# 竹子： 一种引人入胜的植物

摘自论文《竹子仿生学》（作者：乔凡娜·巴巴罗博士www.green-box-design.com，发表于 1997 年 7 月威尼斯 ；中文译文和改编：孙广益 2009 年 3 月于广州）

## 导言

这份研究和实验论文于十多年前在意大利发表，皆因好奇所致： 为什么自然界里会有进化如此完美的植物－例如竹子，既不完全中空、又非完全实心?

在众多可能答案中的一个是：自然界是如此复杂，需要一个有奉献精神的特殊的综合学科团队来进行深入研究，以下由三个有机组成的部分进行阐述：

第一是关于对竹子从植物学观点和关于他们的物理和机械性能的系统研究的结果；第二是对原材料处理的工艺史概览，源生国对这些植物在不同领域里的广泛使用－例如建筑、家俱等；最后是威尼斯建筑大学在实验室做的材料测试：评估竹节对竹杆的整体荷载和抗曲强度的作用。

作者更新了某些章节来与读者分享这种植物吸引人的方面，尽管它对我们这种模式的社会有着可持续发展的优秀潜力，但在欧洲仍然被低估。

## 植物学特性和原产地

起源于印度、有着树型鞭茎与木质化茎干和形状，通称竹子。 草本科竹类。草本科竹类又分为 5 个亚族： 龙竹属、梨竹属、刺竹属、箭竹属和刚竹属。植物学文献提供的竹子科目分类和种类的数量差异很大。 Lubkee 1967 年，指出大约 500 种，美国竹协则认为有 470 种，其中 400 种生长在美国。 总之，我们可以着重于根茎的种类和茎干成长特征的二个主要小组： 单轴竹(如下图片由 Shinji Takama，Die Wunderbare Well des Bambus，Ed Dumont 提供)和合轴竹。（以下照片由 Noah Bell, 2007 提供www.shweeashbamboo.com）

在第一组，根茎间歇地向外扩张生长出细长的竹鞭。 后者有短和厚实的球茎根，末端生长鞭茎。

在东半球竹子分布于南纬 32 度(南非)到北纬 46 度(千岛)的区域。 在西半球，则分布于南纬 47 度(巴塔哥尼亚，阿根廷)到北纬 40 度(费城，美国)的区域。 65%已知的种类在印度、缅甸和印度尼西亚被找到。 在欧洲， 1855 年竹子被引进到法国，座落于 Générargues 的 6 公顷的种植园。

## 奇异的竹子及其分布

竹子最适于热带或亚热带气候，然而也有能忍受零下 25 度生长于厄瓜多尔的安斯山脉长年雪线以上的种属。

单轴竹每年水平扩张 1 到 6 米，持续约 10 年；而合轴竹则扩张距离较短，呈水平辐射网状在每个球茎上发育出 2 至 3 个新株。不同的根系相互交织，形成的根系长度达 25,000 到 187,000 公里/公顷。因而有效地防止土壤流失，特别是在最易受侵蚀的砂壤和和断裂地带，以及沿堤防和河岸。

笋芽从根茎开始，并且可能在地下保持数年。一旦破土而出，它们将以惊人的速度生长： 在 20 至 30 天内，竹茎便可长到它的最大高度，此后便是巩固期。 根据种类，竹茎可能增长超过 30 cm 高和 2.5 cm 直径或在某种状态下达到 40 m 和 5 到 12 cm 直径和 1 cm 壁厚。 除了草，没有任何植物象竹子生长速度那么快。在京都食用毛竹标本中有 1956 年由长冈做的 121cm/天的测量记录。通常成长速度是 25 cm/天，而且每棵竹笋都缩样包含成熟茎将有的所有竹节。

竹的高生长率的结果是，在理想的情况下，可能超出 50 吨/公顷/年的生物量的高生产力。由于种植 5 年后被收获，期间它又自行繁殖，无需重栽，竹子对林业的可持续经营有着重要意义。

竹子的最神奇的一个方面是它的开花。 某一种类凋落以后结果，而其他可能年年开花多次。 小竹类开花间隔 3 或 4 年，而巨型竹种类间隔 20 到 120 年。 开花可以是零星的或成遍的。在一个国家，即，仅几棵在根球附近或单独一棵开花，又或甚至在一个国家所有竹子都开花。 在 1880 年由西印度移植到英国温室的朱丝贵竹，在 1884 年与她们原产地的姐妹在同一时间都开了花。看来竹子开花和太阳黑子的活跃有一定的关联性。

种子育成率低：在 1966 年由 Mc Clure 做的试验期间，仅有 1%种子发芽了。通常植物沿根茎产果后数星期死亡。

如果竹子的生物学方面是令人惊异的，那么它的机械性能则是仿生学家的灵感源泉。 观察分布于茎壁中的输送管道，它的外缘显然是由较高强度纤维更加密集地被编织组成，静态应力更高，俨然是一个用装甲栅加强的筋混凝土大厦。

根据 Stockel，其纤维的径向抗拉强度可达到 4000 kg/cm2。 要理解这个量级，切记木材也不超过 500 kg/cm2，建筑高强度钢 Fe B38K，不超过 3750 kg/cm2，而玻璃纤维可达 7000 kg/cm2。

竹皮含硅量很高，使它有着吸引人的耐火性。

第一次的耐火性测试是上个世纪 80 年代由 Institut für leichte Flächentragwerke 和斯图加特-德国的大学做的，证明竹子是一种阻燃物。 在西班牙，竹子符合新的 CTE (技术建筑条例)的标准，并且耐火性测试根据 UNE EN 准则 13501 分类 CFL-S1 材料类别，因此适用于公共建筑。

竹子的多功能性是一种可持续发展的解决方案。 现今它常被 提起皆因环境的不能持续经营产生的问题，例如温度和海平面上升导致各种生态系统失衡。 空气质量低劣使得在大都市生活变得更加艰难，而环境技术员预测由于缺水和生物多样性减少而产生的近期威胁。 Albert Einstein 说“如果蜜蜂开始消失，人类也就仅存数年”。

在不远的将来－主要干预－专家和所有人，应该致力于保护植物和动物的生物多样性。 如果我们想要交付给下一代一个适于居住的星球，我们必须通过避免多余的废物和效率低的系统来控制不可更新的能源消耗的增长。

木材的无限制开发直接导致气候变化和土壤的水文地质的破坏性的不稳定，以及二氧化碳增加导致地球变暖的严重后果。本人作为一个建筑师和博物学家，我相信我们每一人都应该贡献自己的知识和行为规范来恢复或至少停止这个趋势，通过改变我们的态度和生活方式做为开始

竹子是木材的唯一替代品，因为它100%的可持续性耕作有助于保护生物多样性，并且它的工业化过程是有机的。

如果与松木比较，一公顷竹子可能提供 2 到 5 倍更多原料生产纸、纤维板、桌、竹炭甚而生产密度高于 1000 kg/m3 的极抗擦痕的板材。竹子的密集的网状根系是坡地极好的稳定器防止水土流失，并且他们的叶子为小动物创造了一个理想的栖所。 其迅速的生长速度使竹子成为理想的植物净化污水的生物过滤器，并捕获大气中很大数量的二氧化碳。竹子的典雅的形态和他们在各种各样的气候和土壤中都易于栽培，令其在任何庭院里都是一道美丽的风景，即使在灰色冬天。

# Bamboo: a fascinating plant.

Excerpt from the Thesis published in Venice in July 1997 under the title *The Bionics of Bamboo*. Author dr. arch. Giovanna Barbaro info@green-box-design.com.
English translation and adaptation by Mario Rosato, Barcelona January 2009.

## *Introduction*

This research and experimentation thesis, published more than a decade ago in Italy, has been motivated by a curious question: Why has Nature perfected over the course of evolution plants like bamboo, with a stem neither completely hollow nor completely solid?

One possible answer among many, because Nature is so complex that needs to be studied deeply with dedication and especially by multidisciplinary teams, can be articulated into three sections.

The first is the result of a systematic research on bamboos from the botanical point of view and with regard to their physical and mechanical properties, the second is a historical overview of the technologies in processing raw materials, on the wide use of these plants in their Countries of origin in various sectors like building and home accessories ; and last a valuation made in the Laboratory for Testing of Materials of the University of Architecture of Venice on the contribution of the nodes to the overall resistance of a bamboo pole subject to critical load and bending.

The Author has updated some excerpts to share with the Readers the most fascinating aspects of this plant, which in Europe is still undervalued, despite its excellent potential for the sustainable development of our model of society.

## *Botanical features and origin.*

Bamboo is the common name, of Indian origin, applied to all tree-like plants with woody trunk and shape of cane. The Genus of the family Monocotyledons include grasses, which in turn includes the subfamily of bamboos. From the systematic viewpoint of the grass tribe (subfamily) *Bambusae* is subdivided into five subtribes: *Dendrocalaminae, Melocanninae, Bambusinae, Arundinaceae* and *Puellinae*.
Botanical literature gives very different information on the number of families and species of bamboo. Lübke, 1967, points out about 500, the American Bamboo Society some 470 of which 400 grown in USA. Summing up, we can highlight two major groups based on the type of rootstock and the growth characteristics of the reeds: the monopodial bamboos (picture below by Shinji Takama, *Die Wunderbare Welt des Bambus*, Ed Dumont)

and the sympodial bamboos (picture below of Noah Bell, 2007, www.shweeashbamboo.com).

In the first ones, rhizomes form long and thin extensions of the reeds which grow at regular intervals. The latter have short and thick bulbous roots, which ends produce the canes.

In the Old World bamboos grow from 32 ° S (South Africa) to 46 ° N (Kuril Islands). In the New World, they are found from 47 ° S (Patagonia, Argentina) to 40 ° N (Philadelphia, USA). 65% of known species are found in India, Burma and Indonesia. In Europe, the bamboo was introduced in 1855 in France, with a plantation of 6 hectares in the locality of Générargues.

## ***The astonishing biology of bamboo and its dissemination*.**

Bamboo grows best in tropical or subtropical climates, however there are species that tolerate up to -25 ° C as *Chusquea aristata*, which grows in Ecuador up to the line of perennial snow of the Andes.

Monopodial species spread horizontally from 1 to 6 m / year, for about 10 years, whereas sympodial species spread horizontally over short distances, according to a radial pattern in which each bulb generates another 2 or 3. Different root systems can intersect, forming networks of progressive scale ranging from 25,000 to 187,000 km / ha and thus effectively contrasting soil erosion, particularly in areas most prone to crumble and break, and along embankments and river banks.

The buds develop from the rhizome and can remain underground for several years. Just emerging, they grow with great speed: within 20 - 30 days the cane reaches its maximum height, and from then it strengthens. Depending on the species, the cane can not grow more than 30 cm in height with a maximum diameter of 2.5 cm or in certain conditions reach 40 m in height with diameters of 5 to 12 cm and thickness of the wall of the trunk 1 cm. Except for grass, no other plant grows as fast as bamboo, with a record of 121 cm / day measured in 1956 by Nagaoka in Kyoto in a specimen of Phyllostachys edulis.

Normal growth is 25 cm / day and every shoot that sprouts contains in miniature all the nodes that the mature cane will have.

The high growth rate of bamboo results in a high productivity of biomass that, under ideal conditions, can exceed 50 tons / ha / year.

Because it is harvested 5 years after having been planted and regenerates without having to replant it, the bamboo contributes to sustainable forest management.

One of the most mysterious aspects of bamboo is its flowering.
Some species die after having fruited, while others can bloom several times annually. Small species bloom at intervals of 3 or 4 years, while giant species do after a period of 20 to 120 years. Flowering can be sporadic or mass, i.e., only a few rods around the root ball or individual, or even all bamboos in one nation. In 1880 some rhizomes of Chusquea abetifolia from the West Indies were planted in a greenhouse in England. In 1884 the canes bloomed in the greenhouse at the same time as their sisters in the area of origin. It seems that there is a correlation between the flowering of bamboo and the activity of sunspots.

The flowers give rise to fruits, which generally fall to the ground before ripening. The seeds have a low fertility rate: during an experiment conducted in 1966 by Mc Clure, only 1% of seeds planted germinated. Normally the plant dies along with its

rhizomes some weeks after having produced the fruits.

If the biological aspects of bamboo are amazing, its mechanical properties are a source of inspiration for biomimetics experts. Observing for example the distribution of the vascular vessels in the wall of the cane, it is evident that the fibers of higher strength are more densely grouped at the periphery, where static efforts are higher, in a similar way to the armor bars of reinforced concrete buildings.

According to Stockel, the resistance to traction of the fibers that run parallel to the axis of the reed reaches 4000 kg/cm$^2$. To understand the magnitude of this figure, remember that timber does not exceed 500 kg/cm$^2$, construction steel Fe B38K resists until 3750 kg/cm$^2$ and fiberglass reach 7000 kg/cm$^2$.

The bark of the bamboo has a high silicon content, which gives interesting properties of fire resistance.
The first tests on fire resistance back to the 80s of last century and were made by the Institut für leichte Flächentragwerke, University of Stuttgart – Germany, where bamboo is certified as a *flame retardant combustible material*. In Spain bamboo meets the standards of the new CTE (Technical Building Code) and the tests of fire resistance according to the Norm UNE EN 13501 classify this material as category CFL-S1 , hence suitable even for public buildings.

The versatility of bamboo is a solution for sustainable development. Nowadays it is often spoken about the problems derived from the unsustainable management of the environment, such as the rising temperatures and sea levels, with the consequent unbalances in different ecosystems. Life in metropolitan areas is becoming harder by lack of air quality, while environmental technicians prospect threatening short-term scenarios because of water shortage and biodiversity reduction. Albert Einstein said "If the bees begin to disappear, mankind would be left a few years of life."

In the immediate future, major interventions, both of professionals and of any human being, should be addressed to protect the biodiversity of both plants and animals. If we want to deliver our planet livable to future generations, we must control the growth of non-renewable energy consumption by avoiding unnecessary waste and inefficient systems.

The uncontrolled exploitation of timber is directly involved in climate change and is reflected in a devastating hydrogeological instability of the soil and the increase of carbon dioxide with serious consequences of global warming. Personally, as an architect and naturalist, I believe each of us should contribute with his/her own knowledge and ethics to revert or at least stop this trend, beginning by changing our attitudes and lifestyle.

Bamboo is the only alternative to wood because its 100% sustainable farming helps to protect biodiversity and its industrialization process is organic.

If compared to the pine, a hectare of bamboo can provide 2 to 5 times more raw material for the production of paper, fiber boards, tables, charcoal and even wood with a density higher than 1000 $kg/m^3$ therefore very resistant to heel marks. Bamboo's dense network of roots is an excellent stabilizer of slopes against erosion, and their fronds create an ideal habitat for microfauna. Its rapid growth makes bamboo ideal as a biofilter for phytodepuration of polluted waters and the capture of large quantities of atmospheric $CO_2$. Bamboo's elegant forms and their ease of cultivation in a wide variety of climates and soils make it a beautifier element in any garden, even during the gray winters.