INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

Proceedings of Bamboo housing workshop

March 31 to April 4, 2003
WITC, Kumasi Ghana

Organised by

International Network for Bamboo and Rattan (INBAR) &
Bamboo and Rattan Development Program (BARADEP)

Supported by

British High Commission, Accra
Bamboo and Rattan Network (BARNET)
Ministry of Works and Housing
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1. Introduction

Bamboo has a long history as a building material in many parts of the world. It is light, strong and easy to grow. In spite of these advantages, it is widely perceived as a temporary, poor man's material. However, with careful specification and design, safe, secure and durable bamboo shelter is achievable at a price that is within reach of even the poorest communities in developing countries.

Even when issues of durability and strength are resolved, the question of acceptability remains. A bamboo building need not look 'low-cost' – imaginative design and the use of other locally available materials within the cultural context can make the building desirable rather than just acceptable. For example, in Central America, a region with a long tradition of bamboo construction, bamboo buildings of every description can be found – ranging in price from a few hundred dollars to a few million.

In Ghana, the shortage of affordable housing is one of the acute social problems associated with the country's economic condition. The housing backlog is already 420,000 units, and increasing annually by 120,000 units. Here, bamboo assumes special significance by offering an environment-friendly alternative to declining timber supplies, high embodied energy materials, oil-based plastics and expensive imports.

In rural areas, shortages extend to basic public infrastructure. Only 76% of children obtain primary school education, decreasing to 37% at secondary school level. Many children in rural villages are deprived of primary education simply due to lack of school facilities in the village or immediate neighbourhood. Such circumstances demand cost-effective, quick and sustainable solutions. Bamboo construction offers significant potential, with simple technology able to provide permanent solutions to building shortages nationwide.

School children – hope for the future

INBAR[1], through its housing extension activities, has sought to increase awareness of these possibilities in Ghana. Working closely with TRADA[2], a plan for south-to-south transfer of bamboo building technology was drawn up with the support of the British High Commission in Ghana. The first phase of the transfer has seen two main activities: 1) a bamboo housing workshop and 2) the construction of a demonstration bamboo school.

The workshop, organised by INBAR and BARADEP[3], ran from 31 March to 4 April at WITC[4], Kumasi. The technical assistance for the workshop was provided by BARNET[5], BRRI[6], Ministry of Works and Housing and TRADA. The British High Commission Accra

[1] International Network for Bamboo and Rattan
[2] Timber Research and Development Association, UK
[3] Bamboo and Rattan Development Programme, Ministry of Lands and Forestry
[4] Wood Industries Training Centre
[5] Bamboo and Rattan Network (an NGO)
[6] Building and Road Research Institute, based in Kumasi

provided financial support for the programme. Names and addresses of organisations and individuals involved in the workshop are given in Appendix 1.

2. Objectives of the workshop

The main objectives of the workshop were to raise awareness about bamboo as a sustainable building material, and to achieve a south-to-south transfer of bamboo building technology (developed as part of a UK DFID funded TRADA project in India) Specifically the objectives were:

1. To provide a general overview of bamboo as a resource, and bamboo in construction
2. To disseminate information on bamboo building systems among Ghana's engineers, architects, builders and development practitioners
3. To focus on practical aspects of bamboo construction by sharing the experiences of the Kumasi school building.
4. To provide an opportunity to the participants to interact and share their knowledge and experiences on the use of bamboo in construction.

3. Participants

The main target groups of the workshop were engineers, architects, builders and other professionals. The workshop attracted 30 participants from 17 institutions, including governmental organisations, NGOs, independent consultants, research institutes, universities, building companies and bamboo factories. On the final day ("press" day), a further 25 individuals attended, mainly from the media and national development programmes (a full list of participants is given in appendix 1).

Workshop Participants

4. Workshop programme

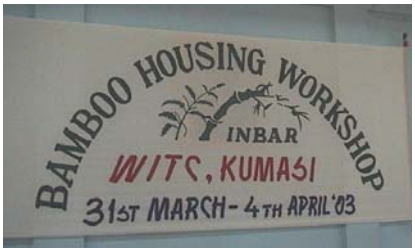
The 5 day workshop comprised a mix of theory and practical sessions, with the emphasis very much on group interaction and discussions. A detailed workshop programme (appendix 2) was prepared and distributed to the participants. A summary of daily activities and presentations is given in the following sections:

4.1 Day one

The focus of day one was on introductions – people to people and people to bamboo. The sessions included an opening ceremony, introduction to the workshop, assessment of expectations and a general introduction to bamboo development and housing worldwide.

Opening ceremony
The opening ceremony was chaired by the Chief Regional Manager of the Regional Forestry Commission (Kumasi), Mr. Atta Owusu. The Guest of Honour of the session was Chief District Executive of Ejisu Juaben District, Mr Y A Afrifa. The Guest of Honour

officially inaugurated the workshop by watering a potted bamboo seedling. BARNET Chairman, Mr David Coleman, welcomed the participants. This was followed by a short address by Mr Lionel Jayanetti, TRADA UK, who outlined the mission of TRADA and its bamboo work in general. The guest of honour then made his remarks, which are reproduced below. The session chairman concluded the session with his final remarks on the importance of bamboo in Ghana. The severe problem of deforestation in Ghana was highlighted. Over the last 50 years, the forest area has declined from 8 million hectares to 1.2 million hectares. If the trend continues, the country will soon face an acute shortage of forest products. Bamboo could offer an alternative or useful supplement to many wood products that are currently being used.



Speech by Guest of Honour

Mr. Chairman, workshop organisers, invited guests and ladies and gentlemen. I have the pleasure to be with you as guest of honour for this important workshop on bamboo housing. I have no doubt in my mind that this workshop has come at an opportune time when the government is in the process of finding an affordable housing programme for the population.

Distinguished ladies and gentlemen, there is no doubt that the world's population is fast growing with special reference to the so called third world. It was around 6 billion in 1999 and it is expected to reach 7 billion by the year 2010 and the overwhelming number would be in the developing countries of which Ghana is a part. It is worthy to note the access to safe and healthy shelter is essential to a person's social and economic well being and is a fundamental part of livelihood. Indeed a house is the first in acquiring a solid, long lasting and decent home.

It is in the light of this that efforts by some estate developers to put into the system more housing should be commended. However, it is important to note that these houses can not meet the pocket of even middle income group let alone the ordinary people in the system. The prices of the buildings being quoted are far above the means of majority of Ghanaians hence the patronage of these houses by expatriates and Ghanaians who have had chance to stay outside. This state of affairs makes mockery of the policy of providing affordable houses to the people.

Mr. Chairman, distinguished ladies and gentlemen, one basic reason for the high cost of these houses is the use of certain material in building. A typical example is the use of cement blocks as against bricks. The present cost of cement is such that if used in constructing houses would definitely lead to high costs. I therefore think that we should begin to find alternative means of constructing houses.

It sounds very paradoxical that Ghanaians should prefer the use cement blocks when even in the advance countries burnt bricks are used in the construction industry. Ghana abounds in the large deposits of clay which could be used in manufacturing bricks for the construction more affordable houses for the ever increasing population.

Distinguished ladies and gentlemen, it is against the background that this workshop is most welcome, since bamboo abounds in commercial quantities in our forest areas. Bamboo also has several other uses. I am told that in China they have been able to construct bridges using bamboo.

It is my fervent to hope that this workshop would offer the technical know how and encouragement to enable the bamboo housing takes off in the country. I also hope that the cost of such houses would be affordable to even the ordinary man in the street. It is only when this is achieved that this workshop is meaningful.

Expectations of the participants

While the main objectives of the workshop were communicated to the participants with the invitation letter, it was important to canvass their views, assuming they might have other expectations which could be achieved during the 5 day programme. Each participant was asked to voice their main expectation of the workshop, and the results of this exercise are summarised below:

Expectations of the participants

Bamboo housing
- Different uses as a building material; construction details
- Simple construction methods in bamboo
- Cost and practicality
- How to use bamboo and rattan for practical low cost housing in Ghana
- How to use bamboo for affordable housing
- How competitive is bamboo housing in respect to cost
- Various designs in bamboo housing

Bamboo processing
- Bamboo drying
- Bamboo processing and problems involved
- Bamboo processing in relation to construction
- Technical details

Bamboo in general
- Everything there is to know about bamboo
- Technology transfer
- Bamboo finishing
- Know the builders work in relation to bamboo and develop through to a higher level education

Introduction to INBAR, BARNET and BARADEP

Mr Andrew Benton described the international role of INBAR and its recent work in Ghana. BARNET, an NGO active in bamboo promotion, was introduced by Mr Dan Ofori, Director of Operations. Mrs Gifty Allotey, Administrator of BARADEP – an initiative under the Ministry of Lands and Forestry – explained the government stance on bamboo development.

Bamboo in construction: general overview

A presentation of the status of bamboo in construction worldwide was made by Mr Lionel Jayanetti (Head of TRADA International). The presentation illustrated the many uses of bamboo, from simple scaffolding to complex bridges, with particular reference to building and housing. Using Central America as a case study, the wide range of achievable building types was shown – from the basic houses of Hogar de Cristo in Ecuador to the palatial designs of Simon Velez in Colombia.

Technical session in progress

4.2 Day two

The second day dealt with bamboo as a material, and constraints associated with its applicability as a construction material – in particular its lack of natural durability. Mr Dan Ofori presented and facilitated the first session. A summary of Mr Ofori's presentation is given below:

ABC of bamboo

A. The bamboo plant

Bamboo is a hollow woody plant, which belongs to the grass family. Bamboos span a wide spectrum of size, shape and color. There are tow main types of bamboo**:**

Monopodial: This is a sub-tropical bamboo. It grows from underground stems called **rhizomes**. The tip of the rhizome grows horizontally in the ground and the lateral bud from each node grows into a stem called a **culm**. As the rhizome runs along the ground, the culms spread over a wide area.

Sympodial: This is the tropical bamboo. The bamboo shoot emerges from the tip of the rhizome and grows upwards to form the culm. The culms grow close to each other to form **clusters** or **clumps.**

B. Some features of bamboo

Fast growth: It is the fastest growing plant on earth. Culms reach their maximum height within 45-75 days of emergence. One Japanese species grows about 1.2m per day.

High biomass: One of the top producers of biomass (plant tissue) known. Up to 88 tons of culms are produced per hectare per year under plantation conditions (depending on species and management).

Highly renewable: Many new shoots emerge each rainy season. When culms are harvested sustainably, the plantation will produce tons of bamboo culms each year indefinitely.

The high biomass and renewability are very significant. It means bamboo if properly managed can provide inexhaustible woody material for the building industry.

C. Environmental importance

Rooting system: The profuse rooting system binds the soil more than any plant and effectively checks soil erosion on hillsides and river banks, helping to prevent landslides and silting of water bodies.

Dense foliage: This has multiple effects. It provides shade, preventing evaporation from soil and water bodies. The foliage breaks the fall of tropical rain preventing compacting of soil. Finally, about 17 tons of fresh leaves are shed per hectare per year. This decomposes relatively rapidly and builds the topsoil and also mulches the soil, preventing erosion.

Carbon sequestration: Bamboo plantations are 'manufacturing' plants which can fix about 17 tons of carbon dioxide from the atmosphere into plant tissue per hectare per year. This helps reduce global warming caused by the greenhouse effect.

Food: Many bamboo shoots are edible. They are very nutritious and tasty. The fresh shoots contain vitamins, minerals, as many as 18 free amino acids and almost no fatty acids.

D. The structure of bamboo

The epidermal layer is made up of small, dense and compact cells. This layer contains a high concentration of silica. Beneath the epidermal layer, the culm is composed of cellulose fibres, parenchyma and vessels. The cellulose fibres, which act as reinforcement, are concentrated near the outside and reduce towards the inside. Parenchyma cells fill the space between the fibres and vessels. Bamboo has no ray cells. Ray cells are present in wood and act as transport and storage cells for water and food materials.

E. Mechanical properties

Density: On average the density of bamboo is greater than timber. For most bamboos, density is 700-800kg/m^3. The density is dependent on the species, the position in the culm and other environmental factors. There is a direct relationship between density and strength. The higher the density, the higher the strength.

Bending properties: Bamboo has a relatively high modulus of elasticity (in absolute terms higher than mild steel, wood and concrete). When subjected to excessive bending, bamboo splits axially along its length due to failure of the lignin bonding the fibers together, and the bamboo loses its circular form. The fibers remain intact though. Upon release of the load, the bamboo largely regains its original shape.

Compression properties: Bamboo has a relatively high axial compression strength, but this is often offset by a lack of straightness resulting in buckling long before the crushing load is reached.

Tension properties: Bamboo has high tensile strength. However, this is difficult to mobilise due to the difficulty in achieving good joints to transfer the load.

F. Bamboos in Ghana

There are currently seven species of bamboo growing in Ghana:

1. *Bambusa arundinacea*
2. *Bambusa bambos*
3. *Bambusa multiplex*
4. *Bambusa pervariabilis*
5. *Bambusa vulgaris*
6. *Bambusa vulgaris var. vitata*
7. *Dendrocalamus strictus*

Only *B. vulgaris* is indigenous to Ghana; the others were introduced from Asia.

G. Management of natural bamboo stands

1. Young stand

- Remove weeds within 2m radius of stand and loosen soil for easy emergence of new shoots
- Fertilise preferably with (organic) compost or manure twice a year just before the rainy season
- Protect young plants against grazing animals and rodents
- Do not thin out until the 4th year. Remove only small shoots leaving bigger ones to grow into culms.
- Thin out during dry season following the horse shoe method

2. Old (mature) stand

- Thin out by removing culms which are 4 years old and above. Do not remove more than 25% of culms at one time.
- Thin out once, twice or even three times a year until the required number of culms per stand is obtained:
- For shoot oriented stand leave 3-4 culms per stand
- For culm oriented stand leave 30-35 culms per stand
- Leave 1-2 year olds and partially remove 3 year olds if necessary. Totally remove 4 year olds and older (not exceeding 25% culm limit at a time)
- Always remove old culms in the dry season (to avoid damaging young shoots)
- Dig a trench or intermittent slots around clump, about 2m from the outer rhizome ring for large species or 1m out for small species. This severs roots to the depth of the trench, but by filling the trench with mulch and fertiliser, new roots soon generate and grow into the trench

3. Pruning or thinning out

- For most large species, maintenance requires only removal of dead and dying culms. However, it is necessary to remove new shoots if the clump is becoming too crowded (pruning or thinning out) by cutting the new shoots before they grow into young culms. If not, the growing culm will be so close to others that it will be unable to grow without having to twist and turn
- In thinning out remove the smaller shoots and leave the large ones to develop into culms. This accelerates the growth of the clump to maturity (larger shoots produce larger culms which in turn produce larger shoots, and so on)

4. Harvesting

- Cut only fully developed culms (3-4 year olds). They have tight texture, maximum accumulation of fibre content and greatest mechanical strength
- Cut culms at base (just above the first node above ground level). This will minimise rhizome damage.
- Harvest only in the dry season to avoid damaging young shoots

Protection and preservation of bamboo

An introduction to bamboo preservation was given by Mr Lionel Jayanetti. The presentation highlighted the need to protect bamboo due to its susceptibility to attack by insects and fungi. The importance of protection by design was stressed, thereby limiting the need for chemical preservatives. A number of environmentally friendly treatments and treatment techniques were described, including the Boucherie and dip-diffusion methods using boron, smoking. Traditional methods such as soaking and post-harvesting transpiration were also discussed and assessed. Reference was made to the chapters on protection and preservation in the book “Bamboo in construction – an introduction”. Participants were then shown the TRADA video outlining the housing and preservation work in India.

Mr Dan Ofori then gave a brief presentation on the bamboo preservation techniques adopted for the school building construction in Ghana. A summary of presentation is given below:

Preservation of bamboo - the Ghana experience

The species of bamboo used for the construction was *Bambusa vulgaris* which was treated using 2 preservatives/methods:

1. Internodal Injection (applied to whole culm, used for columns and roof trusses):

- a 6mm hole was drilled under each node of the air dried culm
- using an oil gun 20 squirts of creosote were injected through each hole
- the holes were sealed with paraffin wax
- the culms were rolled a 2 times a day for 4 days to distribute the creosote
- the cut ends were dipped in creosote for one minute, allowed to drain then kept in a cool place to dry

2. Cold immersion (applied to bamboo strips, used for wall infill panels):

- A solution of boric acid (1%) and borax (1.5%) was prepared by mixing 500g of boric acid with 750g of borax in a container and adding 500 litres of water
- A steel treatment trough was ¾ filled with the solution
- Air dried strips were tied with nylon string into bundles of 20 pieces and immersed in the solution for 1 day
- After the immersion the strips were removed and stood on end in the shade and allowed to dry

Preservation of bamboo: practical session

A practical demonstration of bamboo preservation was held at BRRI. The participants saw at first hand how the work was carried out, and were able to try the various processes for themselves. This approach ensured that the participants had a good understanding of the principles involved, and also that their questions could be answered with reference to a real working environment.

Participants practising preservation techniques

Demonstration bamboo school in Kumasi

Mr Solomon-Ayeh, an engineer at BRRI, described the construction of the demonstration bamboo classroom block, initiated as part of the technology transfer exercise. The building satisfies a real need, since it replaces a much used but dilapidated kindergarten. The site is ideal, since it adjoins the main Accra-Kumasi road and is highly visible. The technical presentation is summarised below:

Demonstration bamboo school building

The school building is made up of 3 classrooms (each 7200 x 6000), a 2 unit toilet (2400 x 3600) and a 2400 wide veranda on one side. The overall plan area is 24000 x 8400. The substructure has 150 thick edge and sleeper walls, 125 thick trench concrete (1:3:6) and minimum 85 thick concrete ground slab (1:2:4).

The bamboo columns are anchored to the foundation using 3 No. mild steel dowel at the ground floor slab level. In this method, concrete is inserted into the base of the upended column, which is then carefully placed on the dowels precast into the floor slab. Shaking of the column ensures almost complete filling of the column base. After about 12 hours a 225 mm high sand concrete brick plinth is laid in between poles. With this method, the columns must be braced in two perpendicular directions during the whole period of wall construction.

The column spacing is 1200 c/c for the walls and 2400 for the veranda. 1200 is suited to window and door frame widths, 2400 coincides with the roof truss spacing.

The wall cladding is made up of 8-10 diameter horizontal steel dowels passing through the columns at 150 c/c, horizontal and vertical 25 wide bamboo strip grid at 150 mm centres wired together and to the

dowels, fine hexagonal wire mesh to both sides and cement sand mortar to a finished thickness of 75.

A timber wall plate (50 x 100) is used to provide lateral support to the top of the columns and to provide a seating for the roof trusses, ceiling joists and clamping devices. The wall plates are fastened to the columns using 100 long screws into 50 diameter hardwood plugs.

The roof consists of bamboo trusses jointed with plywood gussets and bolts, timber purlins and aluzinc sheet covering. A pitch of 15^0 was used to reduce wind uplift forces on the roof.

4.3 Day three

The third day saw an introduction to the bamboos of Ghana, a session on bamboo jointing and a presentation on the UK DFID funded TRADA bamboo building project in India.

The bamboo resource of Ghana

Dr Oteng Amoako, Senior Research Officer at FORIG[7] presented his study of the anatomical and physical properties of Ghanaian bamboo. His research shows that two Ghanaian bamboo species are suitable for construction purposes, namely *Bambusa vulgaris* and *Bambusa arundinacae*. The summary of his presentation is given below.

Sustainable development of the bamboo resource of Ghana

Only 20% of the original forest is left in Ghana, out of which 24% is already degraded. The sustainable timber production is only 1 million m^3 year whereas market demand is more than 4 million m^3 per year. Can bamboo help to bridge the gap? More specifically 1) can Ghanaian bamboo be used to meet the demand for 'wood', 2) can it reduce pressure on the timber resource? 3) can it be used commercially for any product development? and 4) which part of the culm can be used for which products?

To answer these questions, three species of bamboo were evaluated to study variations in morphological, anatomical and physical properties. The results show that *B. vulgaris and B. arundinacae* can be processed into bamboo products. The study on product development shows that satisfactory bamboo flooring can be produced from these species in spite of some technical problems.

Some of the problems and challenges for bamboo development in Ghana are: management of natural stands, establishment of germplasm, sustainable supply of quality culms, preservation of bamboo, sustainable harvesting methods, effective drying schedules, appropriate processing machines and technology, quality glue for effective bonding. Collaborators, partners and donors are needed to work together to face the challenges and to mitigate the problems.

Bamboo jointing

Mr Paul Follett (TRADA, UK) gave a brief introduction to bamboo jointing highlighting some of the characteristics which demand a special approach. These include its round, hollow form and a propensity for splitting. The various types of traditional joint were illustrated, followed by a review of recent developments. An open discussion session followed during which the participants acknowledged that there is no simple solution to the question of jointing. The participants were then referred to the chapters on jointing in the book "Bamboo in construction – an introduction" for further reading.

Building with bamboo in India

Mr Follett then gave a presentation on the bamboo based building system developed by TRADA in India in partnership with IPIRTI, Bangalore. This project, funded by UK DFID, forms the basis of the south-to-south technology transfer activities for the workshop. His presentation is summarised below.

[7] Forest Research Institute of Ghana, based in Kumasi

Building with bamboo in India

Rather than impose new ideas, TRADA has sought to improve existing and accepted technologies. The success of traditional bamboo-mud composite construction provided a starting point. An improved building system has been developed based on preservation trails, mechanical tests and prototyping. The result of modular system is simple to construct, durable, safe and affordable.

Preservation

Bamboo is non-durable in its natural state. It is therefore important that bamboo used in building is adequately protected against insect and fungal attack.

For bamboo in ground contact, such as column bases, tar-oil preservatives offer the best protection. The base of the columns can be treated using the **hot and cold method**. The bamboo is submerged in a tank of preservative, which is heated directly by a fire. After a period at a constant temperature, the tank is allowed to cool. During the cooling process, the preservative is drawn into the bamboo.

Above ground, the column can be treated by **internodal injection** using tar oil. Holes are drilled between each node, and a small quantity of tar oil is injected. The holes are plugged with wax, and the columns are rolled at intervals to distribute the preservative. With both methods, complete penetration of the bamboo wall is possible.

An alternative method of treatment, suited for use with water-soluble preservatives such as boron, is the **Boucherie process**. Preservative solution is fed under gravity from a tank at high level through a manifold into the butt ends of freshly felled bamboo. The bamboos are connected to the manifold using flexible rubber tubing and clamps. The process is terminated when all the sap has been replaced by the preservative.

Another water based method - **dip-diffusion** - involves soaking the bamboo in a tank of preservative solution for a period of several days. The effectiveness of the treatment can be increased by drilling holes in the bamboo. As with the tar oil methods, complete penetration is possible.

Testing

The success of a bamboo building system depends largely on the confidence of specifiers and users. In the absence of design data, prototype testing offers an effective way to demonstrate the performance and strength of assemblies and components.

Walls should be able to withstand impacts, strong winds and earthquakes without compromising the overall strength or stability of the building.

Impact testing, based on the Indian standard for doors, shows that the wall can resist heavy knocks and bumps, such as from animals or light vehicles, without damage.

Resistance to wind and earthquake forces can be established using a simple in-plane load test, or racking test, in accordance with British and American standards. Racking load is applied via a cable and pulley system, in line with the top of the test wall panel. At stages during the loading process, the wall is measured to see how far it has moved from its original position. The maximum test load, which corresponds to the strongest winds likely to be experienced over a 50 year period, can be sustained without damage, and with minimal deformation to the wall.

Roofs must also be able to resist wind, and any other loads that may be imposed during the life of the building. A roof truss can be tested to measure the load it is able to carry. A simple system of levers and dead weights can be employed to apply the load. Load is gradually increased until the maximum desired value is reached. Typically this is two and a half times the expected load.

If the strength of individual **joints** is known, then structural assemblies such as roof trusses can be designed without the need for full-scale testing. Various sizes of joint components, comprising bamboo, bamboo mat board and steel bolts, are tested to provide an overall picture of joint performance, and to enable the calculation of safe working loads.

Bamboo Mat Corrugated Sheet (BMCS)

The roof is arguably the most important feature of a building – this is what defines it as a shelter. Recently developed corrugated sheet, made from bamboo mats, offers great potential as a roofing material.

Traditionally, the bamboo slivers for mat weaving are cut by hand. The bamboo is first split into manageable strips, the outer layer is removed, and then the slivers are cut skilfully using a sharp knife. Industrial equipment is now available to make this process more efficient. Splitting, planing and the cutting of slivers can all be carried out using purpose made machinery.

Whichever method is used, the weaving of mats is still carried out by hand, traditionally by women. Before they can be pressed into boards, the finished mats must be impregnated with resin. Resin is applied by dipping and rolling. The mats are drained, then dried and stabilised in a drying chamber. When dry, several mats are assembled and loaded into a hydraulic press. The specially designed moulding dies give the sheet its permanent corrugation. Once they have been trimmed to size, the sheets are ready for use.

The BMCS sheets are light and tough. As such they are easy to handle, and resistant to breakage. They can be readily cut to size, and fixed using standard methods. Tests show that material is strong, fire and weather resistant with low thermal conductivity. The resulting roof is therefore durable and attractive with good insulating properties.

Construction

The finished building may look like a masonry structure, but its strength derives from an integrated, resilient bamboo skeleton. Bamboo columns, set in individual concrete footings, support bamboo grid infill panels. The grid components are wired to each other, and also to steel dowels passing through the columns.

Bamboo trusses and purlins are supported directly above the columns on a timber wallplate, to which they are fixed with metal straps to prevent wind uplift. The wire ties, bolts and straps ensure the entire framework is positively connected to become a single, composite unit.

When cement mortar is applied to the walls, they become very strong, but still retain their lightness and resilience. These characteristics make the construction inherently resistant to earthquake forces. After the first coat of mortar has dried, window and door frames can be fitted. They are wired into the grid using nails driven into the perimeter as fixing points. Mortar is then applied to the interior to secure them in position.

The walls are finished with a second coat of mortar to give a smooth surface suitable for painting. With the addition of BMCS roofing and bamboo mat board shutters, the building is complete.

Housing

The bamboo building system is sustainable and cost-effective. It is also simple to erect, strong and durable. As such, it incorporates all the essential requirements for affordable shelter.

Moreover, the basic system can be enhanced through improved use of shape, space and colour at little or no extra cost. For example, a shaded verandah provides a useful external space for working or relaxing. Large roof overhangs look attractive, and also provide protection from the sun and rain. Louvred openings and large windows increase light and airflow, providing a comfortable internal environment.

Rooms are pleasant, bright and cool. Electricity and water supply can easily be incorporated in the walls. Colour can be used to good effect. The exposed bamboo roofing provides good thermal insulation, and gives a light and spacious feel.

Overall, the system effectively demonstrates that desirability and quality are fully compatible with affordability. This has led to growing interest in bamboo as a building material, and the potential solution it offers to the shortage of affordable shelter in many developing countries.

Visits to school site and a bamboo factory

A visit was made to the school in Fumesua, where Mr Solomon Ayeh gave participants a tour of the building site, explaining the various stages in the construction process. By this stage, the structural framework was in place ready to receive the roof trusses, and participants were able to see the full extent of the building.

Participants at school building site

The participants were then taken to Kumasi Logging and Lumber, a sawmill and factory, where the proprietor Mr. Amin Zacca has pioneered the processing of bamboo into value added products. Mr Zacca gave a tour of the facilities, showing how he has modified standard woodworking machinery and simple workshop equipment to produce high quality prototype products based on glue laminated bamboo strips (e.g. flooring, furniture and carved craft items).

4.4 Day four

The fourth day was given over to group activities. The participants were divided into four mixed groups of engineers, architects and other professionals (see appendix 3), and each group was set two tasks – the design and construction of a bamboo joint, and the design of a bamboo building.

Bamboo jointing: practical group session
The participants were taken to BRRI where each group was assigned a different type of bamboo joint to design and construct. Engineers and artisans were on hand to help participants understand the different types of joint and their applications, and to overcome any practical difficulties. The exercise gave the groups a real sense of involvement, giving the previous theory sessions a practical focus and resulting in fine work which the participants were very proud of.


Practical session on bamboo jointing

Designing a bamboo building: group session
Each of the four groups was asked to design a different type of bamboo building based on their skills as architects, engineers and professionals, and the knowledge and experience they had gained during the workshop. The building types were 1) a low-cost house, 2) middle-income house, 3) school building and 4) rural health clinic. The groups were asked to work with the following checklist:

- Prepare a full plan and elevation of the building
- If time permits, draw separate foundation, wall and roofing plans
- Make a list of materials required for foundations, walls, roofs, doors/windows with quantities and costs
- Explain where and how bamboo is used
- Estimate the building cost per square metre
- List the prospects, constraints and opportunities for bamboo construction in the Ghanaian context in terms of policy, resource or material availability, cost, technicality, preferences of society etc.
- Prepare a group presentation

The work continued through the evening (as necessary) and into day five.

4.5 Day five

The final day saw the conclusion of group work on building design, and presentations in front of invited members of the media. The workshop was closed with a short formal ceremony and finally a visit to the school site.

Presentation of group design work

Each group made a presentation in accordance with the project checklist. All groups had finished the set activities to a very high standard. Importantly, all groups reported that employing bamboo building technology indicated a significant cost saving over traditional methods. The perceived prospects, constraints and opportunities are listed below (the drawings will be made available on the INBAR website).

	Prospects	*Constraints*	*Opportunities*
Group 1	Bamboo houses are cheap to construct. Provision of accommodation. Employment opportunities. Can withstand natural disasters. Speedy erection. Conserve our forest.	Limited knowledge and lack of expertise. Lack of suitable culms. Problem of social acceptability. Lack of management skill in bamboo stands. Competition with other building materials. Lack of policy framework. Lack of funding. Insufficient cooperation.	Availability of technology Bamboo grows naturally in Ghana Availability of human resource Interest of international organisations in its promotion e.g. INBAR, ITTO, BARNET, TRADA, DFID High yielding Excellent properties
Group 2	Locally available material. It is renewable. Environmentally safe. Job opportunities. Traditional timber source needs to be replaced with an alternative material. Rural communities are familiar with bamboo.	New technology. Bamboo has been socially deemed as poor mans' timber.	Technology is in line with Ghana government's policy to provide affordable houses to the citizens BRRI can or should provide technical assistance
Group 3	Good marketing and promotion. International collaboration and exchange of appropriate technology. Can combine effectively with other local materials.	Market acceptability. Dissemination of information. Development of the industry is still at the elementary level world wide. Well managed plantations.	Interest in the development of bamboo resource. Government's policy to build affordable houses, schools and clinics for workers in the rural areas. Cost competitiveness. Bamboo is available in six out of ten regions of the country.
Group 4	Preservation is economical. Light in weight so easy to transfer from bush to site. Tall and straight, so suitable for columns and beams. Durable when properly preserved. Comparatively it is cheaper. For roofing purpose, it is lighter to lift. It is renewable and helps in the conservation of forests.	Not durable if not well treated. It can easily break up if not properly handled. It is not easy to work with (cut or drill) when dried. Harvesting with cutlass is quite dangerous. It can easily catch fire. Problem of funding. The engineering design has not been fully addressed.	None recorded

Closing ceremony

The closing ceremony was chaired by the BARNET chairman, Mr David Coleman. Mr Coleman introduced the guest of honour, Dr Thomas Fokuo Agyapong, Director of Policy and Planning, Ministry of Works and Housing.

Dr Thomas Fokuo Agyapong

Dr Lionel Jayanetti reprised his first day introduction to bamboo in construction for the benefit of the press and dignitaries, and to restate to the participants the possibilities for bamboo development given their increased knowledge and awareness resulting from the five days of presentations, discussion practical sessions and group work.

Mr Solomon Ayeh spoke briefly about the construction of the demonstration school building. Bringing his recent experience of school construction in the Northern Region to bear, he made the crucial observation that the predicted cost for the bamboo school was only one third to one half of that for an equivalent brick and block building. This very important point provided a memorable juncture upon which to close the technical proceedings.

The closing address was made by Dr Thomas Fokuo Agyapong, summarised below:

Speech from Guest of Honour

Ladies and gentlemen. It gives me pleasure to have the opportunity of addressing you all at this closing ceremony of the bamboo housing workshop.

As we have seen during this workshop, bamboo is an excellent alternative to concrete or wood for building construction. The lightness and strength of bamboo enables the production of high quality, cost effective buildings that are fully weather resistant and easy to repair. Developing the use of bamboo natural resources in a sustainable manner for use in construction and other industrial applications encourages the substitution of timber and the increased growing of bamboo, both of which should have major environmental benefits.

I hope that all of you will be able to put into practice the skills and techniques you have learnt over the past week, to develop the bamboo housing sector in Ghana and to make Ghana even more beautiful. The enthusiasm and energy you have brought to the workshop is a great encouragement to all of us.

Finally it is with great pleasure, and a tinge of sadness, that I declare this workshop closed.

The thoughts, impressions and reflections of the participants were expressed by their chosen representative, Mrs Antonia Ofori. The vote of thanks was proposed by Shyam Paudel, INBAR, and the closing remarks were made by the Chairman.

The workshop had been highlighted in the local media and journalists and development practitioners were invited to join on the final day. At the formal close of proceedings, an informal gathering took place at the school site for all participants, including media representatives. Coverage of the workshop appeared in the national newspapers and on national television.

5. Workshop evaluation

An evaluation questionnaire (appendix 4) was distributed to all participants, asking them to rate various aspects of the workshop. The results are presented in appendix 4. Participants were also asked to offer their comments and suggestions regarding the workshop – these are given below:

Comments and suggestions from the participants

"The workshop was highly successful and more such types of workshops are suggested so as to sensitise the public about bamboo building"

"The workshop has been very educating. It has also brought an awareness of the value of bamboo in relation to housing at higher level than traditional one. I suggest that when such workshops are going to be organised, there should be more publicity through the media and also should be more practical"

"Great opportunity to have participated in bamboo housing workshop. It has improved my knowledge generally. I suggest more emphasis should be on locally grown bamboo and explore possibilities of utilising them to our advantages"

"A lot more interest groups must be included in such workshop"

"The workshop was appreciable. Building with bamboo is new initiative and a new direction in the building industry. More of such workshops are crucial to educate the public and stakeholders and to attract investment in the area"

"The workshop has been very educational and has opened me up to appreciate bamboo very much. However I suggest that subsequent workshops should have more practical sessions and less theory"

"The period for the training workshop is very short. Such programmes should be organised periodically"

"I wish building (Kumasi bamboo school building) had been completed before inviting the media"

"The programme was a good eye opener. Next time it would be nice to have more practical session"

"The government should encourage public education on prospects of bamboo as an alternative to conventional timber. Follow up workshop is requested"

"People who will be invited to attend future workshops should report latest on the 2nd day especially for a few days' workshop"

"All presentation should be made using power point or overhead projector in order to make the lessons more lively"

"Future facilitators must be asked to come out with handouts that will be given to participants. Indeed Shyam is a very good facilitator and needs to be recommended. Almost always keeping participants alive"

"In general, stakeholders of the construction industry did not dominate the workshop, which should have been ideal situation. The group work was very good just that time constraints prevented better designs and detailing. If all presentations could be on power point, it would make appreciation better and copies of the presentations should also be made available to participants. A training programme could be organised for professionals of the building industry. It was enlightening and challenging to me as a person to help make bamboo an acceptable building material"

Appendix 1: Participants, resource persons and organisers

Participants

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The following participants did not provide contact details:
Ekua Affum Odei
Kwabena Adu Baah
Philip Oppong
Amoa Mensah Kwaku
Ahmed Nii Okan
Benjamin Larty

Workshop management group

INBAR:	Shyam K Paudel, Workshop Coordinator
	Annemarie de Ruiter, Communication and Coordination
	Andrew Benton, Financial Management and Exhibition
	Charles Asare, Logistics and Travel Management
BARADEP:	Gifty Allotey, Workshop Coordinator
BARNET:	Dan Ofori, Logistics Management
	Amin Zacca, Exhibition

Resource persons
Dan Ofori, BARNET
Gifty Allotey, BARADEP
Kwabena Solomon-Ayeh, BRRI
Lionel Jayanetti, TRADA
Paul Follett, TRADA
Amin Zacca, KLL

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Final day participants

1. Dr Agiyapong, Ministry of Works and Housing
2. Phelia Arthur, Journalist, Daily Dispatch
3. Portia Kontoh, Journalist, Kumasi mail
4. Kingsley Gyam, Credit Manager, OIC
5. Emmanuel Opare, Teacher, Ghana Education Service, Accra
6. Peter Rasmussen, Consultant, UNCHR Accra
7. Kwame A Oduro: Research Scientist, TROPENBOS
8. Dwobeng Nyantwagi, Forester, TROPENBOS
9. Gifty E Blekpe, Programme Officer, CARE
10. Ama Fosuhemmee, Journalist, GBC
11. Serwah Nigira, Journalist, Graphic TV 3
12. Kuabena Nimih, Journalist: Graphic TV 3
13. Budu Hapa, Journalist, GTV
14. P K Donker, Journalist, GTV
15. Henry Gyasi, Marketing, KLL
16. Yuw Odu Gyeisen, Building Technology: Ministry of works and housing
17. Salome Asirifi, Journalist Fax FM
18. Gloria Kwarteng, Journalist: LUV FM

Appendix 2: Workshop programme

	Day 1
09.00	Registration
10.00	Opening ceremony
11.00	Introductions
11.30	Expectations of the participants
12.30	Lunch
13.30	Introduction to the workshop: background and objectives
14.30	Introduction of INBAR
15.00	Introduction of BARNET and BARADEP
15.30	Tea break
16.00	General overview of bamboo in construction
17.00	Close
	Day 2
08.30	Review of day 1
08.45	ABC of bamboo
10.30	Tea break
10.45	ABC of bamboo continued
11.30	Protection and preservation of bamboo
12.30	Lunch
13.30	Preservation of bamboo: practical session
15.30	Tea break
15.45	Demonstration bamboo school in Kumasi
17.00	Close
	Day 3
08.30	Review of day 2
08.45	The bamboo resource of Ghana
10.00	Bamboo jointing
11.00	Tea break
11.15	Building with bamboo in India
12.30	Lunch
13.30	Visit to school construction site
15.00	Visit to bamboo factory
17.00	Close
	Day 4
08.30	Review of day 3
08.45	Group work on jointing: practical session
12.00	Group work on building design
12.30	Lunch
13.30	Group work on building design
17.30	Evening get-together
	Day 5
08.30	Review of day 4
08.45	Completion of group work on building design
09.45	Presentation of the group work on building design
10.30	Tea break, arrival of VIPs
11.00	Closing ceremony
12.30	Lunch
13.30	Visit to school construction site
14.30	Close

Appendix 3: Project groups

Group 1
Middle income house
Emmanuel Ebanyele
Micheal Quainoo
Sampson K Mensah
Aba Minkah
David Coleman
Paul Ackon

Group 2
Low cost house
Amoa Mensah Kwaku
Joseph Oduro
Afua Asantewaa
Ivy Akonor
Prince A Ofori
Richard A Dadzie

Group 3
Rural hospital
Francis Wilson Owusu
Christina Arthur
Henry Gyasi
Gifty Allotey
Gizella Tetteh
Emmanuel Mate Korle

Group 4
Rural School
Ben Lartey
Antonia Ofori
Stephen Larbi
Ahmad Nii Okan
Abraham Allotey
Yvonne Owusu Sekyere
Philip Oppong

Appendix 4: Workshop evaluation

Questionnaire

(Please place a tick in the box: 1 = very bad, 3 = average, 5 = very good)

1.	Logistics management (food, accommodation)	1	2	3	4	5
2.	Content of the workshop	1	2	3	4	5
3.	Context (relevancy, practicality)	1	2	3	4	5
4.	Presentations (Facilitation)	1	2	3	4	5
5.	Practical work	1	2	3	4	5
6.	Discussion groups	1	2	3	4	5
7.	Overall evaluation	1	2	3	4	5

8. Comments and suggestions

Appendix 4: Workshop evaluation

Summary of responses