BUILDING WITH THE DELTA

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Abstract. Since 2008 research and technology transfer activities were developed in the Paraná Delta (Metropolitan Area of Buenos Aires) with the aim of offering local people a sustainable development alternative through production and processing of bamboo which grows on the islands. To achieve this goal, the Provincial Agency of Islands developed several theoretical and practical workshops that addressed various issues such as sustainable cultivation and harvesting of bamboo, post-harvest treatment, industrial design with bamboo, harvesting and post-harvesting of edible bamboo sprouts, and some basics of construction.

An agreement with the Politecnico di Torino allowed completing the research process through the project “Construir con el Delta” (Building with the Delta), where the constructional possibilities offered by local bamboo were tested. The results of the project were the design and construction of a housing unit using local natural materials as well as recycled materials. The construction activity was performed during a workshop guided by a Procedure Manual developed specifically for this experience. Local people built the various parts, among which: bamboo structure, green roof, raw earth and bamboo walls, and shading systems containing elements for hydroponic farming. The experience culminated with in-field and laboratory characterization of local materials, such as the soil from various parts of the Delta, and the most widespread bamboo species in the area.

This experience is an example of sustainable development that promotes local autonomy in that it transmits the expertise to address all stages of the production process.

Introduction

Since 2008 the Provincial Direction of Delta Islands of Buenos Aires (DPDI) has developed various experiences of technology transfer regarding the production and use of bamboo, which ended with the project Building with the Delta, developed jointly with the Politecnico di Torino. The principal objective of this program was to give local people the skills to develop complete production cycles, going from production of raw materials to the construction, through treatment processes and different degrees of manufacturing. In all cases we started from recognition of local tangible and intangible resources, and considered education as a key vehicle for development. The project encouraged the creation of sustainable processes in ecological, economic, and social terms, achieving a high degree of autonomy in the construction of the habitat itself.

The first objective of the project Building with the Delta was the realization of a complete module (at the 1:1 scale) that might serve as the basis for a functionally resilient housing unit built with local natural resources. This construction followed the indications of a manual we made especially for the experience.
The second objective was to identify and characterize local natural materials through surveys, field testing and laboratory analysis. The third objective was to provide the local population and professionals with an alternative for habitat construction with sustainable materials and processes. It is intended to demonstrate that in the metropolitan area of Buenos Aires one can find the tangible and intangible resources necessary for the definition of an appropriate technological practice, understood as “a willingness to review the role of technology ... associated with the limitation in the use of non-renewable resources, waste reduction, participation, the performance of control and management processes by the users, the recovery of non-monetary factors, the attention to human beings.” [1:128]

History and local context
The use of bamboo in the Paraná delta. The Paraná Delta is a particular forestry space on the edge of metropolitan Buenos Aires. It is located at the upper end of the River Plate estuary, and was formed by the sediments carried by the rivers Paraná and Uruguay. It creates a unique landscape that produces also a particular way of life. It is in the city of Tigre, and particularly in the so-called ‘port of fruits’ that the Delta products are usually traded; in recent years these include items made from bamboo. Often the raw material comes from the same Delta, but the interest in larger diameter rods, and the bad exploitation of the local bamboo groves, force many craftsmen and builders to buy the bamboo from the North of the country, instead of the local bamboo, often ignoring the chances of taking advantage of the quality and abundance of the latter.

Among the products made with bamboo stand instruments, furniture, fences and decorative elements, and also bicycles. In a few self-building experiences this material is used for architectural purposes, but, although most obtained positive overall results, technical inexperience led to rapid deterioration of some details.

Other building experiences show that not all the work done with bamboo implies a sustainable practice. The same town of Tigre has commissioned 100 bus stops to the company Bambú-stop. [2] In less than one year many of them were installed. While the company has been successfully making furniture with bamboo plywood, when making the bus stops it has not shown the same skills, creating prejudice against the acceptance of the material in other buildings. Ignorance of the rules of art, lack of curing, and the use of non-local bamboo and unknown species, summed up to instant decay, and few months later all the stops had to be removed.

We can summarise the local context in the existence of senior craftsmen particularly appreciated for the production of bamboo objects, a growing interest in the material even by the government, and a bad practice in the use of bamboo as a building material which breeds mistrust in it. The latter represents one of the greatest challenges for those who work with bamboo, since faulty practice can shade many successful results.

Bamboo as a Sustainable Resource for the Delta
For this reason the projects developed by the DPDI were conceived in an integrated and holistic manner, incorporating experts from various disciplines such as agriculture, engineering, landscaping, environmentalism, economics, and sociology, and involved public entities, training centres, craftsmen, businesses, and farmers.

The main objective is to position the bamboo as a sustainable resource that allows new economic opportunities and thus encourage the permanence of the population on the islands, which, from the mid-twentieth century, has begun to depopulate due to unemployment caused by the relocation of the fruit industry.
Unlike the dominant forestry production (mainly poplar and willow), bamboo has a huge capacity of generating employment as it is highly labour-intensive. Together with the multiplicity of use, it can bring various benefits to the economy of the area where it is grown.

Through seminars, workshops and publications (all of them free and open to the community), the DPDI has emphasized dissemination of appropriate silvicultural practices to ensure a greater economic efficiency and an increased ecological use of both natural bamboo woods and groves in the Delta [3].

Thanks to its work, several producers have changed the cultivation and harvesting processes, ensuring an annual output and higher quality.

For example, it has encouraged growers to carry out a selective harvest, which will permit the exploitation of the forest, eliminating the practice of ‘clearcutting’ which consists of cutting the full grove. Through selective cutting, one does not just get a yearly production, but the grove becomes stronger and produces better quality material.

The DPDI has also promoted bamboo for various uses (furniture, musical instruments, food), providing new economic opportunities for farmers.

With the support of various experts in the field, it has eradicated the mistaken belief, widespread among environmentalists and local residents, that a bamboo cultivation would be difficult to control and would entail a risk to natural forests. It has demonstrated on the one hand that the islands themselves are the natural limits on the expansion of rhizomes, and on the other hand that the bamboo forest and other forest species can coexist.

Before “Building with Delta”, the Provincial Islands had already developed five workshops that addressed various problems of bamboo production, treatment and processing. For each workshop a technical manual that was delivered free of charge to all participants was developed. The workshops were titled:

**Sustainable Management of Natural Bamboo Forests:** the aim was to promote the sustainable management of natural bamboo forests. The workshop was also held in the Martin García Island Natural Reservation, in order to control exotic species of bamboo (in this case *Phyllostachys aurea*), widespread on the island. In this way it was intended to remedy environmental problems and economic constraints arising from poor production practices. [4]

**Post-harvest Treatment:** During this workshop the characteristics of bamboo, the limitations to tractability, the causes of biological degradation and factors that accelerate or hinder the degradation process were discussed. Participants experienced various preservation techniques, which at the time were little applied in Argentina, with a consequent loss of value of the material. [5]

**Bamboo Design:** Through an agreement with the Metropolitan Design Centre of the City of Buenos Aires, the DPDI has been involved in the “Integrando al futuro” program, making six workshops in which it promoted reflection on the properties of bamboo, and the development and exhibition of products. [6]

**Edible Bamboo Shoots:** In addition to the various uses of the different parts of the bamboo plant, this workshop aimed to incorporate skills and knowledge to take advantage of sprouts as food, both as fresh produce, as well as canned, for own consumption and sale. [7]

**Simple Bamboo Structures:** This workshop was directed by the renowned architect, Horacio Saleme. It involved more than 80 volunteers who experienced truss structures and different technical solutions for joints, both with knots and metal elements. [8]

The results of the program were summarised in a book published in Buenos Aires in 2013, [3] which is freely distributed to local institutions, professionals and especially the people who can benefit from it.

Within this context of experimentation on and appreciation of the resources of the Parana Delta, the project “Building with the Delta” was agreed with the Politecnico di Torino, as a part of the doctoral thesis of Emiliano Cruz Michelena Valcárcel, under the supervision of professors Andrea Bocco and Simonetta Pagliolico. This project was based on the recognition of existing resources and local building
traditions, and was aimed at designing and building a prototype housing module using not only the local bamboo, but also earth and salvaged materials.

Thus the entire cycle is closed because all the building parts which come into a house (other than services) can be locally produced, and therefore the islands may reach a potential autonomy in the construction of the habitat itself. The project gave also the opportunity to identify and characterize natural materials available in the area, acquire technical information on production and processing, and experience innovative solutions that can be transferred to other contexts.

The architectural project
The guidelines, which led the project, on the one hand respond to the properties of the material available and on the other to the local building traditions. The latter are the answer to the specific geographic, climatic and social conditions, as the area has a strong identity, although just 20 km from the centre of Buenos Aires. “The island houses both designed or vernacular have common features, derived in response to solutions found to physical constraints, a number of factors that come together as frequent floods, the floodplain soil, constant moisture, heat, rain, difficulty in hauling materials, availability of labour, and insects.” [9] The location of the houses on the river bank, the existence of verandas on fine columns, the stilts that allow a visual permeability, the use of local materials like wood and earth, and the scale of the residences in relation the surrounding landscape, are a rare example of integration between architecture and nature in a metropolitan area.

The project proposes a minimum housing unit made of repeatable modules that can adapt to the size growth of families. Therefore, the prototype consists of two identical modules with the facilities at the centre, minimising circulation space and surface area.

The building parts are:
- pad foundations and bamboo columns, forming a square plan
- bamboo-framed floor
- a bamboo domed roof with a green hip roof built on top
- earth infill walls: ‘quincha peruana’ (wattle-and-daub-like) panels with a bamboo framework, whose dimensions can be standardised
- hydroponic farming elements.

Among the constructional limitations, the most constricting are the length and thickness obtainable with Phyllostachys aurea. In this species changes of direction at the nodes can sometimes occur. [10] Among the selected samples, straight culms of a maximum of 5 meters were available; thicknesses ranged between 4.5 and 6 cm. For this reason the module’s square plan has been set at 2.5x2.5 m inside and 4x4 m outside – although maximal dimensions 3.5x3.5 inside and 5x5 outside might have been achieved.

Methodology
The working methodology has been organized to respond to each objective:
On the one hand, materials have been characterised according to standards and practical knowledge: we searched for the mechanical properties of the bamboo, and performed field trials and laboratory tests for the earth.

On the other hand we decided to use the manual as a technology transfer method, through cartoons made of simple drawings and short texts, to allow inexperienced people repeat the experience. The main precedent was Yona Friedman’s manuals, [11] from which we took the simplicity of the drawings, the least amount of words and the continuity of the story to describe step by step all the actions. This is supplemented by other references such as the Curso práctico de construcción by Juan Primiano [12] or the work of Jaime Nisnovich. [13]
Friedman did not dwell on detailing, as he assumed that the population he was addressing possessed enough practical knowledge and could carry on local building traditions. In our case, as we were trying to establish a yet unknown technique, it was necessary to delve into some basic details. Finally, for the self-building workshop a ‘learning by doing’ methodology was established, so that although it was based on the information provided by our manual, the participants may propose other solutions, as they acquired knowledge through direct experimentation on the materials.

**Characterization of Materials**
During this project two species of local bamboo were mechanically characterized, as well as various delta earth specimens, so to identify possible materials adapted to building. The case of bamboo sheds more relevant results as it allowed individuating the properties and limitations of local species, that used to be shunned in architecture. Therefore, this article summarizes only some of the results obtained from the analysis of the characterization of bamboo.

**Selection of bamboo, harvesting and post-harvest treatment.** While the rules of art recommend that the canes are harvested at the end of autumn, when the starch content is lower, the times of the project forced us to perform cutting in summer. The species used were *Phyllostachys aurea*, *Phyllostachys viridis*, and *Arundinaria japonica*. The first two were characterized mechanically and were used for structural elements. The third was characterized as it was used for support the floorings and the turf roof. The identification was made possible thanks to the prior work by DPDI, based on the taxonomic description made by Zulma Rugolo.

*Phyllostachys aurea* rods were obtained from the managed bamboo forest on Martin García island, where culms of three to four years old, with a diameter larger than 4.5 cm, were selected. Following the rules of art, the cuts were made flush to the nodes. 250 rods (of an average length of 6 m) were selected in an area of approximately 150 m². *Phyllostachys viridis* canes were obtained at the Tigre Regatta Club, in a bamboo grove also managed by DPDI. The selected rods were three to four years old, and had a diameter larger than 8 cm. 15 canes (of an average length of 12 m) were selected. In this case it was important to take canes whose natural bend was less pronounced, in order to obtain straight or nearly straight segments, 2.5 to 3.0 m long. Although the rules of art recommend a minimum natural drying of six months, the organization of the project did not allow so much time. Therefore, we picked the amount of harvested canes were really required (plus 20% reserve) and burned them to the blowtorch. This action removes moisture, accelerates the form stabilization by drying, and removes the starches and sugars, producing a sap release which forms a smooth, glossy film that protects the cane.

**Methodology for the mechanical characterization of bamboo.** Thanks to the help of Horacio Saleme, we selected nine specimens and sent them to the National University of Tucumán (UNT), where they were analysed by the Materials Testing Laboratory of the Faculty of Sciences. Testing was carried out according to the methodology already experienced by the UNT in order to determine the tensile and compressive strength of the canes. [14, 15]

It is always difficult, and even risky, to standardise the procedures for calculating and even analysing such material. This is because of the differences deriving from the multiplicity of species, the influences of the mechanical production process (from harvest to curing), and the general lack of knowledge regarding taxonomic characteristics, which often hinders the correct identification of the species. Anyhow, the methodology consists of the following steps:
- choice of the bamboo to be used
- laboratory tests (compression between nodes, traction of strips or bamboo wall sections)
- determination of ultimate tensile strength
use of relatively high safety coefficients, and efficient structural forms.

Tensile tests were performed with the walls of the rectified rods, with wedged ends so that the clamps of the machine could not break the cane by shear stress parallel to the fibres. ISO/TR 22157-2:2004 standard “Determination of physical and mechanical properties of Bamboo” specifies the use of rectified walls to test tensile strength parallel to fibre, and also recommends that samples include a node at the half of their length for commercial tests, while for scientific tests it leaves this decision to the researcher. In our case, tests were conducted on samples without intermediate nodes.

Compression tests were performed on specimens including at least two nodes. This decision was taken in order to make the results comparable with values obtained from previous tests.

Six specimens were subjected to load for setting the compression strength, five of which of Ph. aurea, and one of Ph. viridis, taken from different positions in the cane (base, middle, tip) and both green and burnt. Diameters (D) ranged from 40–60 mm, with wall thicknesses (e) of 4–8 mm for Ph. aurea, and D=95 mm, e=9 mm for Ph. viridis. Further three samples were subjected to a tension force, parallel to the fibres; all of these were from Ph. viridis, and had a surface area ranging from 22.5–70 mm².

As indicated in the ISO standard above, ultimate tensile strength is calculated by dividing the load (P) by the area of the cross section wall (A):

\[ \sigma_{uts} = \frac{P}{A}. \]  

(1)

The value of the surface area of the cane (A) can be calculated according to the NSR-10 standard, with the formula:

\[ A = \frac{\pi}{4} \times (D^2 - (D - 2e)^2), \]  

(2)

where:

- D = external diameter of the culm,
- e = thickness of the wall.

For the calculation of the admissible stress, the work of the UNT was taken as a reference: [15] here a coefficient of 10 is applied to the ultimate tensile strength, similarly to wood:

\[ \sigma_{adm} = \frac{\sigma_{uts}}{10}. \]  

(3)

The values achieved – compressive strength: 180–448 kg/cm² for Ph. aurea, 389 kg/cm² for Ph. viridis; tensile strength: 1667–1830 kg/m² – are in the same range as larger species usually employed for construction. The values reported from tests on Bambusa vulgaris canes are of 443 kg/cm² for compressive strength and 1196 kg/cm² for tensile strength; Gigantochloa robusta scores at 511 kg/cm² under compression and 1854 kg/cm² under tension. [16]

Even compared to other species used in Argentina such as Bambusa balcoa, Dendrocalamus spp. and Bambusa tuloides tested at the National University of Tucumán, which were found to reach values ranging from 207 to 391 kg/cm² for compressive strength, genus Phyllostachys seems to be an excellent alternative for climates to which giant bamboos have not yet been able to adapt.

It is worth remembering that this bamboo genus is the most widespread and cultivated in the Buenos Aires area, but it is shunned in the building trade in favour of larger species from northern Argentina. Therefore the dissemination of the data we found could encourage its use.

In our project, the most widely used species is Phyllostachys aurea that, according to the results obtained, has an average admissible compression stress of about 37 kg/cm².
Scale 1: 1
The bamboo construction workshop, held in May 2014 in Tigre city centre, was attended by over 85 volunteers, mostly from the islands of the Delta, who had participated in previous seminars offered by the DPDI. Many had some experience in construction and very few had already experimented with building with bamboo. Participants were divided into three groups, each building different parts which were assembled at the end of work.
The bamboo structure was built in four days. During the workshop one module was completed including loadbearing structure, floor, roof and hydroponic farming panels, but only two wall panels.
In the following, the technical solutions adopted and some problems encountered in achieving them are described.

**Bases.** The structure had to be 50 cm above grade, so pad foundations with emerging cylindrical piles were designed. The under-grade foundation is a lean concrete cube 30x30x30 cm; the piles stem up 25 cm and are made of concrete reinforced with a folded electro-welded mesh, against which ø6 mm rebar were positioned. Two bars at the centre of the pile emerged 40 cm on top of it, while 3 more rebar (protruding just 20 cm) were placed so to coincide with the centres of the canes that would make up the columns.

**Columns.** The position of the columns has been chosen so that the corners are left free, thus allowing a greater number of combinations. Each of the eight columns consisted of three vertical canes, plus two diagonal bracing elements. They were mostly built with *Phyllostachys aurea*, although in some straight sections of the apical part of *Phyllostachys viridis* were used.
The three vertical rods were placed in a triangle. The inwards side consisted of two 2.4 m long rods, with a half fish mouth at the upper end. The third rod, placed outward, was 2.6 m long. In this way a kind of saddle was prepared to house the main frame of the roof. The three rods were joined on site, at two points near the top and the bottom of each column. The two inside rods were connected by a metal bolt, while the third rod is connected to the latter through an anchor bolt.
The diaphragm of the lower node was broken in order to insert the rebar stemming up from the concrete piles. Once verified the position of the columns, a cement-sand mixture was injected in the canes, thereby securing the joint.

**Floor.** It consists of four girders made with two 2.4 m *Phyllostachys aurea* rods of approx. 5 cm diameter, kept apart by segments of the same bamboo species. This configuration created beams with a greater geometric moment of inertia, and prevented deformations caused by bending stresses, by using the least amount of material.
The joints between the rods were made with metal bolts. Separating segments were placed so to coincide with internodes of the main rods, to ensure proper load distribution. Moreover, placing the metal bars as close to the nodes of the canes as possible, minimises the risk of splitting.
Eight transverse joists were tied to the girders at 60 cm centres. Synthetic fibre rope was used. Above these a walkable surface made of 2 cm *Arundinaria japonica* culms tied together. This flooring was tied to the joists with synthetic thread and metal wire.

**Roof structure.** (Fig.1) The roof consisted of two structural frames, one on top of the other. The base is a dome made of bent *Phyllostachys viridis* laths 2.5 to 4 cm wide, and an average 8 mm thick. These bamboo arches are inserted into slits in a frame made of 5 cm rods. This frame is composed of two identical squares, one on top of the other, braced by diagonal rods at 1/3 of the length of each side. The lower square rests on the columns, while the upper supports the dome and the roof beams. The dome structure serves as formwork for organizing the structural elements of the hipped roof.
Coinciding with the location of the columns, 8 double struts were placed, on which the bamboo rafters were laid. At the opposite end these rested on a 80x80 cm frame, resting on the centre of the dome. The hips were materialised by beams resting on a strut, which in turn rested on the diagonal brace of the square frame.

Cross rods were placed on the rafters, and then *Arundinaria japonica* panels were tied to them, in order to hold all the above layers of the green roof.

During the course of the work, we made some changes in relation to the project, which in some cases led to structural improvements (such as placing an additional strut to better distribute the load of the rafters and draw load away from the dome), but on the other hand it produced some flaws in construction details. For example using a single cane for the rafter implied that the joint with the strut was too close to its end, with the consequence that it deformed as a result of crushing. To mend this detail, the joints were filled with cement.

The position of the joints depended mainly on the direction of the loads, that might have split the canes. Notwithstanding the heterogeneity of the material, the work speed and the inexperience of the workforce, the result generally responded to this technical requirement.

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**Green roof.** It consisted of the following layers:

1. Continuous surface of *Arundinaria japonica*, tied with metal wire together and with the rafters of the structure.
2. Battens coincident with the rafters, so to impede water leakage after placing the membrane.
3. Membrane made with sheets of reused silo-bags [17] and banners, stuck with a layer of acrylic waterproofing paint identical to that used for hydroponic gutters (see below). The silo-bag is a

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Fig. 1. Construction of the prototype. Clockwise from top left: instruction manual; the complete load-bearing skeleton; laying the green roof; building sequence of hipped roof layers; the completed roof from below.
folded polyethylene tube extruded in three layers used for storing grains. Once opened it can not be reused for agriculture, hence its use as a waterproofing membrane is a green alternative.

4. Transverse half canes nailed to the battens, to hold the substrate evenly.

5. HDPE foil, average shade type, to contain the substrate.

6. First substrate layer, composed of 2.5 cm of perlite.

7. Second substrate layer, composed of a 5 cm mixture of compost and perlite.

8. A final 2.5 cm soil layer, bearing grass and succulent plants resistant to low rainfall and poor soils, previously cultivated in the nursery.

In addition to the benefits in terms of indoor comfort, the green roof might offer a solution aesthetically in accordance with the lush Delta.

**Hydroponic farming.** We used the columns’ bracing to carry gutters for hydroponic agriculture. (Fig. 2) To obtain these, *Phyllostachys viridis* canes were halved with machete and club. Then internal diaphragms were removed to obtain a smooth inner surface. The halved canes were then coated with a membrane obtained from discarded ad banners and silo-bags. Drilling for water drainage was performed. These canes are held in place by brackets made *Arundinaria japonica* rods. To improve drainage, rope was threaded through the holes previously drilled and was connected to the channels below ladder-like, thereby directing the flow of water. The gutters were then filled with perlite, bark and soil, and covered by a net. Lentils, rocket and other crops were planted. The nutrient used is obtained from organic waste composting, and was chosen for its easy availability. One tablespoon is needed for 5 l of water.

![Fig. 2. The completed prototype.](image)

**Conclusions**
Research and tests on the potential of bamboo for Buenos Aires Delta represented an unprecedented experience in the area for several reasons.
The support of governmental agencies and professional associations strongly encouraged the diffusion of a sustainable technological practice with local materials within the metropolitan area. The prototype construction highlighted the architectural possibilities of local materials and encouraged the development of an interest for them from the general public, and architecture professionals in particular. The characterization allowed to verify the excellent structural properties of *Phyllostachys aurea*, that equate this species with other large-sized bamboos, and demonstrate the convenience of using such cane which is locally available.

The project represented also a distinctive experience of technology transfer, which included different skills and bodies of knowledge, allowing the implementation of complete production cycles that will help creating both appropriate buildings and more income for local people. (Fig. 3)

As a result, cooperative projects, private investments and agreements between government agencies are being presently developed, which will increase the usage of bamboo, taking advantage from the comprehensive methodology here described. The project showed also that a business model based on the transformation of local materials into building components is feasible, which would allow the inhabitants of Buenos Aires slums to both improve the quality of their houses and earn money from selling these products on the formal market. [18]

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**References**

