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Arising Student Consciousness Regarding Structural Properties of Natural Materials with a Structural Challenge Employing Arundo Donax

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Abstract

All our actions claim now sustainable choices, and radical changes in materials need to be made. In this perspective there is the awareness that nature can help to provide viable solutions. In particular, the choice of natural materials for structures, perfectly optimized by the structural point of view, can be made. In this paper an experimental teaching experience regarding the structural behaviour of Arundo Donaxreed, made in a Structural course of *Design of the Industrial Product* of the University of Bologna, is reported. Arundo Donax has been firstly characterized from the mechanical point of view and then used in a structural challenge focusing on the best use of a given quantity of reed for a “bridge type structure” with fixed span and width. The main goals of the course were, on one hand (with mechanical characterization of Arundo), to give students sensitiveness on strength and stiffness of the material, on the other (with the structural challenge) were to make the student think about the combination of material properties and shape of constructions to reach the best structural performances.

Keywords

Arundo Donax, Students, Challenge, Structural Study and Design

1. Introduction

We are facing a broad range of challenges that claim sustainable choices. There is growing recognition and awareness that nature can help to provide viable solutions that use and exploit the properties of natural materials.

The idea of the course was to share with the students the experiences made on natural materials that can be structurally used in substitution of the convectional currently used non-sustainable materials.

The experience acquired on structural behavior of straw bales (Maraldi et al., 2016, 2017, 2018) and the studies on the structural performances of bamboo (Greco & Molari 2019; Greco et al., 2019; Moran et al., 2019; Kaminsky & Lawrence, 2016; Minke, 2012) make clear the extraordinary potentialities of natural materials.

The aim of the teaching experience described in this paper was also to motivate the students to exploit their own nature-based solutions in structural engineering.

The teaching experience here reported was provided in the Structural mechanics course of the graduate program on Design of the industrial product at the University of Bologna.

A natural, sustainable, poor but easily available material, part of the Italian structural history as Arundo Donax, has been chosen. Since millennia, this material has been used to build shelters, huts, warehouses and large houses, before the widespread use of bricks, cement and reinforced concrete. Rediscovering this culture of building sustainable, modest structures, sometimes for seasonal use but resistant to environmental action and to earthquakes (Barreca, 2012), seems particularly formative.

Arundo Donax is the common reed; it is a perennial herbaceous plant with a long, hollow stem, which grows close to channels, extremely widespread in Italy. The culm generally reaches 6 m high but in ideal conditions it can even exceed 10 m. The diameters of the culms generally reach 2 - 3 cm diameter. The culms are formed of alternating series of nodes, which contain diaphragms, and internodes (Spatz et al., 1997).

In particular, the material used in the course was collected in a reed bed at Campotto, near the city of Ferrara, Italy in a research area of the Department of Agricultural and Food Sciences of the University of Bologna where the Arundo Donax is used for research in biomass production (**Figure 1** shows the reed field and the harvest phase).

Figure 1. Reed harvesting and field.

2. Mechanical Characterization of the Material

The course program had a first part with focus on the knowledge of the mechanical characteristics of the material. In particular, compression, tensile and flexural tests were carried out using specimens with and without nodes. Strain gauges were applied to all the specimens to follow the deformation during the tests.

The students were divided into groups of 3 students each. They followed all the phases of the tests: the set up of specimens, the positioning of strain gages and the final post-processing of the collected data.

The standards of the mechanical tests on bamboo were followed (ISO, 2017). In particular, each group prepared specimens for compression, tension and for flexural test (see Figure 2(a)).

Each student applied at least one strain gauge by touching with hand all the steps: cleaning the specimen, gluing the strain gauges and welding the strain gauge to the connectors for data acquisition. Then all the tests were performed (see Figures 2(b)-(d)). The students post processed all the data.

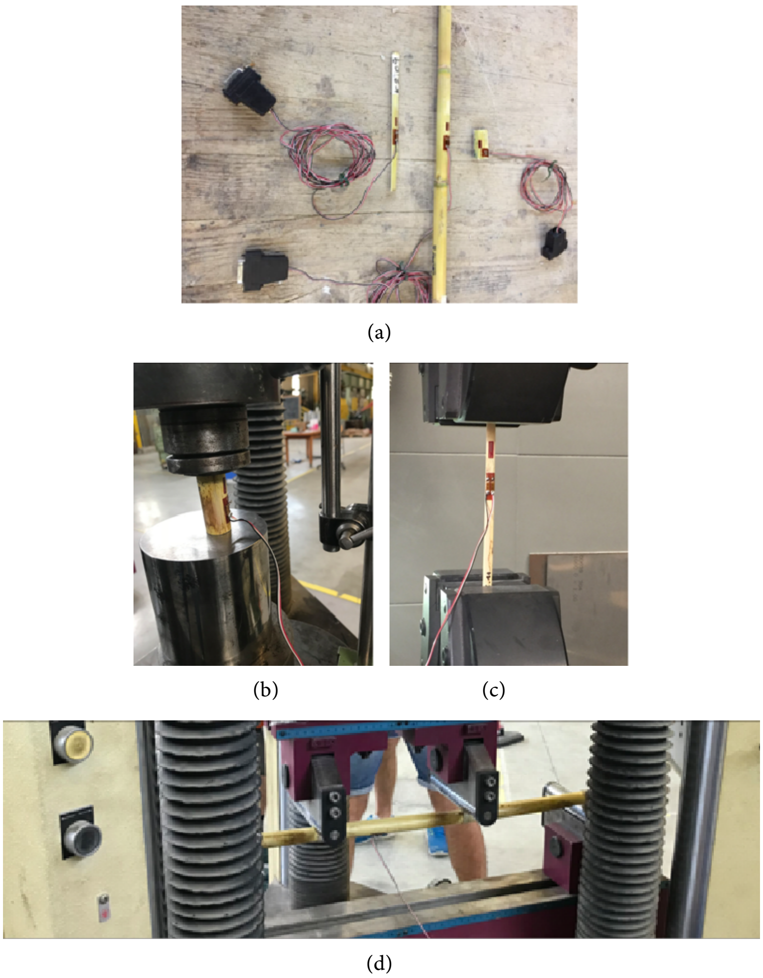


Figure 2. Mechanical tests: (a) Specimens, (b) Compression test, (c) Tensile test, (d) Flexural test.

3. Structural Challenge

At the end of the characterization, the students were assigned to design and build a structure to connect two balconies, placed at the same level and at a distance of 1 m. The total length of the structure had to be appropriately increased, to guarantee adequate support for the extremes; the minimum width had to be 10 cm to allow the loading of an assigned load.

Each group had 1.5 kg of Arundo Donax culms of varying diameter and a 2 cm paper tapes of 50 meters (see Figure 3(a) and Figure 3(b)).

Each group had to proceed with its own elaboration of the structure after a simplified static calculation of the model.

The structure was evaluated taking into account three parameters: the structural performance (evaluated considering the displacement at the span center under 300 N load), the weight of the structure and the aesthetics of the structure (taking into account that the course was aimed at students of the industrial product design course).

For the structural performance a ranking was drawn from the minor measured displacement to the major one and a score from 1 to the number of groups was assigned.

For the weight the structures were weighed and a ranking was drawn from the lighter to the heaviest structure and assigned a score from 1 to the number of groups.

For the aesthetics, it was taking into account a good proportion between the different dimensions of the structures, the score was assigned making an average of the scores from 1 to 5 given by the other groups leaving complete free judgments to the students.

4. Results

Regarding the first part of the course on the mechanical characterization of Arundo Donax, the typical stress-strain maps obtained for tensile, compressive and flexural tests are reported in Figure 4.

(a) (b)

Figure 3. Arundo Donax challenge: (a) Assigned reed, (b) "Desk kit" for each group.

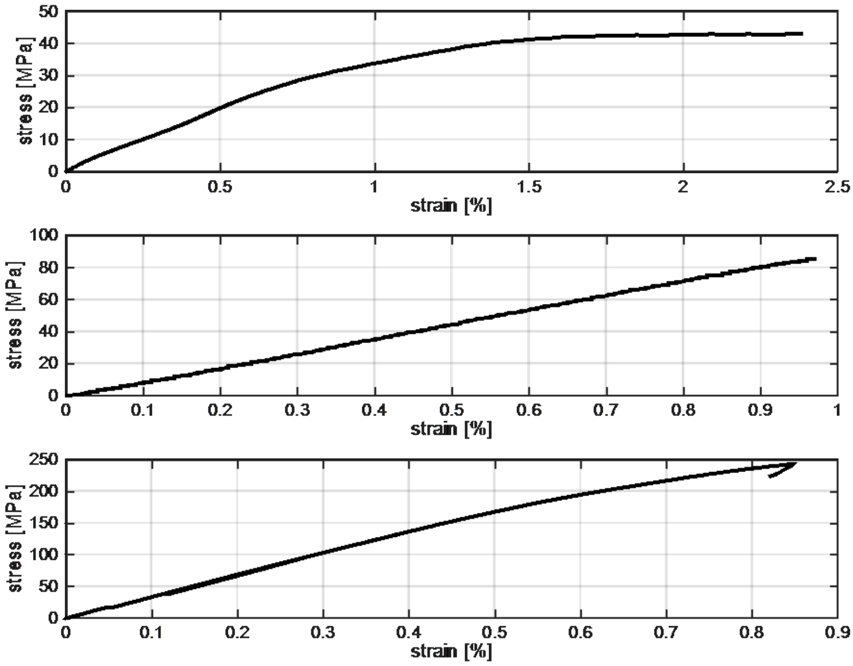


Figure 4. A typical stress-strain diagram for, from the top to the bottom, compression test, tensile test and flexural test.

For the compression and flexural test an elastoplastic behavior was shown, while for the tensile test a brittle elastic behavior was encountered.

The mean value of the Young modulus in traction was 8669 MPa with standard deviation of 963 MPa, while the mean value in compression was 7008 MPa with standard deviation 4530 MPa.

The strength in compressive tests was 46.2 MPa with a standard deviation of 11.0 MPa.

The strength in tensile test was 76.1 MPa as average with standard deviation of 16.4 MPa. During the tensile test some failures occurred at the anchoring position due to the very small size of the section, too different from which considered in bamboo Standards. These events were helpful for students in understanding possible problems arising during the tests and forced to think about different solutions in clamping of specimens.

Regarding the structural challenge, the five groups built 5 structures that were deeply different for typology and structural response. This allowed great discussion about the choices and the results regarding how to the structure reacted to the loads, and how the single parts of the structures were stressed in relation to the shape of the whole structure.

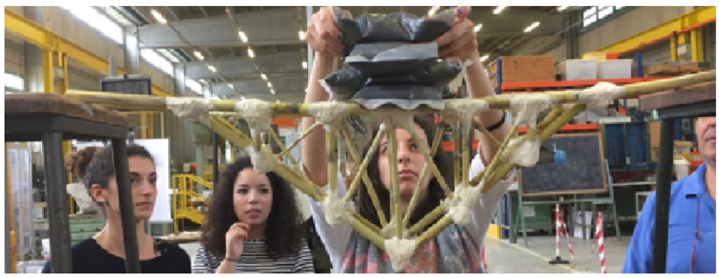
Two groups choose to face the challenge with a bent beam scheme (see Figure 5(a) called S1 and Figure 5(b) S2). The third group opted for an arch structure (see Figure 5(c), called S3). The last two groups opted for reticular structures (see Figure 5(d) and Figure 5(e) called respectively S4 and S5).

The final marks assigned are reported in Table 1. The winning group was the group with the arch structure S3.

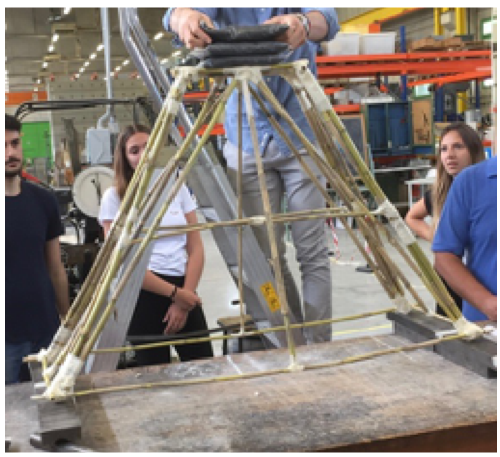
(a)

(b)

(c)



(d)



(e)

Figure 5. Arundo Donax challenge: the structures proposed by the groups of students, (a) S1, (b) S2, (c) S3, (d) S4, (e) S5.

Table 1. Marks assigned to each group.

Structures	Displacement at the mids-pan with 30 kg [mm]	Weight [kg]	Estethic	Final Point
S1	30 (3)	1.23 (3)	2.2	8.2
S2	44 (2)	1.35 (1)	3.0	6
S3	19 (4)	1.0 (4)	4.5	12.5
S4	55 (1)	0.56 (5)	5.0	11
S5	7.0 (5)	1.27 (2)	3.2	10

5. Conclusion

The students participated enthusiastically at all the lessons in the Laboratory and at the final challenge.

The course program was formative for the technical acquisition of knowledge regarding the mechanical characterization of materials. The students also acquired great sensitivity on the values of Young modulus and strength in compression and in tension for such materials. The final challenge allowed students to free their design imagination and verify the structural choices made.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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