

Arundo Donax structures as economic and ecological formwork for concrete shells

Estructuras hechas con Arundo Donax como encofrado económico y ecológico para cascarones de hormigón

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ABSTRACT

As in some other languages, and unlike English, the term Roofless (*Sin techo*) is colloquially used to refer to people without a home and without resources in Spanish, which emphasizes the importance of being under cover, to have a roof that protects you.

The use of this term is very indicative of where the efforts of architects and engineers who are interested in shell and spatial structures should be directed to. In brief, we must look for more affordable ways to build roofs.

It turns out that concrete shells fell into disuse due to changes in the aesthetic fashions, high costs involved in the auxiliary structures needed to build them, and the impracticability of the spaces generated. The key to reverse these three negative aspects is in the formwork.

This paper presents the effectiveness of using structures made with canes (Arundo Donax or Bamboo) as an economic and ecologic formwork to make concrete shells a more affordable and functional construction system. By means of the results obtained from a trial construction.

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KEYWORDS: Arundo Donax; concrete shells; ecological; affordable; formwork.

RESUMEN

Como en algunos otros idiomas, y a diferencia del inglés, el término *Roofless* (sin techo) se utiliza coloquialmente para referirse a las personas sin casa y sin recursos en castellano; este termino enfatiza la importancia de estar a cubierto, de tener un techo que te proteja, y es muy indicativo de hacia dónde deben dirigirse los esfuerzos de los arquitectos e ingenieros interesados en las estructuras espaciales o de cascarón. En resumen, debemos buscar formas más asequibles de construir techos.

Resulta que las cáscaras de hormigón cayeron en desuso debido a los cambios en las modas estéticas, los altos costes involucrados en las estructuras auxiliares necesarias para construirlas, y la impracticabilidad de los espacios generados.

La clave para revertir estos tres aspectos negativos está en el encofrado.

Este trabajo presenta la eficacia del uso de estructuras realizadas con cañas (Arundo Donax o Bambú) como encofrado económico y ecológico para hacer de los cascarones de hormigón estructurales un sistema constructivo más asequible y funcional. A través de los resultados obtenidos en la ejecución de una construcción de prueba.

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PALABRAS CLAVE: cascarón de hormigón; encofrado; Arundo Donax; ecológico; asequible.

1. INTRODUCTION

Growth expectations from now to the year 2050 project that the cities of the future will host more than 7000 million peo-

ple; still many constructions need to be built to house all the new inhabitants [1].

Another layer of complexity is added by the fact that approximately 75% of the houses around the world have been

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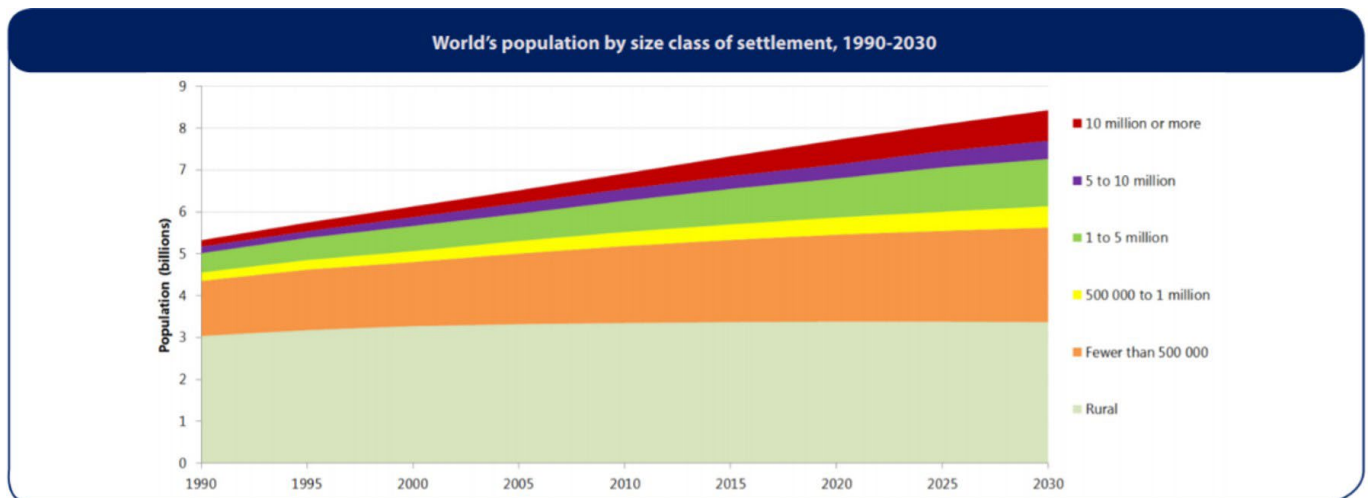


Figure 1. By year 2030 almost 70% of the world population will be living in cities. Data Booklet. The World's Cities in 2018. United Nations.

and are built without any engineer or architect. To best answer this need, we need to provide affordable buildings that are easy to build for widespread use and maintain good aesthetic and technical quality [2].

It is of utmost importance that we take into account the environmental impact of these future constructions. The current building industry has its share on the ongoing ecological collapse, mainly because:

- The most common structural materials, ceramics, concrete, and steel are very polluting.
- Building materials are used in a non-efficient way
- Existing buildings and buildings we are creating waste a lot of energy.

Because of their heaviness, after reinforced concrete foundations, floors and ceilings are the part of buildings that pollute the most. That's why we should turn to vaulted ceilings as an ecological resource. They can be built with materials that have a low primary energy content and that are very efficient because of the shape of its structural typology. Importantly, it also helps to reduce the electricity bill [3].

2. CONCRETE SHELLS. RAISE AND FALL

Concrete and Shell structures were discovered thousands of years ago, the Pantheon is the greatest example. But the epoch of concrete shells really began in the early 20th century, in the context of war and because of its availability, concrete became a popular building material for many construction purposes. In particular, it gained popularity as a cost-effective and fast building system to create big spanning and open air shelters.

After the Wars, the curved organic forms regained popularity. This world-wide appeal and influence lasted till the end of the 70's, after which few notable projects have been built [4]. Between all the reasons that led to the disappearance of concrete Shell, two should be highlighted:

- The impractical morphology of shells
- The cost of labor and materials to raise the formwork

The impracticability it's not only because of the morphology, usually these structures were used to cover big span spaces, this big scale was creating difficulties to make the spaces and volumes generated profitable.

But, as said before, many people need and will need a house, a decent house. This means domestic scale roofs and ceilings (from 3m to 6m span). With Arundo Donax as a formwork we can achieve up to 6m span, with Bamboo up to 10m. In both cases enough to cover domestic roof and ceiling dimensions.

This formwork material is cheap and abundant, and the technique is suitable for self-construction, which implies a considerable reduction in the cost of labor.

3. ARUNDO DONAX

Arundo Donax is the biggest graminea, up to 10 m in ideal conditions; has hollow stems, 2 to 3 cm diameter at the base and gets thinner as we go to the top.

It is distributed in the zones with warm or tropical climate.



Figure 2. Countries in the World where Arundo Donax is present [5].



Figure 3. Prefab cañizo to cover the gap between beams (left), and different cañizo formats (right).

In Spain, Arundo Donax has always been a very important building material for many different purposes from walls to ceilings and roofs, even as a protection for workers at the scaffoldings. It was used in situ at the building site where prefab elements called *cañizo* were placed.

Fifty years ago was still a very requested material [6]; however nowadays it's considered one of the most invasive plants and governments are spending lots of money on its eradication.

3.1. Precedents where reeds were used to build vaulted ceilings

- As part of the formwork
- As a formwork
- As a support to create false domes
- As main structure

3.1.1. As part of the formwork

Wooden structures were built to create vaults at churches time ago in northern Catalunya, the space between the wooden principal elements were covered with Arundo Donax to generate the surface where concrete was poured and stones were placed afterwards.

3.1.2. As a formwork

For small elements, like stairs; a prefab element made with Arundo Donax, called *cañizo*, was bended and fixed between the wall and the floor then the concrete was poured, Gypsum concrete specifically.

3.1.3. As a support surface to create false domes. Encomonada Vault

It was a much cheaper way to create vaults compared with stone vaults. Wooden guides were connected with Arundo Donax, creating the support surface to be plastered.



Figure 4. Groined vault, reed texture of the surface generated because of the the fromwork. Palafrugell, Girona, Spain.



Figure 5. Bended cañizo working as a lost formwork. Fresneda, Teruel. Spain.



Figure 6. Encamonada vault. Artifex Balear, Mallorca.Spain.

4. STRUCTURAL USE OF ARUNDO DONAX

It is possible as well to create loadbearing elements with this material. Joining bundles of canes at their upper ends we can create archs, that once placed are connected to each other with more reeds.

Very interesting shapes can be generated (up to 10m span) with this technique that comes from Mudhif constructions, where only *phragmites australis* was used, in the southern marshes of Irak.

Few years ago was readapted to Arundo Donax by an english architect, Jonathan Cory Wright.

The two main negative aspects with this kind of structures is that:

- they can only bear a little bit more than their own weight;
- this material when exposed doesn't last in good conditions more than 4 years.

5. USING ARUNDO DONAX STRUCTURES AS A PERMANENT FORMWORK FOR CONCRETE SHELLS

Concrete shells need a formwork that it's easy to build as well as economic and ecologic, to make them useful again.

Arundo Donax structures need to last longer in time, and need to be stronger to open up their range of possibilities.

If we put them together, a very interesting simbiosis is generated where the problems of one are solved with the qualities of the other in reciprocal way:

- This formwork material is abundant and affordable,
- It's easy to build once collected and cleaned, just a knife and ropes are needed to create the formwork.
- This system is very compatible with directed and assisted self-construction.
- From straightforward formal expressions to asymmetric and other Shell geometries are possible when using this kind of formwork (synclastic and anticlastic morphologies).
- With this organic formwork up to 6 m span structures can be done with admissible deformations when casting.
- As it is a lost formwork, the intrados surface is not regular and smooth and the typical reverberation problema from vaulted ceilings can be solved.
- Thanks to the concrete layer over the permanent formwork the Arundo Donax structure becomes more durable and stronger.

6. A SMALL EXAMPLE. DIRECTED SELF CONSTRUCTION OF A TOOL SHED

A small construction was carried out, in which the concepts explained before were applied. The structure was done mainly by the future owners assisted by me and with the punctual help of neighbours and relatives.



Figure 7. Arundo donax Organic Structures. Author's Projects.



Figure 8. Before (left) and after (right).

Materials used in the construction of the concrete shell.

- 300 ud Arundo Donax reeds
- 0.2 m³ of gravel for foundations. (from 2cm diameter up to 6cm)
- 100 kg of white cement for foundations
- 125 kg of white cement for the concrete shell
- 300 kg of sand for foundations (up to 1cm diameter)
- 375 kg of sand for the concrete shell (up to 3mm diameter)
- 10 m² of chicken wire. Aprox.
- Money spent on material > 60€

6.1. Harvesting.

Arundo DONAX it's a plant that grows very fast, the first year grows in height, second year the branches grow and the stem lignifies; from the third starts to deteriorate in the bush until it dries and die around the fourth.

It's always better to harvest during cold weather, the 2 year old reeds are the ones that have to be collected for this purpose. It's better to clean them from leaves and branches before the transport to the building site.

6.2. Archs

To create the archs from straight reeds a kind of template is needed. Joining bundles of canes at their upper ends with a considerable overlap with the help of the template, for this little construction consists of 6. Around 20 reeds are needed per arch. The execution time for each arch is 2 hours approximately.

6.3. Foundations

A 30 x 40 x 300 cm foundation was digged, and filled with gravel before the archs were placed.

6.4. Placing the archs

Four of them were placed vertical and two, at extremis, were bended in opposite directions to create an overhang for shade.

6.5. Connecting the archs

Tying the reeds in the opposite direction to the arch we managed to unite them all and cover the space between them generating the Surface on which will be tied the chicken wire mesh and applied the cement later.

6.6. Connection between shell and foundation

After connecting the archs and tying the wire mesh, a minimum reinforcement is placed in the foundations.

The mesh is long enough to be connected to the reinforcement at the foundation.

Then 6 iron rods are placed crossing them 2 by 2 in the spaces between archs, to join the two elements even better, working also as diagonal bracing.

Now its time to pour first the cement mix for the foundations and later the concrete mix is applied at the Shell.

7.

SUMMARY

This constructive technique is easy to make (suitable for self-construction), affordable and environmentally friendly [8].



Figure 9. Collected reeds after being cleaned with traditional tool.



Figure 10. Forming arches with template.



Figure 11. Connecting the archs.



Figure 12. Connection between foundation and shell.



Figure 13. The structure and its surroundings.

The formwork material is natural and abundant; it is distributed in the zones with warm or tropical climate which is also where we can find many of the poorest countries in the world, it does not require special tools and with the range of measures that can be adopted it does not need complex auxiliary elements.

Thanks to the characteristics of the formwork material, it is possible to obtain forms that work very well via compression, being able to avoid the use of chicken mesh in some cases. In addition, pleasant and comfortable spaces are generated by the texture and colors of the cane.

This option is technologically accessible and architecturally beautiful can help to mitigate the social and ecological impact implied by the expectations of urban growth in the coming years. but much remains to be defined to be able to exploit the potential of this construction option. For this end, the support of related institutions and entities will be necessary.

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