# Re. Source—Retained Source

**Giovanni Boccia, Gianluca Lubrano, Valentina Buggè, and Francesco Marmo**

**Abstract** The project takes inspiration from the theme of the contest, the blossoming. In particular, our intent was that of giving the idea of the incipient motion retained in buds. This concept has been rendered in a trivalent way. The most evident interpretation is formal and is represented by the shape given to the structure, which depicts a bud. The mechanical behavior of bent raw bamboo culms that are in the process of releasing their elastic energy and spread upwards is used to symbolize the retained vital energy included in buds. Finally, the building material, chosen to be left almost untouched after harvesting, and the design of structural details, which foster to reuse of structural elements, actualize the reference to the nature given by the contest theme. The design process started from the conceptualization and admiration for raw bamboo culms that are taken as the main and determinant elements of the project. The design choices take advantage of the several aspects connected with the use of this building material such as its strength and weathering, ease of use, assembly, and dismantling costs. We were also concerned about emphasizing the ecological, economical, aesthetic, and mechanical properties of the raw material such as the high specific resistance to traction and bending and the natural cylindrical shape of culms.

**Keywords** Bamboo culm · Active-bending · Reusable joints

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# 1 Concept Design

The main theme of the contest, the blossoming, could be almost automatically linked to the visual idea of the flower, which is colorful, delicate, elegant. But digging in the concept that the word expresses, we can also say that to blossom is an action, which made by the bud (Fig. 1) in order to become what it was always supposed to be. The concept of blossoming recalls a kinetic idea, in perpetual motion, and we decided to play with this interesting concept, in order to express how it beautifully merges with what bamboo itself expresses.

For our project, we focused on the peculiarity of the main material, bamboo. We decided to put under the spotlight the proverbial flexibility of bamboo culms, looking for a design that employs the concept of active-bending [3] and for this reason gives the idea of always being under tension. Also, using the culms would have made our structure modular, easy to assemble with a defined number of similar pieces.

The concept of a tight blossoming relies on the constraining of the bamboo culms with vertical elements, an action that aims to show all the potentiality of bamboo's flexibility in temporary structures (Fig. 2). The natural tendency of the culms to free themselves from the bindings that retain them to expresses the action of blooming in a unique way, like freezing the petals of a flower in the very moment they open up. In this way, the structure is always dynamic in its own essence while being firm and stable.

**Fig. 1** The blossoming and idea of the flower

**Fig. 2** The concept of a tight blossoming with bamboo poles

## 2 Design Development

The planform and elevation of the proposed project are shown in Fig. 3. It operates as an open office, warehouse, educational space, or relaxation suite such as a drink corner. A sustainable choice of material, treatments, and joint design provides a long-lasting resistance over time [1].

The structure base is contained in a square of 9 $m^2$ and is composed of a steel tube curved in such a way to form an open circle. On the superior part of the tube, two groups of tubular pivots, having diameters equal to 4 and 8 cm are used to connect the vertical bamboo elements. Starting from the opening on the left-hand side of Fig. 3, the larger pivots are slightly inclined outwards, while they gradually become vertical in the central part of the base. Smaller pivots are positioned on the top of the remaining portion of the circular base and are all kept vertical.

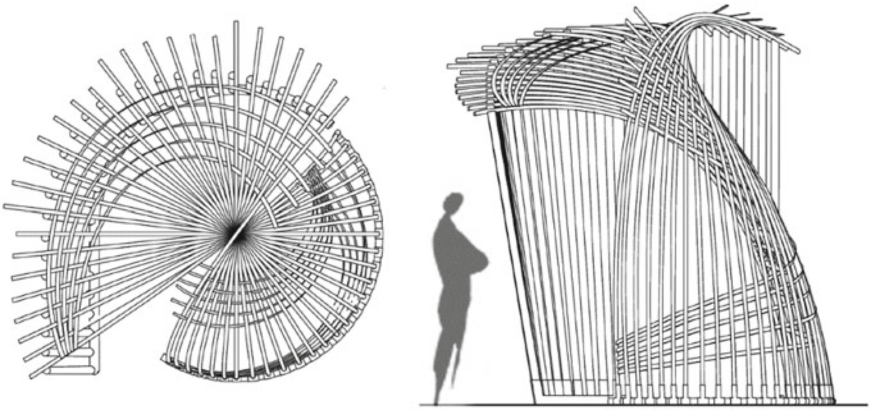

**Fig. 3** The concept of a tight blossoming with bamboo poles

Both groups of pivots serve as the basis for bamboo culms. Larger culms (D80—t8), which are stiffer, are kept straight, until they reach the top of the structure, at about 4 m from the base. Thinner and more flexible culms (D40—t8) are active-bent and cross over the planform to reach the top of larger poles [3]. A series of diagonal bamboo stripes are joining the larger and straight culms, in order to improve the stiffness of the structure. Curved bamboo stripes are used to transversally join the curved thinner culms. The top of the structure is covered with additional bamboo stripes and branches in order to furnish shading and protection yet allowing natural ventilation. Bamboo branches have excellent insulating properties, both from a thermal and acoustic point of view [5, 6].

The choice of the most suitable material for the structure has been dictated by several considerations including the limits imposed by the contest, material strength and weathering, ease of use, assembly, and dismantling costs. We are also concerned about emphasizing the ecological, economical, aesthetic, and mechanical properties of the raw material such as the high specific resistance to traction and bending and the natural cylindrical shape of culms. Other considerations were made for the sustainability of our project. The employment of raw material favors a reduced amount of transformation processes that the material needs to undergo before being used in the construction industry. Obviously, this limits the ecological footprint of the project in terms of $CO_2$ equivalent emissions related to the building process.

It must be said that the best choice to meet these resolutions would have been that of selecting a particular species of bamboo, that is *Dendrocalamus Strictus*, characterized by larger wall thickness and better capability to support larger flexural deformations. However, this choice was not possible due to the contest restrictions. For this reason, keeping the idea of using natural bamboo culms, we decided to prescribe methods and treatments that increase their duration so as to foster its reusability. Among the various treatments that can be used for bamboo, the most sustainable ones regard a proper selection of the harvesting period of stems and the so-called curing, a totally ecological treatment that increases the resistance to fungi and insects and, at the same time, dries out the material in a controlled manner. Culms are then subjected to an additional treatment that employs boric acid to further increase the resistance to fungi.

Although bamboo culms are characterized by unique, exceptional properties, such as strength, form, and texture, they also inherit some drawbacks, typical of most natural materials such as the irregularity of their geometry, which barely meets the tolerances defined by the project. In our case, this issue has been solved by employing a special design of steel joints at the base of the structure. These elements usually require bold control by skilled workers to assess a tight connection between the two materials in order to maximize the strength and stiffness of the joint. To this end we prescribed a suitable finish at the culms ends to be connected in order to avoid the onset of radial and tangential tensional shear states on the internode, which is weaker, that can put the connection to a hard test. The connection between the culms to the base is realized through an interlocking pivot joint welded onto the base tube (Fig. 4). The connection between each culm and the base is made by interlocking male–female elements which are then fixed by a bolt mechanism (Figs. 4 and 5).

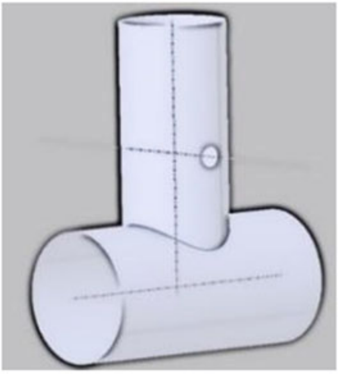

**Fig. 4** Pivot joint between the base tube and the vertical stems

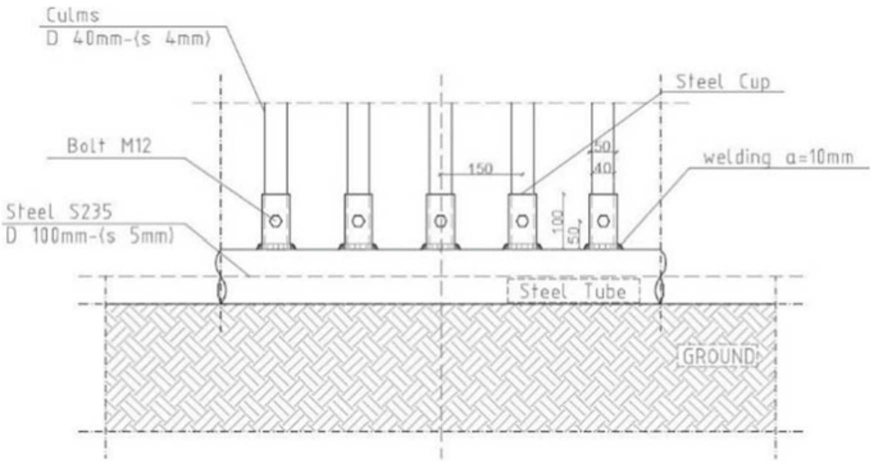


**Fig. 5** Base pivot-joints for 4 cm culms

Here, nodes closer to the connections are trimmed in order to regularize the form of joining parts, which avoids undesired local stress concentrations and increases the adhesion with the support.

To further increase the adhesion to the support, a butyl rubber sealant cover is prescribed for the part of the stem that will enter the joint. This technique also avoids issues related to possible stagnation of water inside the joint and the contact with the end of the culm which may weaken the connection over time [1, 2, 4]. Accordingly, the thickness of the pivot joint is prescribed to be at least 2 mm. Additional constraints connected to the weldability of the pivot forced us to prescribe a thickness of 5 mm (Figs. 6 and 7).

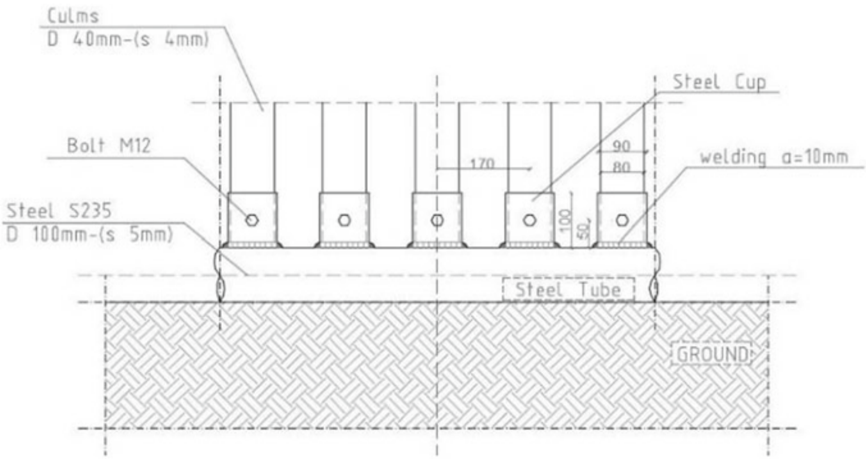


**Fig. 6** Base pivot-joints for 8 cm culms

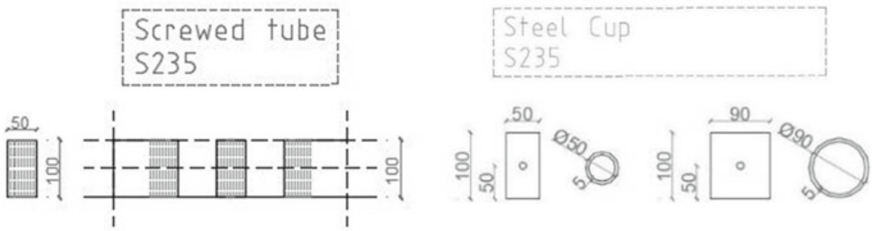


**Fig. 7** Details of screw thread between base tube and pivot joints

The connections between larger and thinner culms and between transversal stripes and both orders of culms are made by knots of natural bamboo rope or by the interweaving of bamboo stripes, for which a thermal treatment is prescribed to increase their flexibility. Knots are positioned in such a way that each damaged el-ement can be easily substituted without compromising the stability of the structure. To ensure higher adhesion between knots and bamboo culms we prescribed a spe-cial treatment for the area in the vicinity of each joint. The connection area has to be cleaned and covered with bi-adhesive butyl rubber sealing tape. This ensures the tightness of the connection due to increased surface friction between surfaces. It al-so improves normal actions between surfaces in contact due to the elasticity of the rubber, which fosters a tighter manual assembly.

In order to verify the deformability and strength of the proposed project, a finite element model of the structure has been employed. The model has been implemented and analyzed within the finite element software Nolian AllInOne (Softing srl, Rome, Italy). Bamboo culms have been modeled by employing beam elements fixed at the base and connected with each other through pinned joints.

The finite element analysis allowed us to verify both the deformability and strength of the structure. According to the numerical simulations, the most stringent requirement is related to deformability checks. To this end, we assumed a limit to the lateral displacements at the top of columns that is proportional to the overall height of the building so as to meet usability and comfort requirements. This limit has been set to one-hundredth of the height of the building.

Figure 8 shows a contour plot of displacements produced by a force of 1000 N, applied at the top of the lateral openings of the lateral walls, which resulted in the most vulnerable points of the entire structure versus the deformability requirements.

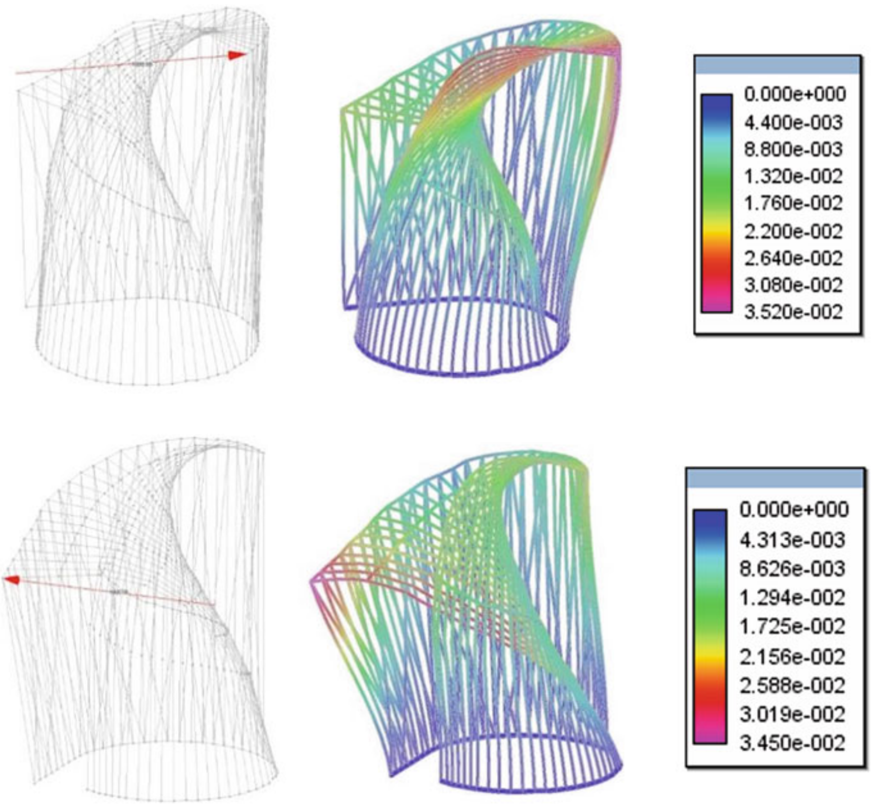


**Fig. 8** Displacements produced by a horizontal force applied at the most vulnerable points of the structure

## 3 Experience

The design of a small bamboo structure has served as a priceless formative experience both for the students and the tutor. The entire team had the occasion to deepen their knowledge and consciousness about the potential of bamboo as a building material. None of us had previous experience with this unique material, which we learned to appreciate for its mechanical, aesthetic, and ecological properties.

The teamwork has been very instructive and stimulating. The three students had different experiences since we came from diverse and disjoint formative paths, related to Building Engineering, Material Engineering, and Architecture. The possibility of sharing our peculiar points of view, our divergent approaches in solving the several big and small problems connected with the design of a structure enriched each of us both from the cultural and professional point of view.

## 4 Renderings

An artistic representation of the proposed structure and an exploded diagram showing the assembling of structural elements are reported in Fig. 9.


**Fig. 9** Artistic representation of the structure and exploded view of the structural elements

## References

1. Arce-Villalobos, O. A. 1999. Fundamentals of the design of bamboo structures (Doctoral dissertation, Technische Universiteit Eindhoven).
2. Jayanetti, D. L., and P.R. Follett. 2008. Bamboo in construction. In Modern bamboo structures, pp. 35–44. CRC Press.
3. Lienhard, J., H. Alpermann, C. Gengnagel, and J. Knippers. 2013. Active bending, a review on structures where bending is used as a self-formation process. *International Journal of Space Structures* 28 (3–4): 187–196.
4. Xiao, Y., M. Inoue, and S. Paudel (eds.). 2007. *Modern bamboo structures*. CRC Press, Taylor & Francis Group.
5. Zhou, S.C., C. Demartino, and Y. Xiao. 2020. High-strain rate compressive behavior of Douglas fir and glubam. *Construction and Building Materials*, 258: 119466.
6. Wang, J.S., C. Demartino, Y. Xiao, and Y.Y. Li. 2018. Thermal insulation performance of bamboo-and wood-based shear walls in light-frame buildings. *Energy and Buildings* 168: 167–169.