the replacement of this roof, it was proved that the removable system works perfectly and the qualities of the structural system do not affect the building in any way.

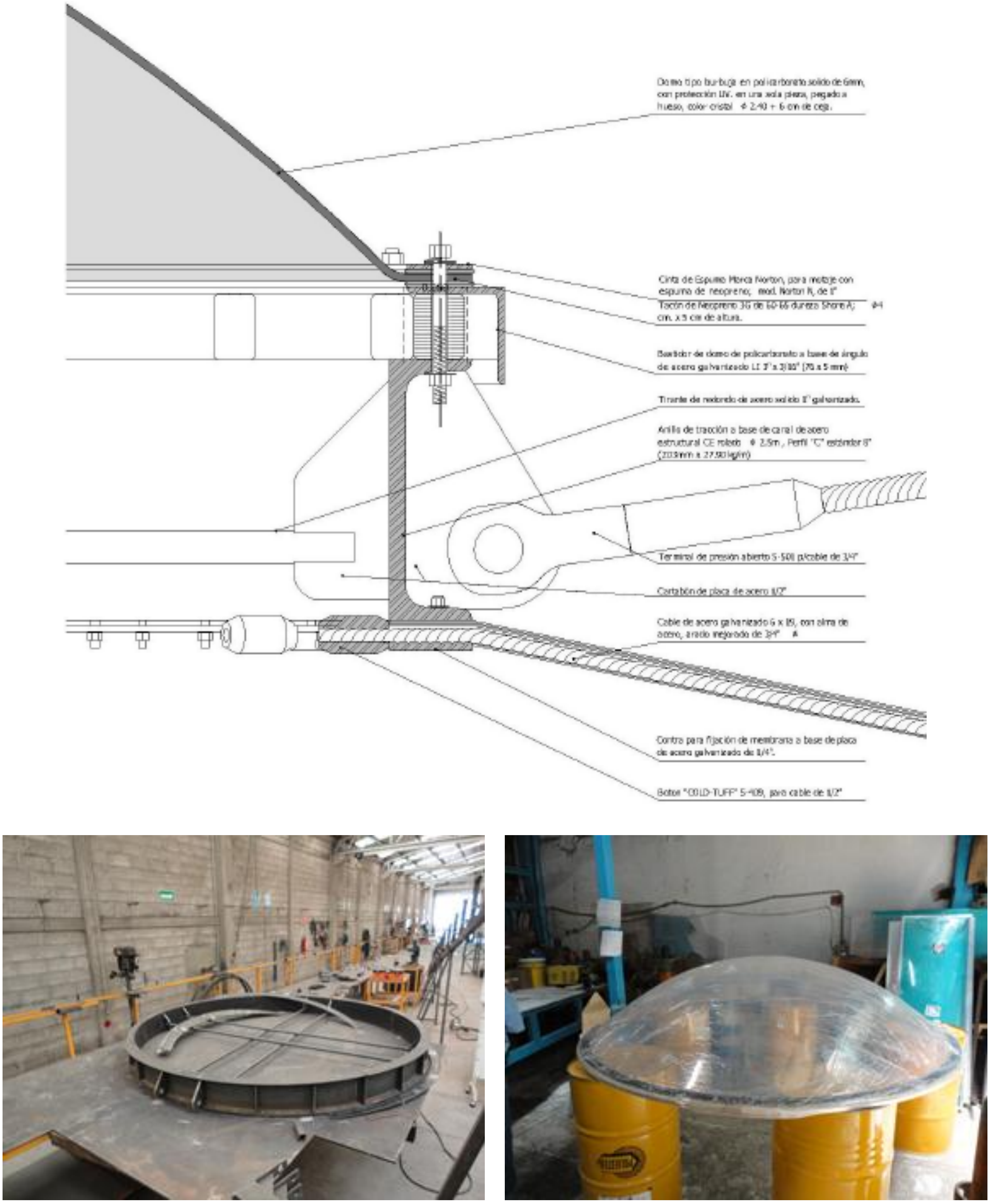

Figure 3: Detail of the lantern and construction of the replacement lantern

2 TELEVISION AZTECA.

Television Azteca, located in the south of Mexico City, is the second largest open television network in Mexico. In 2004, it requested a tent structure to cover an area of approximately 700 m^2 located between its recording studios in order to create a space that would be protected from the sun and rain, which actors, presenters, technicians, administrative staff and the other users within the company could use to move from one area to another.

Based on previous experience with the roof of the central courtyard of the Palacio de Minería building and in developing the initial design for the roof of Mexico City's International Benito Juárez Airport, a structure was designed in the form of a stretched sheet deformed by an ogive shape *lantern*, creating a conical surface. The design is made up of five *lanterns* distributed along the walkway, where they create alternating light and shade, which changes over the course of the day according to the position of the sun, creating spatial sequences that contribute to breaking up the linearity of the walkway.

Figure 4: Image of the initial design and a view of the interior.

The fixed geometrical point of the structure is the intersection of the two circular arcs that make up the ogive. The structure was constructed in structural steel with a series of cross profiles to increase its stiffness and enable the fittings to be positioned where the cables for its installation were to be held. The translucent surface is a conoid, which makes up of a polygon of flat plates of tempered glass. The structure measures 4 m at its widest axis, 1.90 m at its narrowest axis and rises 8 m above the finished floor level.

Figure 5: Lantern made with structural steel and tempered glass.

As in the case of the central courtyard of the Palacio de Minería building, the *lanterns* were designed to work as a lifting system during installation. The difference in this case is that the structure was not strictly required to be removable, although this is nevertheless an inherent characteristic of the structure. It is worth noting that during the construction process, the problem arose of bad quality welding of the aluminium. This was owing to the fact that in Mexico there is little experience in working with this kind of material. As a result, it was necessary to reinforce the joints of the structure with bolted plates.

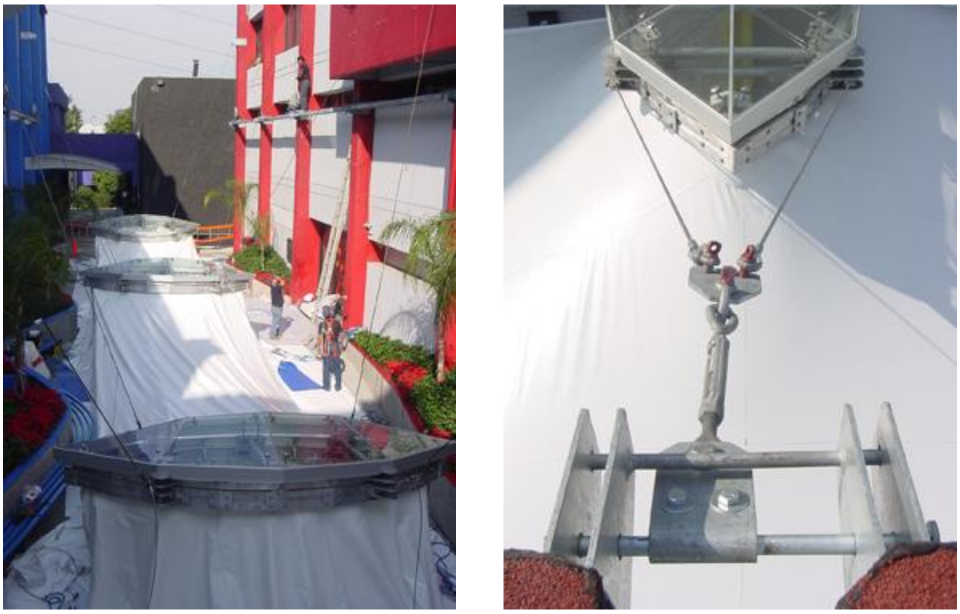

Figure 6: Installation and detail of fittings for assembly

3 PALACIO UNIVERSUM MUSEUM

In 2006, a renovation project was developed for the old Government House building in Oaxaca city. The building is one of great importance. In its day it was the office of Benito

Juárez, Outstanding Patriot of the Americas and it now houses what is known as the Palacio Universum Museum. Based on the prior experience of installing a removable tent structure on a historic building gained at the Palacio de Minería, it was decided that this system was the most suitable for covering the three courtyards, which cover an area of approximately 900 m^2. The previous layout was followed, with lanterns at the centre of each courtyard providing overhead lighting throughout the day.

Figure 7: View of an interior with the lighting effect in the courtyard and detail of a secondary lantern.

In the rectangular central courtyard, a lantern with an elliptic form was installed, measuring 8 m at its widest axis and 4 m at its narrowest axis. In each of the two neighbouring courtyards a lantern was installed with a diameter of 3 m. In all three cases, the lanterns have a height of 0.90 m and rise 16 m above the floor level of the building. The structure was constructed in steel with an electroplating finish created using hot immersion and metal profiles and cables to provide perpendicular reinforcement. The translucent surface follows the same pattern as the lanterns constructed for Televisión Azteca. However, by contrast to the latter, they were made with solid polycarbonate plates, making the lanterns lighter.

Figure 8: View from above and detail of the lantern in the central courtyard.

As in the previous examples, the lanterns incorporate fittings for the installation of the structure. In this case, provisional lifting cables were installed, directed towards the top of the poles of the supporting structure. There they pass around a series of sheaves to change direction towards a mechanical winch located on the shaft of the pole itself. Once the *lantern* was in position, the cables were replaced with other permanent cables. The challenge in this project was to complete the design and construction phases in just two months. This was successfully achieved.

Figure 9: Installation and detail of the lifting system.

4 CENTRO UNIVERSITARIO DE TEATRO

In 2011, the UNAM's Centro Universitario de Teatro (university theatre centre), asked the

Structures Laboratory at the university to design a permanent structure to cover an area of approximately 400 m^2 between two buildings. The aim of the project was to create a space that would be protected from the sun and rain in which to organise activities connected with classical and contemporary theatre performances. The two buildings in question are of differing heights, allowing the creation of a covered area on the roof of one of the buildings, which may be used as a cafeteria or restaurant.

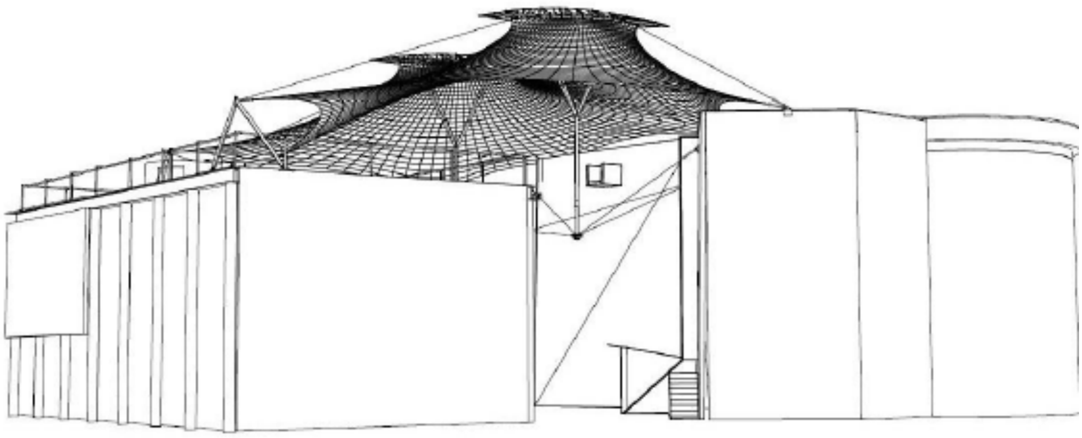

Figure 10: Elevation showing the layout of the roof and the system of lanterns with floating poles.

The design is made up of two membranes joined in a cone-like shape, with two raised *lanterns* with a system of floating poles measuring 8 m in length. An ellipse measuring 5 m at its broadest axis and 1.50 m in its narrowest axis holds the membrane. The translucent surface has been developed as a segment of an intersected cone with a vertical plane, measuring 8 m at the broadest axis and 2.20 m at the narrowest axis and with a height of 0.40 m. Using these dimensions, which exceed the size of the structure itself, ensures that water cannot get in. The lanterns are designed to have a steel structure with an electroplating finish created using hot immersion. The floating poles will be of variable diameters and have a traction system. The translucent surface will be made of solid polycarbonate. The two elements rise 15 m above the level of the courtyard, making up a lifting system with a series of additional cables that ensure the system remains in equilibrium.

CONCLUSIONS

- The use of *lanterns* in addition to the basic components applied in the design and construction of tent structures, such as poles, arches, reinforcement plates and traction fittings is entirely appropriate given that they provide greater quality to the dwelling space. Furthermore, roof lanterns have become an extremely useful element in completing the installation process of this kind of structure in a satisfactory manner.

- Over the last decade, several projects have been developed on varying scales, applying different materials in the design and construction of lanterns, like steel, aluminium, tempered glass, acrylic and polycarbonate. In certain cases, the results were not satisfactory; however, this has contributed to enhancing the design and construction of new projects.

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