Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Caña Viva Pavilion, a Sustainable Low + High Tech organic proposal

Ronan BOLAÑOS*, Marcos J. ONTIVEROS[a], Rodrigo SHIORDIA[b], Lorelí ORTIZ[c,]

*UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
Laboratorio de Arquitectura + Diseño y Tecnología Experimental (LATE)
Edificio Principal K101 · Facultad de Arquitectura · Circuito Escolar CU · Coyoacán
04510 México, CDMX Email ronanb@unam.mx

Abstract

This work presents the results of the academic collaboration between professors and students of architecture from the National Autonomous University of Mexico (UNAM) and experts in natural building techniques with the purpose of designing and building a reticular structure of natural cane from July to September 2023, for a prestigious international architecture festival called Mextrópoli, in Mexico City. The construction system integrates a natural fiber material with simple manual techniques, parametric design processes, and robotic digital manufacturing, proving the viability of harmonious coexistence between different levels of technology and proposing a sustainable alternative for the construction of light short-span structures.

The pavilion consists of a reticular shell composed of a series of plastically deformed and interlocking arches. The sections of these arches are composed of several clusters of “Arundo Donax” reeds coupled by natural rope ties, forming modules that unload their weight on superficial custom fiber reinforced concrete supports designed to receive the curved geometry of the structure without damaging the pavement of their temporal historic location. These supports were fabricated with an ABB robotic arm.
The system used is called Canya Viva and was developed by the British architect Jonathan Cory Wright. In this pavilion, the principles developed by Cory Wright were taken into account, besides creating some other techniques to adapt to geometric conditions that had not been resolved before with this construction system.

The geometric design, which forms a ring in plan and presents warps in elevation, was developed parametrically with Grasshopper and Python. A transition surface is generated between parabolic arcs whose points change height through a trigonometric function. All parts of the structure intertwine to form an original flexible fabric that generates concave and convex sections downwards and upwards with different heights that assemble a continuous and fluid space.

Keywords: Parametric Design, Digital Fabrication, Natural Building Techniques, Sustainability, Natural fibers

1. Introduction

The 'Caña Viva' pavilion is a proposal by the Laboratory of Architecture + Design and Technological Experimentation (LATE) and the Light Structures Laboratory (LEL) of the Faculty of Architecture of UNAM, it was assembled as an urban installation for a recognized international architecture festival in 2023. In previous participations in the same festival, we have sought to develop sustainable criteria such as rain harvesting, the use of organic materials, and the reduction of the number of materials to facilitate construction. Above all, we have sought to experiment by developing complex forms that can be efficiently designed through parametric design, and materialized with digital manufacturing, to test unconventional techniques, while our students get involved in learning throughout the making, and can assess the use of the material in question, the complexity of the forms and the structural and constructive criteria (Bolaños, [1]).

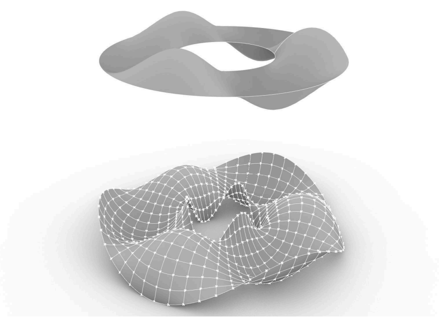
The proposal arises from the search for a reticular shell, a curved and complex geometric configuration, the previous use of wood and bamboo, and the discovery of an attractive and scarcely used material, the reed, or *Arundo donax* cane, canes that when bent while still fresh, or 'alive', can be bent with a very tight curvature with radii less than one meter.

Considering that the reed is an organic material and therefore carbon sequestrant, a renewable material with a useful growth cycle of two years and that even though it is abundant in the region, In many cases it is underutilized, whereby It was considered an attractive material, worth considering testing.

In the initial work team, some graduate students were incorporated, Lorelí Ortiz, who rehearsed with the system previously and Rodrigo Shordia another expert in computational design, also integrating as an external advisor, Marco Berumen an expert in the construction system and who operated as a bridge with Jonathan Cory-Wright developer of the construction system. We, Ronan Bolaños from LATE and Marcos Ontiveros from LEL served as managers and participated in every task of the project.

2. Design Process

The initial geometric proposal as a roof with a ring-shaped plan, with positive and negative elevation warps, was presented to Jonathan Cory-Wright who pointed out that he had never tried negative warps, therefore we wanted to include this as a challenge, for the rest we agreed that it would work, except for some aspects that required adjustment. The idea of a coating that would extend the life of the cane was left aside, and any possibility of a closed cover was also left out since it required temporal and budgetary conditions that we did not have for this ephemeral festival. Following the design evolution, we went from the elliptical section curves to catenaries, we lowered the edges of the positive warps to the floor so that the same structure would transfer the whole load to the bases, while we reduced the height of negative warping so as not to increase the size of the structure, which had a limit of 10m in plan diameter, this, in accordance with a pre-sizing criteria that adjusted to our construction yard, the space designated in the festival, the weight of the project and the span to be covered, which in turn conditioned the number of canes to be integrated. With the reduction of the height of the negative warps, it was possible to free up a continuous path for a walk under the structure throughout the circuit.



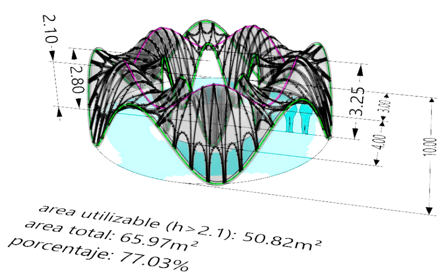


Figure 1,2: (left) Initial geometry diagram [R. Bolaños] (right): Geometric development and internal height analysis [R. Shiordia]

We have to consider that the reeds have a usual growth of between 4 and 6 m, an average diameter of use of 25mm, and an average weight of 241g per linear meter of the construction system, reed plus string. That there are five positive and five negative radial warps in the project, and that in each warp there are three pairs of arcs that start together, separate following an 's' curve until halfway along the development to join with their neighbor on the opposite side to the start, at the end of development they return together with a reverse curve. Since each of these arches has 2 modules of 7 reeds in section, according to the recommended number of reeds in relation to the span (Cory-Wright [2]), and that up to four reinforcement reeds and four reed tips must be added (Wright Cory [3]) where the radius is smaller, we have that each arch has 22 reeds. Now, since these arches have an equal development in number of reeds given that the range of the distance to be covered by the radial arches can be done with the same composition, we have 132 reeds per warp, with a total of 1320 reeds in the 10 warps.

Now in the case of the inner perimeter ring, there are 10 arches of 11 reeds and in the outer perimeter ring, there are 10 arches of 14 reeds, with a total of 500 reeds. Adding the radial and perimeter arches we have a total of 1820 reeds. Considering a waste of ~ 45% of canes that break for different reasons, usually due to incidental perpendicular forces, or that have to be discarded because they do not have the appropriate length or diameter, we have a total of 3309 canes to harvest.

In the growth of cane, the proportion of starches is greater with respect to the amount of fiber in a young stage, while in a mature state, the proportion is inverted. Therefore, when harvesting it is necessary to consider canes that are about two years old, which begin to have secondary branches.

4. The harvest in Xochimilco and the integration of the workshop

Since this species of cane is abundant in tropical latitudes, and particularly in the central area of Mexico, we looked in the *chinampas* of Xochimilco, a wetland section of Mexico City with very fertile manmade islands that are very fertile for crop harvesting, for areas with abundant growth that would allow us an effective harvest. We integrated students from different educational levels from undergraduate to postgraduate to participate in a workshop, by incorporating them into the project where they could, on the one hand, evaluate the construction system and, on the other hand, collaborate for the integration of the representative pavilion of our university.

The proposed harvesting method consisted of giving a strong pull with both hands when putting the weight of the body back, seeking to manually pull out the canes, and thus quickly and efficiently, have an important harvest. The harvested canes were moved to a collection center a few meters away where a preliminary classification was made according to length and level of maturation. To be transported, they were tied with raffia in bundles of 10 reeds.

On two consecutive days, we harvested the majority of canes, among a group of approximately 20 people per day. The transfer was made by *trajinera,* a traditional boat for transferring goods in the canal system, and then by an open box truck to our university.

Figure 3: Cane harvesting in Xochinilco [Photo: M.J. Ontiveros]

5. Cane preprocessing

The secondary branches were removed from the canes, the leaves attached to the stem were left to protect it, the canes were left with the smoothest perimeter possible, and they were then classified according to length and growth of phyllotaxis, or direction of growth in a spiral, whether it rotated in a clockwise or counterclockwise direction, since this growth, in turn, causes the curved deformation of the cane clusters following a spiral similar to that of the growth of the stem itself.

6. Modules and arches

The modules or half-arcs of the radial components were integrated, and later the modules of the perimeter arches were set according to the analysis of the length of each element, and according to the model and the overlap recommended by Cory-Wright in each case. The reinforcements are added along the modules according to the reduction in diameter that the canes have due to their natural growth, this is done in order to compensate the section of the structural element and maintain the same amount of fiber homogeneously along its length of each element.

The mooring of the reeds was made with natural fiber ropes of different diameters to match the type of natural material of the structure in general. The modules already integrated into arches were elastically deformed with a tie rod and, when dry retained about 90% of the induced deformation.

Figure 4: Assembly of reed modules [Photo: R. Bolaños]

7. Structural conditions

Having an average length in the 60 radial arcs of 5.2m, considering a continuous section of 7 reeds. An exterior perimeter section of 14 canes along 43.5m and an interior perimeter section of 11 canes along 31.5m we have, 2184m of cane in radial arches and 955.5 m of cane in perimeter arches, with a weight of 241g per linear meter for the construction system, as already mentioned, we have an approximate weight of 526.34kg in radial arches and 230.27kg in perimeter arches. Shedding a total of 756.61kg of structure weight.

By establishing an ideal arc of support for the structure that comes from sectioning the pavilion with a horizontal plane, we obtain arches of 1.26 meters in the largest arches and 0.80 meters in the smallest arches. When considering the sum of the footage of these supports with 10.31m and assuming a uniform discharge in these, there is a discharge of 73.33/kg per linear meter, resulting in 92.48 kg in the wide arch and 58.83 kg in the reduced arch.

The mechanical model was carried out with the digital tool Karamba3D, characterizing the material with conservative data obtained from previous research on bamboo, developed at the LEL, the results of the mechanical analysis showed the accumulation of stresses in the edge rings, especially in the curved bases of the ring Exterior, these efforts were taken by the reinforced concrete bases that embrace the curve of the cane cluster in the most demanded section.

The total weight of the shell was evaluated at 1.9 Ton. While the vertical reactions in the exterior bases are around 240 kgf with a horizontal load of 60 kgf, which could be resolved with the friction between the pavement of the Plaza and the wooden pad of the surface foundation.

The greatest deformations, due to the accidental loads evaluated, were around 2 cm and occurred at the ridge of the arches. These deformations that are acceptable for this temporary prototype of open fabric must be re-evaluated in case of placing a coating because the actions on the surface would considerably increase the stresses on the arches. (Oliva, Hernández. Ontiveros. Trujillo. [4])

Regarding the actions considered in the estimation of large deformations, they happen essentially during assembly and, regarding possible specific loads due to improper use (unforeseen) depending on the fact that it is located in a public space, it is worth clarifying that neither the earthquake nor the wind would affect, due to its lightness and open network configuration.

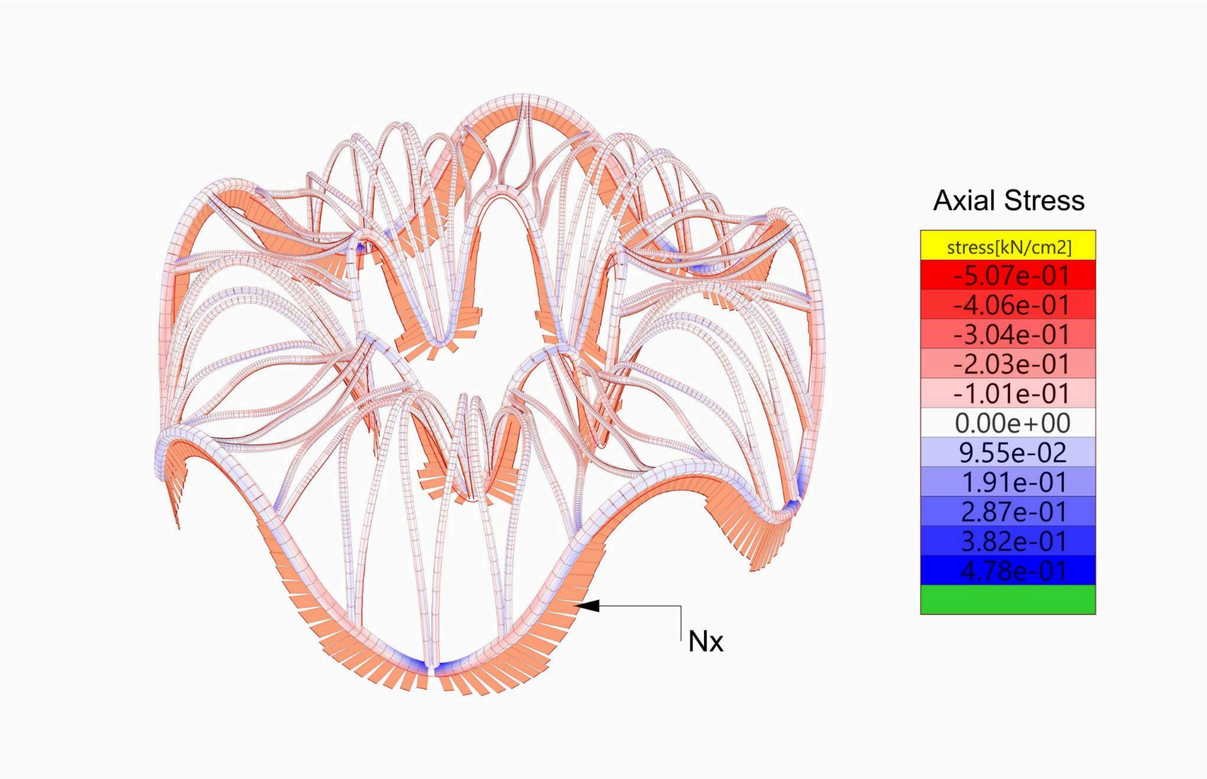


Figure 5: Structural Model in Karamba [M.J. Ontiveros]

8. Foundation development

In order to meet the specific and non-intrusive technical requirements on a marble floor at the festival site, we took on the task of exploring a mechanism for superficial foundations, in search of being able to pick up the lower curves of the structure that alternates ascending and descending curves, surrounding the perimeter in elevation. Thus, we have designed the integration of bases with organic geometry and robotic manufacturing in layers, so as not to exceed a maximum of 20kg that any participant would have to carry, manufactured based on 2.5 centimeter thick boards with extruded polystyrene, cast with a mixture of fiber cement with polymers, capable of more than supporting the weight without the need for metal reinforcement, generating ballast and compensating for the reduced friction with the polished floor.

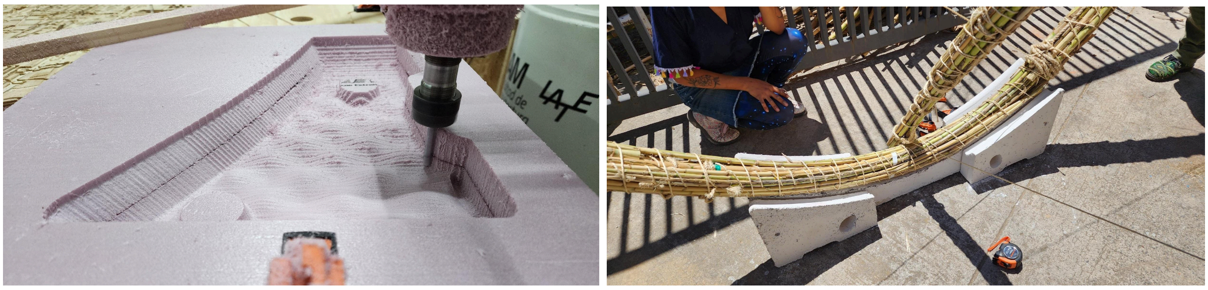


Figure 6,7: (left) Robotic milling for molds and (right) first two layers of a large base assemble [R. Bolaños]

The parametrically designed bases start from the lowest section of each of the five curves of the structure that seek to touch the floor in both the larger outer ring and the smaller inner ring. The bases were designed to couple the cane structure with simple ties along the low arch, compensating for the compound thrusts of the structure.

The design starts from contemplating curved sections in elevation, which are embraced by coupled layers of fiber cement that are assembled with threaded steel bars, where up to 5 layers or vertical slices are integrated parallel to the structure, which in cross-section change height forming a half-round, with the ability to embrace the sections of the structure. These same exterior and interior bases, 1.2m and 0.80m long respectively, allow in the central part the overflow of the clumps of cane that descend with little vertical inclination almost to touch the ground, so that in plan the bases are similar to a bun and in section are more similar to a slide.

The manufacturing of the molds was done in parts, seeking to mill no more than 3cm per layer, in accordance with the polystyrene boards and based on the cutting depth of the milling cutter with a 4cm edge. The first layer of the bottom of the mold was milled in a zigzag pattern, while the upper layers were programmed in concentric movements, faster and more efficient for these layers, seeking to cut in a ring instead of ravaging.

During milling, overlapping layers were added to the work table of the robotic arm with temporary fixtures following the proposed vertical process. At the end of the milling, the layers were adhered with glue and the molds were formworked in plywood boxes that allowed 13mm tubes to be placed that would later be used for the threaded bars that make up the layers of the bases. The castings were made by impregnating the molds with release agents and mixing aggregates smaller than 3mm, hydraulic cement, polyethylene fiber, polymer, and additives. After a setting time of 14 hours, they were removed from the mold and detailed. The polystyrene molds in the best of cases lasted 9 uses, with intermediate provisional repairs, and allowed the integration of bases that supported the weight and prevented horizontal displacements, in addition to allowing their assembly, disassembly, and transportation.

9. The assembly in the Alameda

Templates cut from 15mm plywood were placed with perforations that allowed following a circular line made with chalk, the fiber cement sections were placed on top and compacted with threaded bars, the perimeter rings of previously assembled cane were placed on the ground, They were raised in sections to be tensioned with the perimeter arches and to be tied with nylon tape to the surface bases.

Figure 8: *Caña Viva* Pavillion in Alameda Central, downtown Mexico City, within Mextrópoli Festival [Photo: R. Bolaños]

10. The second life of the pavilion

The exhibition of the pavilion in the Alameda was from September 19 to October 6, 2023, it was later reassembled in the Xochimilco Ecological Park where it was received without a planned time restriction. This opportunity for a second life allows us to know the evolution of the pavilion over time to recognize its useful life exposed to the elements, and even more so by having ruled out treatments that could extend its lifetime.

Figure 9: *Caña Viva* Pavillion in Parque Ecológico Xochimilco, Mexico City [Photo: R. Bolaños]

11. Conclusions

The construction system is developed as one of technological hybridization, mostly as a sustainable system according to the material of the main structure, with locally harvested reeds coupled by natural fiber rope ties that form overlapping and interlocking modules that unload their weight on specially designed supports that receive the curved geometry of the roof with enough weight to stabilize the structure, while in this case taking care of the surface on which they rest.

The project integrates simple and manual techniques, with parametric design processes, digital and robotic manufacturing, which in their integration prove the viability of a harmonious coexistence between different technological levels. The intervention of experts in different areas contributed to the development of a wide range of skills and knowledge among the students involved in the workshop, who at one point assumed independent and assertive responsibility for the manufacturing or assembly of some elements.

Among the additional contributions caused by the pavilion, we can point out the enthusiasm spread by involving volunteers even outside the University; in Alameda, a homeless person joined the team who positively assisted the crew in the construction. It is important to note that the Pavilion in Alameda was established as a landmark, which, according to the police, reduced conflicts in the area.

Acknowledgements

This work was supported by Kali Tlali, Marco Berumen, and was possible through the direct consultation with CANYA VIVA, Jonathan Cory-Wright. We received support and consultation from José Luis Encarnación Miranda.

This work was supported by UNAM-PAPIIT IT400424

References

[1] Bolaños, Ronan. 2023. "Prototipos efímeros del ámbito universitario en el espacio público" en Arquitectura Efímera Reflexiones sobre la mutabilidad del espacio construído coord. Mauricio Trápaga. 186-188 México: Facultad de Arquitectura de la Universidad Nacional Autónoma de México.

[2] Cory-Wright, Jonathan, 2017 "Escenario efímero construido con caña común (Arundo donax)", Ecohabitar, no. 55, pp. 34.

[3] Cory-Wright, Jonathan, 2022. "Manual de Construcción con caña según el método de CANYA VIVA"

[4] Oliva, Hernández. Ontiveros. Trujillo. "Sustainable construction materials and their application to architectural and structural design". Proceedings of IASS Annual Symposia, IASS 2015 Amsterdam Symposium: Future Visions – Timber Spatial Structures, pp. 1-13(13)