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# A low-technology approach toward fabrication of Laminated Bamboo Lumber

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ABSTRACT

Depletion of natural resources has become a major concern in today's modern industrialized world centering much attention on sustainability of the built environment and sustainable alternatives to current development and construction practices. In the green building community, strong interest lies in natural and renewable building materials that can be used in structural applications. Just such a natural and renewable building material, called Laminated Bamboo Lumber (LBL), has recently been developed. This product, however, typically requires sophisticated fabrication equipment and energy intensive pressing processes that generally limit the possibility of local product fabrication. In an effort to foster local and thus more sustainable production of the product, this paper proposes a simple, practical and low-technology approach for LBL fabrication that could be carried out in any part of the world in which bamboo currently grows. Twelve 4-ply LBL specimens were fabricated using the proposed approach and the mechanical properties of the resulting LBL indicate that the end product is mechanically suitable for use in structural applications. The key contribution of this paper, therefore, is the conclusion that structurally reliable LBL can be fabricated using hand tools, screw-driven mechanical presses, and widely available, economical adhesives.

## 1. Introduction

The term *bamboo* encompasses a collection of giant grass species [10]. In the western world, it is commonly used in non-structural applications, such as flooring, fencing, furniture and crafts, and for ornamental purposes. In many countries to which it is native, however, bamboo is used as a structural building material. For example, in Asia, bamboo has traditionally been used in low-rise buildings, short-span foot bridges, long-span roofs and construction platforms [1].

Bamboo has recently attracted considerable interest as a sustainable building material since it possesses mechanical properties similar to those of structural wood products, and, due to its fast growth rate, can support intensive and sustainable use in the building industry [2,10,8,6]. Bamboos grow faster than any other plant, and for most species, full height is reached within 2–4 months [4] with maturity coming in 3–8 years [2]. Bamboos also sequester large amounts of carbon, with Nath et al. [6] reporting an above ground carbon storage of 61.05 tons per hectare for village bamboos of northeast India. After a detailed quantitative lifecycle analysis, van der Lugt et al. [10] found the structural use of bamboo to have less negative effect on the environment than that of other common building materials, such as steel or concrete.

Due to bamboo's natural hollow tube shape, it is not possible to connect bamboo members with existing standard connections. Therefore, it has been of interest to make bamboo available in shapes more suitable to current structural applications. This interest led to the development of Laminated Bamboo Lumber (LBL), which is usually produced as a board of rectangular cross-section [3,7–9].

Generally speaking, LBL is fabricated by flattening bamboo culms and gluing them in stacks to form a laminated composite. While resolving geometric issues presented by the round, hollow culm, this process introduces new issues of cost, labor and need for sophisticated equipment. Moreover, the process adds embodied energy to the final product while erecting financial obstacles for LBL production in developing countries. It is speculated that limited LBL production causes reduced availability and increases the distance between supplier and consumer, leading to greater transportation burdens. It is hoped that development of a low-technology fabrication approach would allow creation of new value-added LBL products worldwide that would help local communities and drive economic growth in developing nations.

The objective of this paper is to examine a new low-technology approach for the fabrication of LBL in an effort to assess the feasibility of using this approach to produce an LBL product that is suitable for use in structural applications.

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## 2. Current Laminated Bamboo Lumber (LBL) fabrication techniques and properties

LBL is a fairly new material with only a limited body of associated research. Further research on, and promotion of, LBL is required in order for this environmentally friendly material to gain popularity for use in structural projects. Here, a brief background is presented on current fabrication techniques, mechanical properties and feasibility of LBL. Detailed methods of LBL fabrication and performance information are available in the literature [7,9,3].

### 2.1. Fabrication

In order to fabricate LBL, bamboo culms (poles) must first be flattened. Then, with fibers oriented longitudinally, the culms are stacked in layers in the presence of adhesive to form a laminated composite. Bamboo culm is naturally strong in its cylindrical shape and high pressures are required to flatten it. Lee et al. [3] reported that placing a bamboo culm under a hydraulic laboratory press at a pressure of 690 kPa sustained for 1–4 min, depending on the thickness and curvature of the culm, was effective in achieving flattened bamboo. However, the stacked layers were later placed under a pressure of 1380 kPa in the presence of adhesive during the lamination process, which could have greatly contributed to the flattening of any curvature remaining after the first attempt. Therefore, it seems best to take 1380 kPa as a reference for the amount of pressure needed to flatten bamboo culm, if pressing is the desired flattening approach. It is important to note that during the flattening process, many cracks are formed between and parallel to bamboo fibers that can negatively affect the final product strength.

The inner and outer surface layers of bamboo poles contain wax and silica which do not allow adhesive to bond well to the surfaces. Therefore, these layers must first be removed. A planer is often used for this [8,7,9,3].

Previous literature provides important information on adhesive application and stacking arrangements of the flat sheets or “mats”. Lee et al. [3] clearly show from their test results that increase in glue spread rate results in a product with higher bending strength. Nugroho and Ando [7] found a significant drop in glue bond strength at interfaces formed by joining two outer faces of bamboo culm.

### 2.2. Mechanical properties

Table 1 compares the reported average values of mechanical properties, Modulus of Elasticity, MOE and Modulus of Rupture, MOR, of similar sized small coupons of LBL, 2600Fb-1.9E Eastern Species Laminated Veneer Lumber (LVL) and 2900Fb-2.0E Eastern Species Parallel Strand Lumber (PSL). LBL properties from three different studies are included [3,7,9]. All values are similar to one another suggesting that, ignoring cost and connection challenges, LBL could be considered an alternative to LVL and PSL in structural applications.

**Table 1**
Average values of LBL’s mechanical properties reported by previous studies shown in comparison to those of LVL and PSL.

| Product | MOE (GPa) | MOR (MPa) | Species |
|---|---|---|---|
| LBL[a] | 8.0 | 86.3 | *Phyllostachys pubescens* |
| LBL[b] | 11.6 | 81.2 | *Phyllostachys pubescens* |
| LBL[c] | 10.0 | 95.1 | *Gigantochloa apus* |
| LBL[c] | 9.8 | 87.8 | *Gigantochloa robusta* |
| LVL[d] | 11 | 93.5 | *Eastern species* |
| PSL[d] | 11.6 | 90.3 | *Eastern species* |

[a] Lee et al. [3].
[b] Nugroho and Ando [7].
[c] Sulastiningsih and Nurwati [9].
[d] Mahdavi et al. [5].

## 3. Experimental methodology

Many of the methods that have been used in the past for LBL production require equipment that may not be available or feasible to acquire in some places where bamboo commonly grows. For example, planers and hydraulic presses – for the purposes of flattening culms and removing inner and outer surface layers – or bamboo splitting machines may be difficult to finance by residents of a rural area in China or India. Simple alternatives to using these tools are necessary in these cases. After some preliminary investigation, it was found that hammering culm can be just as or more effective than a press in flattening culm and creating mats. Also, using coarse sandpaper was found to be very effective in removing inner and outer surface layers. While these alternatives are more labor intensive, they make the process adaptable and available to people in regions where heavy machinery is not readily available.

### 3.1. Fabrication of LBL specimens – the proposed approach

For this study, Moso bamboo *(Phyllostachys pubescens, Mazel ex J. Houz)*, approximately 13 cm in diameter, was used to fabricate twelve 4-ply LBL specimens which were then tested to measure bending stiffness and strength in accordance with ASTM D143 – Standard Test Methods for Small Clear Specimens of Timber. The following discussion outlines the detailed fabrication approach.

#### 3.1.1. Cutting bamboo culm into segments of desired length

Dry bamboo poles were cut into segments 81.3 cm in length, 5.1 cm longer than the length of the final specimen. The extra length was to allow for losses due to cutting and any adjustments that may be necessary.

#### 3.1.2. Sanding outer surfaces of bamboo segments

Previous studies have shown that the concentration of fibers decreases from the outer layers toward the inner layers of bamboo culm [11]. Therefore, care was taken to remove only as much as necessary when sanding the outer surface, so as to preserve as much of the high strength material near the outer surface as possible. This was based on the speculation that removing too many layers with high fiber density would decrease the overall average fiber density and could possibly weaken the material.

Wax and silica are non-fibrous materials. During sanding, when fibrous material begins to appear it is a sign that wax and silica layers have been removed and sanding should stop, otherwise fibers will be damaged. Fig. 1 shows a partially sanded outer surface of dry Moso-bamboo culm. The fibrous and non-fibrous layers are visually distinguished.

#### 3.1.3. Flattening bamboo into mats

Splitting bamboo culm longitudinally into smaller pieces makes the process of flattening the culm much easier. Naturally occurring longitudinal cracks (Fig. 2) can assist with manually splitting the culm. Since Moso bamboo is very weak in the direction perpendicular to the fibers and tangential to the perimeter of the cross-section, longitudinal cracks form very easily. For dry culms, cracks often form naturally; otherwise, a few strikes with a hammer (Fig. 3) will generate a longitudinal crack with fair ease. These cracks can be opened easily by hand, or by using a pry bar.

After culms were split, they were placed on a hard, flat surface with the inside of the culm facing down. They were then further flattened by hammering. The flattened mat, after completion of hammering, is shown in Fig. 4.

It is not possible to determine the widths of the mats prior to hammering. Therefore, after all mats were created, compatible groups of four mats were visually organized. Compatibility was determined based on width and node location. Nodes are rings that exist on a bamboo pole at varying distances from one another (see

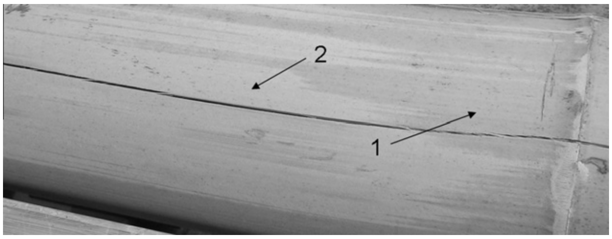

**Fig. 1.** Partially sanded outer surface of dry Moso bamboo culm; (1) Non-fibrous wax and silica that must be removed; (2) Fibrous material.