Designing and Building with Bamboo

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Acknowledgements

In the 26 years of working with bamboo, I have met several good people, working in the field of bamboo, from all over the world. Many of them have become my cherished friends. First among these are those from the National Bamboo Project (later Funbambu) in Costa Rica; I could list enough names to fill up this page. Apart from these Costa Rican friends, I will mention here only four people: Wim Huisman, my professor and first promoter; Walter Liese, who was a member of my Ph.D. committee and with whom I have spent many enriching hours working on bamboo in several places; Ramanuja Rao, with whom I have had as close a working relationship as two scientists can have; and Arun Kumar, who has done a tremendous editing work on the typescript of this book. I would also mention here that this book would never have been written but for the understanding and support of my wife Loek.

J.J.A. Janssen

Preface

Over the past few years, several friends and peers had suggested that I write a book on building with bamboo. Each time such a suggestion was made, I used to recall the wise words of a professor who was famous for his lectures. Whenever pressured to write a book based on his brilliant lectures, he used to decline, saying: “If I present my lectures, my students will hear also my uncertainties, my doubts, the limits of science; but if I were to write them down, then these are exactly what would become invisible.”

Then, why did I write this book now? There were some very persuasive arguments from certain quarters in favor of writing it. One was that the insights and knowledge on bamboo collected during my 25 years of research, guidance of projects and visits to bamboo-growing countries all over the world should not be allowed to go unrecorded. Another was that other areas – timber, for example – too started in a similar way with one author writing a book while the area was still small enough to be captured by the efforts of one. Finally, I thought that some information contained in my large collection of gray literature should be revealed to all interested researchers.

This book has its origin in an e-mail I received in December 1996 from the Hawaii Chapter of the American Bamboo Society, with an invitation to present a series of lectures on all aspects of bamboo. An exchange of ideas followed through several e-mails about the scope of the lectures, the topics to be covered and the time to be spent on each. It was decided that an emphasis should be laid on bamboo’s mechanical properties, joints and structures. I spent a considerable part of January-June 1997 preparing lecture materials and charting out the course.

I reached Hawaii in July, and spent the first two weeks presenting summaries of the lectures in three minor islands. On the third week, on the Big Island, the tempo really picked up. The event started with a demonstration on bamboo jointing to a large audience. This was followed by a three-day seminar, with six hours of lectures each day, involving a large group of participants whose enthusiasm and dedication were contagious. Over 150 people had assembled there, paying on their own for travel and accommodation, and listening to lectures on bamboo six hours a day for three days!

The effort that went into the preparation of that lecture series culminated in this book. It took some time to bring the lectures into the shape of chapters, but doing that has given me a great sense of satisfaction. I hope the readers will find this result of my endeavors useful and interesting. I thank the Hawaiian Chapter of the American bamboo Society without whose invitation to lecture this book might never have been.

Although the emphasis here is on designing and building with bamboo, I have included two chapters – on Technology Transfer and Job Creation – so that the publication provides a wider perspective on bamboo. I believe that this should be so because bamboo is not just a plant or a material; in many parts of the world, bamboo is a vital part of the living heritage that links yesterday with tomorrow.

Jules J.A. Janssen

Contents

Chapter One

Introduction

The Bamboo Plant

In their natural habitat, bamboo plants grow from seeds or rhizomes. The rhizome system is very important to bamboo. As bamboo does not have a central trunk as in trees, the rhizomes provide the foundation. McClure (1966) has described the bamboo rhizome as a segmented (with nodes), complex subterranean system. Bamboo rhizomes can be broadly classified as pachymorph (sympodial) or leptomorph (monopodial). In pachymorph rhizome system, the apex of a rhizome gives rise to a shoot that grows into a culm, the woody stem of bamboo. Such culms grow close together as a clump. In leptomorph rhizome system, the lateral bud from each internode develops into a culm or a rhizome. As the apex of the rhizome grows horizontal to the ground, the clump of monopodial bamboos has a spreading habit, with each culm growing at a distance from the other.

Fig. 1 shows on the left a young shoot, protected by a series of sheaths, which will fall off as the shoot grows into a mature culm. In many cases, these protective culm sheaths are covered with tiny hairs sharp enough to pierce human skin and, in several species, toxic enough to cause skin irritation. Most bamboos are hollow, as can be seen in Fig. 1 (on the right). In the hollow inner area, some horizontal partitions called “diaphragms” can be seen (towards the bottom on the right-side picture). On the outside, these partitions are denoted by a ring around the culm. A diaphragm and the ring on the outside together form a “node”. Branches grow from these nodes. The part between two nodes is called an “internode”. The internodes of most bamboos are hollow; that is, they have a “cavity”. The wall of the culm is called simply the “culm wall” (Fig. 2).

In general, bamboo species have luxuriant foliage: the plant is one of the top producers of biomass, producing about 10 tons per hectare. According to an estimate, bamboo accounts for one-quarter of the biomass in tropical regions and one-fifth in sub-tropical regions.

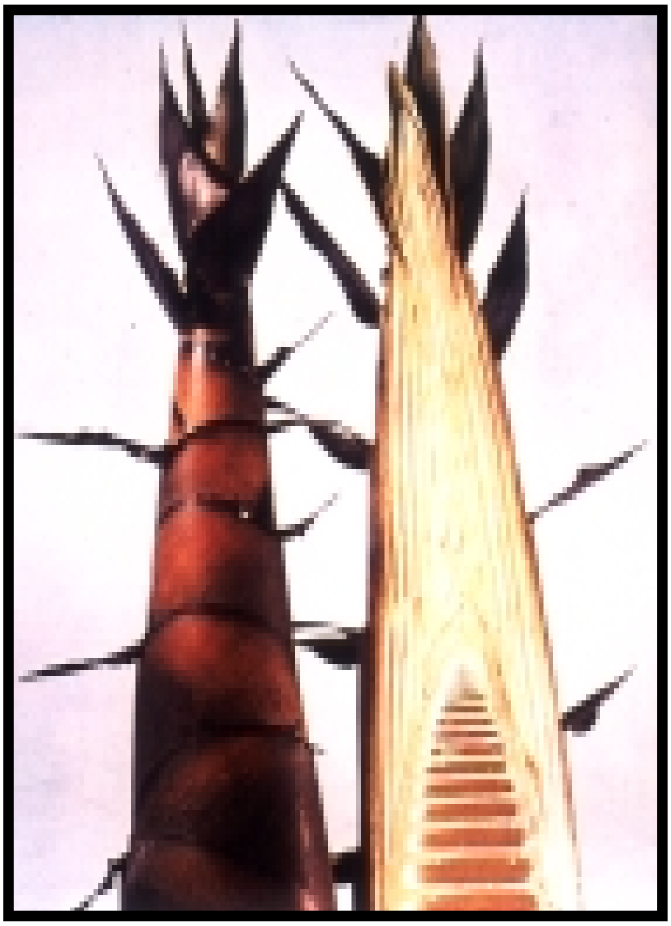


Fig. 1: *A young bamboo shoot – outside (left) and inside (right)*
*(*From CIBA Review, 1969, No. 3, p. 7; by permission of the Company Archive of Novartis AG, Basel, Switzerland*)*

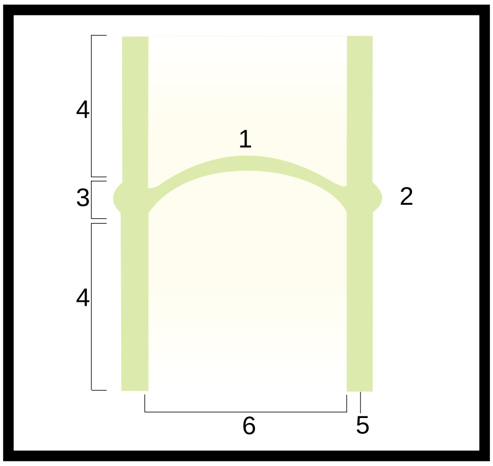


Fig. 2: *The parts of a culm*
(1 = diaphragm; 2 = ring; 3 = node; 4 = internode; 5 = culm wall; 6 = cavity)

Fig. 3: *Bamboo in landscaping (Japan)*

Bamboo in its Setting

Bamboo has the remarkable ability to create an “ambient”, in the artistic sense of the term. Fig. 3 shows how bamboo can set the tone of a landscape. It forms a marvellous contribution to the beauty and an improvement to the environment (bamboo’s role in the environment will be discussed in detail in Chapter 2). The beautiful composition of leaves and culms, often in rich colors, has inspired poets and painters from the ancient to the modern times. In many modern shopping centers and office buildings around the world, bamboo’s stately elegance makes it a cherished component of architectural design. A harsh winter can severely harm bamboo because it is a plant for tropical and sub-tropical environs. But even in countries with cold climates – such as the Western European nations and the US – bamboo can be found in many gardens and parks as the bamboo lovers in these places seem to have developed an instinct for growing species that can survive cold winters.

A bamboo grove or plantation can be viewed as the production site of a building and engineering material; but it is also a haven for the living. Many birds build their nests on bamboo, and one can easily meet among bamboos animals like an iguana or an armadillo, or the smaller ants, snakes and scorpions. In a forest setting, larger animals such as panda, orangutan and elephant frequent bamboo stands. Some rare flowers, herbs and mushrooms can be found inside bamboo groves, the edible "princess fungus" that contains 21 amino acids being one example.

One must not forget to adequately emphasize bamboo's role as a means for erosion control, riverbank protection, landslide prevention and land rehabilitation. Bamboo's extensive network of rhizomes and roots binds the top one foot of soil, which is critical for land productivity (Fig. 4), and effectively resists erosion by forces of nature such as wind and water. There are cases reported wherein bamboo was planted to successfully prevent the erosion of a riverbank and thus protect a village from being washed away.

Fig. 4: *The root system of bamboo (the white scale is 150 mm long)*

Fig. 5: Sasa *bamboo, the green cover*

When the bamboos had grown, not only the village was safe but also the villagers were able to sell the culms and make a profit (Singh 1995).

There are some species of bamboo that can very effectively provide a green cover for the earth and protect the soil. *Sasa* bamboo (Fig. 5), for example, is about 100-200 mm high and is ideal for covering an area to protect it from erosion and sunburn. Its numerous roots keep the soil together, while its leaves protect the soil against the sun. It will also improve the soil through the biomass produced: the blanket of fallen leaves is effective mulch to keep the moisture in and an organic fertilizer to rejuvenate the soil.

Fig. 6: *A field in Costa Rica being readied for bamboo propagation*

While most plants are multiplied by seeds, bamboo is an exception. In general, plants flower at least once a year to produce seeds. But most bamboos flower rarely – once in a period varying from 15 to over 100 years. It is not practical to wait that long for propagation and therefore, bamboo is propagated mainly through cuttings. One place where green culms are extensively used for cuttings is Costa Rica (Fig. 6). Here, green culm lengths, with branches trimmed, are put horizontally on the soil. After 2-3 weeks, new sprouts start to grow at nodes, where a branch has been trimmed. Each sprout will have a root growing downwards and a shoot upwards. After some time, the original culm can be cut into pieces and all young sprouts replanted in a nursery. In Asia, culm cuttings are two or three internodes long. These are planted vertically into the soil, with one node deep into the soil. Roots will start growing from the lower node, and branches will sprout from the upper ones. Other methods that are in practice in different parts of the world include offset method, rhizome method, layering, macroproliferation and tissue culture.

The Structure of Bamboo

The microstructure of culm wall can be seen in Fig. 7. The outside of the culm wall (left side of the picture) is dense, as can be seen from the dark color, and only about a quarter of a millimeter thick. This layer contains much silica, a good material to protect the plant, but a nuisance for tools as silica blunts their sharp edges within a short time. The dark spots, decreasing from left to right in the cross-section, are cellulose fibers together with vessels. Cellulose acts as reinforcement, similar to steel bars in reinforced concrete or glass fiber in fiber-reinforced plastic. These fibers are concentrated near the outside. The stiffness (the resistance against bending) that this distribution pattern creates is ten percent more than the one that a more even distribution pattern could offer – an excellent example of the structural design acumen of Mother Nature (imagine a steel

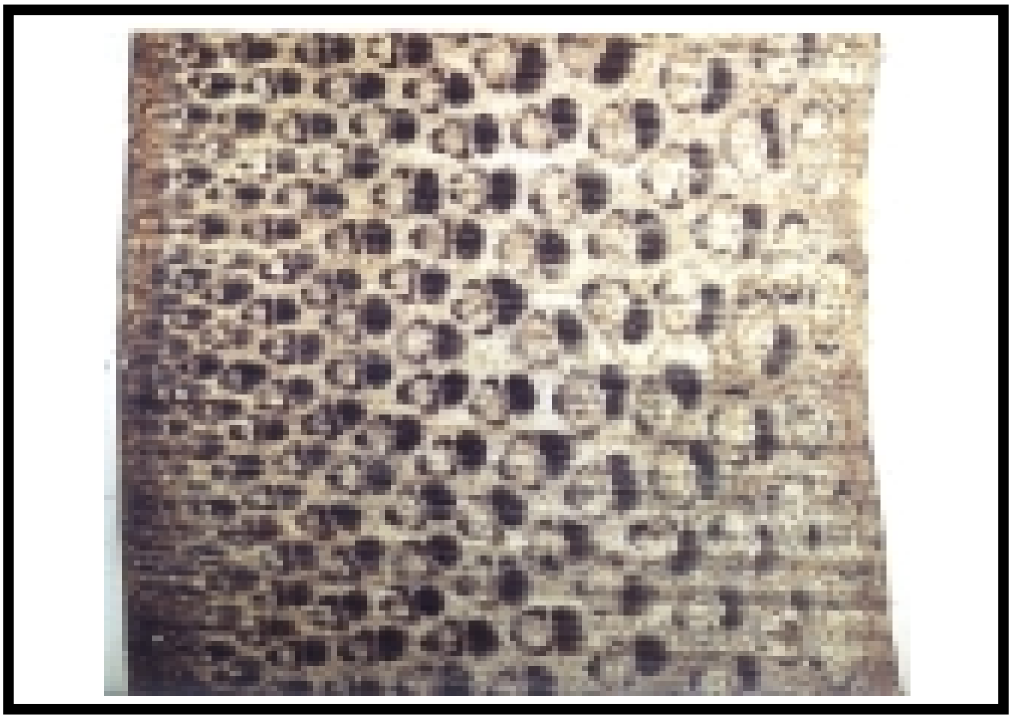


Fig. 7: *The structure of bamboo (specimen size is 6 x 6 mm)*

tube with high tensile steel on the outside and normal mild steel on the inside!). The vessels take care of the transport of liquids during the life of the bamboo. The material between the dark spots is called "parenchyma", and it is the matrix in which the fibers are embedded (like the concrete between the steel bars). Approximately, a bamboo culm has 40% fibers, 10% vessels and 50% parenchyma.

While inspecting the structure of bamboo, one aspect readily catches our attention: bamboo does not have any "rays" like the ones present in wood (best seen in woods like beech as dark spots on the surface of a sanded plank). Rays are places for the transport and storage of food, mostly sugar, but they weaken the material. Consequently, bamboo is stronger than wood, especially in shear (this will be discussed in detail in Chapter 4).

Competitiveness of Bamboo

There are several plantations in bamboo-growing countries where bamboo is harvested just like timber (Fig. 8). However, can one expect bamboo to be as economically competitive? A simple calculation will explain this. Assume the approximate price of an 8-meter bamboo culm to be US$ 1.50. If the volume of woody material in the culm – taking into account only the culm wall and not the cavity inside – is calculated, this price would be US$ 105 per cubic meter. It has been verified that, because of its hollowness, bamboo's effectiveness as a beam is 1.9 better than a wooden beam. Hence, for wood to be economically as competitive as bamboo, it should not cost more than US$ 105 4 1.9 = US$ 55 per cubic meter. However, wood used for beams costs much more than this, emphasizing the competitiveness of bamboo in structural use.

In most of the bamboo-growing countries, trade in bamboo culms is well established. For example, about 25 million bamboo culms arrive every year in the dock seen in Fig. 9 from the northern part of Bangladesh. These come as rafts floating down the river, a transportation process that lasts about three weeks. During this time, the transportation crew lives in the hut set up on top of the raft. Fig. 10 shows a regular wholesale market where the bamboo culms traded. Here, culms are segregated according to their thickness, straightness, etc. for sale to building contractors and others.

Fig. 8: *Harvested bamboo culms in a plantation in China*

When considering a material for structural use, the first question that arises is about its safety. Fig. 11 shows a comparison between bamboo, timber, steel and concrete in terms of their behavior under stress. The stresses, with the symbol “s” (pronounced “sigma”), are plotted on the horizontal axis. To make stresses between these different materials comparable, the value of the stress in the material when the building is in normal use is taken as the unit. This is indicated by the term “s use” (also called the “allowable stress”) and is about 140 N/mm^2 for steel and 10 N/mm^2 for timber. In each of the three diagrams in Fig. 11, a formation like a hill can be seen. This is the area of stresses at failure during

Fig. 9: *A dock near Dhaka, Bangladesh, from where bamboo culms are transported*

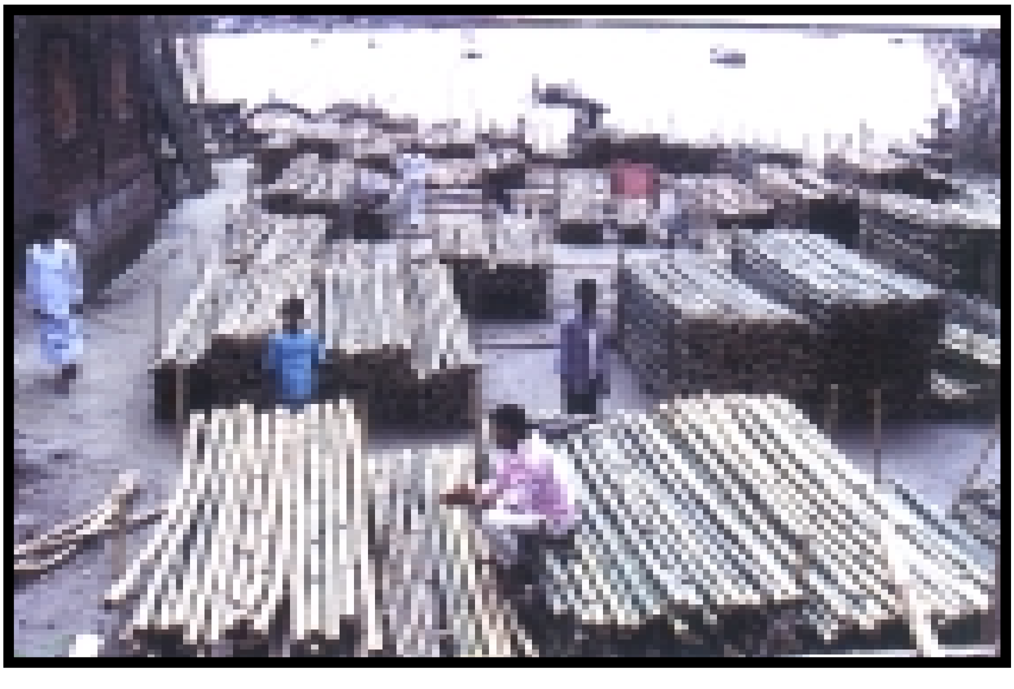


Fig. 10: *A wholesale bamboo market near Dhaka, Bangladesh*

tests, the middle part of the "hill" indicating the mean stress at failure (denoted by "s mean"). Each hill also shows an "s" value, which is the standard deviation indicating whether the results of a test are widespread or not. Technicians consider the stress under which 5% or 2.5% of the specimens fail as the limit, and the allowable stress shall be at a safe distance below this limit. These limits are indicated as s5% or s2.5%. On the vertical axis, we see the value "p", which is the chance that a stress will occur. If a hill is wide and flat, the "p" is low; if a hill is narrow and steep, the "p" is high.

The lowest diagram is for steel, a material that is produced using a very controlled process and hence, bad specimens are very rare. It shows a narrow and steep hill, indicating

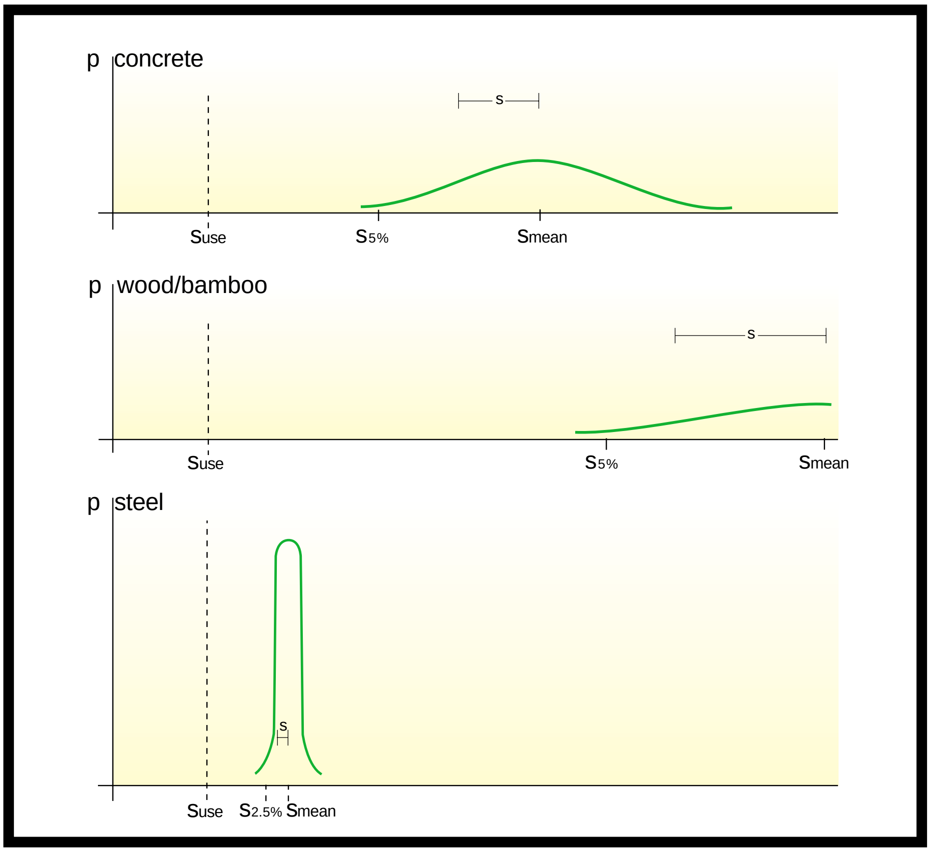


Fig. 11: *A comparison of safety of bamboo and other materials*

that failure under stress occurs in a narrow range indicated by a small value for “s”. This means that the allowable stress (“s use”) can be at a short distance from the stress at failure. The diagram in the middle for wood and bamboo, which are natural materials, shows a wide variety of stresses around the mean stress at failure. In these materials, specimen quality varies widely from very bad to very good. Because of this uncertainty, one finds a large distance between the stress at failure and the allowable stress. The top diagram is for concrete, which is between the other two as far as safety is concerned. In normal circumstances, the use of steel is economical because of the short distance between allowable stress and stress at failure, signifying the optimum use of the material. The use of timber and bamboo, on the other hand, is less optimal since the allowable stress is very low when compared with stress at failure.

In the case of a disaster like a hurricane or an earthquake, however, the stresses will get multiplied. They may become double the allowable stress. In such cases, stresses in steel will come into the area of failure, but not in timber and bamboo. This means that steel structures will suffer much damage, while most structures of timber or bamboo will remain in good condition. A bamboo house is a good place to stay during a hurricane or an earthquake (provided the house has been built with proper care).

Another comparison between the materials is shown in Fig. 12. Two questions are dealt with here – how much strength and how much stiffness (resistance against deformation) does concrete, steel, timber or bamboo give? The diagram shows that, as far as strength is concerned, concrete is the worst, followed by timber (the green bars in the diagram are calculated as the strength divided by the mass per volume or the density). Steel is the best and bamboo the second best. In terms of stiffness, the fourth place is for concrete, third for timber, second for steel and the first place is for bamboo (the brown bars in this diagram are calculated as the E-modulus divided by the mass per volume or the density).

Mechanical Properties

Mechanical properties will be dealt with in detail later, and the following is only a short introduction. The most important mechanical property is the mass of the material per

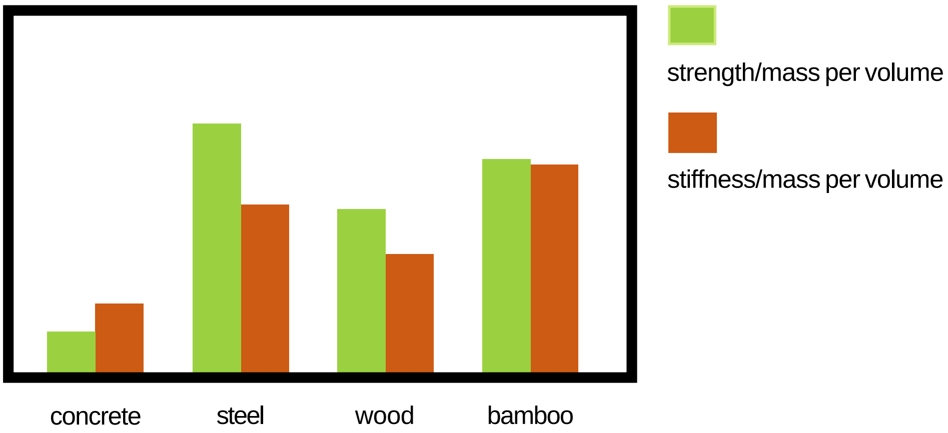


Fig. 12: *Strength and stiffness comparison*

unit volume (which is the density) expressed usually in kg/m^3. For most bamboos, the density is about 700-800 kg/m^3, which varies with the quality of the site of growing, the species, the position in the culm, etc. Why is this property important? The greater the mass per volume, the heavier the bamboo because more molecules are present in unit volume. In other words, the greater the mass per volume, the denser the material. Evidently this results in properties that are desirable in most situations. This relation between mass per volume and strength gives some rules of thumb. For instance, the bending stress at failure (in N/mm^2) can be estimated as being 0.14 times the mass per volume (in kg/m^3).

A notable feature is that failure in bending of bamboo is not a failure. This seemingly illogical statement needs an explanation. If a bending test is performed on a beam of timber or any other building material, first a “crack” develops and then the beam breaks into two pieces – a real failure. Bending tests, such as the long-term bending test shown in Fig. 13, were performed at the Technical University of Eindhoven from 1981 till 1988. The tests showed that “creep”, which is increasing deformation on the long term, does not occur in bamboo, while most timbers are well known for this.

Fig. 14 shows a bamboo after “failure”. If the specimen was a timber beam, it would have cracked and broken into two. In bamboo, however, all fibers along its length still

Fig. 13: *Bending tests for bamboo (Technical University of Eindhoven)*

Fig. 14: *Failure in bending for bamboo (Technical University of Eindhoven)*

exist without any damage. The only thing that has happened is that the bond between the fibers has broken down and, consequently, the circular form of the cross-section has lost its strength. Remarkably, if the load placed on it is taken away, the bamboo specimen will return to its original straight form. This phenomenon has great practical importance. If a bamboo house has suffered from a heavy earthquake, some bamboo elements in it might show some damage. But the house will still be standing and habitable! Some temporary repair measures – such as winding a rope around the damaged bamboo – are all that would be required till the damaged posts or beams can eventually be replaced.

It was mentioned earlier in this chapter that bamboo is stronger than wood in shear. Fig. 15 shows a test on shear, performed in Costa Rica, according to a test method developed at the Technical University of Eindhoven in the 1970s. Shear is important in joints that connect one bamboo with another. Nails, bolts, pins and similar fasteners are used in such joints. In all these joints a hole is made in the bamboo, and the fastener is put through this hole. When in use, a tensile force from this fastener will be applied towards the end of the bamboo joint, resulting in shear. The test method in Fig. 15 has

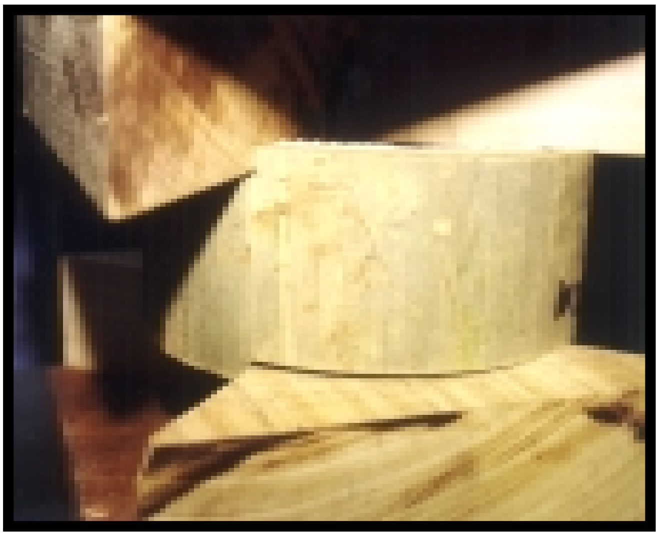


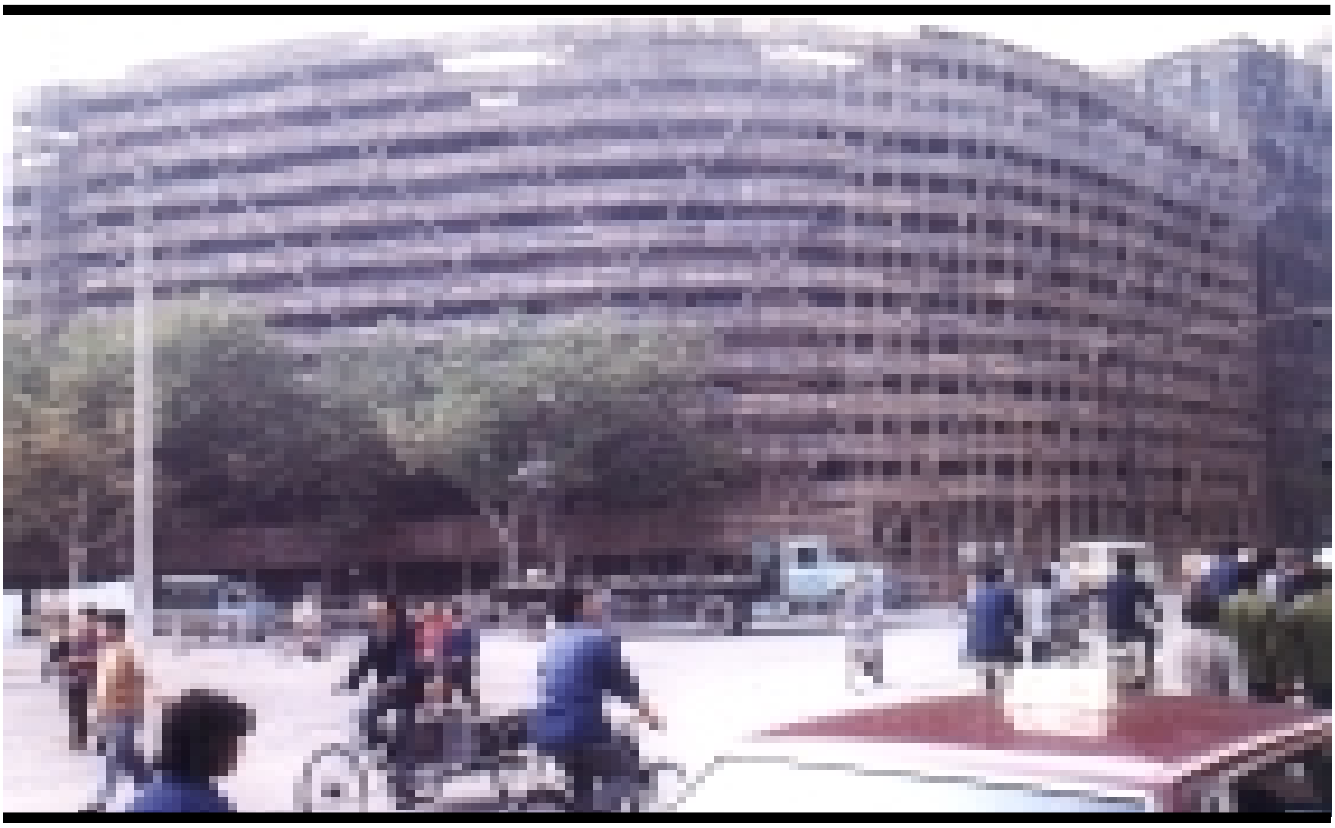
Fig. 15: *Test on shear (Technical University of Eindhoven)*

been selected as the best after a long series of comparisons among different test methods (it is also an excellent example of North-South technical cooperation!).

Uses of Bamboo

Bamboo can be put to thousands of uses. Since most of the trade in bamboo articles happens on the informal market, annual value of the global trade in bamboo products is difficult to determine. However, a conservative estimate puts it at US$ 10 billion. This section will examine some of the major uses of bamboo.

Fig. 16: *Bamboo scaffolding on a building in Shanghai, China*



Bamboo scaffolding is a rich tradition in many Asian countries such as China, India and Thailand. Bamboo scaffolding is well known for its capacity to resist hurricanes. Cases are known wherein bamboo scaffolds survived hurricanes that blew away steel ones as if they were matchsticks. Bamboo scaffolding now is suffering from competition with steel scaffolding, because the latter is an industrial product with standardized dimensions, which make it quick to erect and dismantle. In this respect, bamboo scaffolding needs some technical upgrading. There are some aspects that resist development. For instance, in most cases, the labor force that puts up scaffoldings is organized in guilds that are closed to people who do not belong to certain families. This structure is a guarantee for good transfer of traditional knowledge but a major obstacle for bringing in modern developments.

Bamboo is a superb option for good and cheap housing. Fig. 17 shows one of the 1987 prototypes of the National Bamboo Project in Costa Rica. It is an example of good

Fig. 17: *A prototype bamboo house in Costa Rica*

Fig. 18: *Prefab concrete foundation for bamboo column*

design: overhanging roof, a structure of bamboo culms, walls of panels of split bamboos with cement mortar on both sides, and ventilation through the upper part of the walls (this building method was later simplified and improved). The use of bamboo in housing is discussed in detail in Chapter 9.

The capacity of people to invent their own solutions for difficult problems plays an important part in development. Fig. 18 shows an example of such a solution. Everybody knows bamboo should not have any prolonged direct contact with the soil, particularly wet soil. But a bamboo column needs to be anchored securely to the foundation in order to keep the house down during strong winds. The staff of the Costa Rican National Bamboo Project invented a prefabricated foundation. The bamboo column is extended

Fig. 19: *Panels being prefabricated for mass housing*

at the lower end using concrete, which penetrates the bamboo for about 400 mm (the length of an internode) and extends outside the column for over 600 mm. The concrete is poured into the bamboo culm kept in upside-down position. A piece of PVC tube, cut lengthways and wrapped around the bamboo is being used as formwork. This solution is commendable because it is a simple and effective answer based on a sound analysis of the problem.

If bamboo is considered for mass housing, then it becomes necessary to look into prefabrication options. Fig. 19 shows a panel factory in Costa Rica. Imagine a situation where 1 200 houses have to be built annually, and each house needs 17 panels. This means that one panel has to be produced every six minutes, given an 8-hour shift per day and 250 working days – really an industrial process. Most people think of bamboo as a rural commodity for the small farmer and his family. While this is true to a large extent, there is an industrial side for bamboo as well. More such industrial processes need to be developed if bamboo is to contribute towards housing the one billion homeless people in the world. It must also be remembered that industries provide large-scale employment, which is an economic necessity in most developing countries.

The last statement leads to the role of bamboo in job creation. Bamboo is a material that provides several job creation opportunities because many products can be made from it with low capital investments. The precondition for this is a social structure, mainly in the villages, that fosters cooperatives, and education and training in making bamboo products. Fig. 20 shows a chair, a good example of furniture that can be made at village level. Only simple tools are needed; more essential is a good design that takes into account not only the aesthetic value but also the way the product can be made, its

Fig. 20: *Bamboo furniture (Costa Rica)*

Fig. 21: *Bamboo handicrafts (Japan)*

durability and, most importantly, its marketability. In most cases, the last item is the bottleneck. In Europe and elsewhere, some people do buy products made in developing countries, but this can never amount to structural support for the economy of bamboo-growing countries. For that, there has to be bamboo products that can compete with products made from wood or even plastic. The chair shown in Fig. 20 does not meet the standards of the markets in Europe or the United States. Unfortunately, there is a long way to go to design and develop bamboo products that meet export requirements. Fig. 21 shows a more simple item, two pieces of handicraft for tourists. This really is a promising area, provided there are tourists around. Here too a good design is essential but the quality level can be lower, as tourists buy items with a less critical mind and more for souvenir value. A sound system of cooperatives is needed to ensure sure that the profit does not remain in the shop in town but reaches the people in the village who create the artefacts.

PLYBAMBOO

Plybamboo, which is plywood made of bamboo, provides a good avenue for job creation at village level. Weaving of split bamboo strips is a fairly long tradition and in the case of plybamboo, it takes the road towards a modern industry. One unique appeal of the process is that it can still start at the village level, but end in a modern factory.

Fig. 22 shows a group of villagers, mostly women, involved in weaving bamboo mats. They can do this on days they cannot work on their land, or during their leisure. An organization in the form of a cooperative is needed to effectively manage the work and ensure equitable distribution of profits. From a social point of view, work like this is very good for community health – people of a disadvantaged group (women) are working together in a relaxed atmosphere to earn cash income, leading to both social and economic empowerment. Typically, at the end of the day, the woven bamboo mats are brought to a cooperative-owned factory, where the mats are glued together with an inner layer of cheap wood to make plybamboo boards (Fig. 23). This whole process will be examined more closely in Chapter 11 on job creation.

Fig. 22: *Weaving of bamboo mats (India)*

Fig. 23: *Production of plybamboo (India)*

The discussion so far had focused on the suitability of bamboo both as a traditional and modern material. One important aspect that prevents the wider utilization of bamboo is its depleting resource base. Even in countries like China and India, two countries that have the largest bamboo resource base, lack of availability of the material is being acutely felt. The situation is not very different in other bamboo-growing countries. Hence, before any serious attempt to industrialize bamboo processes can be made, the resource situation needs to be improved. It has become very evident that natural propagation is not adequate to regenerate the resource to the extent needed. Active and systematic plantation programs are required if bamboo is to ever reach a utilization level that does justice to its potential.

Chapter Two

Plantations

Forests, Homesteads and Plantations

Bamboo can be seen growing in natural forests, homesteads and plantations. In most parts of the world, the largest stock of bamboo still grows in natural forests, the primary habitat of bamboo. The extraction of forest bamboos raises some important questions regarding resource ownership and management.

Historically, the people living in and around a forest had the customary right to harvest the bamboo growing in that forest for their use and in pursuit of their livelihood. But this custom has come to pass in most parts of today's world. Now, almost all forests are state-owned, and agencies like State Forest Departments have taken control over the forests with the intention of protecting them.

The taking over of forests by the state was a setback for the forest-dependent people as it meant that harvesting "their" bamboo was now restricted or, in many cases, forbidden. In some regions, a management system was put in place so that the people can obtain a permit to harvest a fixed number of culms per year from the forest. This permit was issued on payment of a fee and, as reported in several places, bribes for the forest department staff as well. A "free" resource thus became a controlled and expensive one, making bamboo-based occupations unattractive.

A major problem for bamboo stand management is that people prefer to harvest the culms at the shortest possible distance from their village. This leads to over-harvest of clumps at forest edges, while the clumps in the inner parts of the forest grow so thick that mature culms towards the center of the clump become totally inaccessible. Since "state-owned" also translates into "nobody's property", none feels responsible for the maintenance and management of forest bamboo. One need not emphasize how detrimental such a situation is for bamboo, and for the forest as a whole.

The relationship between bamboo and the natural forest deserves special attention. For many people, this relationship might hold negative aspects as bamboo is related to human disturbance of pristine forests. As Stern (1995) says: "*Chusquea scandens* was significantly ubiquitous on transacts in forests with the greatest degree of human disturbance. This result was qualitatively supported by the abundance of bamboo at trail heads and near the entrance of the reserve." Zhang (1995) reports bamboo in Xishuangbanna, China, as secondary vegetation after removal of the original primary forest. Bamboo stands can extend to cover up to 70-80% of the area below an altitude of 1 000 m.

The destruction of the primary forest is caused by shifting cultivation, or the increasing need of a growing population for farmland, fuel wood or building area. Another minor cause is the harvest of timber for export. A lack of "fair trade" plays a role as well. For example, in the Costa Rica of the old days a tractor could be paid for with 50 bags of coffee; now the same tractor requires 2 000 bags of coffee. No wonder if more forestlands come under coffee plantation!

Unregulated extraction of forest products by forest-dependent communities for their subsistence living has been ascribed as a factor for the destruction of forests. Any strategy to remedy this should be based on grassroots participation and an understanding of the basic needs and aspirations of the said communities. As most of us tend to think, they are not a minority. The indigenous groups living in or bordering tropical rainforests number about 600 million, while the tropical forests, bush lands and Savannah measure about 2.9 billion ha. As Stiles (1994) puts it: "Together, indigenous peoples and their traditional lands would constitute the third most populous country in the world and the eighth largest in area." Bamboo occupies an important place in this extraction system because of its wide utility to forest-dependent communities. With appropriate management, it can become a natural resource that can be used forever.

Homesteads (Fig. 24) are small areas on the lands of small farmers where some bamboo is grown for their own use. Evidently, the farmer will maintain the bamboo stand well as it is considered a part of the capital asset. The farmer family uses most of the harvest and only a minor part is sold on the local market. Bamboos from homesteads rarely reach the formal market. Preservation is an area of concern, as only traditional preservation methods can be afforded by the farmer. A local cooperative might be a solution, as it would have the capital to own the equipment required for modern methods. In most regions, however, the needed social structure is absent and consequently, modern preservation is not an available option.

The economics of homesteads would bear a glance at this point. The following data come from an unpublished survey in Bangladesh in which the author had participated

Fig. 24: *A bamboo homestead in Burundi*

(SDC 1991). In the homestead mode of production, bamboo is calculated to give a net return of US$ 1 285 per ha, as compared with US$ 1 860 for banana and US$ 8 000 for jackfruit. In the plantation mode, however, bamboo yields a net return of US$ 2 285 per ha, as compared with sugarcane at US$ 1 430 and jute at US$ 340.

It must be mentioned here that the homestead mode turns out to be less profitable only if the farmer wants to sell the bamboo on the market. The real value of homestead bamboo lies in its utility to the farmer and his family.

An ideal place for a bamboo homestead would be the narrow strip of land by the side of a road, a railway line or a drain canal. Normally such places are not put to any good use, and a row or two of bamboo (clumping type, not runners!) can provide a fair income to the family that nurtures the plant. However, the rights of property and harvest need to be well formulated before this could happen.

Growing bamboo as a plantation crop hardly comes into the realm of an individual farmer; it is a large-scale commercial activity. Plantations are owned by either companies or cooperatives. In the first category, there are several pulp and paper companies that grow and use bamboo as a raw material. These companies need huge quantities of bamboo and hence large plantations, preferably along a river connecting the plantation with the factory downstream. Allocation of such huge areas for non-food agro-industry is something that most bamboo-growing countries cannot afford. Harvesting of plantation bamboo and its processing do create several jobs in the area, but it is an unstable occupation since all people in the area will be working for one single company and there might not be another avenue for income. Unless the production of bamboo equals or surpasses consumption, such a plantation will not be viable. Then there are other probabilities such as gregarious flowering, especially when overgrazing hampers the regeneration of bamboo, which could swiftly put an end to the plantation-based local economy.

If this is compared with a plantation owned by a local cooperative, one can see a better equilibrium between the plantation on the one hand and the needs of the local population and the environment on the other. Even a large-scale plantation for pulp can be made sustainable and profitable in the long term. This requires an in-depth analysis of the needs and the opportunities of each of the four components in the process – the management of the cooperative, the shareholders, the local population and the environment. Here too, politico-legal issues about the use of public land for private income may have to be resolved and this can be a cumbersome process.

The profit is much better in the case of bamboo plantations. Dhanarajan et al. (1989) quote the following data on the profitability of a bamboo plantation in Thailand:

Year	1	2	3	4	5
Cost (US$/ha)	255	167	190	255	330
Revenue (US$/ha)	-	-	160	710	1880

The situation remains stable from the 5th year onwards. This profit may be compared with that of other crops to get an idea as to where bamboo stands in terms of profitability: crops such as cotton, oil palm, sugarcane and cassava give a revenue of US$ 575 per ha. At a discount rate of 13% the benefit-cost ratio is 1.90. The higher profit offered by bamboo is more from shoots (85%) than culms (15%).

Fig. 25: *A bamboo plantation in Costa Rica*

Take a close look at the plantation in Fig. 25. If someone asks for a description of a factory that absorbs carbon from polluted air, you can show this picture. For this plantation is such a factory. Carbon is being absorbed from the air and stored in the bamboo, a process called “carbon sequestration”. The Guadua plantations in Costa Rica were calculated to absorb 17 tons of carbon per hectare per year. One could easily recommend bamboo groves for all lung spaces in our polluted cities.

The working of carbon sequestration is very simple: bamboo is composed of cellulose and lignin, and both contain much carbon. In other words, bamboo needs to take in a lot of carbon to grow. But the effect of carbon sequestration will be nullified if bamboo is used as fuel-wood, as burning will release the stored carbon back into environment. Long-term uses of bamboo, such as in housing and furniture, are ideal to ensure that the carbon stays locked in for a long period.

Ecological Aspects of Bamboo Plantations

In 1990, a thorough study was made on the environmental impacts of the National Bamboo Project in Costa Rica (Billing and Gerger 1990). They classified the impacts of bamboo on the environment as follows.

IMPACT OF MAJOR POSITIVE MAGNITUDE

- Erosion. Bamboo grows fast, and in a short time develops an extended root system, supporting the soil and preventing it from being washed away by heavy rains (for a more details on bamboo and erosion, see Chapter 1 and Singh 1995). The dense roof of branches and leaves protects the ground from forceful tropical rains. In a bamboo plantation clear-cutting does not happen; only the adult culms are taken away, leaving the plantation intact. Bamboo is a lightweight material, without a need for heavy machinery for felling and transportation.
- Sedimentation.
- Physical soil structure. The root system (Fig. 26) loosens up the soil, which was made hard and compact by exposure, machinery and cattle. The leaf roof protects the soil from further exposure.
- Ground water level. Bamboo consumes water, but this is more than compensated by the reduced evaporation created by the leaf roof, and by the layer of fallen leaves. Owing to the increased permeability of the soil, water run-off is reduced, allowing more water to penetrate the soil and to remain in the area.

Fig. 26: *The root system of bamboo*

MINOR POSITIVE

- Soil fertility. This is improved by protecting the soil from exposure, and by fallen leaves providing organic material. Soil fertility can be diminished by extraction of certain nutrients; this depends on the fact whether the bamboo lives in the wilderness as a monoculture or with other plants. In a plantation many culms are harvested which is likely to cause the use of fertilizers.
- Drainage by the root system and the layer of fallen leaves.
- Soil micro fauna.
- Ground water quality.
- Micro and local climate. Stabilization of humidity and temperature.

- Feeding area and habitat for fauna. Bamboo provides a rich environment for insects, birds and some mammals. Insects find sufficient food in the bamboos, and they in turn act as food for birds. For mammals in need of fruit, access to other types of forest is necessary.

NEGLIGIBLE

- Soil micro flora, regional and global climate, fire hazard, species diversity in flora.

MINOR NEGATIVE

- Laterization of soil (pH). Bamboo Guadua is found to have a slight negative effect on the pH-level; the soil is already slightly acidic in these areas.

Another important aspect of bamboo is the biomass. The biomass of bamboo depends on the botanical species, the site quality, the climate, etc. Data vary between 50 and 100 tons per ha, divided into 60-70 % for culms, 15-10% for branches and 15-20% for foliage (Liese 1985). More detailed information is in the following table for natural stands of *Gigantochloa scortechnii* bamboo in Malaysia (Abd. Razak 1992):

Part	Biomass (in tons/ha)	
	Fresh	Dry
Culms	82	53
Branches	20	10
Leaves	17	9
Total	119	72

The dry matter density, the dry biomass divided by the mean height, is 72 tons/ha 4 13.3 m = 0.54 kg/m^3.

The data given below are for *Phyllostachys* spp. in Japan (five different sets of data are from five different authors):

Culms (dry t/ha)	88	49	61	55	37
Branches (dry t/ha)	13	9	14	12	7
Leaves (dry t/ha)	5	4	6	5	4
Total (dry t/ha)	106	63	81	73	48

Other data are:

Density (kg/m^3)	0.80	0.47	0.57	0.44	0.52
Leaf index (ha/ha)	12	9	-	-	8

Density is the dry matter density, the dry biomass divided by the mean height (Suzuki 1987). These data clearly indicate the importance of bamboo in biomass generation.

When discussing plantations it is necessary to answer the question whether a bamboo plantation constitutes a monoculture. This is a matter that calls for an educated opinion. Evidently, if one compares a bamboo plantation with a natural forest, there is no doubt that a bamboo plantation is a monoculture. The richness of a rainforest is the maximum attainable. But if the comparison is with another crop plantation (bananas, for instance) or grassland, then one can see that a bamboo plantation is much more diversified. As mentioned earlier, many herbs and flowering plants thrive in bamboo plantations, which also play host to many species of birds, insects and other living beings (Fig. 27). This situation owes much to the fact that application of herbicides and similar chemicals does not form part of the normal management regime for an adult bamboo plantation.

Fig. 27: *A hummingbird's nest in a bamboo plantation in Costa Rica*

Plantation Management

The management of a new plantation starts with a market survey, the selection of appropriate species and the selection of a site. The market survey is mainly to identify the end uses to help select the appropriate bamboo species, as well as to determine the quantity requirement. The local climate also forms a factor in species selection. The site has to be selected with regard to soil quality, water, transport, labor force, etc., and there has to be a species-site matching.

The plantation work starts with clearing the site off shrubs and other unwanted vegetation, and the construction of access roads and sheds. Planting material (plants, cuttings or offsets) may be obtained from a bamboo forest, another plantation or a nursery. It is advisable to obtain planting material from different sources to insure against the possibility of losing the entire plantation to gregarious flowering. The following data from Costa Rica give the daily labor requirement for a new plantation that has 220 plants per hectare (Venegas 1996):

Clearing of land	4.3	laborers/ha
Collection of planting material	3.0	laborers/ha
Preparation of planting material	2.0	laborers/ha
Digging holes and planting	3.7	laborers/ha
Total	13.5	laborers/ha

As previously mentioned, there are several propagation methods. One of the methods, used widely in Costa Rica, is the culm cutting method (Fig. 28). Whole fresh culms with branches cut off are buried in the soil to stimulate alternating buds. After two or three weeks, shoots will appear above the ground where branches have been cut off, and rooting also takes place to produce plantlets. After some months, the young plants can

Fig. 28: *Preparing culms for producing culm cuttings (Costa Rica)*

Fig. 29: *A plant with well-developed roots and shoots*

be removed (Fig. 29) and replanted in another place. In the span of six months, a young plantation will be flourishing (Fig. 30).

The daily labor requirement for the maintenance of the plantation in the first year is as follows:

Clearing shrubs, etc.	9 laborers/ha
Other work	4 laborers/ha
Weed control	3 laborers/ha
Fertilizer application	2 laborers/ha
Total	18 laborers/ha

Two liters of herbicides and four bags of fertilizer are used per hectare. The herbicides are needed only in the first and second years; in the third year, the bamboo can compete with other shrubs on its own (Figs. 31, 32).

In the 3rd, 4th and 5th years, maintenance needs become much less. Harvesting starts in the 5th or 6th year. Only adult culms are harvested and the younger ones, constituting about 80%, remain. There is no clear-felling as with tree plantations. This keeps the microclimate and the environment in good shape. A well-managed plantation yields 20-30 tons (air-dry) of bamboo per ha per year; and the plantation keeps on going and growing (Fig. 33). This means that a sound marketing plan needs to be in place before first yield.

Fig. 30: *A Costa Rican plantation after 6 months (foreground) and 12 months (background)*

Fig. 31: *The effect of herbicides is to give space for the young bamboo plants*

As people become more and more environment conscious, plant nurseries have started coming up in many places. A nursery might be the easiest source for the planting material for a bamboo plantation. It would also be a good idea for an established plantation to have its own nursery. Schlegel (1994) gives the data for a *Bambusa blumeana* nursery in the Philippines. The assumptions are:

- Planting distance is 7 3 7 meters, 225 plants per hectare.
- For plant propagation, 270 two-node cuttings are needed (225 plus 20%).
- 23 culms have to be harvested from 3-4 different clumps; 12 two-node cuttings can be collected from one culm.

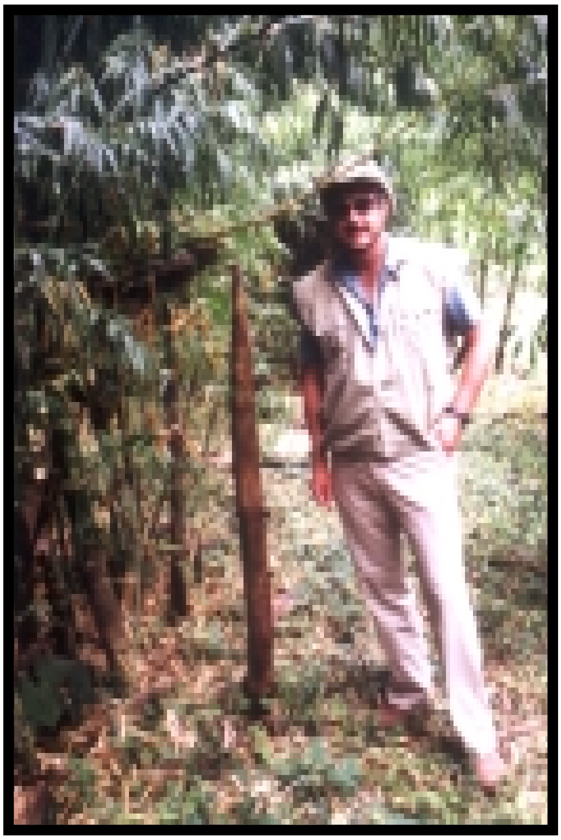


Fig. 32: *Young culms after two years*

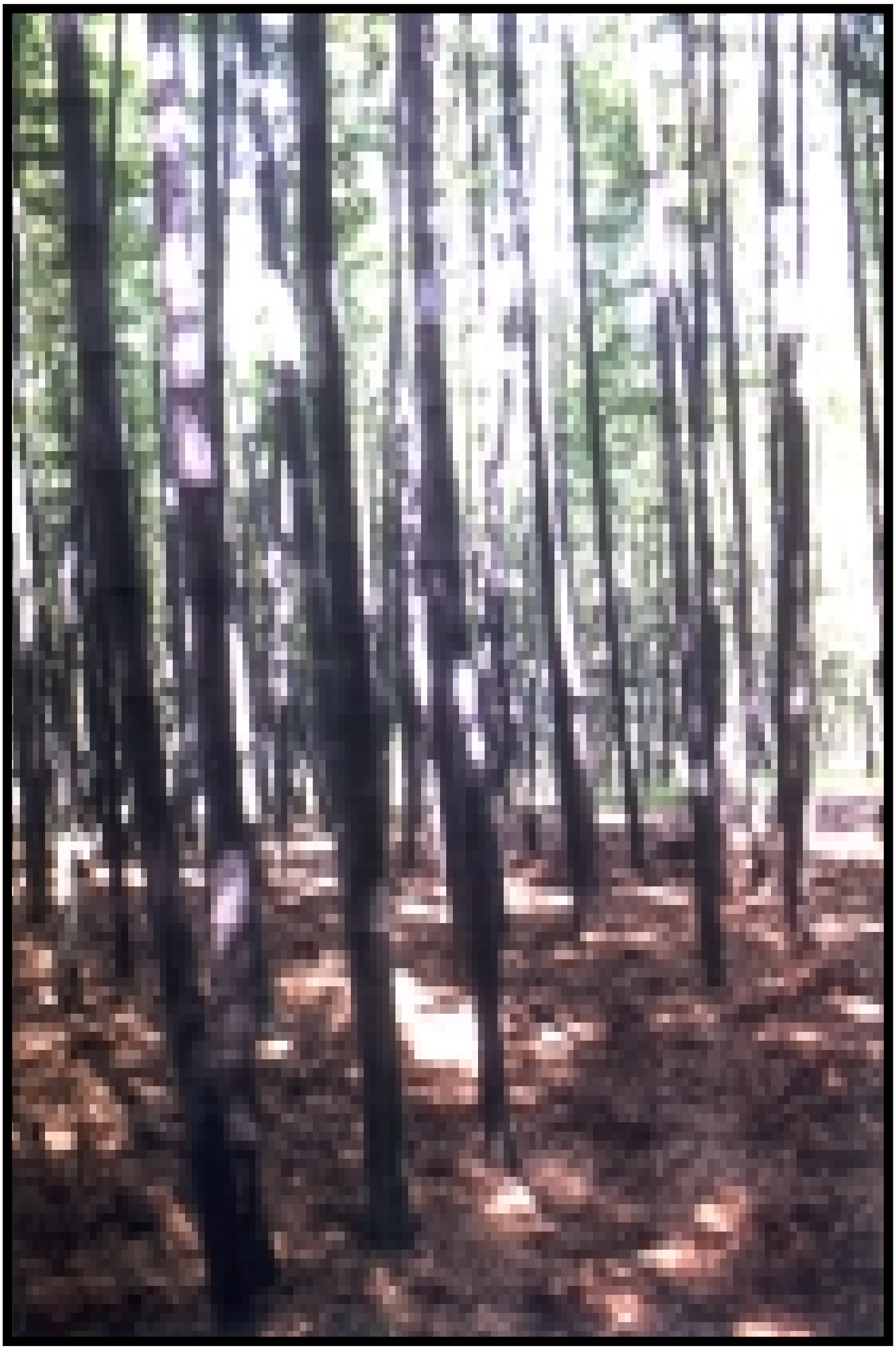


Fig. 33: *A well-maintained, open plantation in China*

The number of workdays needed for setting up the nursery is:

Nursery construction	7 days
Collection of planting material	2 days
Preparation of planting material (135 cuttings per day)	2 days
Soil collection and potting (40 pots per day)	7 days
Nursery care and maintenance (10 days/month, 4 months)	40 days
Field layout, planning holes digging, hauling and transplanting	20 days
Care and maintenance in the first 2 years (6 months/year, 10 days/month)	60 days
Care and maintenance for the remaining years until harvest	60 days
Materials like plastic bags, farm tools, fertilizer, etc. costed as equal to	27 days
Total workdays required	225 days

S.D. Thatte (1997) gives similar data for a plantation in India, with bamboo as an intercrop. Expenses in the first year are US$ 1 195 per year per hectare (price level 1996), diminishing to US$ 688 in the second year and to US$ 45 from the third year onwards. Beginning the fourth year, the harvest is 3 600 culms per hectare. With each culm selling at US$ 0.22, the total profit per year per hectare is US$ 800.

Chapter Three

Durability

and

Preservation

Natural Durability

The main concern of any actual or potential user of a bamboo house or product is the short durability of the material. The service life of bamboo is generally considered as being too short for any worthwhile investment. This, unfortunately, is true to a large extent. Bamboo has less natural durability than most woods, owing to a shortage of certain chemicals that occur in most woods but are absent in bamboo. Information on the natural durability of different bamboo species is still sparse. Research on the differences among various species would allow for the selection of species with better natural durability. Whether the extent of natural durability of such a selected species will meet the expected service life requirement for a particular product, however, will remain an open question.

A problem that compounds the low natural durability is the hollowness of the bamboo culm, particularly when compared with the end-to-end massive cross-section of wood. If fungi or insects attack and destroy the outer layer of wood, say to a depth of 2 mm, most of the cross-section will still be in good condition. In the case of bamboo, a loss of 2 mm may mean the loss of one-quarter of its thickness. The hollowness also offers a relatively safe hiding place for the agents of destruction.

In most tropical countries, the high relative humidity of the air adds to durability problems. A high moisture content in the bamboo – which makes complete drying difficult and thus provides an opening for fungal attack – poses uncertainties in its application in housing, furniture, etc.

A rough guideline on the service life of untreated bamboo is:

- 1-3 years in the open and in contact with soil;
- 4-6 years under cover and free from contact with the soil; and
- 10-15 years under very good storage/use conditions.

Preservation can improve these periods considerably.

The consequence of the low durability of bamboo can be seen in Fig. 34: the wall of a hut in Bangladesh has started crumbling just after six months. The woven bamboo mat

Fig. 34: *Deterioration of bamboo (the white scale is 150 mm long)*

used for the wall was made from unpreserved bamboo, and the clay foundation of the hut kept the bamboo always wet. One can easily see how much the quality of the walls has deteriorated in such a short time. The fact that such bamboo houses are those built by low-income groups compounds the gravity of the problem.

Data on natural durability are scarce (Kumar et al. 1994), with most authors providing only general statements. Some reports identify a certain species as having a better durability than another, but such data are still insufficient for a classification similar to timber. People in villages know by experience the durability of the bamboos in their homesteads. The lower part of a culm is said to be more durable, and so is the outer part of the culm wall. The starch in the bamboo makes it attractive to fungi and beetles. It has been observed that the culms harvested during the dry season have a better durability than those felled in the rainy season. Also, bamboo is more resistant to insects after flowering, owing to starch depletion. The correlation between natural durability and the phases of the moon is difficult to establish; presumably, it is based more on culture and tradition than on physical reality (Kirkpatrick and Simmonds 1958).

Fundamental Rules

The remedy for insufficient natural durability is preservation, be it traditional or chemical. However, the following fundamental rules can help save much trouble (and money).

1. Harvesting in the season when the starch content is low.
2. Selecting only those species that the local people have identified as better suited for the intended purpose.
3. Sound management in storage – keep dry and free from the soil. Store the culms under roof, protected from rain, and in horizontal layers with sufficient room in between for air movement.
4. The period when the material/product is in transit from one place to another is crucial. The climate in a container during transportation by sea is perfect for most fungi and insects (Fig. 35). Hence, furniture and similar export items need to be

Fig. 35: *Mold growing on untreated bamboo*

treated before transportation. In most cases, brushing or spraying the bamboo material/product with a preservative like borax-boric acid might be adequate.

5. When used in building construction, one cardinal rule is to ensure that the bamboo is kept dry. This means that it should be kept free from splashing rainwater by a watertight foundation and by an overhanging roof. Correct design of all building details is a must; no chemical treatment will be good enough to solve the problems caused by incorrect design (Fig. 36).

Fig. 36: *Concrete foundation for a bamboo building, but the bamboo gets wet enough to invite fungal and insect attacks*

Despite these precautions, the bamboo used in a building might get wet. To address such a possibility, the design of the building should be one that allows unrestricted airflow to facilitate quick drying. This might be a burden on the creativity of the designer, but the effort would pay on the long term.

Only after these rules have been observed can one consider preservation in its technical sense.

Bamboo and Preservation

Bamboo is not made up in a way that facilitates preservative treatment. The outer skin, with its high silica content, forms a good raincoat and resists insects but also prevents preservative from entering the culm. The inside is covered with a waxy layer that is impermeable as well. So, a preservative can enter only through the conducting vessels, which are not more than ten percent of the cross-section. They close forever within 24 hours after harvest – which means that preservation has to be carried out within this short time limit.

In the case of timber, preservation is carried out nearly always on sawn timber. A result of sawing is that numerous vessels and cells open up, considerably easing the penetration of any preservative. Also, timber has rays that provide cross-connections between the vessels. Bamboo is unlike timber in both these aspects.

Bamboo preservation methods fall into two categories: traditional and chemical.

TRADITIONAL PRESERVATION

In many places, traditional preservation methods – such as curing, smoking, soaking and seasoning, and lime-washing – are used. The real effect of these methods is not known. However, these methods are popular as they can be applied without any capital investment and with low skill levels.

For curing, the harvested bamboo culms are left in the open, with branches and leaves intact. Transpiration process, which continues even after felling, causes the starch content to fall. Smoking, treatment of the culms over fire, is effective against fungi and insects. Soaking and seasoning involves immersing the culms in stagnant or running water for a few weeks to leach out the sugars. After this, the wet bamboos are air-dried under shade. Lime-washing – literally washing with lime water – is reported to protect against fungal attack.

A notable example of soaking is the use of bamboo permanently under water, as in floating restaurants. Fig. 37 shows such a floating restaurant, the floor of which is made with four layers of bamboo, placed crosswise. The top layer has a service life of less than a year, but the other three are permanently under water and their lifetime is very long.

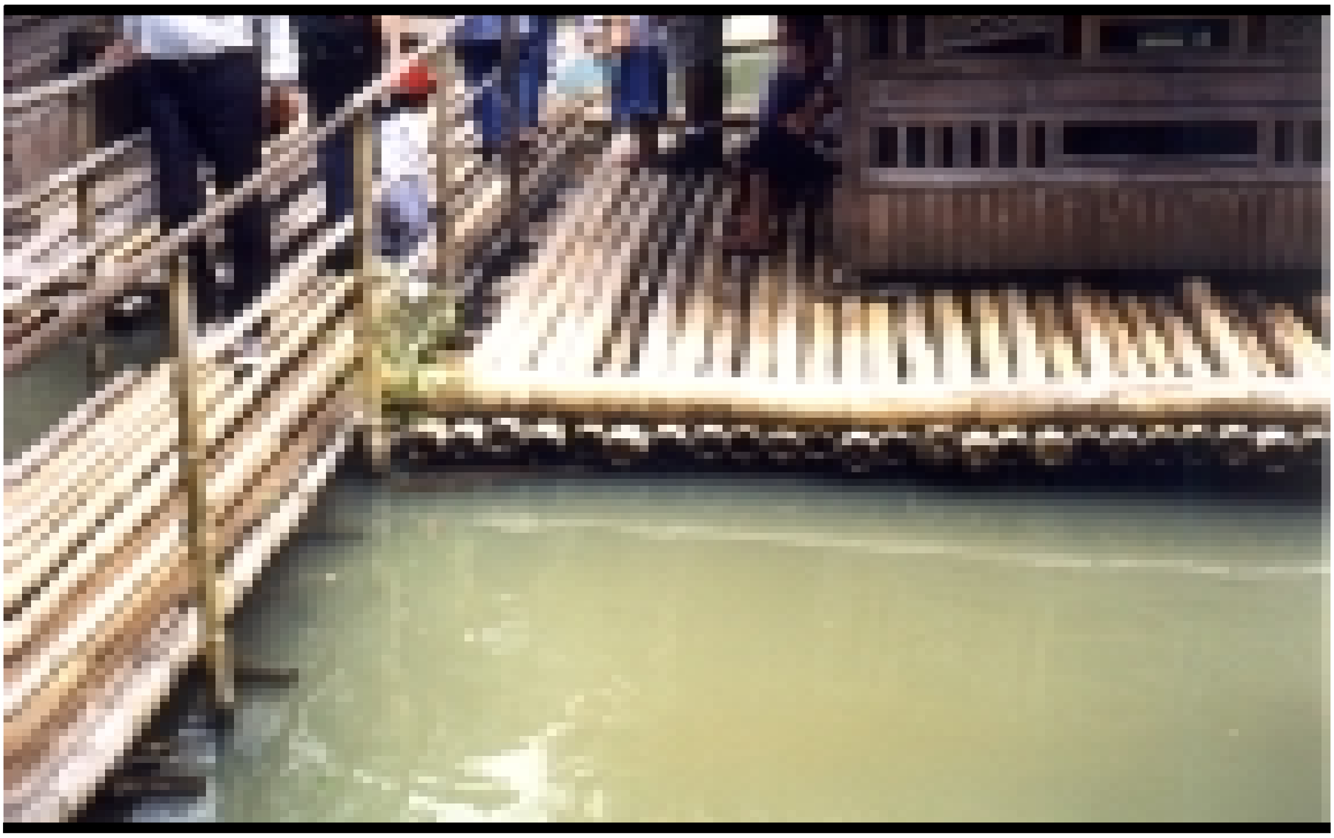


Fig. 37: *A floating restaurant in the Philippines*

CHEMICAL PRESERVATION

If bamboo is to be used in modern industry or in large-scale projects for housing or other buildings, chemical methods of preservation are unavoidable. It is better to avoid preservatives with chemicals like arsenic as they pose a risk to the environment as well as to the health of those handling them. Effective and safe chemicals are based on the element boron, such as copper-chrome-boron (CCB). Chemicals like boric acid, borax and boron are cheap and effective. Good preservation has been obtained in Costa Rica with a boron-based fertilizer, disodium octoborate tetrahydrate (chemical formula $Na_2B_8O_{13}.4H_2O$), with 66% active boron content. A big advantage of using this chemical is that there is no waste at all. Once it has been used in the preservation process for some time and is mixed with starch and sugar from the bamboo, it can be applied as a fertilizer!

Two methods are available to introduce chemicals into the bamboo: modified Boucherie process for whole green culms and dip-diffusion for split culms.

☐ Modified Boucherie process

In this method, the preservative is passed under pressure through the culm vessels till it comes out at the other end of the culm. This can be applied only to fresh bamboo, within 24 hours after the harvest. As the preservative is passed through the vessels, the remaining 90% of the cross-section does not get any contact with the preservative.

The preservative liquid is kept in a closed drum, which is connected to one end of the bamboo with rubber tubes and sleeves tightly clamped around the end of the bamboo (Figs. 38, 39). An air pump provides the pressure. Air in the upper part of the sleeve has to be removed; otherwise, the upper part of the culm will remain unpreserved, resulting in badly treated culms. At first, sap will start dripping from the lower end (Fig. 40) without preservative in it. As the process continues, the concentration of preservative in the sap will increase. The process has to be continued till the whole length of bamboo gets sufficient quantity of preservative. To determine end of process, the concentration of the solution dripping from the lower end must be checked. If it nearly equals the

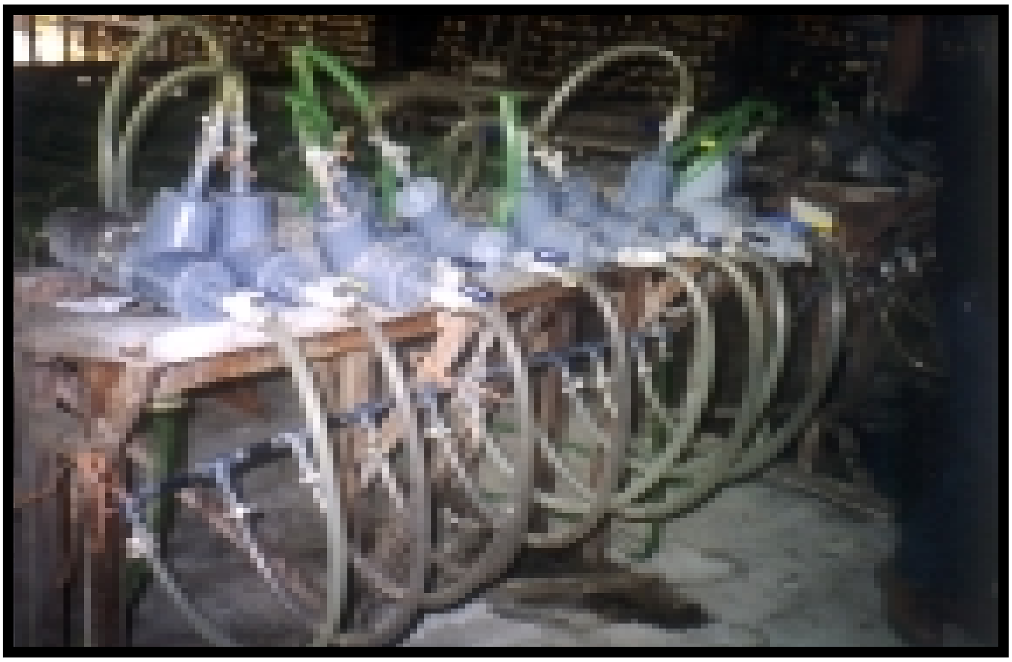


Fig. 38: *Modified Boucherie treatment equipment: the rubber tubes and air outlets*

Fig. 39: *Modified Boucherie treatment in progress*

Fig. 40: *Sap beginning to drip from the lower end of the culm during treatment*

Fig. 41: *The liquid coming out at the lower end may be collected for recycling*

concentration of the preservative in the tank, the process is complete. The liquid passing out of the culm may be recycled (Fig. 41) after cleaning and adding chemicals to achieve the original concentration. After treatment, the culms must be stored under shade to dry.

An alternative Boucherie treatment method is to scrap the inner wall surface of the bottom-most internode of the culm, then hang the culm vertically and fill the prepared internode with the preservative. Scraping the inner wall gives the preservative access to the culm wall tissue.

Dip diffusion

In this method, the culm is first immersed (or dipped) in the preservative so that a slow penetration process (diffusion) takes place. This method can be applied only to split or sawn bamboo strips since whole culms will not allow the preservative to penetrate.

Split bamboo pieces of required size are immersed in a bath with the preservative solution, and weighed down with bricks to keep them immersed. After about 10 minutes of soaking, the bamboo pieces are taken out of the bath (wear gloves!). Excess preservative is drained into the bath. The bamboo pieces are wrapped in plastic sheets and left for one week. The sheets are removed, and the bamboo seasoned in a vertical position for one week.

The preservatives should be prepared carefully, following all instructions to the letter. This may sound as a needless remark, but it is a point that can never be over-emphasized. The author had once been involved in a preservation project in which the preserved bamboos were much more infested with fungi than the unpreserved ones. An investigation revealed that the person who carried out the process did not understand the implication of the preservative being heavier than water, and did not stir the preservative and the water well enough. Consequently, the preservative was lying at the bottom of the bath throughout the “preservation process” and then just drained out. The chemicals never got a chance to get into the “preserved” bamboo.

Treated bamboos should never be burned: the gases that emanate from them would be quite toxic. If they need to be disposed off, bury them in the ground, at a safe distance from water bodies (for example, in a pit latrine). The same applies to waste preservatives. Never make light of the harm that the chemicals can do to the environment or to drinking water.

Do not underestimate the problems to run a preservation process on an industrial basis: training of staff, safety precautions, management, quality control and the economy of the process, all these require close attention. The economics of preservation is clear: the price of the bamboo increases by about 30%, but its service life increases to 15 years in the open and 25 years under cover. So a cost-benefit analysis will easily bear out the desirability of preservation.

There are, of course, bamboo applications wherein chemical preservation is not a good idea, such as in the case of bamboo used as water pipes. There was a large water-pipe project carried out in Tanzania in the early 1980s. The basic problem was that bamboo pipes followed the natural destiny of any dead organic material buried the ground – they decomposed to become fertile soil again. The water running inside the bamboo pipes hastened the process. Chemical preservation was intensively researched by the project, but without much success. No method could be found to prevent the chemical being leached out by the water, and the leaching chemicals did not improve the quality of the drinking water (Slob et al. 1987). Although the project failed to establish the use of bamboo water pipes, it greatly improved the knowledge base on bamboo and its preservation as much as any "successful" project. This progress in knowledge and understanding must not be disregarded.

Chapter Four

Mechanical Properties

Bamboo, a Hollow Tube

Fig. 42 shows a piece of bamboo and a piece of timber with the same cross-section area. As can be seen, the bamboo on the left is hollow tube, while the timber on the right has a massive structure. How do their respective structures affect the efficiency of these materials? Or, expressed in technical terms, what effect does this structural difference mean for the ratio between the moment of inertia (I) and the cross section (A)?

For bamboo, the following formulas are valid:

I = p 3(D^4 - d^4) 4 64 and A = p 3 (D^2 – d^2) 4 4, in which:
p = 3.14
D = external diameter
d = internal diameter (for most bamboos d = 0.82 3 D)
t = wall thickness (evidently D = d + 2t)

If we take for d the value of 0.82 3 D, and we work out the formulas with this value, we get: I = 3.14 (1 – 0.824) D^4 4 64 = 3.14 3 0.55 3 D^4 4 64 = 0.03 D^4. In a similar way we get for A the value 0.26 D^2. We need a comparison between I and A, but I is related

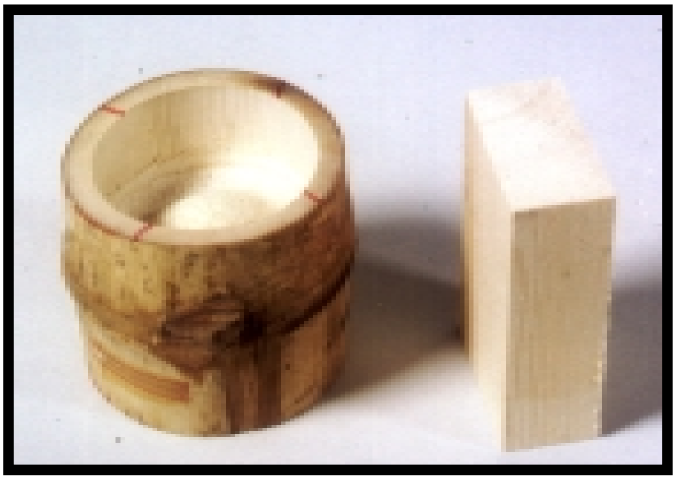


Fig. 42: *Bamboo and timber pieces with the same area of cross-section*

to D^4 and A to D^2. So we take the square of A, $A^2 = 0.07\ D^4$. This allows us to calculate the ratio between I and A: $I = 0.40\ A^2$.

Timber mostly has a rectangular cross section: h = 2 3 b. From this ratio, and because $I = b\ 3\ h^3\ 412$ and A = bh, it follows that: $I = 0.16\ 3\ A^2$; a difference of 2.5 in favor of bamboo.

If numerical values, D = 100 mm and d = 82 mm, are substituted, then for bamboo:

$I = 2.69\ 3\ 10^6\ mm^2$ and $A = 2\ 570\ mm^2$.

If the same cross-section is considered for timber, then:

for a beam of 36 3 72 mm, $I = 1.12\ 3\ 10^6\ mm^2$
for a column of 51 3 51 mm, $I = 0.56\ 3\ 10^6\ mm^2$.

In both cases, the value of I for timber is much less than that for bamboo. This indicates that the structural efficiency of bamboo is very good.

This brings up a question: why do most engineers think that the tube-like bamboo cannot be used as a beam? The tube material they are accustomed to is the steel tube, which is very expensive. Consequently, engineers always use I-shaped profiles for beams. Now consider Fig. 43 in which the cross-section of a bamboo culm is on the left. Next,

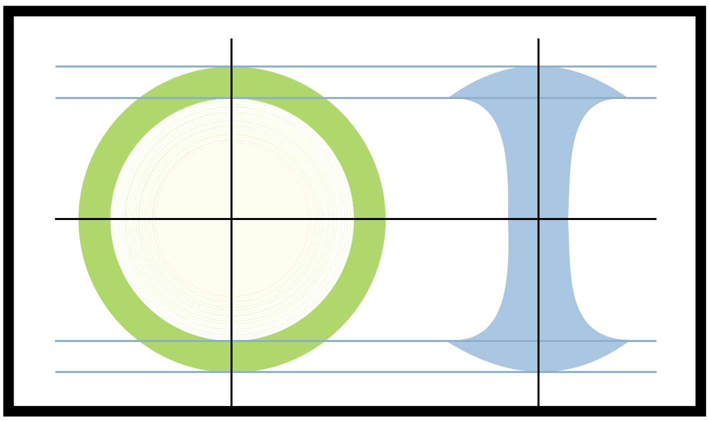


Fig. 43: *Cross-section of bamboo and comparison with an I-profile*

imagine that the material from both sides are pushed horizontally towards the vertical axis of symmetry, and see what happens. The result is something about the same as a steel beam profile!

Nature's Structural Design

The cellulose fibers in bamboo act as reinforcement similar to reinforcing steel bars in concrete or glass-fiber in polyester-resin. The distribution of these fibers increases from the inside to the outside (Fig. 44).

The E-modulus for cellulose is 70 000 N/mm^2 and about 50% of the cross-section of the fiber is cellulose; the E of the fiber is 35 000 N/mm^2. A rule of thumb for bamboo is: E = 350 3 % of fibers. In most bamboos, fibers constitute about 60% on the outside and 10% on the inside. Hence:

Outside E = 350 3 60 = 21 000 N/mm^2

Inside E = 350 3 10 = 3 500 N/mm^2

This is shown in Fig. 45.

It is clear from this data that EI for the culm is more (by about 10%) because of the non-uniform fiber distribution – another example of the efficient structural design of bamboo and of optimum material use.

Bending Tests

Bending tests have been briefly discussed in Chapter 1 (Figs. 13, 14). Here we will examine another aspect of bending tests.

A bending test causes compression stresses on the upper part of the bamboo beam, parallel to the fibers, which does not pose a problem for the material. However, this compression causes strain perpendicular to the fibers, and this occurs in the material between the fibers (lignin), which is weak in taking strain. This, then, is the weak point

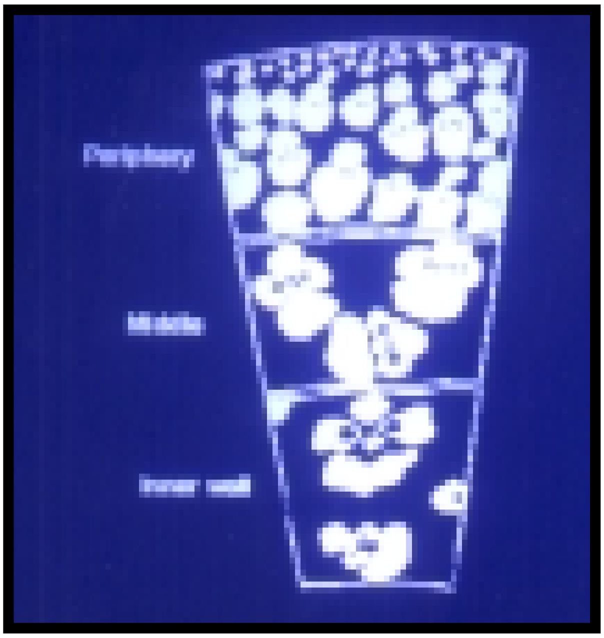


Fig. 44: *Cellulose fibers in culm wall*

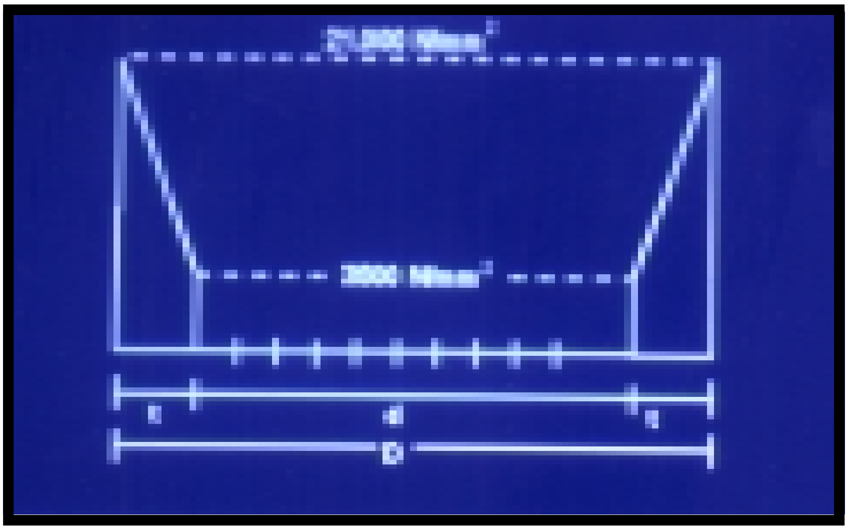


Fig. 45: *E-modulus in culm wall*

for the bamboo beam. The critical value for this strain is 1.1 3 10^{-3}. This deformation means that the material is becoming shorter. With the Poisson's Coefficient for lateral contraction (0.3 for bamboo), one can calculate the corresponding lengthwise strain: 1.1 3 10^{-3} ÷ 0.3 = -3.7 3 10^{-3}. This deformation means that the material is becoming thicker or wider (the minus sign is added to differentiate it from "shorter"). If we assume E = 17 000 N/mm^2, the resulting ultimate bending stress is 62 N/mm^2, which is a typical outcome in tests.

One point to remember is that the fibers as such are still in good condition despite the strain on lignin. But coherence in the cross-section is lost and consequently, the value of EI drops dramatically. If the load is removed, the specimen will return to its original straight form – a definite advantage in case of a hurricane or an earthquake.

Bamboo and Shear Stress

In the previous section, we discussed the splitting of the upper part of the culm during bending. What happens in the neutral layer? How big is the shear stress?

Let us consider an example, taking the bending stress as 62 N/mm^2, and a bamboo specimen with an outer diameter (D) of 100 mm and moment of inertia (I) of 2.69 3 10^6 mm^2. A four-point bending test with a span of 3 600 mm is employed. Based on these values,

M = s 3 L 4 R = 3.34 3 10^6 Nmm.

The point load F = M 4 1 200 mm = 2780 N.

This causes a shear stress in the neutral layer of 2 3 F 4 A = 2.2 N/mm^2. This is the critical shear stress. Consequently, a typical failure pattern in bending test in bamboo is that the bamboo splits into four quarters.

In a massive cross-section like that of timber, the shear stress is 1.5 3 F 4 A, which in this case is 1.65 N/mm^2 only. Does this mean a disadvantage for bamboo? Yes and no.

The disadvantage is that owing to the hollow form, bamboo is in a weaker position than timber. Consider a sample of bamboo with 100 mm outside diameter and a wall thickness

Fig. 46: *Test on shear with bolt in bamboo*

of 9 mm. A sample of wood of the same cross-section will have an area of 51 3 51 mm. In the neutral layer, bamboo has only 2 3 9 = 18 mm to cope with shear, while wood has 51 mm. For joints made with fasteners such as bolts, this poses a problem.

The advantage is that bamboo does not have rays like timber. Rays are mechanically weak and as a result, bamboo material is better in shear than timber material. However, this advantage gets nullified in most cases owing to the hollow form.

Carrying out tests on bamboo is not easy. There at least two planes in a shear test on bamboo, and these are asymmetric as well. How to accurately determine the ultimate shear stress? An example has been shown in Fig. 15. Research done by the author has shown that this is a simple and reliable test method.

Tests with bolts through a piece of bamboo are not only important for the design and calculation of joints, but also challenging (Fig. 46). One has to determine the cause of failure, which could be:

- pure shear in the bamboo between the bolt and the free end; or
- the bolt acting as a wedge, opening the bamboo; or

- the bamboo in direct contact with the bolt being not strong enough to resist the pressure.

Wind Load on Bamboo Culm

Many poets of the East have written about wind on bamboo. On another plane, so have some scientists such as Shigeyasu Amada of Japan, who has studied the effects of wind load on live bamboo culms (Amada et al. 1996). What is the wind load on a living culm? The culm is part of a plantation or a grove; how can one know the wind load there? Let us assume a constant load over height 'L' of the culms (Fig. 47).

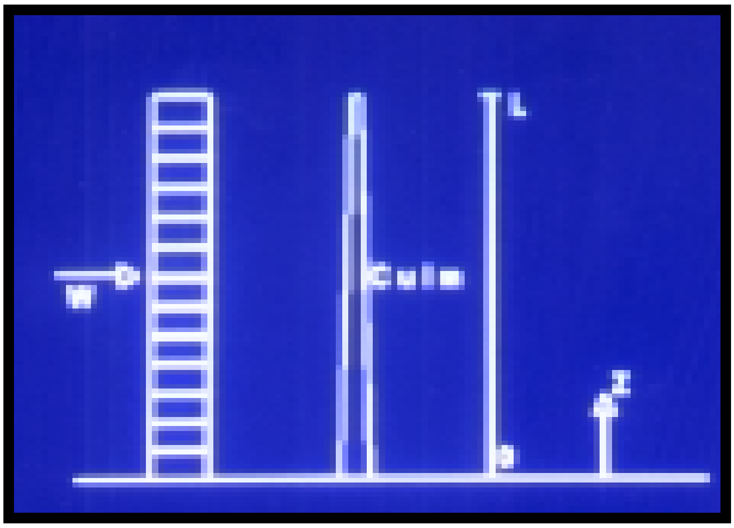


Fig. 47: *Wind load on a live culm*

The diameter 'D' and the wall thickness 't' of the culm decrease from bottom to top. Assuming this to be linear with height, from z = 0 at the bottom to z = L at the top, the bending moment 'M' from the wind is:

$$M = 0.5\ 3\ p\ 3\ (L - z)^2.$$

The modulus of section ‘W’ is:

> $W = p\ 3\ (D^4 - d^4) \div 32\ 3\ D$ or $(p \div 32)\ 3\ (2D^2t - 4Dt^2)$, both M and W being functions of z^2.

From these it follows that the bending stress owing to wind remains constant over the height. This conclusion, however, leaves one point unexplained. Towards the topmost quarter of the culm height, a steep decrease of D and t occurs. Should not the correspondingly increasing stress cause problems? At the top, the number of leaves dramatically increases and the number of vessels decreases. Cellulose fibers, which take the place of the vessels, are capable of taking the increasing bending stress – another example of the Nature playing its part to perfection.

Compression Test

Most people consider compression test as simple, and in the case of timber it is simple – put a piece of timber between two steel plates and press. The hollow form of bamboo, however, makes the test more complicated. Assume that compression tests are run on timber and bamboo specimens, each with a cross section of 2 570 mm^2. This means a diameter (D) of 100 mm and a wall thickness (t) of 9 mm for bamboo, 51 3 51 mm for timber. From these dimensions, one can see that the material in bamboo is at a greater distance – about 50 mm, half the diameter – from the center than in timber – between 13 and 17 mm (the size of timber is 51 mm, so the distance from the center to the side is 25.5 mm, and half of this is 13 mm; along the diagonal it is 17 mm).

Compression means longitudinal shortening and, consequently, lateral strain (called Poisson’s Effect). Because of the greater distance to the center, this effect is much more important in bamboo than in timber. During a compression test on bamboo, one can see the bamboo becoming thicker in the middle, but the two steel plates are keeping the specimen together by friction. This impedes lateral strain at the top and bottom, giving a false impression of the compression strength. Fig. 48 shows clearly how bamboo becomes like a beer barrel, and how the steel plates on top and bottom keep the bamboo specimen together.

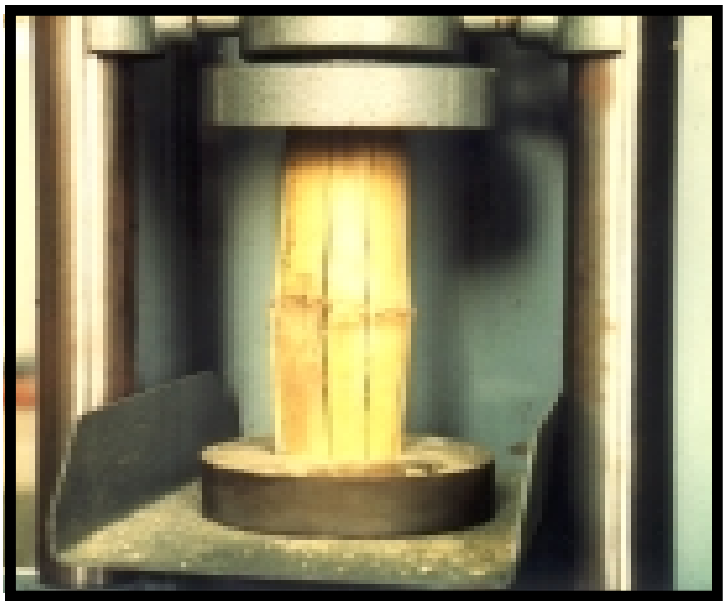


Fig. 48: *Bamboo in compression between steel plates*

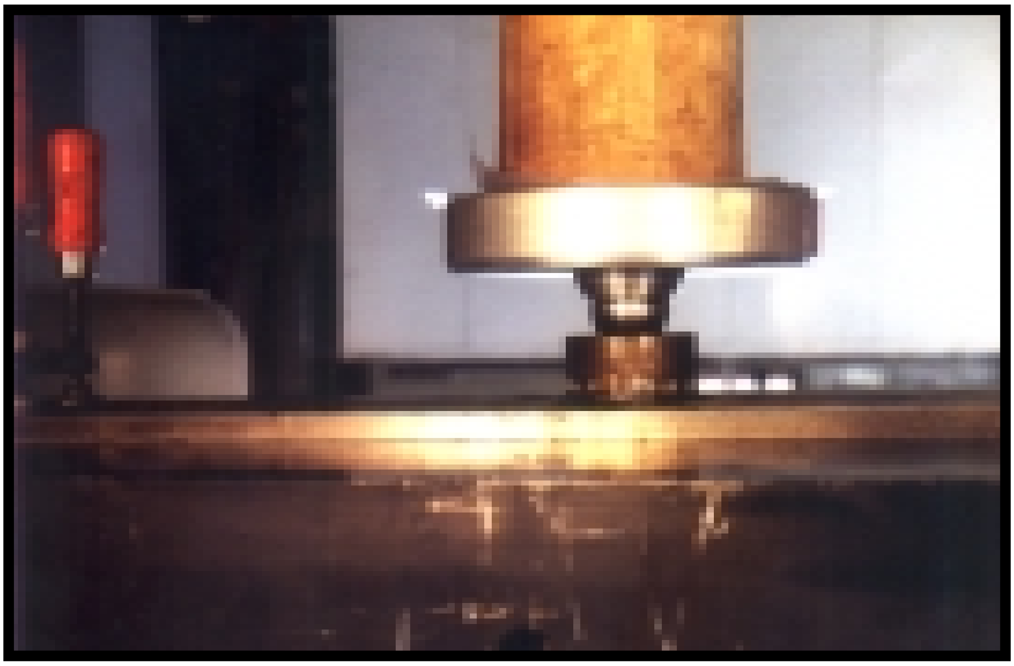


Fig. 49: *A reliable compression test using friction-free plates*

A reliable compression test on bamboo has to be run between steel plates with friction-free surface, such as those coated with Teflon or wax. An example can be seen in Fig. 49, showing a compression test between such steel plates. Fig. 50 shows this steel plate in detail; the Teflon cannot be seen but a series of thin steel wedges, which can move freely in the radial direction, are clearly visible. This allows the bamboo also to move freely in the same direction.

Remarkably, this phenomenon was being discussed in China as far back as in 1921 by Meyer and Ekelund (1923). They tested with lead plates between the steel plates and the bamboo, and without lead plates. In the first case, “When the pressure approached the ultimate stress, big cracks appeared on the sides of the specimen, which opened wider and wider and the piece finally broke down”. In the last case, without lead, the samples were about 20% stronger than with lead, “as the increased friction at the ends kept the fibers together, thus delaying the cracking”.

This phenomenon remained unrecognized until 1991 when Oscar Arce (1993), during his Ph.D. study at TUE, affirmed the need for friction-free plates for correct compression test.

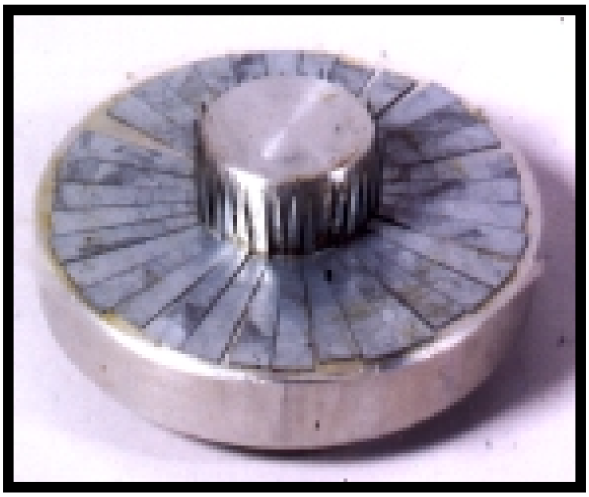


Fig. 50: *Detail of the friction-free steel plate used in the test*

As in the case of bending, it is lignin, with its weak resistance against strain, which determines the compression strength. Notably, the percentage of cellulose is not important.

One has to keep in mind that the use of a compression test is to predict the behavior of a bamboo column or a member in a truss, not between steel plates. This means that the test with Teflon-coated plates predicts the behavior of bamboo in compression in a structure better than the test between steel plates.

Bending vs. Shear

Bending of bamboo has already been discussed earlier in this Chapter. One more issue, however, remains to be discussed: is bending strength determined by bending stress or by shear? This depends on the length of the free span: in case of a short free span, the bamboo does not act as a beam but as an arch, and transversal forces are the first reason for failure. If the free span is long, and if a four-point bending test is being run, pure bending stresses will determine the strength. Evidently, there must be a boundary below which shear is the limit and above which bending is the limit. Can this boundary be determined?

It can be. In 1993, Arce from Costa Rica and Gnanaharan from India derived the boundary between transversal force and pure bending. Later on, Maarten Vaessen derived a mathematical model for this phenomenon, and checked this model with bending tests (Vaessen et al. 1997). If a four-point bending test is run, with a free span L, we get for pure bending:

$M = F\ 3\ L \div 3 = s\ 3\ I \div R$, in which:
M = bending moment;
F = each of the two loads;
L = span;
s = bending stress;
I = moment of inertia; and
R = outer radius of culm.

The maximum value for F is 3 3 s 3 I ÷ L 3 R. If t = wall thickness, we get:

$$I = p\ 3\ t\ 3\ (2R\text{-}t)^3 \div 8 \text{ and } F = 3\ 3\ s\ 3\ p\ 3\ t\ 3\ (2R\text{-}t)^3 \div 8\ 3\ L\ 3\ R.$$

This is the result for bending test.

Now we will make a similar calculation for the transversal force. The critical shear stress is:

$$t_{crit} = 2\ 3\ F \div A, \text{ from which follows: } F = t_{crit}\ 3\ A \div 2 = t_{crit}\ 3\ p\ 3\ t3\ (2R\text{-}t) \div 2.$$

The boundary L_{crit} between bending and shear can be found by taking these two values of F to be equal. Then, calculations result in:

$L_{crit} = 1.763\ 3\ e_{crit}\ 3\ E_R\ 3\ R \div t_{crit}$, in which:
$e_{crit} = 3.2\ 3\ 10^{-3}$, the critical strain;
E_R = the E on the outside, e.g. 24 000 N/mm^2;
R = the outer radius of the bamboo culm, = D ÷ 2; and
t_{crit} = 2.6 N/mm^2.

The result is: L_{crit} = 26 3 D (or 30, to be on the safer side)

If the free span is less, the bamboo will fail in shear (transversal force); so a bending test is run only with a longer free span.

Many misunderstandings follow from a lack of knowledge on this phenomenon. In a real bending test, the nodes with the diaphragms act like a plastic hinge, resulting in more deformation. But in a test with a short free span, they strengthen the arch-like behavior of the beam, resulting in less deformation. Several researchers have come to wrong conclusions because they were unaware of this.

Bending tests have to be carried out with wooden saddles between the steel parts of the bending machine and the bamboo itself. These saddles should rest on the nodes, to avoid crushing of the internodes.

Several researchers have tried pre-stressing. It is only positive if the bamboo is perfectly circular, which is rarely the case. Consequently, most of the time, the outcome was disappointing.

Creep (which is increasing deformation under long-term loading) is negligible in bamboo; the permanent plastic deformation is only 3-5% of the immediate elastic deformation.

Buckling

Buckling is the instability that can occur in a slender column under axial loading. Buckling for a bamboo column can be calculated according to Euler's equation; but how to determine the moment of inertia 'I' for a tapered bamboo, with nodes, a variation in E-modulus, and sometimes an initial twist of the culm?

Arce studied this problem and found that Euler's equation can be applied, irrespective of the presence of an initial twist of the culm (Arce 1993). The other factors (tapered bamboo, nodes and variation in E-modulus) can be expressed as correction-factors to Euler's equation. For some bamboos, it has been agreed that linear relations between the length of the bamboo and 'E' and 'I' can be assumed. This means that one can measure the diameter and wall thickness at both ends, calculate 'I', and proceed with the linear mean of the I-values at both ends to calculate the buckling behavior of a column. Similarly, the value for 'E' can be taken as the mean of 'E' at the two ends.

Rules of Thumb

The author has derived some rules of thumb for the ratio between the mass per volume of bamboo and some mechanical properties (Janssen 1981). The ratios are as follows:

	Compression	Bending	Shear
Air-dry bamboo	0.094	0.14	0.021
Green bamboo	0.075	0.11	

The ultimate stress in N/mm^2 = the given factor times the mass per volume in kg/m^3. For example, if the mass per volume (air-dry) is 600 kg/m^3, one can expect the bamboo to fail in bending at an ultimate stress of 0.14 3 600 = 84 N/mm^2. The allowable stress could be taken as 1/7th of the ultimate stress; in the example this means 12 N/mm^2.

An unpublished INBAR study had found a ratio between the E-modulus and the mass per volume for air-dry bamboo: E = 24 3 the mass per volume. If the mass per volume is 600 kg/m^3, the E-modulus will be 24 3 600 = 14 400 N/mm^2.

Rules like these are very convenient if one does not have access to test facilities. But sometimes, such rules can also misguide. For instance, the rule for bending is valid only from a statistical point; from a physical point of view it is nonsense. As Arce explained to the author, the ratio between ultimate bending stress and mass per volume is based on the presumption that bending strength depends on the quantity of cellulose fibers (the more cellulose, the heavier the bamboo). But bending is determined by the lateral strain in the lignin between the cellulose, not by cellulose fibers.

Earthquake Resistance

As said earlier, bamboo is a perfect material for earthquakes: it is lightweight, and the hollow form gives much stiffness. But how to assess whether a bamboo house would survive an earthquake of a given intensity? A dynamic test on a full-scale house is extremely expensive. At the National Bamboo Project of Costa Rica, only typical walls were tested, using a static test. The wall was fixed on a steel frame and using a hydraulic jack, a horizontal force was applied at an upper corner and in the plane of the wall.

Fig. 51 shows a panel made of split bamboo. The hydraulic jack, which applies horizontal force, can be seen at the top right corner of the frame (the blue cylinder). This jack simulates the effect of earthquake. Different walls have been tested: with and without diagonal, with and without mortar, etc. The results were more than satisfactory. Fig. 52 shows the deformation being measured at the lower end of a panel with plaster. The deformation was 120 mm, without any visual damage to the plaster and the panel. From this reading the bamboo housing system was assessed as earthquake-resistant. The real proof came in April 1991, when about 20 bamboo houses survived quite near to the epicenter of a 7.5 Magnitude earthquake.

Fig. 51: *Test on resistance against earthquake*

Fig. 52: *Measurement of deformation*

Chapter Five

Modelling

and

Calculations

The Art of Modelling

Engineering calculations are made based on a model of the intended structure. Most building materials are straight and have an easy cross-section. A straight line, for example, can easily represent a beam of steel, concrete or timber. Bamboo, however, is different: it is tapered, has nodes at irregular intervals, and the cross section is not a circle. Most culms also have a curve. How can one make reliable calculations with such a material?

Calculations start with the modelling or schematization, which is the process of translating the physical reality of a building structure towards a schematized system of symbols to be used during the calculation process. An engineer always needs a moment of inertia to consider in his calculations. With a tapering material like bamboo, the right method is to first measure the outer diameter and the wall thickness at both ends. From these, the mean diameter and the mean wall thickness can be calculated, and from these values the moment of inertia. This is on the conservative side; one can also calculate the moment of inertia at both ends and take the mean value, but this method usually results in a high value.

A curved culm is not suitable for use as a beam or column, but a proper grading system can be used to allow the selection of bamboos that are straight enough. Nodes are a problem because they do not occur at constant intervals and in practice, joints or supports are preferably located near nodes.

Material properties throw up a question as well. For materials like timber and steel, one can use tables with data based on a grading system. For bamboo, such tables are not available as yet and hence, the material properties of bamboo need to be derived from test results. The engineer has to use a limit state design procedure, or allowable stresses, according to the local practice. Two factors make the process a little easier: the behavior of a bamboo culm is elastic because the plastic behavior is considered to be insignificant, and the cross-sections of bamboo remain flat (Bernoulli's theorem).

When using bamboo as a building material, sound construction practices need to be followed. Only air-dry bamboo is to be used, and design details must ensure that the bamboo used has a fair chance to remain in dry state. Design details need to also ensure that the bamboo used, if it were to become wet, shall have the opportunity to dry fast so that it does not deteriorate from the moisture.

The designer also have to pay attention to the permeability of walls, floors and roofs made from bamboo: they cause internal pressures, which change the net wind load acting on the roof, wall and floor. Special care has to be taken to ensure that the workmanship in the factory and on the building site is of required standards.

Allowable Stresses

For structural engineering calculations, reliable data on material properties are needed. For bamboo, such data can be deduced from tests on a representative sample and then normal statistical methods applied to determine a five-percent lower boundary.

The previous chapter explained how some rules of thumb could be used to estimate mechanical properties from the mass per volume. If one wants to determine allowable stresses, the British Standard Code of Practice 112 for timber may be followed, as shown below:

s_{all} = (m – 2.33 s) 3 G 3 D 4 S, in which:

s_{all} = the allowable stress in N/mm^2;

m = the mean ultimate strength in N/mm^2 from tests on short-term loading;

s = the standard deviation in these tests;

m – 2.33 s = the 1% lower boundary;

G = the modification for the difference between laboratory quality and practice, with a default value of 0.5;

D = the modification value for duration of load: 1.0 for permanent load, 1.25 for permanent plus temporary load, and 1.5 for the permanent and temporary loads plus wind load; and

S = the factor of safety, with a default value of 2.25.

(Note: with a standard deviation of 15% and for permanent load, the allowable stress is $1/7^{th}$ the mean ultimate strength)

Instead of this, any other relevant local standard may be followed. The next allowable stresses (N/mm^2) for air-dry bamboo can be derived using the rules of thumb discussed in the previous chapter.

Compression – 0.013 3 mass per volume in kg/m^3;

Bending – 0.020 3 mass per volume in kg/m^3;

Shear – 0.003 3 mass per volume in kg/m^3.

Obtaining tested results is, of course, better for making optimum use of the material.

As an example, let us calculate the parameters of a footbridge with a span of 4 m. The bamboos in stock have a mean outside diameter (D) of 90 mm. The wall thickness (t) can be measured at the ends only – one end 6.2 mm, the other 7.8 mm, and a mean value of 7.0 mm. The uniformly distributed load (q, N/mm) that one bamboo can carry follows from 8 3 M ÷ L^2. Let us neglect the dead weight of the bamboo, and determine the mass per volume as 608 kg/m^3, from which the allowable stress for bending is estimated as 12.2 N/mm^2. With a factor 1.25 for live load, this becomes 1.25 x 12.2 = 15.2 N/mm^2.

With D = 90 mm and t = 7 mm, the modulus of section W = 35 100 mm^3. Now we can calculate:

$$M = s\ 3\ W = 15.2\ 3\ 35\,100 = 535\,000 \text{ Nmm}$$

$$q = 8\ 3\ M \div L^2 = 8\ 3\ 535\,000 \div 4\,000^2 = 0.267 \text{ N/mm}$$

As live load, let us take people, each 75 kg (or 750 N) and walking at 0.75 m interval; this is 1 N/mm, for which 4 bamboos are needed (4 is 1 ÷ 0.267, approximately). The bamboos should be joined tightly together and the supports should be as close to a node as possible.

Deformation is another important aspect to be considered. The relevant formulas are:

$$f = \frac{5\ 3\ q\ 3\ L^4}{384\ 3\ EI} \quad \text{or} \quad \frac{F\ 3\ L^3}{48\ 3\ EI}$$

With an assumed E = 20 000 N/mm^2, we get:

$f = 10\ 3\ L^2\ 3\ s \div D$ for a uniformly distributed load, or

$f = 8\ 3\ L^2\ 3\ s \div D$ for a concentrated load, in which:

L = free span in m;

D = outside diameter in mm;

s = actual stress in N/mm^2.

In the given example the stress is 14.25 N/mm^2, and the deformation becomes:

$10\ 3\ 4^2\ 3\ 14.25 \div 90 = 25$ mm.

In practice, a good guideline is to limit the deformation to 1/300th of the span. For this purpose, we have to limit the stress to:

$s = D \div 3\ 3\ L$ or $D \div 2.5\ 3\ L$ for distributed or concentrated loads.

For the example, this means: $s = 90 \div 3\ 3\ 4 = 7.50$ N/mm^2.

This results in the following bending moment per culm:

$M = s\ 3\ W = 7.50\ 3\ 35\,100 = 263\,000$ Nmm, from which

$q = 8\ 3\ M \div L^2 = 8\ 3\ 63\,000 \div 4\,000^2 = 0.132$ N/mm.

For 1 N/mm, we need 7 culms.

Design of Joints

In timber or steel we know, after a century of research, the properties of all types of fasteners (nails, screws, bolts, etc.) and with these data can calculate the parameters for any joint. But in bamboo, we still have to go a long way.

The fundamental idea is to design joints so as to achieve structural continuity between elements. This essential requirement includes force transmission in a prescribed manner, and deflections that can be predicted and need to be kept within acceptable limits.

Bamboo joint design needs to be based on calculations (with the exception of the method described in the following section). There are three methods of calculation:

1. Calculations based on reports from tests on full-scale joints. In this method, the complete joint for a given load and geometry is fully specified for bamboos of a particular size. This includes the description of all fastener sizes and locations. Provided it is published in a well-known journal, and written by an acknowledged researcher, this will be reliable information. The hitch is that the results cannot be applied to other bamboos or fasteners.

Fig. 53 shows a test on a truss of 8-meter free span, run on full scale, at TUE in the late 1970s. A load-deformation diagram of such a test gives information for an allowable load and an allowable deformation. The truss has to be copied exactly; otherwise the result will not apply. Fig 53 captures the difficulty of running such a test, the main problem being the need to simulate the physical reality of the structure in laboratory circumstances.

Fig. 54 shows a frame in the building built by the Chinese for the Phenomena exhibition in Zurich, Switzerland, 1984, and Rotterdam, the Netherlands, 1985. They built such frames on full scale in Kunming, China, and tested them before erecting them in Europe.

2. Calculations based on data about the allowable loads for each of the elements in the joints. This method is called the “component capacities alternative”. Nailed joints in timber structures are often designed this way: nails have given allowable loads, so that by combining an appropriate number of nails in a certain geometry, an efficient joint can be designed with relative ease. For bamboo, this method has to wait for a future time, when the strength of all components (bamboo, nails, bolts, etc.) are determined and held in a database for ready reference. The designer has to keep in mind aspects such as: the capacity of a multi-fastener joint will often be less than the sum of the individual fastener capacities; and if in a joint more than one type of fastener is used, the effect of different fastener properties needs to be considered.

3. Calculations based on data about the basic mechanics of joints and their materials. This method is called the “design principles alternative”. These principles give the factors

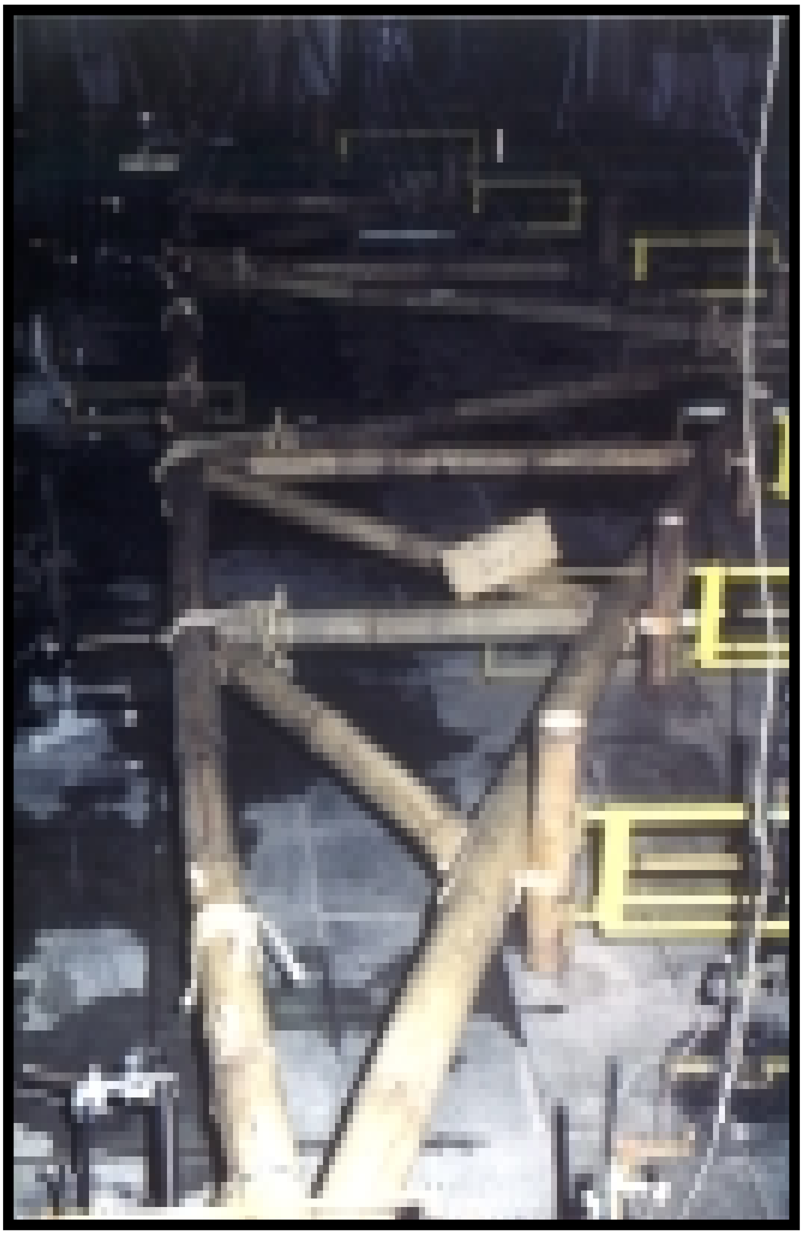


Fig. 53: *A truss under test*

Fig. 54: *A frame of the Phenomena building*

that must be in place for the capacities to be valid. These are frequently non-numerical details, such as the spacing and connections between elements in a built-up column member, or the required rigidity for buckling restraints.

In disaster-prone areas, the design of joints is more important and more difficult. There are several practical questions that need to be considered. For instance, wind suction during a hurricane can reverse the direction of the load – can the joint withstand this, and will the strength remain the same?

Damage in bamboo structures, caused by typhoons and earthquakes, have been found to be initiated by structural failure of the joints. The structure, hence, must be designed such that it has adequate strength to overcome the forces caused by the severe earthquake or wind motions. Solid walls or bracing in walls may be considered for resisting in-plane shear.

Building on Tradition

In some cases, construction does away with calculations, and relies on traditions instead. This is more or less a common practice in rural areas. Tradition forms a very valuable knowledge base, but less accessible to engineers. This knowledge base can be defined as “experience from previous generations, well preserved in a local tradition, and carefully transmitted to people living today”. This “experience” may be considered as an informal, non-codified “standard”.

Criteria for reliability are:

- the content must be generally known and accepted;
- it must be considered as old and pure tradition, as general wisdom; and
- the community must be characterized by an undisturbed social structure, with a well recognized social pattern.

Limitations are:

- the content is only applicable in similar situations; and
- after migration the presence of this tradition is no longer self-evident.

Reports are another source for sound information on construction. They can deal with performance evaluation of a particular type of construction, improved construction methods, specific tests on components, etc.

Evaluation reports made after disasters like earthquakes and hurricanes are particularly useful since they contain descriptions about structures that survived a quantitatively described disaster. Similar structures can be built in similar sites, and they can be considered as adequate to withstand similar disasters in the future.

Criteria for reliability are:

- The report must be composed by acknowledged engineers, with adequate experience in the field;

- The report must be accepted by the international technical community and/or proven by referees;
- The report must give full details and full information to replicate the process or method involved.

The main limitation is that most reports are applicable only in similar situations.

The discussion above has shown the current situation – bamboo is still a traditional material, and much needs to be done before it is to be recognized as a modern and reliable material like steel, timber and concrete. An all-out effort is required to develop international standards, rules for calculations and handbooks. Bamboo may have one advantage of late starter. For steel and timber, different rules of calculations are used in Europe, Australia, the US, etc.; there will never be one system accepted worldwide. Bamboo will definitely escape this fate.

Chapter Six

Joints

Making joints in bamboo is rather difficult because bamboo is hollow, tapered, has nodes at varying distances and it is not perfectly circular. One has to keep all these constraints in mind while designing a joint. Although traditions, local practices and publications give some information on bamboo jointing, this information is far from complete as essential data are missing in most cases. Many traditional joints suffer from weakness or deformation. In many of these joints, the strength of the culm itself is lost.

Publications are plenty, but a complete and reliable description of strength and deformation is more an exception than rule. Gray literature is a good area to search for information, as many jointing techniques are described in project reports and other such publications; but one should know how and where to get hold of them.

Timber and steel became proper building materials only after the problem of joints had been solved. The same goes for the recent development of prefabricated concrete; how many cumbersome solutions for joints have one seen when prefabrication was still young? Bamboo has to tread a similar path. If the problem of jointing can be satisfactorily addressed, the battle is more than half won. Then on, one can reasonably expect to see bamboo in quite a number of modern buildings, bridges and furniture.

Classification of Joints

To get a grip on the problem, it would be a good approach to design a system, a classification. This would allow the creation of an order in all aspects. In this case, the following may be adopted as the guiding principles for classification:

1. A joint between two whole bamboo culms can be made either by contact between the full cross-sections, or by collecting forces from the cross-section to a joining element.
2. Collecting the forces may occur from the inside, from the cross-section or from the outside.
3. The joining element can run parallel with the fibers or perpendicular to them.

Based on these criteria, we can arrange the types of joints into the following groups:

- Group 1 – full cross-section
- Group 2 – from inside to an element parallel
- (Group 3 – from inside to an element perpendicular)
- Group 4 – from cross-section to element parallel
- Group 5 – from cross-section to element perpendicular
- Group 6 – from outside to element parallel
- (Group 7 – from outside to element perpendicular)
- Group 8 – for split bamboo

Groups 3 and 7 (in parentheses) have some theoretical significance, but hardly any practical application. Group 8 does not fit into the system, but has been included since this group of joints is very important. We will briefly examine the different groups before going into them in detail.

Group 1: Joints involving full cross-section. Perhaps the most prevalent and traditional jointing in practice; lashings used to keep the bamboos in position will fall into this category.

Group 2: Joints from inside to an element parallel. Some designers have made joints by filling the culm with mortar and putting a steel bar in it. A recent development is a wood fitting, glued into the culm. Both solutions transfer the joints to the area of steel or wood joints.

Group 4: Joints from cross-section to element parallel. Elements of steel or wood, however, are held in place mostly with pins from Group 5.

Group 5: Joints from cross-section to element perpendicular. Jointing with pins, bolts, etc. comes in this category.

Group 6: Joints from outside to element parallel. This is a modern variation of the traditional lashings, such as the “Delft wire lacing tool” that wraps a steel wire tightly around the bamboos. This type offers a simple and strong joint.

Group 8: Joints for split bamboo. This too is a modern development. Thin pieces of galvanized steel are fastened with nails. Used in prefabricated housing.

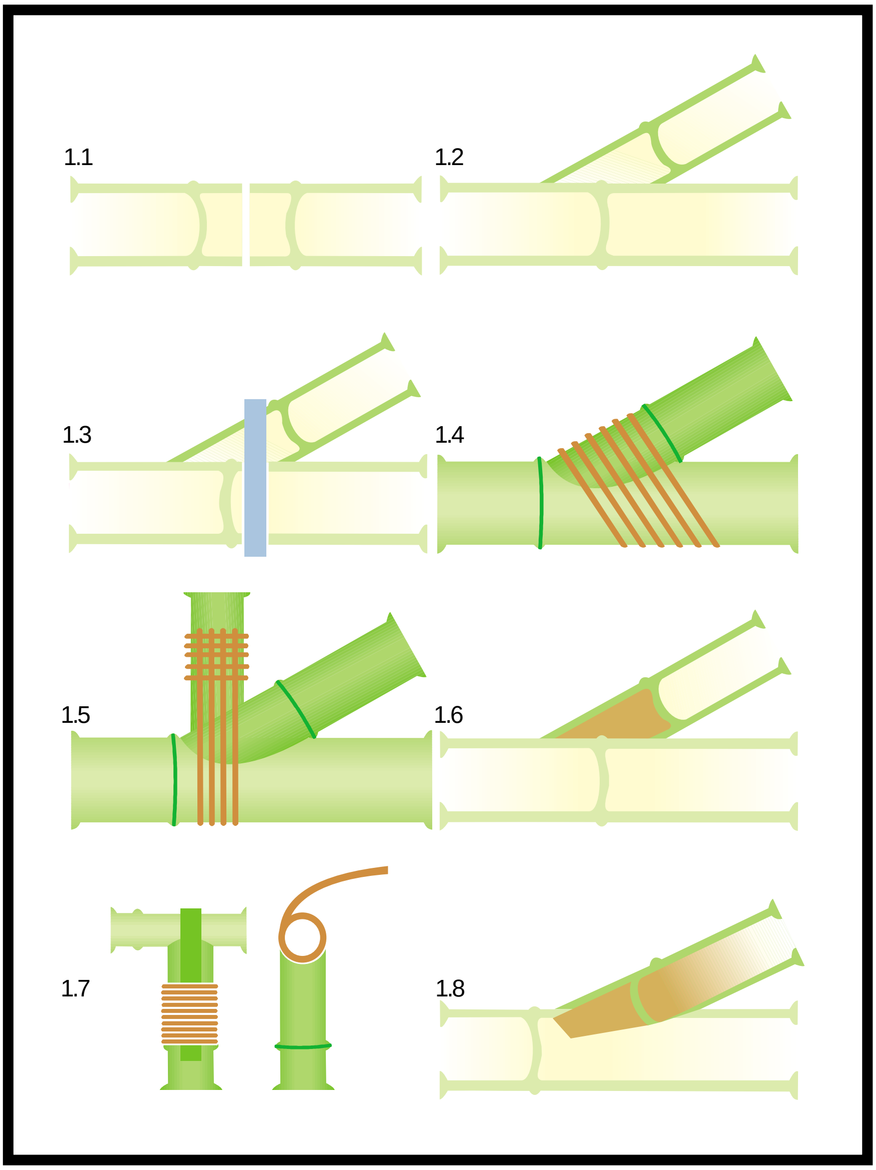


Fig. 55: *Joints with full contact between cross-sections (Janssen 1981)*

GROUP 1: JOINTS INVOLVING FULL CROSS-SECTION

This group of joints is characterized by contact of the full cross-section of the bamboo culm. Mostly lashings are used to keep the bamboo culms in position.

In Fig. 55, joint 1.1 is the most pure example but the most theoretical as well. It could serve in compression applications, but would require an adhesive for reasons of stability and shear resistance. For tension applications, this joint is totally ineffective.

Joint 1.2 can be seen in trusses; the upper end (from the diagonal in the truss) should fit precisely around the form of the horizontal lower member. This requires good craft skills. Glue is essential for perfect contact between the two members, but the waxy outer layer of the lower member is a problem for any adhesive. This joint can take only compression and shear.

Joints 1.3 and 1.4 solve the problem that remained in joint 1.2. In 1.3, this is done with a pin through both members (in fact this belongs to Group 5). In 1.4, a lashing keeps both bamboos together (this solution would fit into Group 7, which we declared to be of no practical application!). The lashing can be made with split bamboos, and this will be a perfect solution – if green bamboo is used, it will shrink in a short period after construction and the joint will be very tight. Other lashing materials are cane, coir, tough vines, sisal fiber, bark of some trees or soft galvanized iron wire. With organic fibers, one has to worry about ants or other insects that might eat the lashing; with iron wire, corrosion is a problem. Deformation can be considerable for joint 1.4; even if the lashing is tight, it might be that the joint only resists shear force after some displacement.

Joint 1.5 is based on a clever understanding of the forces in a truss: in the vertical member the force is a compressive one, and in the diagonal it is tensile. The compressive force in the vertical keeps the diagonal in place, preventing it from moving horizontally (to the left in this drawing). The quality depends on the lashing material, which might belong to Group 6.

Joint 1.6 is filled with cement mortar, preventing crushing of the diagonal. One has to be careful – wet application of cement mortar might result in swelling of the bamboo, which then will split on drying or result in a weak joint. This joint has been the topic of study by several researchers, such as Spoer (1982).

Joint 1.7 is well known in Asia; it can be seen in many garden fences. A part of the vertical member is folded around the upper member, as a tongue, and kept in place by a lashing.

Joint 1.8 looks like it has been designed by a designer familiar with wood construction. In wood, this type of joint is well known as the tooth-joint. In bamboo, however, it is an “air-to-air” connection that has no use.

GROUP 2: JOINTS FROM INSIDE TO AN ELEMENT PARALLEL

In most cases, the hollow of the bamboo is filled with a material like cement mortar (reinforced with a steel rod) or a piece of timber, after which the jointing moves into the better known area of joints between steel bars or wooden pieces.

Joint 2.1 in Fig. 56 shows the principle, the force in the bamboo culm is collected from the inside and transmitted by adhesion and shear to something on the inside.

Joint 2.2 shows an application by Duff (1941). The end of the culm is filled with a tapered wooden plug, and surrounded by a tapered steel or aluminium ring. A steel bolt fastened to the wooden plug forms the third element. The author reports a strength of 27 kN for a bamboo culm of 64 mm diameter.

Joint 2.3 is a Russian proposal for trusses with a span of 15 m for the building of the Building Materials Research Institute in Tblisi. Spoer (1982) performed some tests on this design: “Two holes were drilled through the last two diaphragms of either member and short rods of reinforcement steel of various cross-sections were passed through these holes to join both members. The cavities around the steel rods were filled with cement grout, poured through holes in the walls of the bamboo. Nodes were designed in a similar way, but in addition to steel rods, bolts were also used for joining the beams and spars verging in the node.” This joint was reported to be as strong as the bamboo itself. It is not known whether this joint was used in the said building and if so, how its performance was.

There are possibilities of shrinkage and splitting problems in this type of joint with bamboo and cement mortar. If the relative humidity of the air around this joint changes from 75 to 55 percent, the shrinkage of the concrete is about 0.0004. The radial shrinkage of the bamboo will be around 0.0075, which is 15-20 times as much. This can result in splitting of the bamboo around the concrete or cement mortar inside.

Joint 2.4 is shown in a photograph by Hodge (1957). It looks similar to joint 2.2. In joint 2.4 aluminium rings are used, and furniture and sporting equipment are mentioned as possible uses.

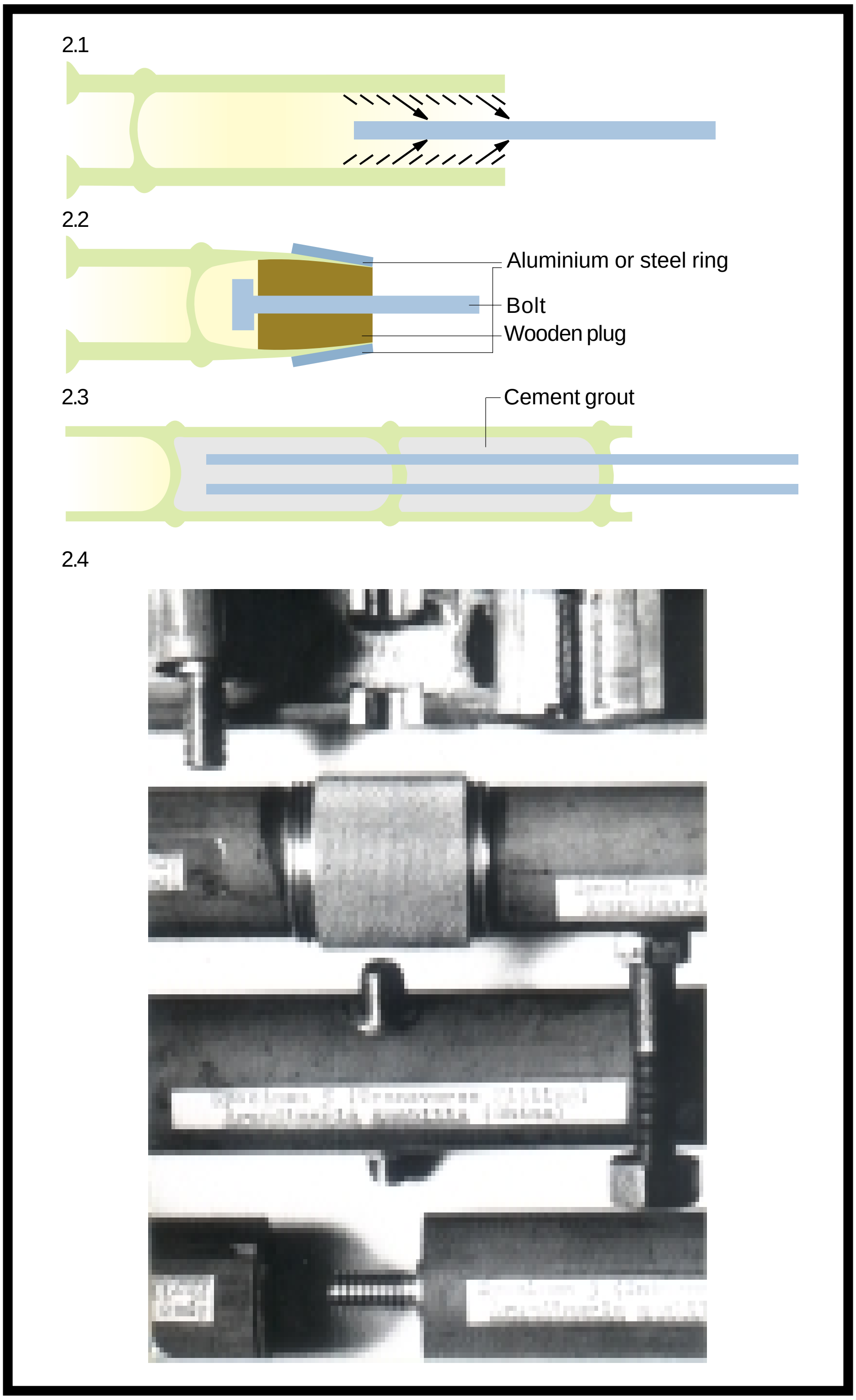


Fig. 56: *Joints from inside to an element parallel (Janssen 1981)*

Arce (1993) has designed and studied joints in which the open end of the bamboo is filled with a round piece of timber, held in place by wood glue. There are two ways to fit the bamboo around the timber. One is to use a special drill to widen the inside diameter of the bamboo culm to a series of standardized diameters – to 70 mm if the bamboo inside diameter is about 67 mm, to 75 mm if the bamboo inside is about 72 mm, and so on. Pieces of timber are made with the same diameters – 70 and 75 mm – and wood glue used to keep the parts together. The second way is to join a bamboo with an internal diameter of, for example, 78 mm with a wooden piece of, for example, 75 mm. During the gluing, the bamboo is kept tight with a hose clamp around the wooden piece, and to make this possible a slot is sawn in the bamboo. Fig. 57 shows this slot clearly.

Fig. 57 also shows how any timber joint can be used to connect two bamboos. Joints like these look promising for prefabricated housing and for furniture.

GROUP 4: JOINTS FROM CROSS-SECTION TO AN ELEMENT PARALLEL

In this group, we will see joints with pins of steel or wood, parallel to the axis of the bamboo culm. However, in most cases, these pins are kept in place by other pins or

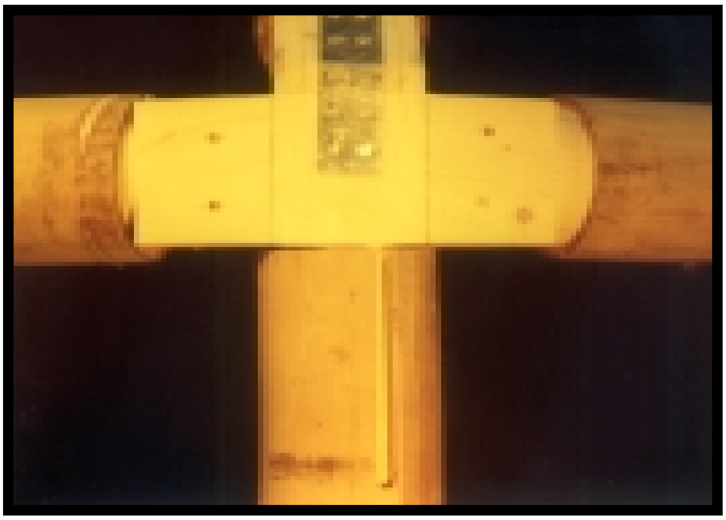


Fig. 57: *The joint designed by Arce*

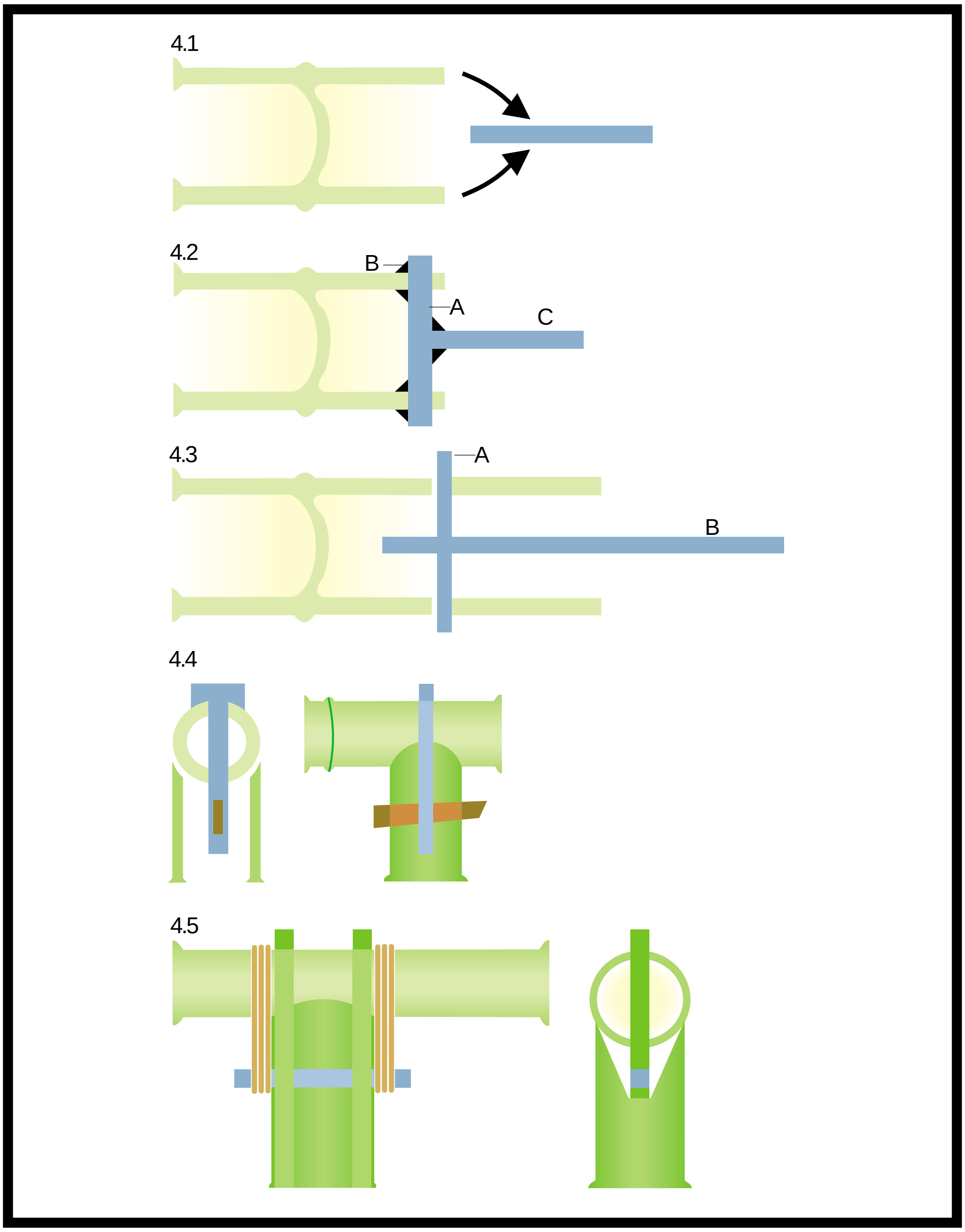


Fig. 58: *Joints from cross-section to an element parallel (Janssen 1981)*

bolts perpendicular to the axis and belonging to the next group. Fig. 58 gives an overview of this group of joints.

Joint 4.1 gives the theoretical scheme: the forces are collected from the cross-section and transferred to a pin placed in the axis of the culm. This theory can be put into

Fig. 59: *A joint of the type described in 4.3*

practice in joints such as 4.2, using glue (B) and a disk (A) ending in a pin (C). The disk and the pin could be one part, made of plastic or steel, or the disk can be made of wood and the pin could be a bolt though the disk. This joint, however, has never been seen in practice, the problem being the glue.

A more realistic solution is joint 4.3, with a pin (B) parallel to the axis; the connection with the culm, however, is through another pin (A) perpendicular to the axis. Both pins could be made of steel, plastic, wood or bamboo. Disadvantages of the first two materials are the price and the availability, while the last shows weakness in shear. Fig. 59 gives a modern version of joint 4.3, employed in Costa Rica. It shows a column made with two bamboo culms, put on a concrete foundation. The connection between the bamboo culms and the concrete foundation is made with two reinforcing steel bars, put vertically into the concrete. A horizontal steel bar with rectangular cross-section runs through both bamboo culms (notice its ends protruding outside the bamboo culms). Two nuts on top of the steel bars complete the connection.

Joint 4.4 can be seen described in literature. It is, however, clear that this joint must be weak in tension in the vertical direction, owing to shear problem.

Joint 4.5 has two bamboo pins, cut from the culm itself, which connect the lower (vertical) member with the upper (horizontal) one. These pins take care of horizontal forces. For vertical (upward) forces, a rope has been applied on both sides, with a pin through the lower member (in fact, this rope and this pin belong to the next group). Both joints 4.4 and 4.5 can be seen in garden fences and furniture.

Figs. 60 and 61 give examples of joints 4.4 and 4.5 as found in Indonesia by Dunkelberg (1985), who gives an exhaustive overview of many of the joints mentioned here.

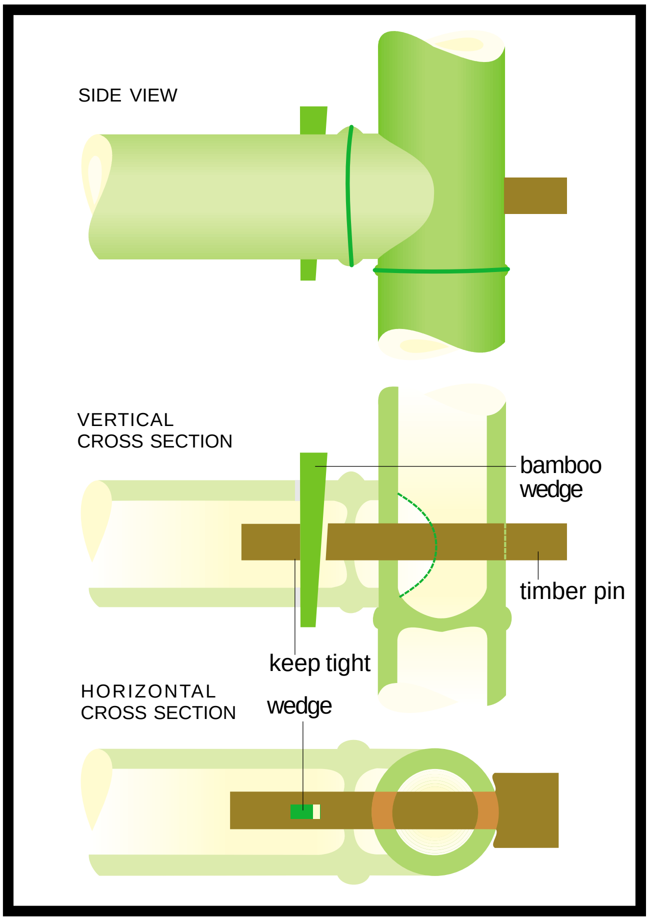


Fig. 60: *A joint of the type 4.4 (Dunkelberg 1985)*

Fig. 61: *A joint of the type 4.5 (Dunkelberg 1985)*

GROUP 5: JOINTS FROM CROSS-SECTION TO AN ELEMENT PERPENDICULAR TO THE CULM

As in the previous group, here too pins of wood or bamboo and steel bolts find prominence. A new feature is the use of flat pieces of plywood or plybamboo, glued into slots sawn in the bamboo culm.

The illustration of joint 5.1 gives the principle. The pin is introduced in the hole drilled through the node because the thickness there is more than that in the internode.

Joint 5.2 shows a solution using only rope. This joint is unable to take any shear force. It is a joint commonly seen in fences. It can also act as a support for a beam or a water pipe. Sometimes a wooden plug is added on the inside to allow for shear forces; with this addition, this joint can even be used as a beam-column connection.

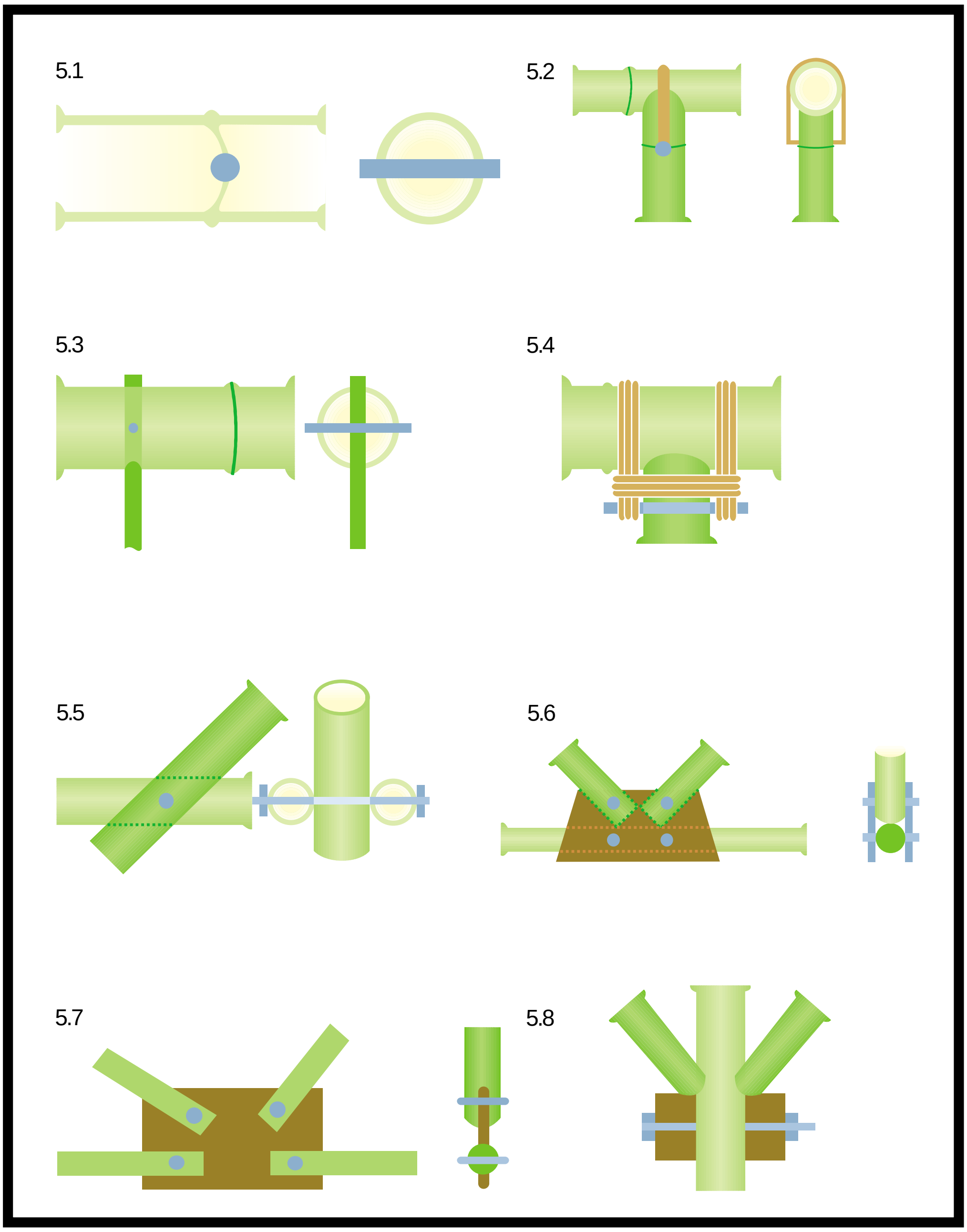


Fig. 62: *Joints from cross-section to an element perpendicular to the culm (Janssen 1981)*

In joint 5.3, a thin bamboo is attached to a thick one. This joint is for fences only. In structural use, the thin bamboo will be too weak unless it takes only tensile forces.

Joint 5.4 is similar to the joint 4.5. It can take both compression and tension.

Joint 5.5 is a common joint in trusses, used to connect the diagonal with the lower member. It is normal to design a truss with two culms for the lower member and one culm for the diagonal and vertical members. Any bolt or pin can transmit the forces from the diagonal to the lower member.

Fig. 63 shows the use of bamboo pins in a Group 5 joint. This photo was taken after a test, in which the joint was loaded till failure. Then, the bamboo culms were cut open to see the extent of plastic deformation that the straight bamboo pin has undergone (notice the pin yielding like high-quality steel!). Fig. 64 shows the use of steel bolts to make an effective and reliable joint for structural application. This type of joint has a long reputation. The U.S. army has published tests on a bridge in the Philippines with this joint as far back as in 1937 (Kumpe 1937).

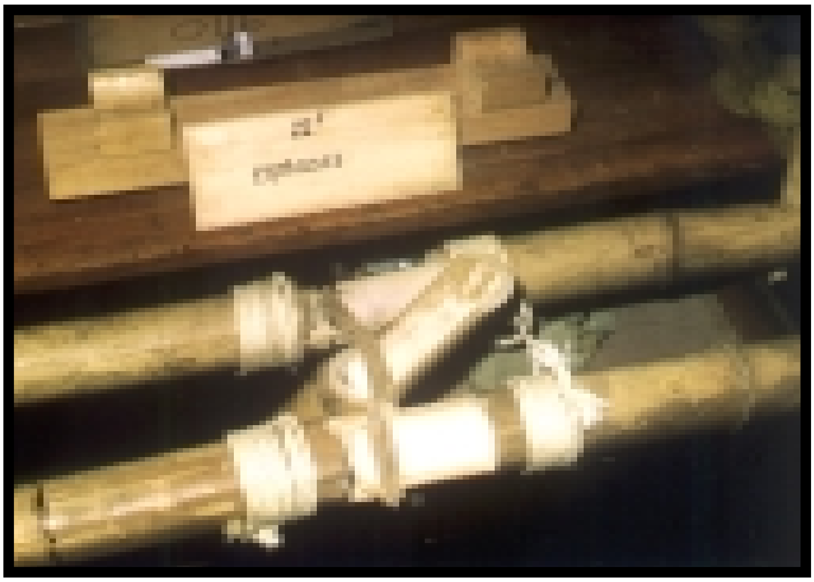


Fig. 63: *A joint in Group 5, with bamboo pin*

Fig. 64: *A joint in Group 5, with steel bolts*

Joints 5.6 and 5.7 are made with pieces of plywood or plybamboo, on both sides or in the center. These joints are very strong and stiff, and appropriate for prefabrication. Fig. 65 shows an example from Costa Rica, developed at the Technological Institute in Cartago in 1987. Further development has not taken place because of the open ends of the culms that allow insects to hide inside. Glue is used instead of bolts.

In joint 5.8, a wooden block is bolted to the vertical bamboo and it supports two diagonals. Joints of this type are common in Latin America.

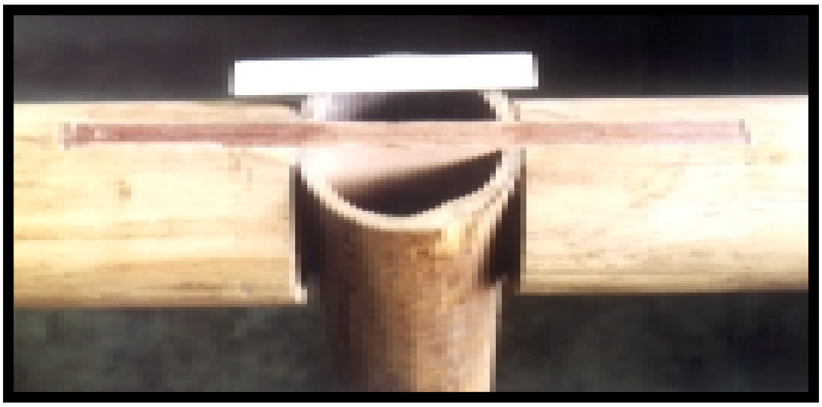


Fig. 65: *A joint with plywood*

GROUP 6: JOINTS FROM OUTSIDE TO ELEMENT PARALLEL

The traditional way with this joint is to use lashings, while the modern way is to employ steel wire or clamps. The drawing of joint 6.1 shows the principle involved: attach something to the outside of the bamboo culm and connect this with an element in the

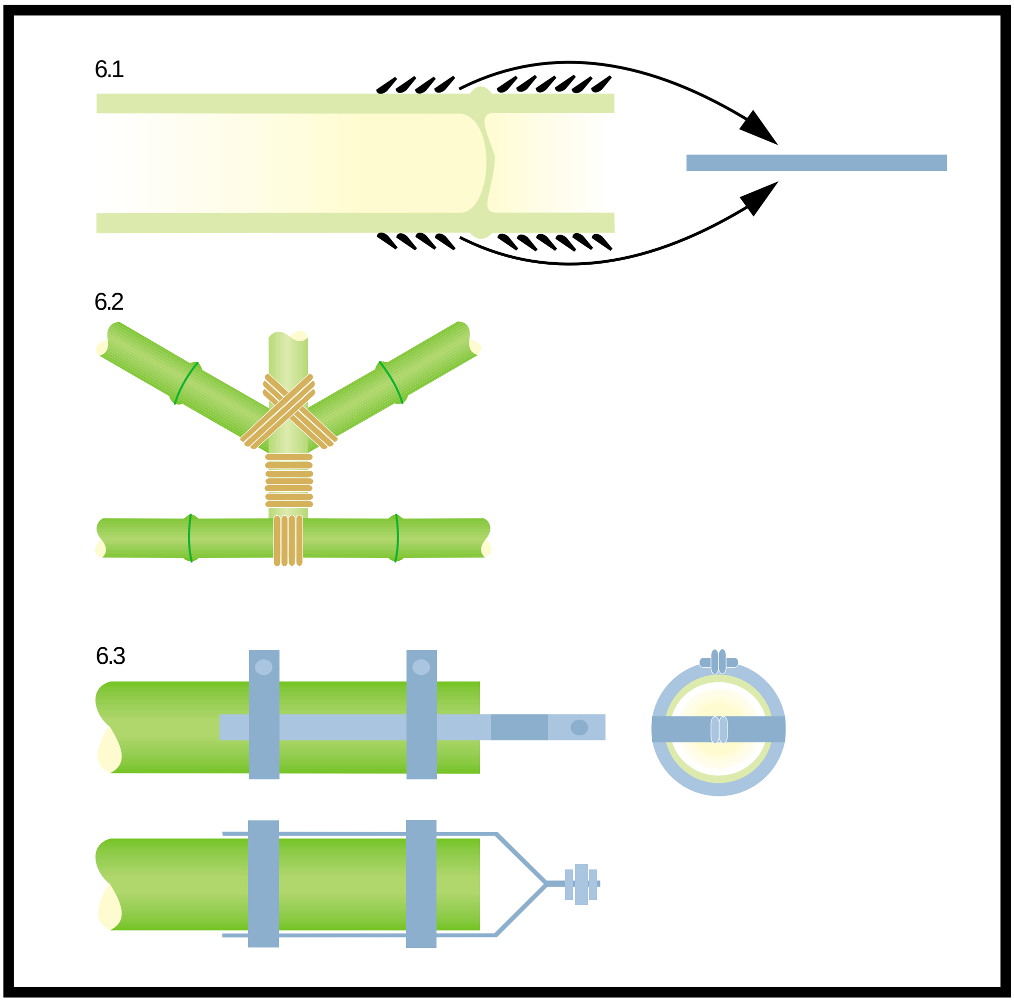


Fig. 66: *Joints from outside to element parallel (Janssen 1981)*

axis of the culm. The outside of a bamboo culm is very smooth, and it is difficult to find something that will properly bond to this surface.

Joint 6.2 shows traditional lashing. The secret is to apply the bamboo strips green or at least wet; the shrinkage will take care of a perfect bonding. Duff (1941) describes this essential fact: “The bamboos are lashed together with thin bamboo-skin thongs which...are especially suited to this purpose on account of their strength and flexibility; the thongs, which are soaked in water before use, shrink upon drying, thus forming a very tight lashing.” Fig. 67 shows a beautiful example of this, with rattan lashing.

Joint 6.3 is made with metal parts that look expensive. In India, Das (1989a, 1989b, 1990) has tested these joints and proven their usefulness. It is reported that this joint was being used in Peru in 1949. A modern example is with steel wire. The problem is to attach the steel wire tight around the bamboo.

At Delft University, a clever tool called the “Delft wire lacing tool” has been designed for this purpose. This tool fits the steel wire easily and perfectly around the bamboo to give a strong and stiff joint (Fig. 68). Unfortunately, nobody seems to be using it for

Fig. 67: *Joint with rattan lashing (Dunkelberg 1985)*

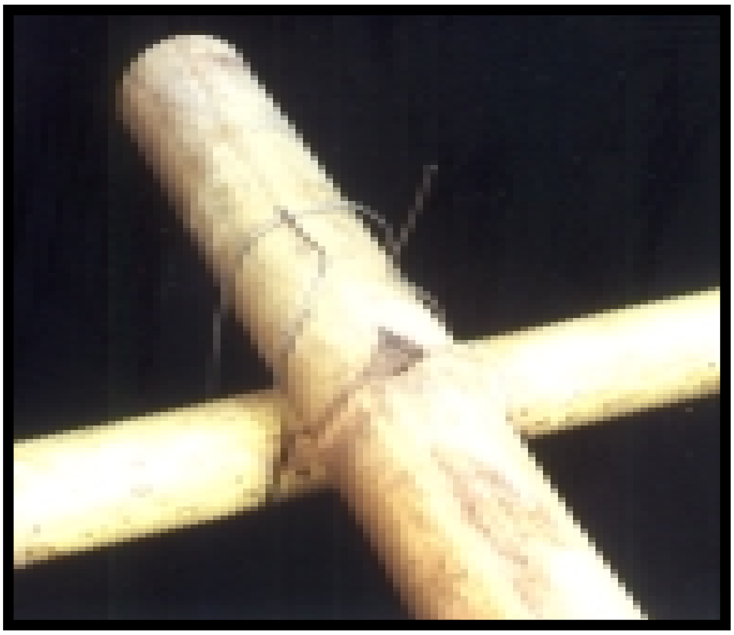


Fig. 68: *Joint with steel wire, made using "Delft wire lacing tool"*

bamboo, despite a high degree of initial enthusiasm. For some unknown reason, the tool has been forgotten.

GROUP 8: JOINTS FOR SPLIT BAMBOO

Split bamboo has a future in prefabricated and industrialized types of construction. Joints for split bamboo are rather simple. One can split a bamboo culm into six or eight pieces, and scrape the weak inside flat. This has two advantages: it provides a flat surface for gluing, and it removes most of the soft material from the inside of the culm. Besides glue, nails or pieces of galvanized steel also can act as jointing material. With this system, not only trusses but panels for prefabricated houses also can be made. We will deal first with the houses. Figs. 69 and 70 show examples from Costa Rica.

The doorframe has been made from split bamboo. The joints are made with thin galvanized steel strips, nailed to the bamboo – very simple and effective. Splitting of the

Fig. 69: *Joint for the lower corner of doorframes*

Fig. 70: *Joint for the upper corner of doorframes*

bamboo where the nail goes in can be a risk with some species, though not with the Guadua species used in this example. Stapling could be a solution: even if the bamboo splits, the staple will keep the piece intact.

The structures shown in Figs. 71-74 were exhibited during the International Bamboo Workshop and Congress in November 1998 at San José, Costa Rica. They illustrate the great potential that split bamboo has in structural use.

Some Examples

The practical examples of jointing theory discussed above can be breathtaking. Many wonderful structures – from houses to schools – have been built using these joints. Two representative examples of these are being presented here. First, scaffolding. Everybody knows bamboo is an ideal material for scaffolding. Fig. 75 shows an example of a modern building being constructed with the help of bamboo scaffolding.

Scaffoldings like the one in Fig. 75 are made with lashings (see the discussion on joint 6.2). Bamboo scaffolding is well known for its capacity to survive hurricanes, and for its low cost. Despite these advantages, however, bamboo scaffolding faces strong competition from steel scaffolding. This latter is more expensive, but it is an industrialized and fairly standardized system. To compete with steel, bamboo scaffolding has to seek improvements that would keep its inherent advantages and, at the same time, gain some beneficial aspects of modern industrial design. If bamboo scaffolding is to be used worldwide, a standardized system is essential.

The second example is the Chinese building for the Phenomena exhibition in Zurich, Switzerland, and Rotterdam, the Netherlands (Figs. 76-78). This building, designed by the Architectural Design Institute in Kunming, China (Li Qihuang 1987), brings out the best in bamboo construction. Tests on frames in full scale have been carried out in Kunming, and all structural elements and labor force came from China. The building was erected in 1984 in Zurich, where 1.5 million people visited it during the exhibition. The building was dismantled, packed in containers and shipped to Rotterdam. There,

Fig. 71: *The principle of trusses with split bamboo*

Fig. 72: *Trusses in an exhibition area*

with guidance from the author, a local building contractor erected the building again. During the summer of 1985, about one million people visited the building.

As an interesting side story, obtaining permission from the building authorities for the erection of the building in Rotterdam proved to be a problem. Although the author explained the tests done in Kunming, the test results, which were in Chinese, failed to convince the authorities. Finally, the 1.5 million visitors who went in and out of the building in the previous year proved to be the convincing argument. The exhibition was a great success, and the bamboo building a great hit.

(opposite page)

Fig. 73: *Trusses in a bamboo house*
Fig. 74: *Connection between truss and column*

Fig. 75: *Bamboo scaffolding (Chiangmai, Thailand)*

The detail of a joint used in this building is shown in Fig. 78. It is something like joint in Fig. 60, but with a piece of wood that fills the interior of the bamboo and does not protrude on the exterior. The wedges can be seen clearly in Fig. 78.

Theory of Joints

Arce (1993) has developed a philosophy about the design of bamboo connections which can be summarized as follows. The objective function of a joint is to achieve structural continuity between elements. This means that forces can be transmitted according to a safe and prescribed manner, and that deformations can be kept under control. During the design process we meet internal and external constraints, which we have to overcome. Internal constraints deal with material properties and shape.

Fig. 76: *The Phenomena building*

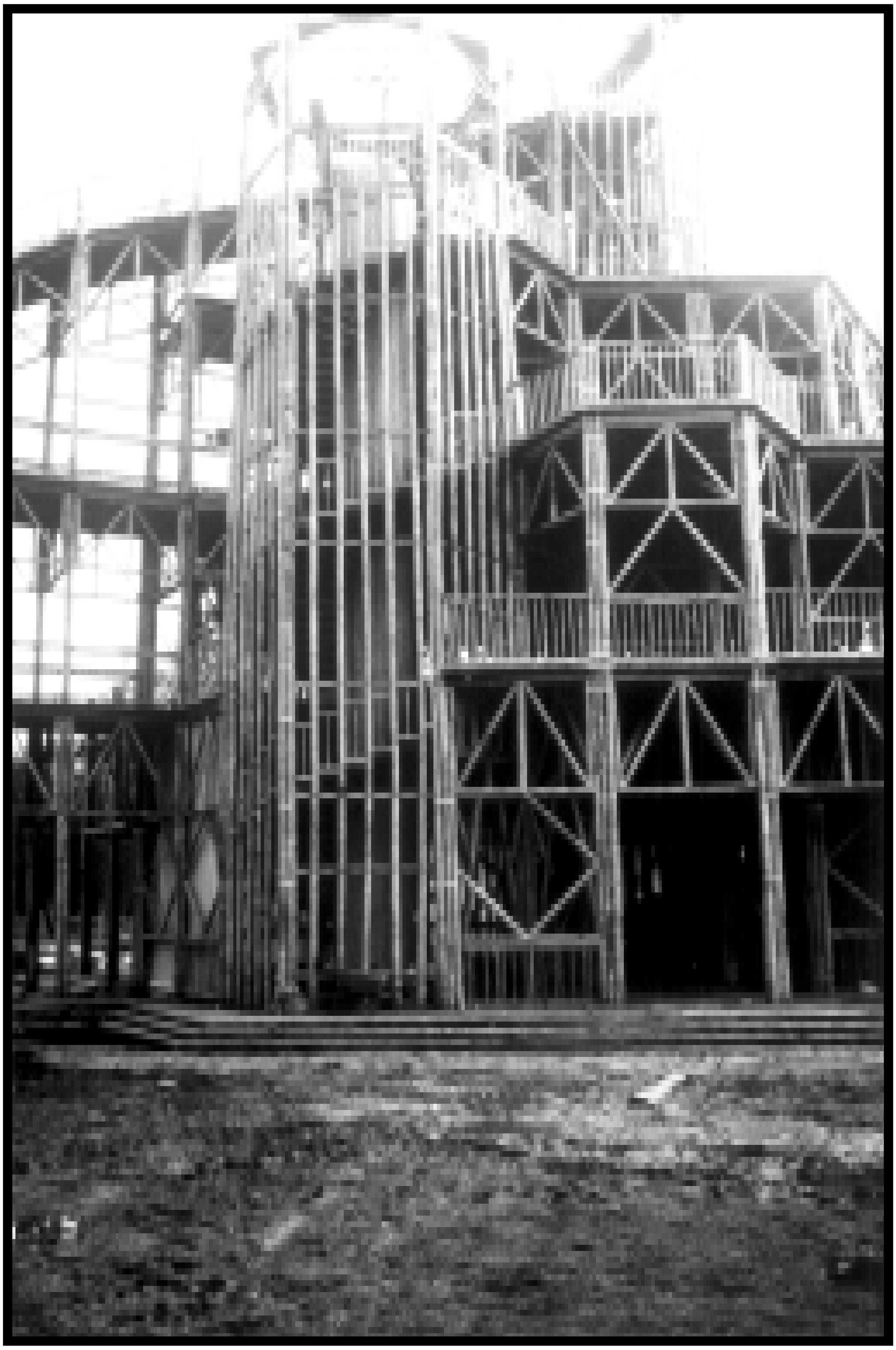


Fig. 77: *The Phenomena building under construction*

Fig. 78: *Detail of a joint used in the Phenomena building*

Bamboo is an anisotropic material: properties in the longitudinal direction are completely different from those in transversal direction. In the longitudinal direction there are cellulose fibers, which are strong and stiff. In the transversal direction there is lignin, which is soft and brittle. Therefore, bamboo is a unidirectionally reinforced composite with comparatively little tangential capacity.

The next internal constraint is the shape. The form of bamboo is hollow, and variable in size, thickness and shape. As internodes and open ends can be crushed easily, the best place for joints is near nodes. These, however, occur at varying distances.

External constraints are as follows.

1. As with any building material, one has to look for maximization of use. Bamboo has both good and bad properties. One should take full advantage of the good properties, while avoiding the bad ones.

2. Simplicity. Bamboo construction is basically meant for solving infrastructure problems in areas where sophisticated equipment and technical capacity are not readily available. Therefore, good design must be simple in terms of the skill and

equipment involved in its production. This is especially important in case of self-help building projects.

3. Stability. Joints should be stable in relation to time. Durability must be related to the required service life of the building.

4. Adaptability of dimensions to a modular system. In tradition, this appears to be unnecessary. But in view of the enormous housing problems in developing countries, modular design is a necessity. Only with modern techniques can one hope to work towards addressing the housing problems of millions of people in the world. Modular design opens the possibility of production in specialized shops and use of unskilled labor on the building site.

5. Strength predictability. This is something that is almost non-existent in the literature about joints. Design rules are needed for extrapolation, strength prediction and safety estimation. Plausible mechanical models and/or sound experimental data should accompany proposals for joints.

6. Cost effectiveness. Joints are a very important component in building, but also in the overall structural costs. One has to consider the influence of joints on the total cost. Simple comparison of one joint with another is insufficient.

Before concluding this chapter, it would be worthwhile to remember some aspects about the process of design:

1. Study the problems thoroughly and make a clear overview.

2. Sketch all possible solutions on paper, without trying to make a selection right at the beginning. Accept even the most dubious proposals; one never knows what valuable idea they might hold.

3. Try to improve further the solution that appears as a good one.

4. Keep aside a sketch in a ‘reject pile’ if the idea contained seems wrong, but do not hesitate to return to the same pile to dig up that sketch in search for another idea.

5. Discuss openly and frankly with all people involved the pros and cons of each sketch.
6. Build prototypes in-house, preferably with your own hands.
7. Keep in touch with the building contractor and all other parties during the process.
8. Finally, apply a process of analysis, followed by a process of synthesis.

An excellent example of the design process mentioned above is shown in Fig. 79. It shows a bamboo joint designed by John Cauty during his work with Funbambu in Costa Rica. He employs plastic bands, which are used to pack cartons, to create two rings, one around each vertical member. He uses these rings to fix a support made from thin steel sheet on which the horizontal member is placed. This example illustrates the merit of thinking independently, which gives new ideas.

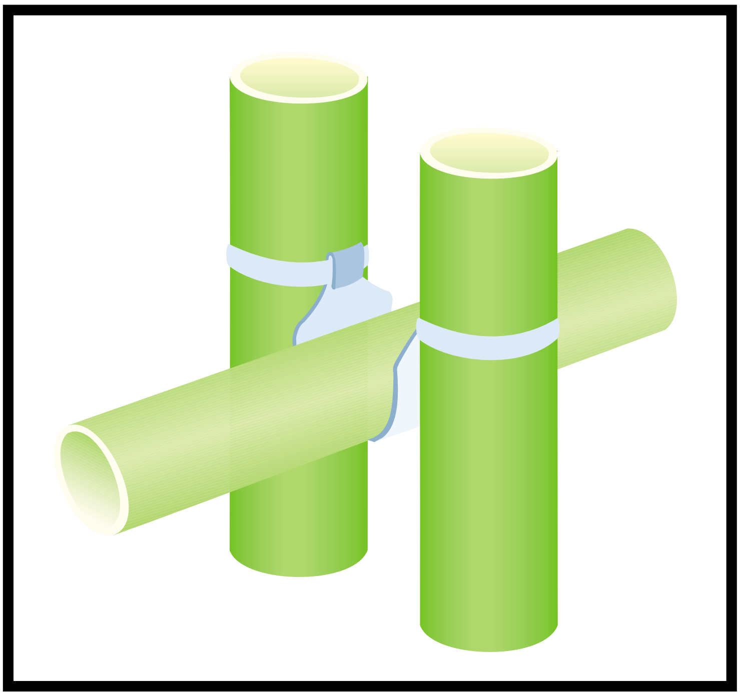


Fig. 79: *Design of a bamboo joint by John Cauty of Costa Rica*

Chapter Seven

International Standards

The Relevance of Standards

A standard is a regulation for (in this case) the building industry regarding materials, workmanship and structures. At the national level, a common example is a building code, or a code of practice. These standards are essential if bamboo should become an internationally recognized and used building and engineering material. This issue is so important that it merits a discussion.

Many cases are known in which standards or regulations are based on middle-class housing and consequently, houses of low-income groups become entities that may be bulldozed because these do not meet the “minimum acceptable standards”.

Standards are not meant to harm anyone; they are meant to protect consumers, workers and the environment, and they promote economic growth. The issue is not whether standards should be implemented, but who defines them and how.

Standards generally protect the rich, and if they are meant to protect the poor (for instance, their safety at work) they are often not implemented. Standards are known as a part of the development problem, but they can also play a part in the development solution.

Good standards must meet the following requirements:

1. Protection of the consumer. Sub-standard items are a loss of money for the client, and may even be a danger for the consumer.

2. Protection of the environment. Effluent disposal and other forms of pollution are kept within acceptable limits.

3. Reduction of cost of production. Standards can eliminate most of the waste, and improve quality, without raising production costs.

4. Minimum standards of work. Standards address, for example, issues such as health and safety at workplace.

5. Safety of the inhabitants. As an example, standards may specify special safety provisions and precautions for constructing high-rise buildings in earthquake areas.

6. Market requirements. A product made according to standards can more easily penetrate various markets, especially export market.

We are living in an increasingly regulated world. This urges every one concerned, particularly developing countries, to work together for uniform standards that meet the requirements. A core issue in formulating standards that cover production and consumption in developing countries is that the provisions contained recognize the environment. Standards have to be defined in the South, by the South, for the needs of the South, and using the resources of the South.

Looking more specifically at housing, standards must define a minimum level of quality, mainly to prevent disasters and reduce health risks. Currently, standards in the South apply to, or are implemented in, urban areas only. This situation needs to change since a huge majority of population in the South live in rural areas. Standards should aim at the following goals:

- They should be widely accepted in the country.
- They should be in line with local traditions.
- They should recognize that building is an incremental process.
- They should take into account the needs of the masses.
- They should recognize the economically upper class, but at the same time assist the lower class to improve their dwellings.
- They should take into account the lack of funds to meet the standards.
- They should take into account people's priorities.
- They should work with local materials.
- They should not add to bureaucracy.
- They should make use of traditional housing resources.
- They should help prevent overcrowding.

The basic needs of the masses have to be met, starting with a minimum level of standard and providing scope for gradual improvement. New standards should use the potential of bamboo to help people solve their problems, starting at a low level and growing to a higher level.

A standard should not be prescriptive (“walls should be 50 mm thick”) but indicative of an expected level of performance (“the roof should be able to withstand a hurricane with wind speeds up to 100 km/hour”). A considerable part of a bamboo standard should be based on observations – Which type of housing did survive what disaster? Which houses are more durable or need less maintenance? A bamboo standard should impart valuable lessons.

Such a bamboo standard will help stimulate the use of bamboo, and help bamboo attain recognition through wider and better use. A report from UNIDO (1991) says about wood: “In most developing countries, building legislation is inappropriate and does not recognize wood as a durable construction material. This has prevented banks and other financial institutions from supporting the use of wood in construction.” The same remark is valid, perhaps more so, for bamboo.

Towards an International Standard

When considering an international standard for bamboo, the first problem is that bamboo does not appear in any national building codes as of now (beginning of year 2000). This not only fails to contribute to the recognition of bamboo, but also gives scope for an interpretation that the use of the material is to be discouraged. It is only logical to think so since bamboo has been in active use in building construction for hundreds, if not thousands, of years. The omission of bamboo from national building codes is a constraint for the development of bamboo as an efficient engineering and building material. A good national standard can open the way for engineers and designers to the world of bamboo.

If the development of national bamboo standards is handled by the respective national authorities, a wide diversity in standards will result. If, instead, an international model for national standards is designed by an international body in consultation with national entities, the position of bamboo will be strengthened considerably.

Take a look at the situation of timber. Standards have been accepted in the US, Australia and European countries, but there is no concurrence among these nations on a common standard. If an international body can facilitate the acceptance of a common standard for bamboo, that will put bamboo half a century ahead of timber in terms of scope for application and development. This is the reason why the International Network for Bamboo and Rattan (INBAR) has taken up the task of creating international standards for bamboo. At the time of writing this, INBAR is in the process of developing the first ISO standard for bamboo.

The International Organization for Standardization (ISO) defines standards as: “Technical specifications or rules, based on consensus, and approved by a recognized standardizing body.” We should make obtaining consensus our task; for approval, the proposal needs to be submitted to the ISO.

Boughton (1989) has described other arguments in favor of an international model. Many countries are facing a huge shortage of housing. Therefore, governments are willing to consider bamboo’s contribution to the solution. But bamboo still has the stigma as “the poor man’s timber” and is not considered as a modern material. A building code would be the solution to this problem, and it would help formalize the position of bamboo.

The advantages of a codified design with bamboo can be summarized as follows:

1. Engineering recognition. A code will stimulate engineers to use bamboo. “Engineers and architects prefer to work with the determinacy of a well-known system or material, supported by solid knowledge of its properties, backed by the existence of a minimum of code specifications on which they can base their judgement and design decisions” (Arce 1993).

2. Contractual advantages. A code makes any contract much easier.

3. Trade advantages. A code provides for the quality control of products.

4. Increased use of bamboo. Socially better accepted, codification leads to innovation, specified more regularly in designs.

CAPABILITY AND TIMING

There is a strong argument that we do not know enough about bamboo to design an international model for standards. This is the eternal discussion between scientists and engineers. It is true that, when compared with the large quantity of information available on timber or concrete, the information available on bamboo is not much. But it is equally true that the eternal fate of the engineer is to give a reliable answer based on a limited amount of data. This is exactly what one faces with any proposal for an international bamboo standard.

Another point of concern is the rapid developments being witnessed in the structural use of bamboo in building, and in the production and export of bamboo products. There is a real danger that bamboo will go timber's way, if a concerted effort is not made now to arrive at a universally acceptable standard. It would also help to remember the first international standards for steel or reinforced concrete, which are now considered primitive but had played a key role in the progress of these materials. And finally, as discussed earlier, there is a lack of tools to make calculations for bamboo structures, and a widely accepted standard will do much to remedy the situation. The development of international bamboo standards, which can act as models for national standards, is therefore an urgent necessity now.

FORM AND CONTENT

An international model on bamboo for inclusion in national standards should contain the following items.

A. Philosophy. A similarity with timber codes will be an advantage for the users (to get accustomed to) as well for those who write the model. The international model may adopt two approaches: for some chapters, it has to provide a complete code; for other chapters, it has to give only a guideline for the national codes.

B. Structural safety and sound design. Like in other codes, but one has to take into account the specific properties of bamboo. Bamboo is a totally different material when compared with materials like steel or timber. The model must also guide structural engineers who have no experience bamboo but are expected to work with the material in their practice.

C. Materials testing and properties. The current state of affairs in the determination of the properties of bamboo is that each laboratory is performing tests according to its own “standards”. Bamboo researchers have done, and are doing, a good job in determining properties, even under trying circumstances. But compared with timber researchers, they are at a disadvantage because of the lack of standards on bamboo. It is a problem for the researchers because they cannot perform “standard” tests; it is a problem for the users since it is impossible to compare the results from different sources. Although the absence of standards has not hindered the construction of bamboo houses at low-income levels, it has certainly impeded the wider acceptance of the material.

The text should give a description of properties of bamboo and how to determine them in the laboratory. For timber, this has been described in detail, and the test results form a basis for structural engineers to make their calculations using reliable data. The text has to give a full code for tests in the laboratory and field. The text must also provide guidelines for evaluation reports from the field. It may be remembered that only a few properties are relevant for the prediction of failure loads; other properties are of academic interest only.

D. It is necessary to determine how tests in the laboratory will be translated into data for calculations – using the system of an overall safety factor or the modern system of partial safety factors.

E. The standard must lay down rules for the calculation of structural elements (such as beams and columns), a full calculation code, as well as basic principles like “do not concentrate forces” and “spread load over a number of elements”. Buckling in bamboo is a challenge, and so are bamboo’s tapering form and variable cross-section. One has to also think about tolerances since no two pieces of bamboo are identical. One can order a 125 mm steel beam from a catalog and be sure of getting exactly what was ordered. But with bamboo, one has to think of a range, such as “between 120 and 130 mm”. The problems are similar in the case of mechanical properties.

F. Even more complicated is a standard for the design and calculation of joints and trusses. The shallow depth of our knowledge on bamboo does not become more evident elsewhere than here. But this is a path that researchers of timber and concrete have trodden earlier. It is a difficult path, but if we do not negotiate it, bamboo will never become an accepted building material.

G. Aspects such as resistance to hurricanes and earthquakes are important. We have seen bamboo coping well with the loads caused by these disasters, but how exactly does this work? An important resource of information is the evaluation of houses after such a disaster. If certain houses did survive, one can be confident that similar houses will be adequate to withstand similar disasters in the future. This principle does not appear in any standard for any building material; but for bamboo, it should be mentioned.

H. A grading system is important to develop the market for bamboo as a building material. For timber this is common; we buy a beam grade A or B and we know what can be done with such a beam. A similar simple, cheap and effective system needs to be developed for bamboo. That would make trading much easier and reliable.

I. Bamboo's use as reinforcement in concrete needs to be dealt with. In the rules for design and calculations, the expected lifetime of bamboo in this alkaline environment and other problems (like shrinkage) should be covered.

K. Durability and preservation should guarantee an appropriate service life for the bamboo structure. Durability starts with the selection of the species, but we really do not know much on this at the moment. Preservation starts with good details to improve the lifetime, and to allow for maintenance. Preservation includes (1) selection of sound bamboos, (2) design of proper details and (3) chemical preservation. We should include safety for the workers and the inhabitants, and also consider pollution and the environment.

L. Export items from bamboo. It would be good for the economic development of the South if there is a major export market in the North for bamboo products. At the moment, a constraint is that buyers in the North are not familiar with bamboo products. Once internationally accepted standards are in place, export will become much easier, particularly because bamboo products are "green" (environmentally friendly).

COMMERCIAL AND NON-COMMERCIAL SECTORS

In the case of bamboo, the differences between the formal and the informal sectors are very important. The purposes of regulations for the commercial sector are as follows:

- They should provide a healthy environment.
- They should reduce the frequency of environmental, structural and other functional failures.
- They should derive improvements in the quality and economy of construction, by setting up standards that form a reasonable and readily administered basis for contracts between builders and owners, and at the same time permitting innovation and development.
- They should protect the interests of the neighborhoods, and those of the community as a whole, from the irresponsible development of sites, which may otherwise take place.

The purposes of regulations for the non-commercial sector are as follows:

- They should provide improvements in the standards of hygiene.
- They should mitigate suffering and loss in the event of natural disasters, such as earthquakes, winds, storms, floods and fires.
- They should meet the needs of the owner or the occupier, rather than serve the convenience of the regulating authority.
- They should educate owners, occupiers and builders in the means with which to achieve the above at low cost (Mansell 1984).

Chapter Eight

Bamboo as Reinforcement

Use of bamboo as reinforcement falls into four categories:

1. Bamboo fibers in cement mortar for roofing sheets, which is a success.
2. Split bamboos as reinforcing bars in concrete, about which the author is very critical. In both cases, the basic idea is the high tensile strength of bamboo.
3. Bamboo as a formwork for concrete (is not a reinforcement but it has to do with concrete).
4. Bamboo as soil reinforcement.

Fiber Reinforced Cement Mortar

The 'fiber' used can be any organic fiber, such as sisal, although we are concerned only with bamboo fiber. The fibers should act as reinforcement in the cement mortar. The material being reinforced is called the "matrix". The reinforcing material should be stronger and stiffer than the matrix: that is, the deformation should be less or, in other words, it should have an E-modulus much higher than that of the matrix. Otherwise, both reinforcement and matrix will deform together and cracks will develop immediately. The problem with bamboo is that the tensile strength is more than adequate, but the E-modulus is not. Hence, theoretically, bamboo fibers in cement mortar are useless as reinforcement. In practice, however, bamboo fiber is really a good reinforcement. Cement mortar reinforced with fiber was first developed in the U.K. The author was a member of the group in the Intermediate Technology Development Group (ITDG), which was in charge of developing corrugated roofing sheets from fiber-reinforced cement during the 1980s.

After some years of study, Dr Gram from Sweden had concluded that the lifetime of organic fibers in cement mortar was only six months. The reason was the high alkalinity of the cement mortar: the pectin between the cellulose in the bamboo fibers cannot survive this alkaline environment. The fiber-reinforced sheets developed at ITDG, however, proved to have a long lifetime, though a theoretical explanation for the behavior eluded the researchers. Following Dr Gram's thesis (Gram 1983), the donor cut the budget for fiber-reinforcement research.

Financial troubles can often act as a stimulus, and the research group soon worked out the theory behind the longer service life of the fiber-reinforced cement sheets developed at ITDG. The action of the fibers is only during the first month, during the hardening process. The fibers take in the shrinkage to provide a roofing sheet with a good bending stiffness resulting from a crack-free cross-section and the high tensile strength of the cement mortar. Without fibers, shrinkage will result in many cracks, and a loss of the moment of inertia of the cross-section. Thus, although the fibers have only a short life in cement mortar, they literally leave a lasting impression. The hollow pockets they leave behind arrest the development of cracks. If a crack develops in the cement mortar, it will soon meet a hollow pocket and will be unable to continue growing (this trick is well known in the maintenance of machinery: a hole drilled in front of a crack saves the rest of the machine). The explanation made the donor happy and the funds started coming in again.

Fig. 80 shows one of the corrugated roofing sheets during tests at ITDG. For tests on suction, the roofing sheets were kept upside down and loaded with sandbags. The sheets

Fig. 80: *Roofing sheets under test*

without fibers failed immediately, while the ones with fibers could carry enough load to resist a storm. More information on this can be found in a brochure by Evans (1986), while Cabrillac (1992) provides very useful information on the properties of the sheets.

Bamboo Reinforcing in Concrete

This application of bamboo has some advantages, but the disadvantages are more. One can overcome the disadvantages, but the result may not be worth the effort. This means that the original concept itself is wrong and the criteria employed in the design need a recheck.

The advantages of using bamboo as a reinforcing material in concrete are: (a) the high tensile strength and (b) the low price. The common tensile stress in steel reinforcement is 160 N/mm^2 and in bamboo 20 N/mm^2, a ratio of 8 to 1. The mass per volume of steel is 7 850 kg/m^3 and of bamboo is about 500-600 kg/m^3, a ratio of 16 to 1. Evidently, bamboo will be cheaper because the price of bamboo per weight will be less than half that of steel.

To assess the applicability of bamboo, one can calculate the bending moment (M) in a concrete beam using the following formulas. Both formulas read: distance between compression and tensile forces in the beam, multiplied by the percentage of reinforcement, multiplied by the tensile stress in the reinforcement. The formulas are:

Steel reinforcement, concrete cracked, stress in steel 140 N/mm^2:

$M = 0.9h\ 3\ (0.6\ 3\ bh\ 4\ 100)\ 3\ 140 = 0.76bh^2$.

Bamboo reinforcement, concrete cracked, stress in bamboo 20 N/mm^2:

$M = 0.75h\ 3\ (4bh\ 4\ 100)\ 3\ 20 = 0.60bh^2$.

These need some explanation. First, the distance between compression and tensile forces in the beam: 0.9h for steel reinforcement but 0.75h for bamboo reinforcement. This is because quantity-wise more bamboo is needed than steel for the same reinforcement, resulting in a larger area of reinforcement, which means a higher beam and a relatively smaller value than the 0.9h for steel.

Next, the percentage of reinforcement, which is 0.6% of the cross-section area bh for steel. For bamboo, several authors recommend 4% to keep the deformation within acceptable limits. Finally the stresses: 140 N/mm^2 for steel and 20 N/mm^2 for bamboo.

The conclusion is that the bending moment in a beam with bamboo reinforcement is 78% when compared with steel reinforcement. This is not bad. However, the 4% reinforcement, which is seven times as much as steel reinforcement, poses practical difficulties. As an example, consider a beam of 200 3 400 mm. A typical steel reinforcement would be 4 bars of 12 mm diameter, which is about 0.6%. For bamboo, 4% reinforcement of 200 3 400 mm will result in a huge cross-section of 3 200 mm^2 for the bamboo. If split bamboo strips of 6 3 20 mm are used, 27 strips will be needed, and one will have to arrange several layers of bamboo reinforcement. To circumvent this problem, some researchers have developed concrete beams with a cross section like a T upside down. This is a clever innovation but it serves to acknowledge the problem as well.

Similarly, one can calculate the width of the cracks and the deformation; both are of acceptable levels. The width of the cracks can be calculated as follows. The stress in steel reinforcement is 7 times that in bamboo (see above), and the E-modulus of steel is 10 times that of bamboo. Consequently, the strain (which is the elongation per length) in a beam with bamboo reinforcement is about 1.5 times the strain in a beam with steel reinforcement. With steel, the strain is 0.67 3 10^{-3}, and with bamboo, it is 1 3 10^{-3} (this means 0.67 mm/m and 1.0 mm/m, respectively).

The deformation of a concrete beam with steel reinforcement is $1/1000^{th}$ of the span, and of a beam with bamboo reinforcement is between $1/500^{th}$ and $1/1000^{th}$ of the span.

The real problem is in the bonding between the bamboo and the concrete; this is never a problem with steel reinforcement. Concrete will shrink during the hardening process and this results in a firm bond of the concrete around the steel reinforcing bars. But bamboo will absorb water as soon as the concrete is poured around it. When the concrete hardens and dries, bamboo will dry as well and shrink. The shrinkage of bamboo can be four times that of concrete. Clearly, this will completely break down any bonding between bamboo and concrete, and the result will be that bamboo cannot act as reinforcement.

Many researchers have understood this problem, and have suggested solutions to overcome this problem. Some of these are as follows.

- Put the bamboo in melting bitumen or apply the hot bitumen with a brush, as a moisture barrier, and coat the bitumen with coarse sand while the bitumen still is fluid, to ensure bonding. (Krishnamurthy 1986)
- Put nails through the bamboo so that they function as dowels.
- Use three thin bamboo strips, twisted together as a cable (Hidalgo 1992).

Many structures built with bamboo reinforcement still are standing, but with a factor of safety much less than required. Only one author has been frank enough to publish a photo of a collapsed structure (Hidalgo 1992). Failures, like the one in Fig. 81, are usually not publicized.

Fig. 81: *A failed example of bamboo-reinforced concrete*

As said earlier, if a designer needs to solve so many problems, the basic idea needs to be checked. Bamboo reinforcement, in the author's opinion, is an attempt to imitate western technology using inappropriate means. One could design much better with local materials in ways that are more suitable for developing countries – domes and arches of concrete, bricks or even clay. But this is an area outside the scope of this book.

Many interesting reports have been published on the results of tests on bamboo as reinforcement in concrete. Unfortunately, almost all these deal with the short-term behavior only, which is not the real problem. These reports are listed in the reference section.

Bamboo for Formwork

This has no connection to the use of bamboo as reinforcement; however, it is a promising application of bamboo that merits a discussion. A representative example of bamboo formwork is shown in Fig. 82 (Hidalgo 1992). This is a good application of bamboo, saving much concrete, and the need for reinforcement since much of the dead weight of concrete is avoided.

An ingenious application of woven bamboo mats has been observed by the author during his work in Bangladesh in 1991. Timber is at a premium there, and building is mostly with brick and concrete. They have worked out a clever solution to substitute timber for formwork. A floor is made of corrugated iron roofing sheets, on top of which fine particles of soft bricks are laid to get a smooth surface. A thin plastic sheet is laid (blue) on top of this and woven bamboo mats are used to prevent adhesion between the plastic and the concrete (Fig. 83). This formwork is supported by bamboo columns (Fig. 84).

Soil Reinforcement

As in concrete, bamboo can be used as reinforcement in soil, mainly to stabilize slopes or riverbanks, or to support roads. The protection of riverbanks by living bamboo has already been discussed in Chapter 1. Here, we examine the use of woven bamboo mats

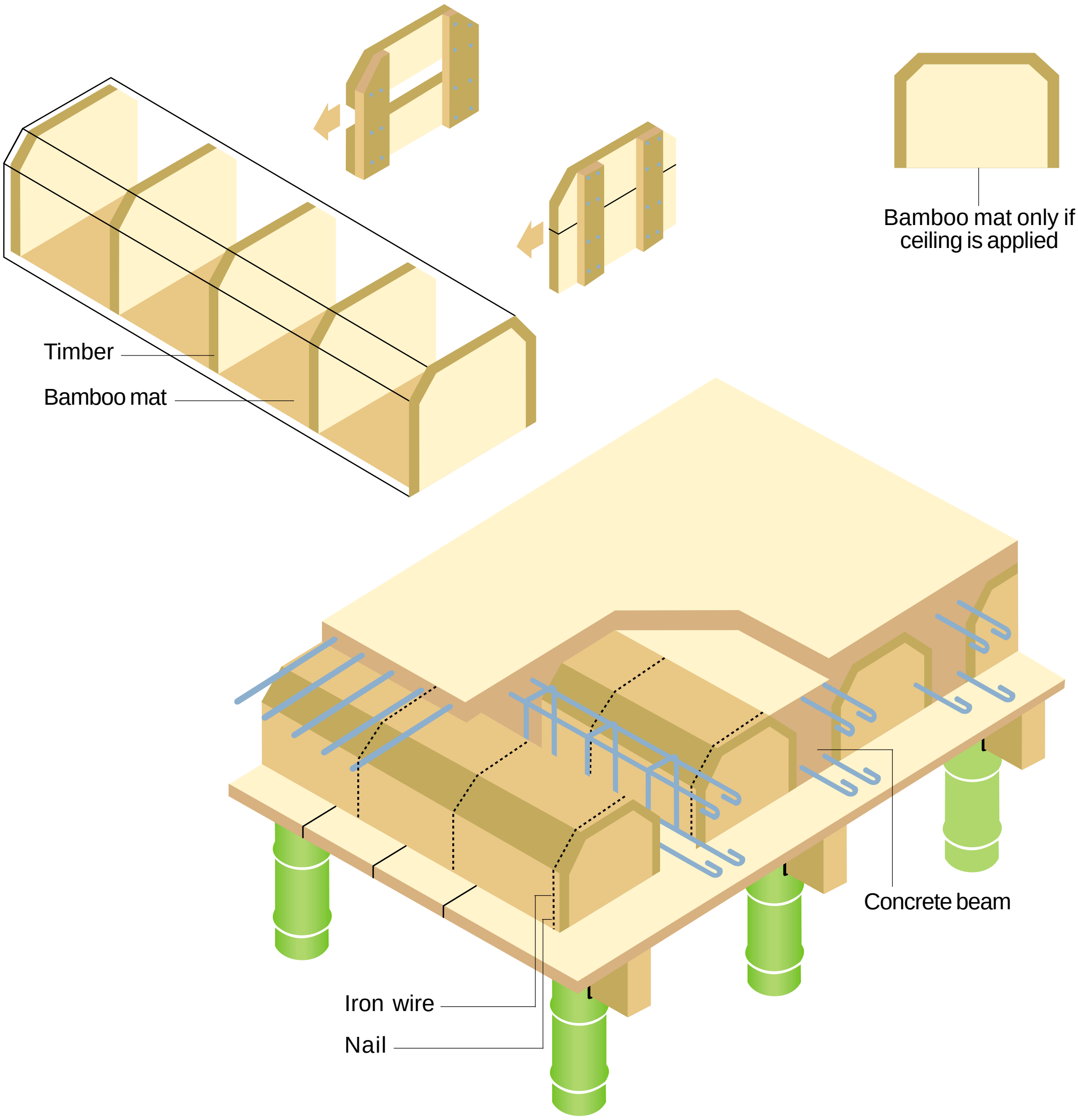


Fig. 82: *Bamboo boxes in formwork (Hidalgo 1992)*

Fig. 83: *Woven bamboo mats in concrete formwork (Bangladesh)*

Fig. 84: *Bamboo culms support concrete floor (Bangladesh)*

in a way similar to the well-known “Geogrids” (plastic mats that reinforce the soil) or the use of bamboo culms, which are put vertically in the soil to act as a kind of dowels. Both uses are meant to keep the soil together and to prevent landslides.

At the International Bamboo Workshop in Cochin in 1988, two interesting papers were presented on the subject by Douglas and Low (Douglas 1990, Low 1990). Both show how bamboo can be used to reinforce the soil. Bamboo takes the tensile stresses and the shear, and the soil takes the compressive forces and provides a safe environment for the bamboo (provided it is clay and not sand; clay protects the bamboo from the air). If termites occur in the region, one has to check the lifetime carefully. Others have used bamboo-reinforced soil for foundations (Kurian 1977) and even for reinforced soil-cement walls (Chadda 1956).

Chapter Nine

Bamboo Housing

Housing is a basic human right. A proper place to call one's home, a shelter for protection against the weather, a safe place for the protection of valuables, a place that provides one's children with the opportunity to grow up in good health – all these aspects are essential for a life with dignity and welfare. This is the purpose behind including the right to housing as an item in the UN declaration on human rights.

In practice, however, it is difficult to provide all the people with decent houses. In many cases, the family income is not enough to buy land and build a house. Food, clothing, children's education, etc. get priority over saving for a house. These issues must get a closer attention if the housing shortage is to be effectively addressed. For this reason, self-help projects will be the first item we will discuss. This presupposes a social structure, like cooperatives, in the community. As far as housing problems are concerned, social (and of course, economic) aspects are more important and primary than technical aspects.

Social Aspects

SELF-HELP

The most basic need, perhaps, is to make people conscious of the poor housing situation and of their ability to contribute essentially to the solution, with their own hands, by self help. Bamboo housing offers enough scope for self-help house construction. With appropriate training, which should be given by experienced teachers, a family can easily build their own house. Organizations involved in mass housing projects may find their task easier if the participants were to be organized as a cooperative. Hands-on training may be imparted to cooperatives by involving the members in building a prototype unit which, on completion, can be used as the office of the cooperative. One has to keep in mind that in farming communities people are busy with their land during a major part of the year. Hence, training courses have to be planned for the season with less agricultural activity.

Self-help has the risk of being time consuming. In one project, the building time was nine months, which was considered as too long. No participant can remain enthusiastic

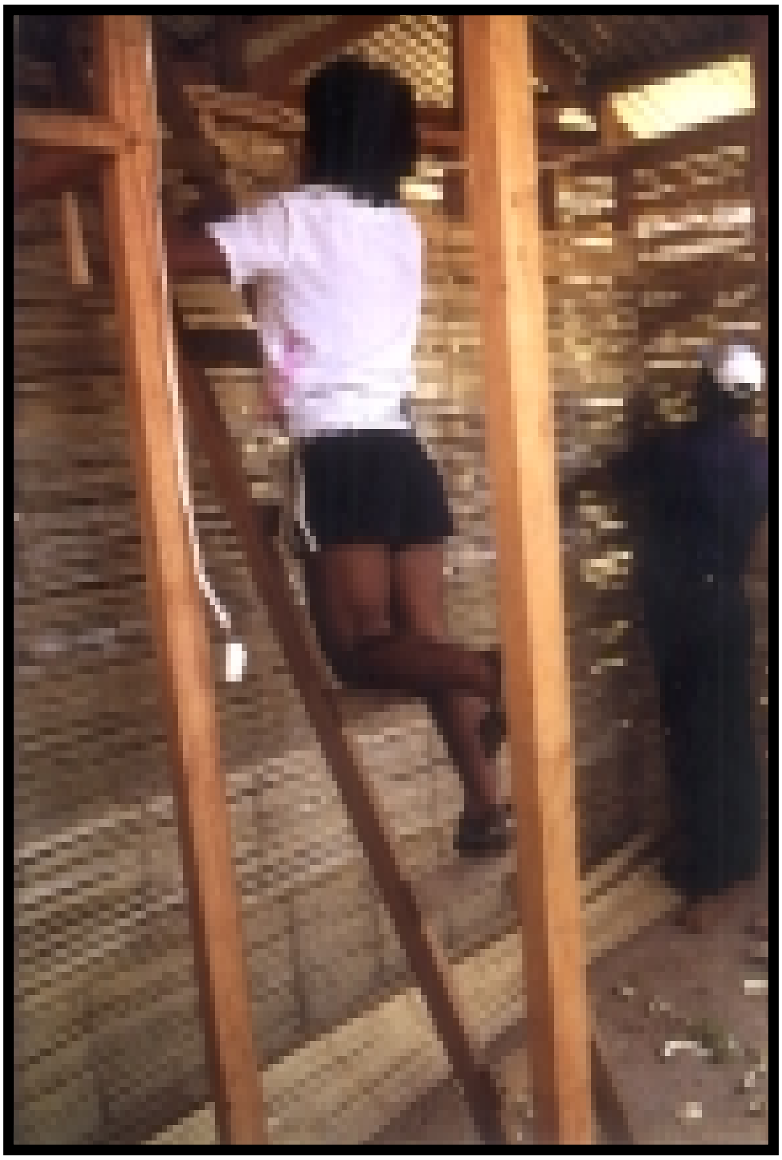


Fig. 85: *Self help in bamboo housing (Costa Rica)*

for nine months, and people need to devote most of their time for earning income. In such cases, one solution might be to reduce the self-help component to a minimum and to involve a building contractor for doing most of the construction work. One has to find a compromise between the building time (about three months) and the building costs. With a contractor costs will become more than with total self-help projects.

Fig. 85 shows self-help in practice: a father-son duo is building a house for their own use. Fig. 86 shows an example of the result of discussions and decisions taken within a

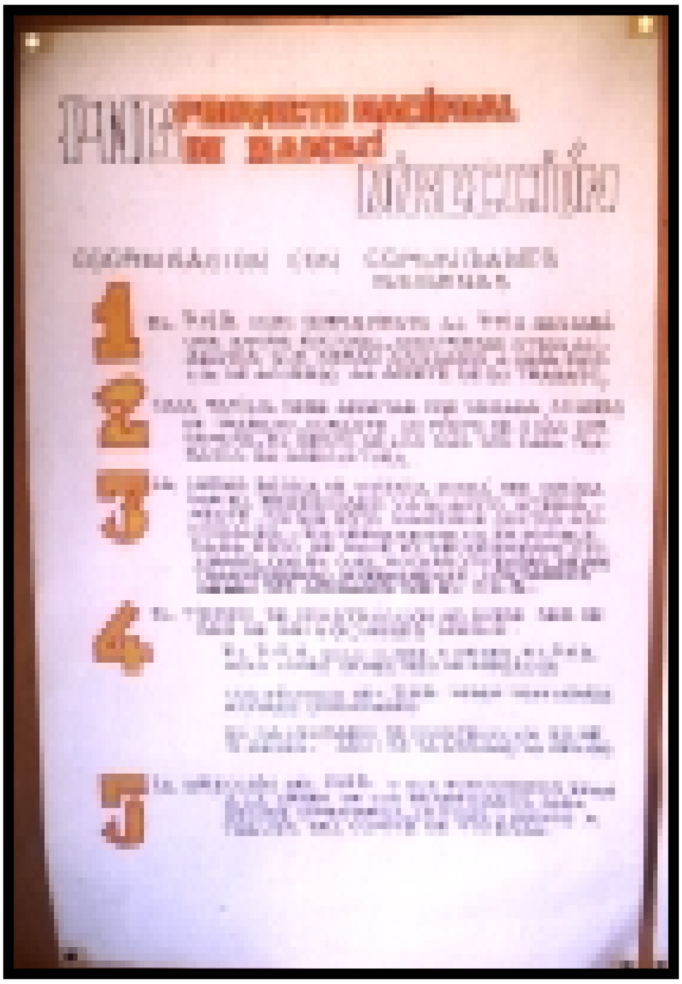


Fig. 86: *Rules and regulations of a self-help housing project (Costa Rica)*

community: all rules and other outcome of meetings are published on the wall of the meeting room. The process is transparent, as everybody involved in the project is made aware of all decisions.

TRAINING

Training is not limited to the know-how on bamboo house building; it also addresses the social aspects that come into play in moving from a shanty to a proper house. The latter part is more important as the people involved has to be convinced that (1) they need to actively participate in the self-help project and (2) owning a decent home in a short period is a reality under the project. The process may be slow since people, exposed to years of neglect, might be skeptical about the possibility of such a project ever materializing, let alone succeeding. Further, the process is one of social change, of getting adjusted to a new reality, perhaps even a new way of life. A slow pace in such circumstances is desirable. Using models of houses is a great help in presenting the project to the people (Fig. 87, 88).

Such models constitute a method to effectively convey messages on various issues – What does a new house mean for the family? What are the advantages of living in such a house? What should be done to keep it clean and to maintain it? Models may also help people get accustomed with the idea of owning a proper house – the sense of ownership

Fig. 87: *Models of new houses*

is very important in the upkeep and maintenance of mass housing schemes. The author had the occasion once to visit a housing project, which was completed very quickly because of political expediency. The occupants did not get the time or occasion for the process of adjustment. By the time the visit was made, some months had elapsed since the inauguration. In one house one glass in a window was broken. The head of the

Fig. 88: *A realistic model of bamboo house*

family explained a cock had flown through the window, as he was accustomed to do in the old house. The event had happened three weeks before the author's visit, but the broken glass pieces were still lying on the floor. It was evident that although the house was legally the property of the occupants, the sense of ownership had not taken root yet in their minds. Otherwise, they would have repaired the window or at least cleared the broken glass pieces.

ACCEPTANCE

Bamboo is still considered as the poor man's timber in most parts of the world, and living in a bamboo house can be a stigma on the family. There are several examples reported from around the world of people plastering their bamboo houses to make them look like concrete houses (and in the process, weakening the structure and endangering their lives!). The best way to overcome the “poor” image of bamboo in a community is to first build an office with bamboo for the staff of the project. An aesthetic yet functional design for the houses will also help minimize prejudices. It is advisable to ensure that the outer appearance of the buildings is in harmony with surroundings, and not at too much variance with other non-bamboo houses. If the project also includes building hotels and restaurants, or houses for middle-income groups, it would much help to inculcate social acceptance of bamboo.

KNOWLEDGE TRANSFER

A bamboo building project often involves a North-South transfer of knowledge, since much of the building research work takes place in industrialized nations while the need for bamboo housing is mostly in developing countries. The knowledge transfer is usually through expert consultation. It is important that the project management remains with those who have developed the project and not with the foreign expert consultant, whose role should only be advisory.

It is also important to realize that the expert knowledge required for such building projects is often available in other developing countries. Such knowledge may even be more suitable than the expertise available in industrialized countries. Hence, the scope for a South-South knowledge transfer must be ascertained before turning for assistance elsewhere. For instance, many Asian nations have a rich tradition in bamboo and could offer their experience to Africa or Latin America. Similarly, Latin America has built up valuable experience in certain bamboo technologies, which could be offered to Asia or Africa and so on. If the initiative, the staff and the management are local, the chances are that the success of the project will continue even after the foreign consultant has left; otherwise, the danger of a sudden collapse is possible.

WOMEN EMPOWERMENT

In a cooperative set-up, women can play an important role in the decision-making process, as well as financial management involving tasks such as collection of funds, repayment of the loans and monitoring of expenses. One of the strong points of bamboo-based solutions is that they provide ample scope for involving women and other disadvantaged groups in the socio-economic process. In fact, there have been many projects designed specifically with this aim. That women traditionally form an important part of the labor force in the construction sector in most developing countries is a plus point. The organizations that undertake bamboo building projects could easily factor in women empowerment as one of the secondary aims of such projects.

INTEGRATED PROJECTS

Wherever and to the extent possible, projects must be designed as integrated initiatives as these are the only ones that sustain over a long period. Make a start with a plantation or with proper management of a natural stand. Next organize good harvest, storage and treatment facilities. Keep in mind that a bamboo plantation will continue to grow forever. Plan to use the culms for more than one purpose: such as, for income generation activities (handicrafts, basketry, furniture, etc.) and for housing. The idea is to make bamboo an integral part of people's life – as a source of income, as a building material for their houses, as a material to fashion out articles of everyday use, etc. Use of bamboo as an income-generation tool will certainly be appreciated, especially if this can be linked to payment for the houses. Make sure all issues involved, such as the per capita financial commitment and the mode for paying for the house, are discussed clearly in the meetings of the community. The gist of such information (itemized expenditure for the house, payment schemes, etc.) may be posted prominently in places where the community congregates (Fig. 89).

A well-structured scheme makes it easier to write a proposal for funding. The long-term social, economic and environmental benefits of the plantation will be a very strong point in the proposal. Also, a well-managed plantation will become self-sustaining in a matter of few years. Donors generally like to see their money being put to self-sustaining projects with long-term benefits, and an integrated bamboo project is very much along those lines. That a bamboo plantation lends itself to sustainable use is an added attraction. For instance, it has been calculated in the Costa Rican context that 70 ha of bamboo

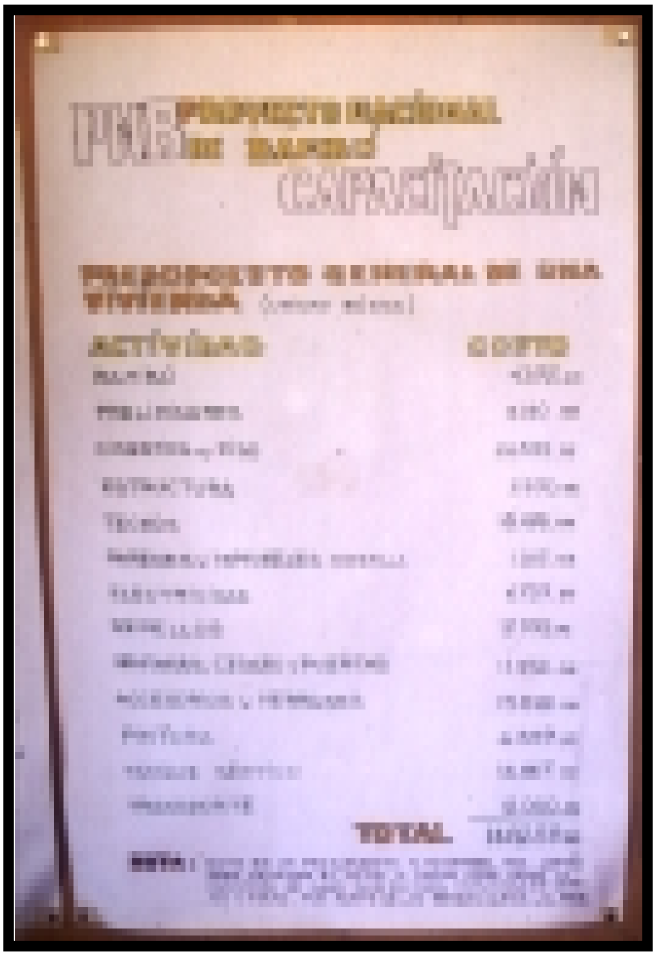


Fig. 89: *Itemized budget for a house, posted in the community meeting room (Costa Rica)*

plantation are sufficient to build 1 000 bamboo houses per year. If these houses were built with timber, 600 ha of natural forest would be destroyed each year. This comparison may not be accurate as it pits the careful management in a plantation with the rough way trees are cut in a natural forest. Still, it emphasizes correctly the nature of bamboo as a “green” material that can be sustainably harvested in an integrated project environment. Of course, a sound social structure and a stable cooperative are essential preconditions.

Technical Aspects

In discussing the technical aspects of bamboo housing, this chapter could easily be filled with hundreds of detailed engineering drawings. That, however, will not serve any useful purpose, as there could still be more drawings of other possibilities. It is better to lay down a philosophy, a basis for the reasons why some details are good while others are not, and also why a detail that might be good in one cultural or climatic setting is not so in another. Examples shown will clarify and support this approach. We will start our discussion on technical aspects with safety, as this is one of the first requirements in housing: we want our house to protect us.

SAFETY

While discussing safety in a meeting some years back, Mr. John Parry, an ex-colleague of the author, said: “Disasters are man-made!” Other participants countered this, saying that most major disasters are caused by Nature. Mr. Parry explained that even a natural disaster becomes a disaster only when people are not prepared for it. If an earthquake or a hurricane hits an area that has no inhabitants, it is not considered a disaster. Even when it hits an area with many houses, it will become a disaster only if the houses are not adequately designed and maintained to meet the calamity. The following section gives some basic ideas on how to design and calculate the parameters of houses.

Let us consider earthquakes first. As explained in Chapter 4, tests carried out on full-scale bamboo walls have clearly demonstrated their resistance to earthquakes. The elastic behavior exhibited by bamboo panels under simulated earthquake loading is really fascinating. The laboratory test results were reaffirmed when the April 1991 earthquake, registering 7.5 on Richter’s scale, failed to damage the 20-odd houses that were built (by chance) near the epicenter of the quake. The author had the occasion to check them personally, and could not find even a crack on them. Many buildings of brick and concrete in the vicinity of these bamboo houses were destroyed. The success of the bamboo houses was so telling that some vested interests felt compelled to spread a rumor that many bamboo houses had suffered from the earthquake. Probably they could not understand how the “flimsy” bamboo houses withstood the earthquake while their “strong” brick-and-concrete structures collapsed!

The load caused by an earthquake is the product of the mass of the house, and the acceleration, which is the increase of speed and a property of the earthquake. Building codes or similar information materials give the data regarding the acceleration for each class of earthquake. This data form the basis for the design. Bamboo is a lightweight material, and has a strength that is much greater in relation to its weight. Consequently, it does not attract forces from an earthquake and also has the capacity to resist these forces. Minke (1984) has done an interesting study on walls made with rammed earth and bamboo reinforcement, and subjected them to successful on-field tests in Guatemala. The design of the wall was quite inventive: the bamboo was used as full culms in the interior of the walls.

Hurricanes (or typhoons, if your prefer) are tropical storms characterized by high wind speeds. They can easily destroy a settlement in a few hours. The key to saving a house

Fig. 90: *A bamboo house that emerged unscathed from the 1991 earthquake (Costa Rica)*

during a hurricane is to keep the roof down. Wind in the open field has a high energy, which is the product of half the mass of the air (in kg/m^3) and the square of the velocity. The latter provides a storm with a huge amount of energy that, together with the energy represented by the pressure in the air, forms the total amount of energy in the air. This total amount is a constant: if the velocity goes up, the air pressure comes down, and vice versa.

As soon as the wind blows from the open field and meets an obstacle (the house), this obstacle causes friction to the wind and the velocity comes down. The difference in energy between the higher and the lower velocities changes into a higher air pressure, bouncing against the wall of the house. The part of the wind that is going over the roof, however, is speeding up and the part of the wind that hits the wall is trying to escape over the roof. This escape path is narrower and the result is a higher wind speed. This causes a lower air pressure, which causes a suction force on the roof. If the wind succeeds in blowing away the roof, the house will soon be destroyed completely by it.

If bamboo's lightweight is an advantage in the case of an earthquake, it is a disadvantage in the case of a hurricane. If a roof is heavy, and the house is heavy, the wind cannot blow it away. But the weight of bamboo is negligible, and a bamboo house will be blown away easily. The remedy is to connect everything together, starting with the roofing sheets and the purlins to the whole roof. Anchor this roof structure tightly to the walls or the frame, and fasten these securely to the foundation. The foundation must be heavy enough to resist the suction of the wind on the roof. Fig. 91 details the way to keep the roof down.

In the center of Fig. 91 one can see a rafter and a purlin crossing each another. The upper one is fixed to the lower with a piece of reinforcing steel (about 6 mm diameter) bent over the upper one and drawn both sides through holes in the lower member. The ends are then bent against the bottom of the lower member – very simple, very cheap and extremely effective. Care must be taken to ensure that no detail is overlooked. Boughton and Chavez (1990) have presented a paper that inventories the damage done by typhoon Herming in 1987. This inventory shows which bamboo details did survive and which did not; a valuable lesson from the past and a useful guideline for the future.

Safety from burglary is another aspect that should be taken into account while designing details for the walls, windows and doors. Bamboo is a material that can be easily cut. Hence, the design has to incorporate materials that will negate this weakness of bamboo.

As bamboo can easily catch fire, fire safety is an issue to be addressed in bamboo housing. Measures such as plastering both sides of woven bamboo walls (common in some countries in Latin America) can eliminate this risk. Fire retardant treatment of bamboo is often not an option since it is expensive. Further, one cannot be sure if it really is effective. If cooking is done inside, plastering around the kitchen to protect the bamboo is a must, as is a good chimney. The roofing material should preferably be of a material that cannot burn. A thoughtful design, such as keeping the kitchen at a distance of 2-3 m from the house and connected by a simple corridor, can add to fire safety. If fire starts in the kitchen, the roof on this corridor can be removed very quickly, saving the house.

Fig. 91: *The roof structure securely anchored to the frame*

Cooking inside, though considered dangerous because of the fire and health risks, has its advantage. Smoke preserves all organic parts of the roof from deterioration. Timber, bamboo, grass, reed, all these will live eternally because of the permanent preservation by the smoke from the hearth!

COMPONENTS

Here, components mean parts of the house, such as the roof, the walls, doors and windows, the floor and the foundation. We will start with the aspect of durability, which has been briefly discussed in Chapter 3. As in the previous section, we will discuss only the issues involved. For detailed technical treatment of the subject, one may refer to Hidalgo (1974), Dunkelberg (1985) and Janssen (1995).

In general, bamboo is less durable than timber. But good design details can extend the durability of bamboo. To go one step further, one can start thinking about durability in the more narrow sense of term only if the house has been designed properly from this point of view.

As said earlier, good detail means ensuring aspects such as allowing the bamboo to be kept dry, and facilitating quick drying by sun and wind if it gets wet, etc. to make sure that the bamboo is given maximum opportunity to have a long service life. This translates into:

- a good watertight roof with an overhanging to protect bamboo from rain;
- a watertight foundation to avoid contact between the bamboo and wet soil; and
- something like plaster, or a sidewalk of brick or cement mortar, to protect the lower part of the outside wall from splashing rainwater.

A well-designed outside wall can be seen in Fig. 92. This example of good design shows a watertight roof, a proper overhang, and cement mortar on the lower part. It requires more investment in building costs, but the savings on maintenance will be much more. The lifetime of the house will be much longer as well, allowing for more years to repay the loan. The higher investment will be rewarded with lower annual payments for maintenance and loan, and more comfort.

Another feature of a good design is that it facilitates the easy replacement of a part that has deteriorated. For example, woven bamboo mats in between structural bamboo columns should be fixed in such a way that they could be replaced easily. Gutierréz (2000) reports an interesting incident. While on a field study, he saw a bamboo house

Fig. 92: *A well-protected outside wall*

and asked its owner how old the house was. The owner answered that it was 22 years old, which surprised Gutierréz. Then he specifically asked whether the bamboo mat on the outside wall was 22 years old. The answer was: “Oh no, it is replaced every two to five years”! This is an example of good design because it has factored in the need for maintenance, and allows for the replacement of an important component without having to dismantle the structure.

Roofs protect the house from rain, strong winds and sunshine. Roofing material could be:

- Organic materials, like grass, reed, leaf, etc. These are locally available but their lifetime is short. However, as they are cheap and the labor costs involved are low, the total expense per year may be acceptable.
- Metal, such as the well-known corrugated iron sheets. These will become very hot and a ceiling with ventilation in between is a must. They are watertight, which is a big advantage.

- Fiber-cement mortar roofing sheets.
- Bamboo corrugated roofing sheets (see Fig. 93).

Bamboo corrugated roofing sheet is being developed at the Indian Plywood Industries Research & Training Institute in Bangalore, India. This product is very promising in terms of its performance, looks and the job opportunities it would create. It is made

Fig. 93: *A bamboo corrugated roofing sheet being tested (India)*

from woven bamboo mats, and Fig. 93 shows a bending test being conducted on it. The service life and the production costs are the two most important items that would establish the marketability of this product.

Walls have many functions. They protect the inhabitants from rain, wind, sun, theft and so on, and also provide them with privacy and give the house a nice look. Apart for these, they play an important structural role:

- They carry vertical loads from the roof and from a top floor to the foundation;

Fig. 94: *A wall made of* esterilla *(Costa Rica)*

- They transmit horizontal forces from earthquakes and hurricanes to the foundation; and
- They transmit tensile forces from storm suction on the roof to the foundation.

Components of a bamboo wall could be:

- Woven bamboo mats, as can be seen in countries like Bangladesh and India. If these mats are used double with a cavity in between, one should be careful of rats.
- Vertical whole or halved culms. In a vertical position they dry more quickly after rain than in a horizontal position.
- Flattened bamboo strips, which are called *esterilla* in Latin America (Fig. 94).

Esterilla is made as follows. A green culm is cut on one side longitudinally, from one end to the other, and opened up till it is flat. The soft inner layer and the diaphragms are removed. This practice is applicable only when the fibers in the culm do not run exactly parallel; they need to be crossing one another to keep everything together. This is a common feature in Latin American bamboos such as Guadua, but not in most Asian bamboos (essentially, this is a difference between clumping and running bamboos). This *esterilla* can be used as such or it can be plastered with mortar (cement or mud). Without plaster it provides good ventilation, and with plaster it protects better from rain, sun and fire.

Walls can also be made with bamboo as a minor component, and mud as the major one. This is the Latin American *bahareque* wall, which is similar to the well-known wattle and daub technique. Instead of timber poles, bamboo culms are used. There are two basic types, the solid and the hollow. In the solid type, horizontal canes or bamboo laths are fixed on both sides of the culms. The space in between is filled with mud and a finish plaster is applied on both sides. In the hollow type, *esterilla* is fixed on both sides of the bamboo culms, and plaster is applied on the outside. Fig. 95 shows a house with solid type *bahareque* wall, while Fig. 96 shows a close-up view of a portion of the wall where the plaster has given way.

Houses such as the one in Fig. 95 can easily be a hundred years old. They resist earthquakes well, provided they are properly maintained. A wall that was not properly maintained can be seen in Fig. 96: one can see the reed *caña brava* (*Arundo donax*) used.

Fig. 97 shows a house built in the premises of the Forest Research Institute in Dehra Dun, India. The house, built in 1955, has mud plaster on the inside. The bamboo on the outside has been treated with CCA.

A major function of doors and windows is that they provide an opening for communication with the world. The author once noticed a good example how different this might be for different people during a visit to a small village, with about 20 houses situated along a path. All the windows of these houses were on the side facing the path; their purpose evidently was social contact. Just a few kilometers away was another village, situated close to a valley. All the windows of houses in this village were on the side facing the valley! It is not that the people in the first village did not appreciate natural

Fig. 95: *A house with solid* bahareque *wall (San José, Costa Rica)*

Fig. 96: *A close-up of the solid* bahareque *wall (the plaster is missing) showing the basic technique*

Fig. 97: *A bamboo-walled house (Dehra Dun, India)*

beauty or those in the second did not care for socializing; but this difference in the position of windows tells one more about different social structures than a book on the subject.

During the design of doors and windows one has to keep in mind not only the need of the community to keep contact with the outer world, but also aspects such as daylight, ventilation, protection against elements, need for privacy, etc. Doors and windows can contribute considerably to the beauty of a bamboo house, at low costs (Figs. 98, 99).

The window in Fig. 98 is a combination of a great design, good daylight and good ventilation. The door in Fig. 99 is a wonderful design as well. Both are not expensive, because these can be made by the occupants themselves and the technical aspects are

Fig. 98: *A bamboo window*

simple. These examples show how versatile bamboo is. It allows people to build their own shelter at a basic level, and to upgrade their house (and improve their social status in the process) by adding more components easily and economically.

If the floor is of bamboo, it will mostly be elevated. Bamboo houses do have floors touching the soil, but these are not made of bamboo. In some houses, bamboo mats are used to cover the soil. In these cases the floor will be at a higher level than the surrounding area to keep it dry in the rainy season. If available, a layer of porous material is the perfect means to keep the floor dry. It will not only save the flooring but also help avoid moisture to be trapped inside the house, thus protecting the health of the inhabitants.

The advantages of a floor raised on stilts are that: (1) it is dry at all times, (2) the ventilation of the house is better, and (3) the space below the floor can be used to keep poultry or store household equipment. The bamboo floor has to be supported by bamboo

Fig. 99: *A bamboo door*

beams on a substructure. If the area is frequented by earthquakes or hurricanes, one has to design, calculate and construct the substructure carefully in order to meet the loads (mostly horizontal loads) that come from the house on top of the substructure and which have to be transmitted to the foundation. The floor itself can be made from flattened bamboo, woven bamboo mats or split bamboo. Sometimes sawn bamboo strips can be seen, as well as whole culms of small diameter.

Bamboo flooring can also be very trendy and up-market, as some elegant bamboo panel and parquet flooring products available in the market can testify. Designers of fashionable homes and other buildings are increasingly turning to these products to satisfy the need to be environment-friendly without discounting on the aesthetics. There are several bamboo panel products developed or under development, as reported by Ganapathy et al. (1999).

The foundation is very important for the service life of a house. Other than supporting the superstructure, its function is to transmit forces to the soil. These forces are caused by the weight of the structure itself plus the weights of the furniture and other household articles and the inhabitants. More important are forces caused by earthquakes and hurricanes. As far as enhancing the service life of the house is concerned, the function of the foundation is to keep the bamboo away from the soil; mainly from the water in the soil, ants and termites. Bamboo in contact with the soil will survive only for a very short time. Hence, a proper foundation is made of concrete or a similar material, which will not allow water to move towards the bamboo. A good example was shown in Fig. 18; Fig. 100 shows another. The prefabricated pieces of concrete have a length of about 1.20 m, 0.9 m of which is placed below ground level. The reinforcing steel bars seen protruding from the top have a diameter of 6 mm. These concrete pieces are put in place, the bamboo culms are placed on top of these pieces, and cement mortar is poured through the hole on the culm to fix the bamboo to the foundation. The presence of a node below this hole is recommended because the diaphragm of this node will greatly improve the bond between the culm and the foundation.

Bamboo housing can be done on small scale, by self-help in a village community. But this will not make much dent on the huge housing shortage that is increasing each day. A problem as massive as this requires large-scale solutions involving industrial methods. Prefabrication and standardization are, therefore, necessary developments in bamboo housing. Fig. 101 shows industrial production of wall panels for bamboo housing. Bamboo culms are sawn with circular saws into strips, and these are pneumatically stapled to a frame. These frames are brought to the building site and fitted on top of the foundation. Fig. 102 shows the interior of a bamboo house, built using this method.

Costa Rica gives one of the best examples of a bamboo housing project. Bamboo houses are a good option in Costa Rica as they are about 20% cheaper than the usual type of

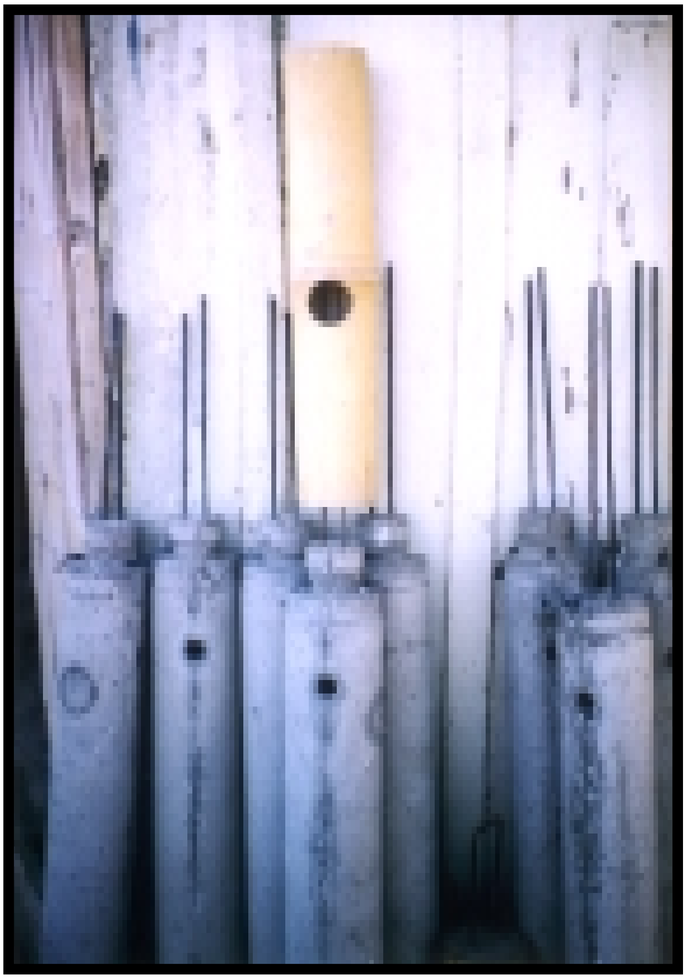


Fig. 100: *Prefabricated foundation parts for bamboo houses*

social housing. The low price of the bamboo and an ingenious design of the wall system – split bamboo, covered on both sides with a cement plaster, total thickness about 40 mm – are what make the houses low cost. The floor is cement-plaster, and the roof is made of corrugated galvanized iron sheets. A typical house measures 26 m^2 for a couple or 48 m^2 for a family with children. The price is about US$ 100 per m^2, including kitchen and bathroom, electricity, sidewalk, inner doors, and painting. Only 20% of the labor is done by self-help. A poor family can obtain such a house because they receive from the government a subsidy that is sufficient for a bamboo house, but not for a house of timber or concrete. Figs. 90 and 92 showed standard housing units; Fig. 103 shows a prototype of a unit with an elevated floor.

Bamboo housing started in Costa Rica mainly because of the efforts of architect Mrs. Ana Cecilia Chaves, who managed to convince many people in 1987 about the potential

Fig. 101: *Industrial production of houses*

Fig. 102: *The interior of a prefabricated house*

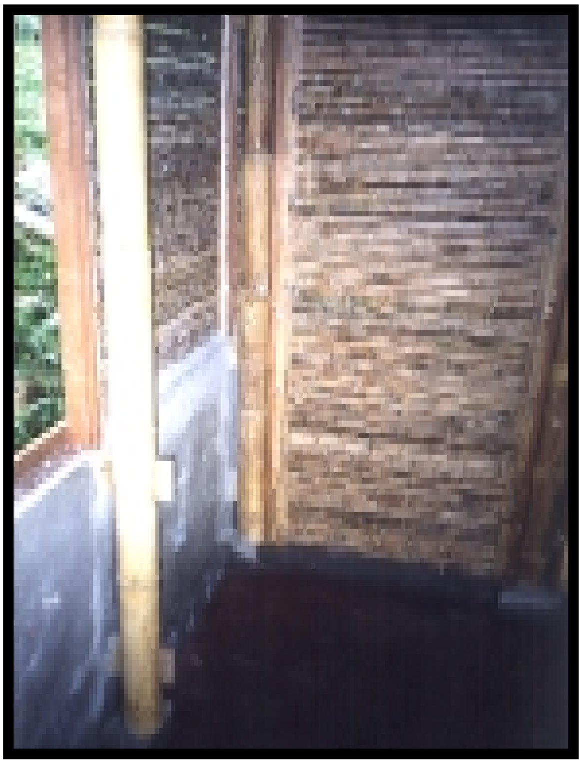


Fig. 103: *Prototype of a bamboo house with elevated floor (Costa Rica)*

of bamboo for social housing. With support from the Dutch Government, an integrated bamboo project started in 1987 and continued till 1995. In 1995, it became a commercial enterprise. Unfortunately, owing to factors that have nothing to do with bamboo, this enterprise had to wind up after some years. Many articles have been written about this project. A good review is included in *The World Habitat Awards* (Anonymous 1989).

Colombia is another country that has a notable bamboo housing project for squatters, under the name “Viviendas Hogar de Cristo”. A two-room basic house costs US$ 360; the very poor get a significant subsidy. The house is built with seven prefabricated panels. In most cases, the roof is made of corrugated iron sheets. For a detailed description see Parsons (1991), Diacon (1998) and Gutiérrez (2000).

Guidelines for a Housing Project

It is difficult to spell out a set of rules that would hold good for all housing project initiatives, as there are many variables involved. However, some general guidelines can be set forth so that such initiatives can avoid certain pitfalls.

Any housing project has to go through three stages – the preparation, the implementation and the conclusion – although the precise nature of these three stages may vary from project to project. While all the stages are important, the key of this sequence is the conclusion – that is, how the project will wind up. It does not make much sense to start a project if there is no possibility to continue after some years as a self-sustaining enterprise. This is because a housing project, which mostly begins as a development project, must have ingredients to sustain itself once the development funding ceases; otherwise, it may end up as another shanty cluster. Furthermore, as said earlier, donors like to fund projects that contain mechanisms to ensure financial autonomy at the end of project period.

Develop a project proposal in close consultation with the intended beneficiaries; never do anything without their agreement. Start with the broad outline:

- How many families will participate?
- What are their space needs?
- What is their financial capacity?
- How much extra income they need to afford a house?
- How much spare time they have to earn that extra income?
- What bamboo products can be manufactured and sold to realize extra income?

Make a scheme factoring in all these aspects. The number of culms needed each year can be worked out based on the housing and income needs. This is will provide an idea about the area of natural stands or plantations required for the project. After collecting these basic data, a detailed project proposal with a timetable of activities and annual budget can be prepared for submitting to potential donors. Once an agreement is reached with a donor, the implementation of the project (the second stage) can commence.

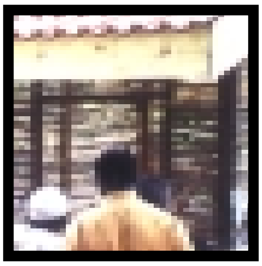
After the project period, the initiative must be able to continue without donor support. This change of status is something that should not be underestimated, because from then on each penny has to be earned and there are no crutches to lean on. It is also the time to register as a cooperative or foundation, according to the law of the land, so that the legal responsibilities and liabilities are clear.

At this juncture, the author would like to lay down some points based on personal experience.

- Never become a single-client company. A single-client business can never be independent in the real commercial sense of the word. If the only product is cheap housing for low-income groups, then dependence on the government is almost unavoidable. The client, the families from the lower income groups, is dependent on subsidy regulations that often change from government to government. So with the changes in the subsidy regulations, the fortunes of the business entity will also fluctuate, which is not a healthy business situation. Hence, it is necessary to attract clients of different types.
- Similarly, never be a single-product company, as this is another sure recipe for commercial disaster. The financial health of the company should be tied to the marketability of one product. A range of varied products would ensure that market fluctuations of one product get absorbed by the other products.
- It is essential to maintain a good relationship with government officials and politicians. At the same time, care must be taken to avoid getting identified with them; otherwise the fortunes of the company will go up and down with election results.
- The number of staff should be limited to the minimum. This is a major difference between a development project and a business enterprise. While in a project the staff salaries are covered by the project budget and hence assured, in a commercial enterprise the salaries have to come from the mark-up margin on products. If this margin is too much, the product will be too expensive to compete in the marketplace. So the number of staff needs to be one that can be covered by the limited mark-up margin.

Chapter Ten

Transfer of Technology



The Context

In simple terms, transfer of technology means one party sharing a body of knowledge (know-how, do-how, etc.) it possesses with another party that requires such knowledge. Since technology too is a commodity, the “sharing” is usually a business transaction; however, non-commercial transactions in technology are also known. The advantage of technology transfer is that the needy party is saved from having to “reinvent the wheel”, and can thus avoid wastage of human and financial resources. Unfortunately, trying to “reinvent the wheel” is the standard practice: time and again people try to find some solution, which already exists but unknown to them. The problem is so serious and widespread that the author, despite being a researcher, feels that the money (and human effort) spent on transfer of knowledge rather than on research would fetch much more dividends at the present stage.

Several instances in the author’s own experience can be listed to support what is said above. Some years ago, the author was able to assist a group in a Latin American country by sending them a report. The report was from their neighbor country, and gave a complete and detailed solution to their problem! Recently, a request came from a student who wanted to study some particular properties of bamboo. The author sent him a selected list of articles from journals published in his own country. He wrote back to say that his University did not have any of those journals! These two anecdotes serve to emphasize the point that transfer of technology must be our first priority for some years to come.

The Means

We will keep aside commercial technology transfers since bamboo housing technologies are at a stage where such transactions, if any, are more the exception than the rule. In general, non-commercial transfer of technology is effected through (1) projects, (2) seminars or (3) networking.

By project, what is meant here is a planned major housing initiative by an organization involving investment of money and people. Depending on its specific needs, the organization may contract a foreign party for the import of technologies. When the transfer of technology from one country to another (or from one region of a country to another) is being considered, there are several factors that need to be taken into account, such as:

- Will the differences in culture and climate hinder technology assimilation?
- Does the recipient have a labor pool with the required skill levels?
- Does the recipient have facilities for testing, quality control, instrumentation, etc. that are related to the technology process?
- Does the recipient have guaranteed channels for unhindered raw material supply?
- What is the market forecast for the product in the short, medium and long term?

Limiting the area of discussion to bamboo housing, one has to check the following:

- Is bamboo house a feasible option, according to the local climate and social and cultural preferences?
- Is there a demand for bamboo houses?
- Is the family income of the clients sufficient to pay for the costs of a house, in part or full as the case may be?
- Is unhindered supply of bamboo guaranteed, or can it be grown in the region in sufficient quantities and of an appropriate quality?
- If bamboo is grown in the region, is this bamboo-growing area located at a convenient distance from the area where the houses are needed?
- Is the price of the locally grown bamboo competitive when compared with the prices of traditional building materials?

As said earlier, when the housing project is planned as a development project, an integrated approach is often the best. It helps weave together various elements that are needed for the overall success of the project. For instance, the family income of the target clients might not be enough to pay for the house, in which case the first need is to adopt measures to increase the family income. Household production of bamboo articles can be a solution to this problem. If so, transfer of technologies other than housing technology might be needed.

Technology transfer through projects often involves training as a major component. Training is important in the sense that it is the medium for the actual transfer of skills and knowledge. It also helps generate a local pool of skills that, after the completion of the project, could be utilized in future projects. The training could be for the labor or for trainers who will, in turn, train the labor. If the project is not a one-time venture but the first of many, then training a group of people as trainers should be considered. Training may be imparted in the country of origin or destination of the technology.

The next step after training is the building of a prototype house at or near the housing site. As stated earlier, this prototype can serve as the project office as well. The prototype and the process of building it can become a hands-on demonstration. Such demonstrations definitely have more worth than hours of lecture (Fig. 104).

This brings up the topic of the right approach to prototypes. Prototypes should be treated as the perfect means to transmit your message to the clients. Since a prototype constitutes the visible proof of the declared intentions and expected end-result of the project, it is better to build and test the first prototypes away from public gaze. A project can have nothing more self-defeating than a failed prototype. Build a couple of prototypes in the backyard, and leave them there for one year to see the influences of all seasons. Only after the sure success of these should one try to erect a prototype for public demonstration.

A South-North technology transfer is possible in the case of bamboo technologies, provided some concerns are adequately addressed. The first thing to keep in mind is the totally different ratio between the price of the bamboo material and the wages. If wages are low, then a labor-intensive production is economical. In developing countries, this is even a desirable option as it creates jobs. In developed countries, however, the price of the product is determined mostly by the cost of labor; the price of the raw material is often of secondary importance only. There will be no mass production since the market is small. Bamboo requirement will be high in quality and low in quantity, and the labor involved will be minimal. The end product will cost much more than a comparable

Fig. 104: *A demonstration at a prototype house in Dar es Salaam, Tanzania*

product in most developing countries. Hence, a bamboo product in a developed country will materialize only if the client can see the arguments in favor of bamboo: it is functional, attractive and environment-friendly.

Events like seminars and workshops constitute another forum to effect technology transfer. Such events can be organized by inviting select people, identified according to a set of criteria to maximize benefits of technology transfer. Often, it might be possible to piggyback such events on other major events – such as a regional or international trade fair – to save on costs. For example, INBAR and Funbambu organized a "Bamboo Housing Technology Transfer Workshop" in November 1998, immediately after the International Bamboo Congress, for about 20 people from Asian and African countries, selected from among the Congress participants. The criteria set for participant selection aimed at people with maximum potential for technology dissemination, while the timing of the event helped save travel costs.

The most effective – and ideal – tool for transfer of technology would be a worldwide network that links all people interested in bamboo-related information, providing them with a communication channel. This network would allow members to raise questions and get answers fast. These answers could be from a data bank that stores information available in handbooks, technical reports, manuals, etc. The real problem in communication, however, is how to inform users about available information. A wide variety of channels – such as extension workers, NGOs and other grassroots organizations, and donor agencies that fund development activities – may have to be used if such information is to reach the people who need it from across the globe.

A database on subject experts is another information component that a network must possess. Questions that are too difficult or too specific for a data bank to answer can be referred to a subject expert. The Dutch universities had such a system in the 1970s; development work volunteers in developing countries could write to any Dutch university seeking answers to problems they encounter. A distribution system forwarded the letter to the right specialist, who would write back to the volunteer. This system worked very well, although it slowly came to a stop owing to some logistical problems (Janssen 1975).

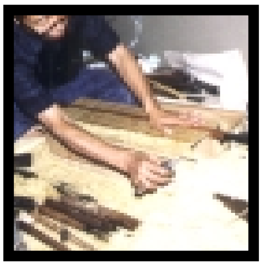
An international network that works along the lines mentioned above is the International Network for Bamboo and Rattan (INBAR). It started in an informal way, as a regional network in 1979, and was established by treaty as an international organization in 1997 with headquarters in Beijing, China.

INBAR's mission is to "improve the well being of producers and users of bamboo and rattan within the context of a sustainable resource base by consolidating, coordinating, and supporting strategic as well as adaptive research and development." It places great emphasis on global networking and transfer of technology, and has been using many of its well-made publications as a technology transfer tool. At the time of writing this, INBAR is also readying specific Transfer of Technology Models (TOTEMs) for easy dissemination.

The Web is, of course, a marvellous tool to disseminate information. In the case of bamboo, however, it is not a medium of choice since most people who work with bamboo live in rural areas in developing countries, far away from computers and web pages. A survey conducted by INBAR during an international bamboo workshop and congress in Bali, Indonesia, revealed that even the majority among scientists prefers the printed word to the electronic one. In preparing to write this chapter, I counted the number of publications registered in my literature retrieval system. From a mere 2 in 1900, it grew to 428 in 1990. It appears that printed publications will continue to be the vehicle for transfer of knowledge for some time to come.

Chapter Eleven

Job Creation



Bamboo has a tremendous potential to create jobs at the village level as well at the industrial level in countries where bamboo is indigenous. In many ways – socially, economically and environmentally – bamboo appears an ideal material on which a labor-intensive development plan can be based.

Job creation with bamboo should follow the lines of a social contract between the environment and the local population, including a symbiotic linkage of these two parties with the process itself. The harvest of bamboo from the environment (be it from a natural stand or plantation) should be in equilibrium with the capacity of bamboo for regeneration. Coming to the production itself, the design should be such that it cuts across the socio-economic strata. For instance, the initial processing could be at the level of the rural families so that it offers an opportunity to them to earn steady, additional income. The final processing could be at the industry level, involving semi-urban or urban labor. This may require redesign of the industrial processes involved, but the outcome will be worth the exercise.

A major obstacle with job creation using bamboo is the prevailing impression of bamboo craft as being an outdated and socio-economically non-rewarding occupation. Over the years, bamboo craft has come to be identified with people who are at the lowest rungs of the social and economic ladders. The material itself has been negatively associated with tradition, and is widely viewed as irrelevant to modern life. The prevailing conditions are such that even bamboo craft workers, especially those in villages, do not see a future for their children in this profession.

Traditionally, the handicraft sector has been an enormous source of employment, skills and know-how (Ranjan 1996). Earlier, there were local mechanisms that could support the sector. Extensive economic changes that have swept across the globe, however, have necessitated the exploration of markets beyond the local ones for sustenance. As protective trade regimes are being dismantled, bamboo products too will have to compete at the global marketplace through organized quality production and creative marketing. There are several impediments to this: the low level of education of the workers, lack of capital, lack of knowledge about the market, lack of appropriate technology, etc. On the positive side, consumers are increasingly becoming environment-conscious and are asking for “green” materials and designs that take into account the total life cycle of the product, including its long-term environmental impact.

Larasati (1999) has done a detailed study on these aspects, focusing on the situation of the craft industry in Indonesia. She observes that changes are required in supply, production and distribution methods, and in the design of products and the material use of bamboo. She sees “hybrid” technology – a combination of traditional processes with elements of advanced treatments, non-traditional processes and the input of designers – as the key solution. Hybrid technology allows the creation of an improved and functional product that will meet the needs of users, at the same time providing for local employment and economic development. The author concurs with this view: what is required is a marriage between modern knowledge and modern design on the one hand, and old tradition and local skills on the other.

Bamboo Craft

Bamboo is an important part in the daily life of the rural and tribal population in bamboo-growing countries. It is available in the nearby forest or in one’s own backyard, and is a handy material for craft items and other articles. It is used to build shelter, and make a wide variety of daily use objects (baskets, grain storage bins, cradles, winnowers, raincoats) and tools (for agriculture, fishing, hunting). Bamboo features in many stories, songs and proverbs. Bamboo craft is often a buffer to tide over difficult days, and an avenue for extra cash income (Nagi 1996; Ramirez 1996).

Centuries of tradition have given the craft workers incredible professional skills. With just a knife for a tool, they create magic from bamboo. In Fig. 105 a craft worker is creating a profile in a series of bamboo strips for fans. In Fig. 106, an artisan is making bamboo strips 1 mm thick, 1.5 mm wide and 4 000 mm long for weaving fine baskets.

Rao and Saxena (1996) conducted a study in Himalayan villages to assess the use of bamboo. They counted the number of families using bamboo products: mats and baskets, 88% to 96%; and musical instruments, 20%. In two villages, they found the profit from bamboo craft industry to be 17-18%. The net annual profit from bamboo to the

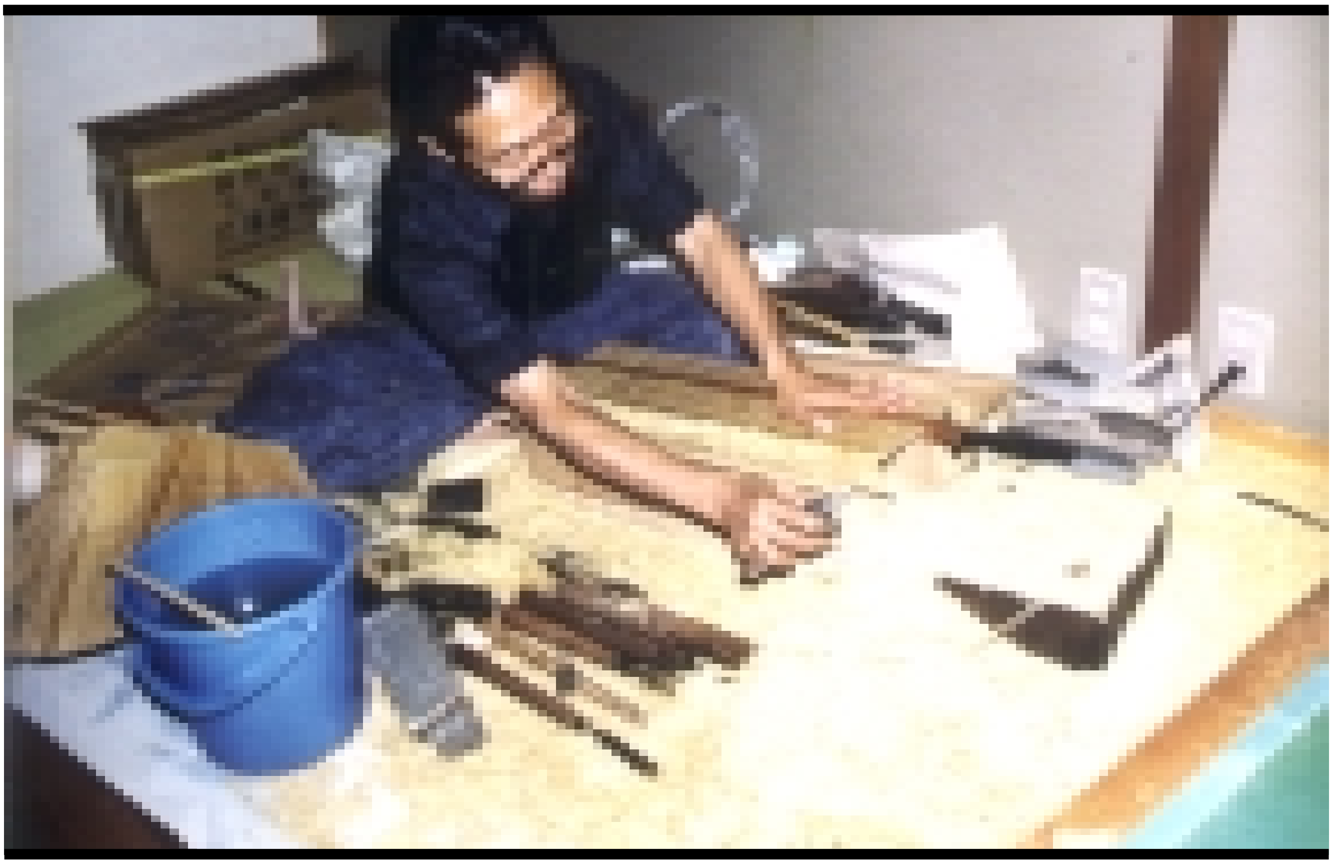


Fig. 105: *A craft worker in Japan*

Fig. 106: *A basket weaver in Burundi*

village community was between US$ 8-15 per hectare, with the bamboo coming from forest.

The harvest of bamboo is within the power of the village community. Bamboo craftwork is a cottage industry. As an occupation, it is not economically attractive: the artisan just covers the cost of his labor if the article is sold in the village market; however, if the product is sold in the urban market, it fetches a good profit.

Bamboo and Sustainable Development

Sustainable development means improving human welfare without degrading environment (Belcher 1995). It is becoming increasingly difficult to fulfil the needs of the people and, at the same time, ensure the sustainable use of natural forests. Stiles (1994) describes the problems to be expected if sustainable harvest of forest products were to become a business. Protection of legal rights and of tribal land warrants close attention, as examples of abuse are already on record. Groups of indigenous people are increasingly emphasizing their tradition in sustainable forest management, and their knowledge of the locations and life cycles of forest products. This is something that no authority can deny. However, it is essential to effectively organize the forest-dependent communities and draw up formal agreements to ensure sustainable use and protection of forest resources.

Nagi (1996) cautions against trying to force tribes into a 9-to-5 routine and 365-days work schedule. The real goal of sustainable development plans must be to inculcate self-reliance – using local resources and local skills to satisfy local needs. In this context, bamboo is an ideal starting point. For it is a locally available material that has a strong craft tradition and ready local markets. The initial stages of most production processes can be home-based and the consumer is right in the neighborhood. Bamboo craft is often not practiced as a full-day activity; it is done in balance with other activities like agriculture and livestock husbandry. This theme is further elaborated by Ranjan (1996) in a paper presented at the Bali International Bamboo Workshop.

Bamboo and Employment

For an industry to be significant in terms of job creation, its constituent units should either be large-scale operations that require a large number of staff or be numerous enough to absorb a large number of workers. In all bamboo-growing countries, the general situation is the latter. Large-scale production operations are relatively few, and definitely not enough to make any impact on the employment situation. Nevertheless, bamboo has the potential to support large-scale operations, such as paper mills or board factories. The main constraint here is the lack of sustainable and adequate raw material supply. There have been cases where factories established with much expectations having to cut back on production because of the paucity of quality raw material. Liese (2000) reports that some wood mills in Asia, which had changed their product from timber parquet to bamboo parquet, had to close down because of the low quality of culms available and increased culm prices. There have also been reports that even the traditional craft sectors, which provide employment to a large number of people, in some regions are failing to obtain adequate bamboo supplies. This, however, is a problem that can be addressed largely through judicious and sustainable management practices. The point that should be taken note of is that bamboo has the capacity to provide employment and income to a fairly large number of people.

One attractive facet of employment in bamboo-based enterprises is that it is especially suited for women. In most bamboo-growing countries, the household chores are the burden of women. In such a condition, it is essential that any other avenue of employment they seek should be nearer home and allow flexible working hours. Primary processing of bamboo fulfill both these conditions. Rivera and Lapis (1995) have done a study on various aspects associated with the employment of women in bamboo and rattan sectors. The involvement of women in the bamboo industry is often overlooked, despite the fact that their participation can be observed from the nursery and plantation through processing and utilization to marketing and sales. Documentation on these activities is poor, and available statistics tend to highlight male participation. Close observation, however, shows that women play an important role, though more on a contract basis than on a job basis. We will examine the state of employment in the bamboo sector in two major bamboo-producing countries: India and the China.

Projects in India (Adkoli 1996) have revealed how to increase “the productivity from existing bamboo forests by simple and regular silvicultural practices, such as water conservation, soil working and maintenance of health and hygiene of clumps.” Including the process of thinning existing clumps, this silvicultural regime provides about 10 to 25 unskilled workdays per hectare. These efforts result in a twofold output of bamboo and better quality of culms. This is a good example of the “social contract” that we earlier discussed.

Harvesting creates much employment: 8 to 10 workdays are needed to harvest one ton of bamboo. In India, this job is done by the members of the lowest income groups. About six million tons of bamboo are harvested commercially in India each year, generating about 48-60 million workdays. Post-harvest work – loading and unloading, stacking and handling – needs two workdays per ton, translating into another twelve million workdays. That is, a total of 60-72 million workdays per year even before primary processing!

Weaving, mostly to make baskets and trays, is an activity that is traditionally familiar to most people in rural areas. If one takes an average of 120 bamboos per ton, 40 workdays are needed for processing one ton of bamboo. It is estimated that three million tons of bamboo are being used annually for this weaving; that is, weaving alone generates 120 million workdays in employment in India.

Rao (1996) reports that one ton of bamboo in the craft sector can generate an average of 150 workdays. This means that two tons of bamboo are enough to employ one person for one year. This is a very positive factor for a village cooperative because one hectare of bamboo plantation can easily yield 20 tons per year, thus providing jobs for 10 people in the community.

As a specific case, let us examine the Kerala State Bamboo Corporation Limited (Paulose 1995). This Corporation has helped thousands of poor workers by providing them with bamboo from the state-owned forests and buying the mats they weave with this bamboo. There are about 17 000 families of mat weavers, 2 500 reed cutters and 1 000 other workers involved in this operation. In addition, the Corporation also supplies bamboo to thousands of workers for handicraft and other purposes. Each year, about 30 000 tons of bamboo (21 million culms) are utilized through these channels. The reeds are harvested, observing all silvicultural principles. The woven mats are sold as such, or converted into bamboo-ply (similar to plybamboo). The Corporation pays the workers a fair income and makes a profit.

An analysis of the bamboo production-to-consumption system in Kerala State (Mathew 1998), published by INBAR, describes in detail the history, the process, and the strengths and weaknesses of the Corporation. Some of the weaknesses that the report cites are:

- Families earn less from bamboo processing in a day than from farm work (Rs. 40 for bamboo work, Rs. 75 for farm work).
- Only 23% of the workers felt that bamboo work helped improve their living standard.
- Forest laws generally overlook the interests of people who are dependent on the forest for their livelihood.
- Rules, which are meant to protect the forest, are sometimes used to protect the interests of industrial users.
- Local users have to do selective felling, but clear-cutting by industrial users is not checked, thereby harming the sustainability of bamboo resources.

The report also highlights the low profit margins and the skewed distribution of income, citing as an example the prices for a woven mat of 1.20 m x 2.4 m:

- The shopkeeper (retailer) receives Rs. 60 from the consumer;
- The wholesaler gets Rs. 45, of which Rs. 5 goes for transport;
- The itinerant dealer receives Rs. 30; and
- The weaver, who creates the mat, receives only Rs. 25, of which Rs. 13 goes towards the cost of the reed used for weaving the mat.

As can be seen, the weaver who creates the product and thus does the most value addition gets a low margin! If this is the condition in Kerala, which has the highest literacy rate (over 90%) in the country and a high socio-political consciousness, one can imagine the plight of bamboo workers in other Indian states that lag behind in these aspects. To a large extent, these drawbacks can be addressed if a cooperative handles all the stages from production to sales. Such a move will remedy, in most cases, situations wherein bamboo contractors control the workers and or the flow of raw material.

Bamboo mats are now being used in the production of bamboo mat board, which is seen as an alternative to plywood. Looking beyond the employment and the associated socio-economic benefits this provides, one can also see substantial environmental benefits. To quote Ganapathy et al. (1999), “it is tentatively reckoned that if bamboo mat boards replace plywood to an extent on one-fourth the present production in India, 400 000 m^3 of round wood from natural forests will be saved, thereby preventing disturbance to 30 000 ha of forests per year.”

Another interesting example of job creation with bamboo is provided by Anji County in China. Ruiz-Perez et al. (1996) report the following data. China has 7 million hectares of bamboo, of which 3.2 million ha are natural stands and 3.8 ha are plantations. In Anji, bamboo is present in an area of about 60 000 ha, which is 43% of the total area of the region (1 325 km^2). Considering the dense population of 337 people per km^2, this is remarkable. In 1994, 435 factories with 6 590 employees were producing bamboo mats and flooring for a combined output worth US$ 27 million. The shoot industry employed 2 900 and gave another US$ 15 million in output, while the handicraft and furniture sectors had 800 workers and a turnover of US$ 7.2 million.

Zhong Maogong (1998) et al. have described the whole process, from production to consumption, of the bamboo sector in Anji. An average household earns 27% from bamboo. An interesting aspect is the ratio between male and female workers: 60% is female. Their wages are, however, only 80% the wages for male, attributed to the difference in the nature of the work: men are mostly at the managerial level, while women are primarily workers. The profit margin is about 20% for mats and boards: so bamboo is a good option in Anji.

Chapter Twelve

Costs

and benefits

We had earlier mentioned, in Chapter 1, about a project that profited from using bamboo for erosion control along a riverbank. The project had made a total investment of US$ 4 million for the safety of the villages, and started realizing an annual income of US$ 73 000 from bamboo culms after some years (Singh 1995); a return of 1.8% from an essential safety measure! Of course, the returns in terms of lives and livelihoods saved will be incalculable. Two other cases, giving data on profits from homesteads in Bangladesh (SDC 1991) and plantations in Thailand (Dhanarajan et al. 1989), were quoted in Chapter 2.

Ruiz-Perez et al. (1998) have done a thorough research on the income-generation aspects of bamboo in Anji County, China. According to a comparison they made on the income from bamboo for different income classes, bamboo contributes about 20% for lower and higher income groups, and up to 30% for middle-income class. The income is generated by activities in bamboo, as well as non-bamboo farm and off-farm work. All these three income components increase from the lowest to the highest income group. The increase is the lowest for the agricultural (or non-bamboo farm) activities: the ratio between the highest and the lowest income is 1.59. This ratio is 2.37 for income from bamboo and 5.88 for off-farm income. The inference is that agricultural income is the basic family income. Most of it is for self-consumption and the contribution to the cash economy is relatively small. Bamboo offers the main farm-based income, while the best income opportunity is in off-farm activities. From the data collected, one could conclude that bamboo is most important for the middle-income group. This information is important because generally bamboo is considered as a source of income only for the poor. The authors also checked the influence of bamboo on income growth and found it to be considerable in the low to middle class categories. Mathew (1998) reported a similar trend among bamboo worker families in Kerala, India. Both men and women earn income in more or less three equal parts from bamboo work, non-bamboo work and other services.

Bamboo Plantation

Bamboo species can be given a qualitative ranking according to their potential for different uses, such as:

- Commercialization – high, medium or low;
- Industries (rural) – high or medium; and
- Environmental rehabilitation – high, medium or low.

Such classification and ranking help focus on easy selection of the appropriate species and their optimum management. Rao and Ramanatha Rao (1995) give data on the appropriateness of several bamboo species for each of the above-mentioned application areas. Once the species appropriate are selected, one can consider aspects such as whether they grow wild or domesticated, in which climate (humid tropics, dry tropics, etc.) and on which soil (rich, medium, poor). INBAR is currently carrying out a study on site-species matching of several commercially and environmentally important bamboo species. The results of this study are expected to facilitate species selection for commercial and non-commercial applications.

The economic aspects of a plantation need a close study. Abd. Razak et al. (1995) give a clear description how to carry out the financial analysis of a plantation. A short summary of the method, mixed with the author's personal views, is as follows.

Cost calculations cover the entire plantation management process, starting with site preparation (including planting) through silvicultural treatments to harvesting.

Before site preparation and planting are attempted, one has to obtain data on aspects such as the cost of planting material (plantlets), the distance to be maintained between plantlets when planting, the number of days required to plant them, the survival rate of the young plants, and the costs of replanting. The quantity of fertilizer needed each year, the price of fertilizer and the labor costs need to be ascertained. One should not forget the costs of road construction, boundaries, etc. and factor in transportation and communication facilities. One key point to remember is that the goal is to run a plantation, and all other items are useful only in as far as they improve the plantation and its yield.

Silvicultural treatments include weeding and cleaning, normally only during the first three years because by that time the culm would have grown higher than the weeds. Pesticide application may be required within the first three years.

Harvesting involves the collection of shoots and/or culms. Estimate the yield, and calculate the labor that would be required and the associated expenditure. Both over-harvest and under-harvest are to be avoided: the former will deplete the plantation, while the latter will suffocate it. The equilibrium between the growing capacity of the bamboo plants and the quantity harvested needs to be maintained for sustainable management.

Fertilizers may be used to maintain the soil quality by replenishing the nutrients that the growing culms take away from the soil. Fertilizer could also be used to increase the yield, provided it would translate into corresponding increase in turnover (and hence, profit). This may sound a straightforward thing but requires careful assessment, as it is so easy to get misled by wishful thinking. MacCormac (1987) gives some theory and examples of the calculations involved in fertilizer application. It must also be remembered that fertilizer is only one of the several components in a good management regime; a good site and proper and timely silvicultural practices may do more good than most fertilizers! Data on plantation management regimes can be obtained from literature. These may be applied in setting up trial plots, which will give more accurate site and species-specific data. Those interested in these aspects may read Aoki's (1987) comparative studies in Japan.

There are some points to remember, particularly if a donor is expected to finance the project. There should be a clear idea as to the time gap between planting and the first harvest of shoots and/or culms, as a donor would like to know from when to expect some return on the investment. It is also important to quantify the expected harvest, which will gradually increase over the years. Estimate how much of the produce can be marketed and how much is for local consumption (remember, the main aim of the plantation is to provide raw material for a building project). It may take a few years for the plantation to start showing clear profits (depending on the local situation this will take 5-7 years), but this should be clearly mentioned in the project document along with a scheme for repayment of investment (if applicable). It would be a good idea to include sensitivity analyses for market prices (what happens if prices go up or down by 2% or 5%?), maintenance costs (what if the cost of one or more item of maintenance goes up?), number of culms harvested (what if the harvestable culms fall?), etc. Abd. Razak et al. (1995) have provided examples of profit calculation methods.

One of the most attractive aspects for an investor would be that bamboo, unlike timber, lends itself to continued harvesting. When one harvests timber, the plant is killed, forcing one to start again from the beginning. Since bamboo harvest is selective (only thinning), the plant will live its full life cycle, guaranteeing income each year for a number of years.

Bamboo Enterprise

For assessing the viability of a bamboo enterprise, one has to adopt the normal procedures of a feasibility study, taking into account the ratio between the costs of raw material and wages in the proposed project area. When compared with timber, most processing machinery for bamboo has some definite advantages: they are light, need only a small floor area and use only a small quantity of energy. For example, a bamboo splitting machine (Fig. 107) is a small machine powered by a motor of about 0.25 hp. Compare this with the huge sawing machines one sees in a timber factory!

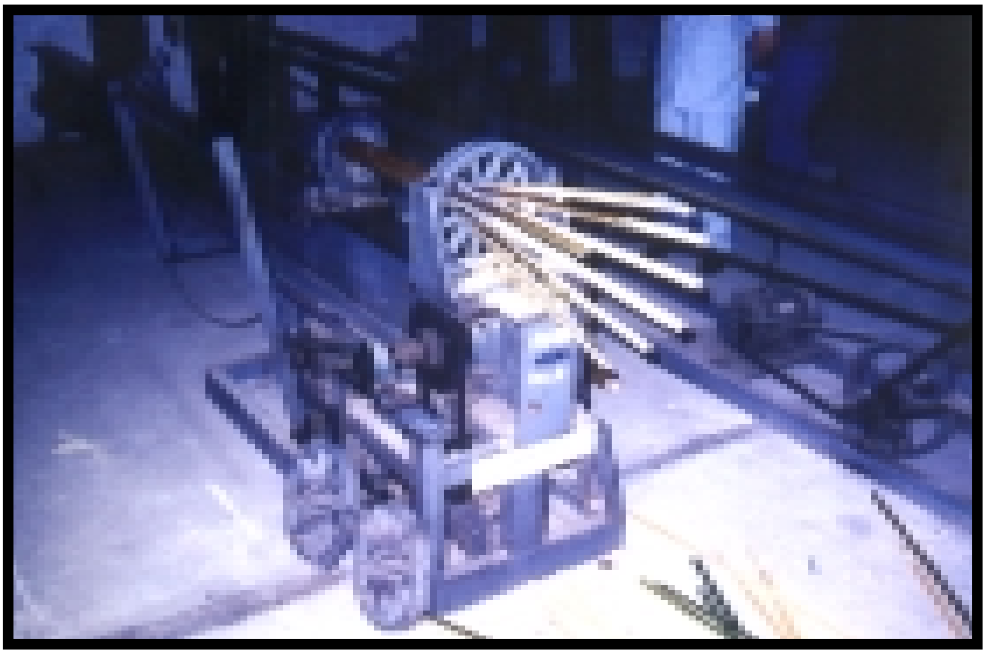


Fig. 107: *Bamboo splitting machine*

There are two factors that need to be made the overriding concerns in an enterprise: proper management and productivity. A student of the author once made a feasibility study of a small bamboo furniture enterprise that employed just four laborers. He found that the productivity of the staff to be as low as 60% as against a minimum 80% required in such an industry. The study revealed that this was due to the layout of the factory: people spend most of their time in moving things from one place to another. A smooth production line was absent. Another observation was the high overhead: five staff members spent part of their time to manage the four laborers, causing an overhead of 60% on the direct labor costs. Shen (1992) gives a good analysis of failures that have been made in the practice of bamboo enterprises in China. Some of the causes for failures are:

- If sales increases, a shortage of raw material supply might occur, resulting in over-harvesting;
- It might also force enterprises to seek bamboo from far away sources at high transport costs;
- Often, errors occur in cost calculations, and sensitivity analyses are not made;
- Use of untested technology; (first do a try out on small scale); and
- Clients prefer traditional products.

Harper (1992) has studied the workings of a plybamboo factory in Orissa, India. Plybamboo is made by pressing together two or more woven bamboo mats, which are coated with an adhesive. Making woven bamboo mats is a profitable activity for people in a village area, particularly for women. The market has been shrinking because the product is meant only for low-income families. These mats, however, are a good starting for making sheets, for walls and similar building parts. The plybamboo factory employs 15 people, and can process 300 sheets of 1.8 x 1.2 m in an eight-hour shift. The break-even point is at 2 100 sheets per month, which equals the output of seven days. The weavers bring the mats to the factory and the buyers buy the sheets from the factory. At the time the study was made, the factory was in operation for two years. The capital investment was US$ 70 000 for the building and equipment, 80% of which was for the press. The factory produces 300 sheets per day, 25 days per month.

A summary of the production costs and profit is as follows:

The price paid (per mat)	: US$ 0.90
Cost of resin (per mat)	: US$ 0.60
Cost of wages, coal, electricity, office, depreciation, interest, etc. (per mat)	: US$ 0.34
Total production cost (per mat)	: US$ 1.84
Selling price (per single-ply sheet)	: US$ 2.70

Multi-layer sheets are sold at multiples of this price. The total production cost per month is US$ 13 770 and the sales turnover is US$ 20 250 – a monthly profit of US$ 6 480. Although this is only an example and the figures will vary with the location of production, the prospects of similar ventures are promising. An important aspect of this type of operation is that it provides women the opportunity to earn cash income and thus enter the socio-economic milieu of the society. In the example cited the net income of a woman per day, if she weaves two mats, is a better-than-average US$ 1 (in 1992).

In a developed country, an entrepreneur has to look for bamboo products, which can enter the market on strength of their being "green" and their exotic look, and can be produced profitably given the local ratio between the (high) wages and the (low) cost of the material.

In conclusion, the key aspects for all initiatives with bamboo remain the same: calculate the production cost of the item planned; find out the price at which it can be sold; and check whether the difference is enough to make a decent profit. This sounds deceptively simple, but practice and experience have often shown it to be difficult to realize.

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notes

INBAR

INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

The International Network for Bamboo and Rattan (INBAR) is an intergovernmental organization established in 1997 by Treaty. As of January 2000, 21 countries (Bangladesh, Benin, Bolivia, Canada, Chile, China, Colombia, Cuba, Ecuador, Ghana, India, Indonesia, Malaysia, Myanmar, Nepal, Peru, The Philippines, Sri Lanka, Tanzania, Togo and Vietnam) have signed the Establishment Agreement. INBAR's mission is to improve the well being of producers and users of bamboo and rattan within the context of a sustainable resource base by consolidating, coordinating and supporting strategic as well as adaptive research and development. INBAR programs link partners from the government, non-government, academic and corporate sectors with knowledge and technologies that directly improve the well being of people in developing and developed countries.

INBAR publishes an ongoing series of Working Papers, Proceedings and Technical Reports, occasional monographs, reference materials and the INBAR Newsmagazine. It also provides an on-line library featuring relational databases on bamboo and rattan products, organizations, projects, experts and scientific information.

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