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SECTOR



# ARUP

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**Rohingya Refugee Camps and  
Sites, Cox's Bazar Region,  
Bangladesh**

Technical Guidance Note 03:  
Durability and Treatment of Bamboo  
in Cox's Bazar

REP/079032-30/S0001

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This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

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**Ove Arup & Partners Ltd**  
13 Fitzroy Street  
London  
W1T 4BQ  
United Kingdom  
[www.arup.com](http://www.arup.com)

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## Executive Summary

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The Shelter and NFI Sector in Cox's Bazar, Bangladesh have asked Arup to produce a Technical Guide on the durability and treatment of bamboo for all structures (shelters, community facilities and bridges) in the refugee camps and sites in Cox's Bazar. Bamboo is currently being used as the primary construction material for nearly all structures in the camps because it has been readily available, however it is naturally vulnerable to insect and rot attack, more so than timber. Durability is the main reason why bamboo is considered a "poor man's construction material", and why so many bamboo structures do not last. **Without consideration for durability, some parts of the existing structures will deteriorate in as little as 6 months following construction, leaving them more vulnerable to wind and structural failures.**

This guide has the following aims:

1. Provide information on the natural durability of bamboo, and the three main causes of decay in bamboo: termites, beetles and fungal attack (rot).
2. Discuss the main options for improving durability, recommending the most appropriate for Cox's Bazar.
3. Discuss the main treatment methods using boron, recommending the most appropriate for Cox's Bazar.
4. Challenge a number of misconceptions regarding the durability and treatment of bamboo.

It is recommended to read this guide in conjunction with the Humanitarian Bamboo guide (Humanitarian Bamboo, 2009).

The two key recommendations for improving durability of bamboo in Cox's Bazar are presented below, in order of priority and impact. Both are required (introducing one does not negate the need to have the other):

1. **Incorporate durability by design, in particular by the use of footings to isolate the bamboo frame from the ground, and by creating as watertight walls and roofs as possible.** This is considered as important as treating the bamboo, since even treated bamboo will still rot quickly in the ground.
2. **Treat bamboo with boron.** The most appropriate method of treating bamboo is considered to be boron. All three of the following treatment methods could work, and will be more appropriate depending on the local circumstances:
  - a. Cold-water bath. Lowest complexity, low output per bath.
  - b. Hot-water bath. Highest complexity, high output per bath.
  - c. Vertical soak diffusion. Moderate complexity, high output, requires high access tower and shelter, not suitable if bamboo is cracked.

Boron treatment will require tight controls over disposal of waste products. Boron treatment should use freshwater – the use of saltwater would first require a laboratory test to see if and how much the salt interferes with the solubility of the boron, which could reduce the efficacy of the treatment.

In addition to the above, the following are also recommended – these will have a smaller impact on durability, but are still worthwhile:

3. **Select mature bamboo.** Attempting to influence the bamboo supply chain by harvesting mature bamboo only. Harvesting immature bamboo can also reduce clump productivity.
4. **Keep bamboo away from insects during transport and storage, prior to treating with boron.** This can be best achieved by keeping the bamboo away from ground contact, and periodic fumigation.
5. **Keep bamboo dry during transport and storage, both before and after treating with boron.**

If boron treatment is not available:

6. **Alternatives to boron.** If boron treatment is not possible, it is recommended to attempt to influence the bamboo supply chain by harvesting at optimal times, and soaking the bamboo in fresh water for 4-8 weeks, but effectiveness will be limited.

Table 1 presents suggested approximate lifespan of untreated and treated bamboo in Cox's Bazar, and illustrates the effectiveness of both treating and keeping the bamboo dry.

Water exposure risk	Example in Cox's Bazar	Likely lifespan of untreated bamboo	Likely lifespan of bamboo treated with boron
None	All structure protected by plastic sheeting	0.3-5 years (as little as 3 months has been reported in the camps)	30+ years
Intermittent wetting by driving rain but can dry easily	Externally exposed vertical columns above ground	0.3-4 years	2-10 years
Intermittent wetting by driving rain but difficult/slower to dry	Externally exposed horizontal beams above ground	0.3-2 years	1-2 years
Permanently exposed to water	Columns in ground contact	0.3-0.5 years	<1 year

**Table 1: Approximate likely lifespan of untreated and treated bamboo in Cox's Bazar**

If any existing bamboo structures are experiencing issues with rot or insect attack, or there is a wish to improve their durability, in most cases it is simplest and most effective to demolish the building and rebuild.

The following methods often proposed to improve durability are not considered relevant when considering durability for this context:

- Selecting more durable bamboo species. It is not considered important to select a specific bamboo type which anecdotally may have greater natural resistance – there are much more important factors which influence durability.
- Seasoning. The bamboo used in shelters will effectively season in-situ (with the exception of the bamboo placed directly into the ground, which will rot). Therefore, seasoning can be considered unnecessary.
- Clump curing. This has only minimal benefit, yet adds complexity to the supply chain.
- Smoke or fire treatment. This method has limited efficacy, uses valuable fuel, potentially weakens the bamboo and exposes people involved in treatment to smoke.
- Conventional paint. This provides limited efficacy against water and none against insects, and needs to be reapplied frequently.
- Painting with coal tar/bitumen/used engine oil. This provides limited efficacy against rot, is slightly more effective against insects, but is a known carcinogen to humans. Although widely used in the humanitarian and development sector, it is in fact much less effective than many believe.
- Modern preservatives. While some of these can be very effective, they are all either expensive, complex to apply or carry significant health risks during application and at end of life.

# 1 Introduction to this Technical Guide

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## 1.1 Introduction

The Shelter and NFI Sector in Cox's Bazar, Bangladesh have asked Arup to produce a Technical Guide on the durability and treatment of bamboo for all structures (shelters, community facilities and site management and infrastructure works) in the refugee camps and sites in Cox's Bazar. Bamboo is currently being used as the primary construction material for nearly all structures in the camps because it has been readily available, however it is naturally very vulnerable to insect and rot attack, more so than timber. Durability is the main reason why bamboo is considered a “poor man's construction material”, and why so many bamboo structures do not last (Kaminski, 2013). Without consideration for durability, some parts of the existing structures will deteriorate in as few as 6 months following construction, leaving them more vulnerable to wind and structural failures (Kaminski et al., 2016a).

This guide has the following aims:

1. Provide information on the natural durability of bamboo, and the three main causes of decay in bamboo: termites, beetles and fungal attack (rot).
2. Discuss the main options for improving durability, recommending the most appropriate for Cox's Bazar.
3. Discuss the main treatment methods using boron, recommending the most appropriate for Cox's Bazar.
4. Challenge a number of misconceptions regarding the durability and treatment of bamboo.

## 1.2 Glossary of technical terms used

**Clump:** a single bamboo plant, consisting of a group of culms growing together connected by a rhizome.

**Culm:** single stem of a bamboo plant, growing from the rhizome.

**Internode:** the space between the nodes – normally hollow, but in some species can be solid.

**Nodal diaphragm:** a solid wall of fibres at the node that separates the internodes.

**Node:** a local thickening along the length of the culm, where branches grow from, and where the nodal diaphragm connects.

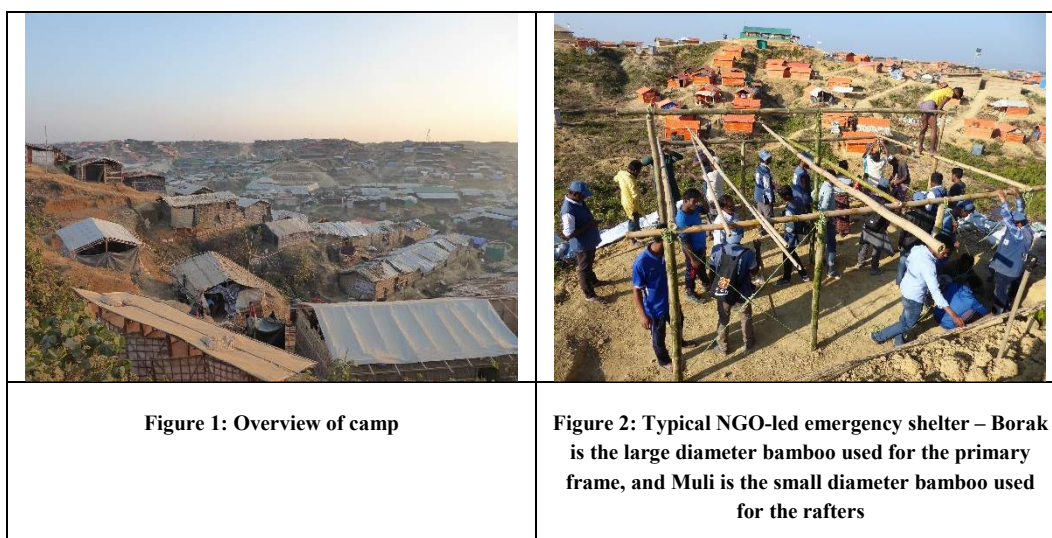
**Rhizome:** the underground part of the bamboo plant, with culms and roots growing from it.

## 2 Current Status of Bamboo in Cox's Bazar

As of **September 2018**, the current status of the use of bamboo in Cox's Bazar is understood to be as follows:

### Species

The primary species delivered to site continue to appear to be *Bambusa balcoa* (known locally as “borak”) and *Melocanna baccifera* (known locally as “muli”). Other species that are arriving include *Bambusa vulgaris* (Baijja bash) and *Dendrocalamus Giganteus* (Budum Bash) (Amer, 1992). A simplification has taken place on site, where all large diameter bamboo (>~50mm) is now known as “borak”, and all small diameter bamboo (<~50mm) is now known as “muli”, irrespective of the species (Figure 1 and Figure 2).



### Source

In November 2017, most of the bamboo was coming from the Chittagong Hill Tracts (Shelter/NFI Sector, 2017). This market assessment has not been redone and therefore it is difficult to know definitively where the bamboo is now coming from, however it is reported that bamboo is arriving from further afield, including further parts of Bangladesh, and now Myanmar and India.

### Harvesting

No information is known on how the bamboo is harvested, however it has been observed that some bamboo arriving is not mature. This suggests that some bamboo is being harvested before it is fully mature. Bamboo has also been arriving throughout the entire year, which suggests it is being harvested in the rainy season as well as the dry season.

### Transport

Transport from harvest sites to the camps continues to be by river over long distances (Figure 3) and by road over short distances. Transport times are unknown, but are estimated to be between 2-8 weeks.



Figure 3: Bamboo transported en masse by river to the camps (Shelter / NFI Sector, 2017)

## Storage

Before use, bamboo continues to be stored on site in bundles on the ground without protection (Figure 4).



Figure 4: Typical storage of bamboo in the camps

## Use

Bamboo is used as the primary construction material for nearly all buildings and structures in the camp. It is used not only for the primary frame, but once split, it is woven into mats for the walls.

Current designs for shelters (Figure 5 and Figure 6) and community buildings (Figure 7) typically have the following characteristics:

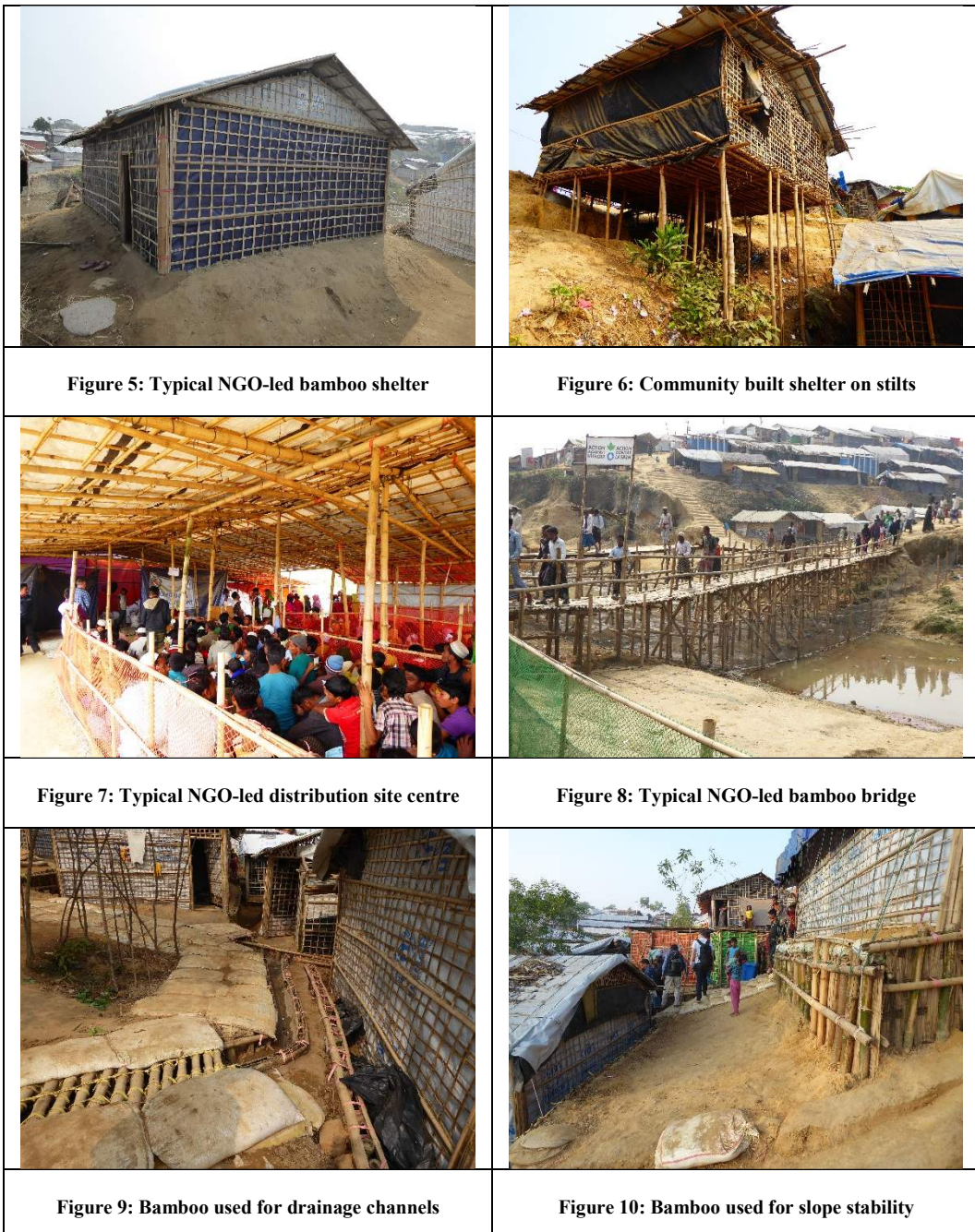
- Bamboo is not treated or seasoned in any way prior to use.
- Bamboo columns are placed directly into ground or in some cases embedded in concrete (typically for the community structures).
- Bamboo frame tied together with rope or wire.



- Plastic sheet on outside of structural frame (lattice is usually outside).

Current designs for bridges (Figure 8) typically have the same characteristics, except the bamboo frame above ground is completely exposed to the elements (rain and sun).

Bamboo is also used for drainage channels (Figure 9) and slope stabilisation (Figure 10).



## End of life

Leftover bamboo from construction and at end of life is burned for fuel.

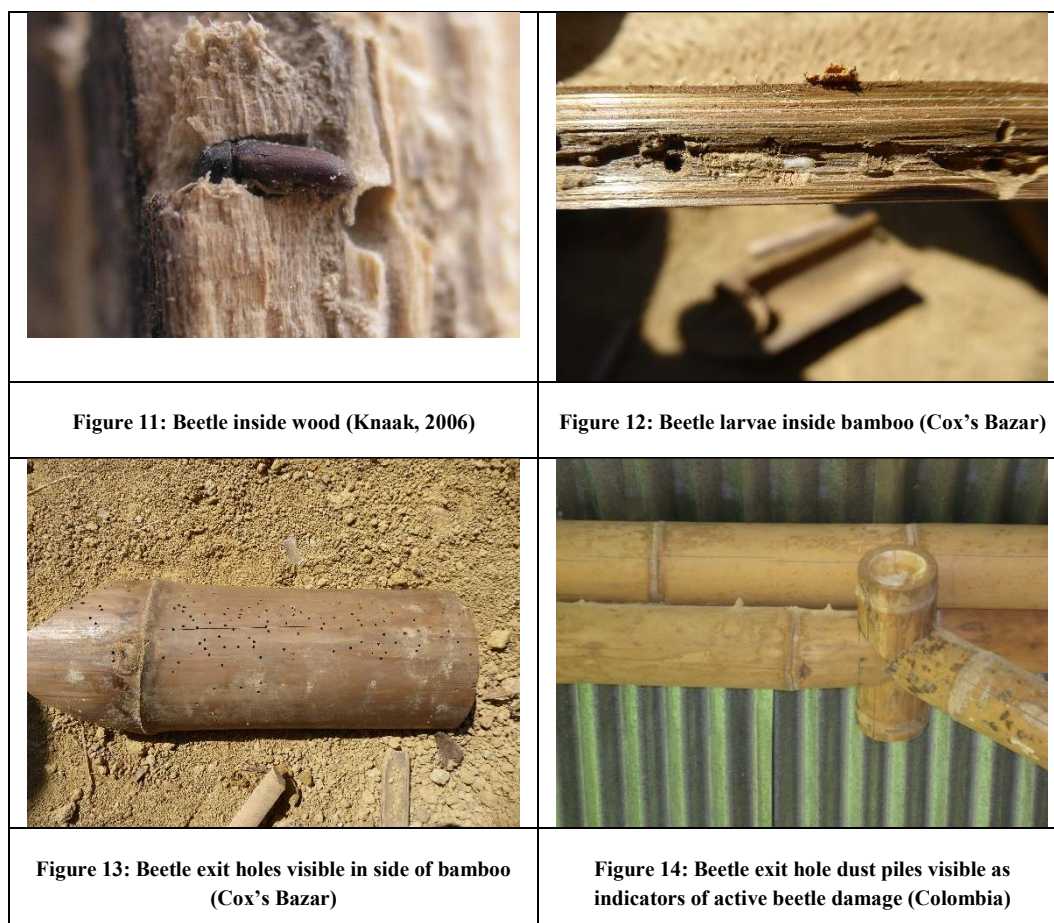
## 3 Natural Durability of Bamboo

### 3.1 Introduction

Bamboo is more susceptible to decay than timber, due to a lack of natural toxins (Janssen, 2000), generally higher levels of starch and its typically thin walls, which means that a small amount of decay can have a significant percentage change in capacity. There are three causes of decay in bamboo (Kaminski et al., 2016b): beetle attack, termite attack and fungal attack (rot).

### 3.2 Beetle attack

Certain beetles are attracted to the starch in bamboo and lay their eggs inside the culm, after which the eggs hatch and the larvae eat along the culm and eventually through the culm walls to escape, leaving small round or oval exit holes (about 1mm–6mm diameter) (Figure 11, Figure 12, Figure 13, Figure 14). This attack effectively makes many holes inside the bamboo, weakening it by reducing the area available to carry the load.



There are many different types of beetles that attack bamboo, of different sizes and activity, however since the method of protecting against them remains the same, there is generally no need to distinguish between them. The rate of attack is fastest with fresh green bamboo and bamboo that is immature when harvested (both of

which are more susceptible), but even dry mature bamboo can easily be attacked (Liese et al., 2002).

Beetles are prevalent in Cox's Bazar, and attack is worst when humidity and temperatures are high (i.e. during the wet season). Evidence of beetle attack includes beetle exit holes (Figure 13) and small piles of dust of the same colour as the bamboo (Figure 14).

### 3.3 Termite attack

Termites are small ant-like insects which live in colonies and feed on plant material (Figure 15). They are also attracted to the starch in bamboo, but unlike beetle have enzymes which also enable them to break down the cellulose. Because they live in large colonies they can cause significant and rapid damage (Figure 16). This attack also makes longitudinal tunnels inside the bamboo, weakening it by reducing the area available to carry the load. There are three generic types of termites: subterranean, drywood and dampwood. Subterranean termites live in large colonies in the (preferably damp) ground, and connect their nests to food sources via mud tunnels (Figure 17), which provide protection against sunlight and predators (BRE, 1999). Drywood termites live in dry wood/bamboo, but do not require contact with soil; they can also fly and live in generally smaller colonies. Dampwood termites live in damp wood/bamboo, but are rarely found in buildings since wood/bamboo in these structures typically does not have enough moisture. Subterranean termites normally cause the most damage to timber/bamboo structures because of their large colony size (Antonelli, 2002).

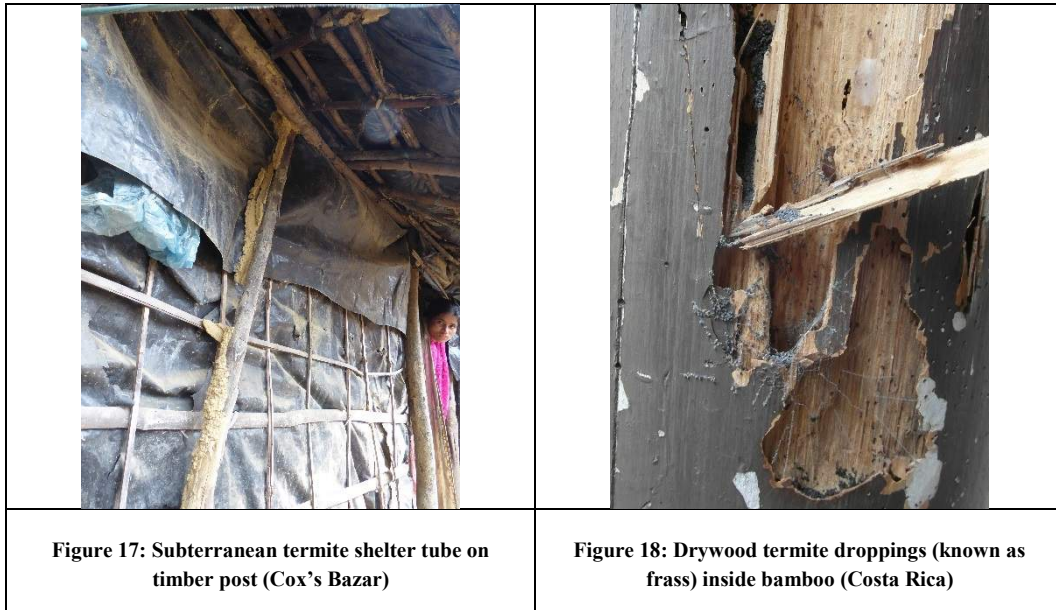


Figure 15: Subterranean termite (Cox's Bazar)



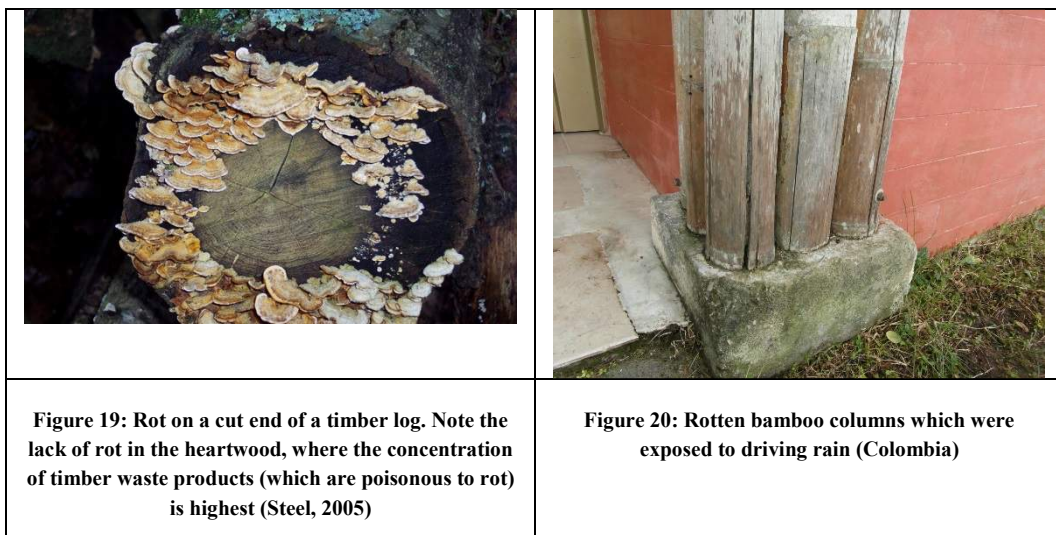
Figure 16: Significant termite damage to bamboo column (Costa Rica)

Termites are prevalent throughout Cox's Bazar, and attack is worst when humidity and temperatures are high (i.e. during the wet season). Evidence of termite attack is a hollow sound when the timber/bamboo is tapped (as the termites eat the inside while leaving a thin protective outer layer of the bamboo wall). Evidence of subterranean termites is termite tunnels, and evidence of drywood termites is frass (termite droppings) which are normally dark in colour (Figure 18).



### 3.4 Fungal attack (rot)

Rot is caused by a fungus. For the fungus to survive the bamboo needs to be relatively wet with at least 20% moisture content, which essentially means the bamboo must be exposed to rain or ground moisture (Ridout, 1999) for a period of time, without being allowed to dry out (Figure 19). This makes the lower part of walls, penetrations (splits/holes) through the culm wall, horizontal beams and bamboo cast into concrete all particularly vulnerable (Figure 20, Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, Figure 26).



Cox's Bazar experiences a tropical climate, with rainfall up to 1000mm per month at the peak of the monsoon (climate-data.org, 2018), high humidity and high temperature. The combination of these means that in the rainy season, exposed bamboo will get very wet for a prolonged period, leading to a high risk of rot.

Rot is not always immediately evident as it is more likely to occur in hidden areas (which cannot breathe and so stay wet), and also the fruiting bodies shown in Figure

19 are not always visible. Evidence of severe rot is a change in sound if the bamboo is tapped, a softening of the culm or a change in colour and texture of the fibres when drilled. Because rot is not always obvious, it is often an underestimated risk to bamboo.

	
<p><b>Figure 21: Rotten bamboo chord of a bridge, where a bolt hole allowed driving rain to enter (Colombia)</b></p>	<p><b>Figure 22: Rotten base detail of bamboo cast into concrete (Colombia)</b></p>
	
<p><b>Figure 23: Dampness penetrating an exposed wall with no overhang (Colombia)</b></p>	<p><b>Figure 24: Rotten timber and bamboo inside the wall (Ecuador)</b></p>
	
<p><b>Figure 25: Rotten bamboo at the base of the wall, where the cement render failed to adequately protect it (Costa Rica)</b></p>	<p><b>Figure 26: Rotten bamboo where a beam was exposed and collected water</b></p>

### 3.5 Summary

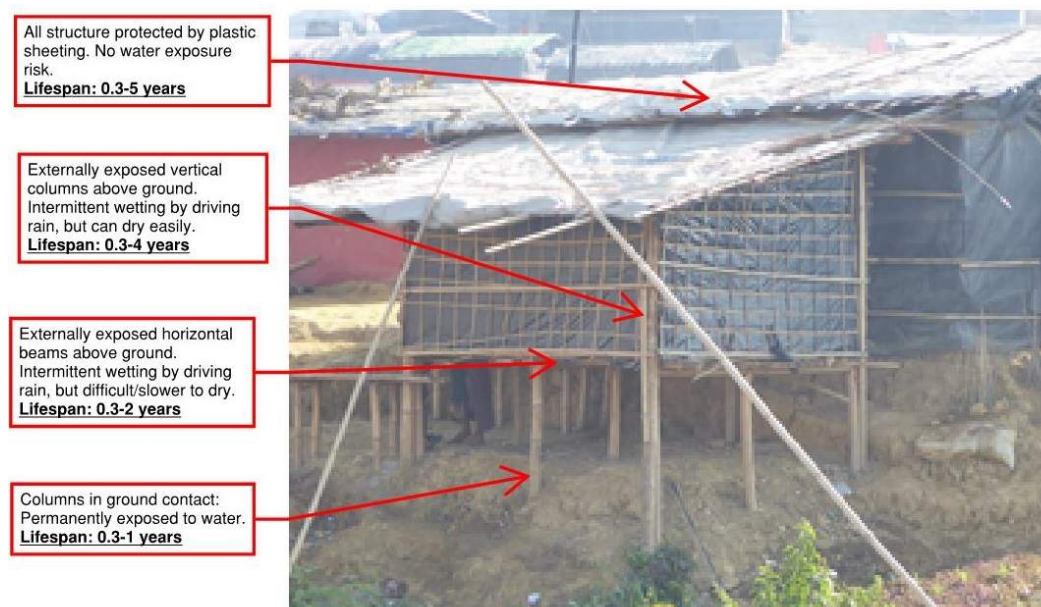
All species of bamboo are very susceptible to rot, termite and beetle attack (Liese et al., 2002). Some species are reported to be more naturally resistant, especially to

beetles, while others are reported to be more vulnerable, primarily due to differences in starch content. However, any difference is not considered to be significant, and becomes largely insignificant once the bamboo has been harvested, seasoned and used in construction with proper detailing. The difference becomes irrelevant once bamboo is properly chemically treated. Therefore, in the Cox's Bazar context, *it is not considered important to select a specific bamboo type which anecdotally may have greater natural resistance – there are much more important factors which influence durability.*

Suggested approximate lifespans of untreated bamboo in different scenarios in Cox's Bazar is provided in Table 2 and Figure 27.

Water exposure risk	Example in Cox's Bazar	Attack mechanisms	Likely lifespan of untreated bamboo
None	All structure protected by plastic sheeting	Beetle and termite	0.3-5 years (as little as 3 months has been reported in the camps)
Intermittent wetting by driving rain but can dry easily	Externally exposed vertical columns above ground	Beetle, termite and rot	0.3-4 years
Intermittent wetting by driving rain but difficult/slower to dry	Externally exposed horizontal beams above ground	Beetle, termite and rot	0.3-2 years
Permanently exposed to water	Columns in ground contact	Beetle, termite and rot	0.3-0.5 years

**Table 2: Approximate likely lifespan of untreated bamboo in Cox's Bazar (Liese & Kumar, 2003, Kaminski et al. 2016c, Practical Action, no date)**



**Figure 27: Illustration of likely lifespan of untreated bamboo in different parts of shelters in Cox's Bazar**

## 4 Methods of Improving Durability

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This section discusses the various ways of improving durability of bamboo in structures in the Cox's Bazar context. In practice a mixture of these is required.

### 4.1 How to select appropriate ways of improving durability

When selecting appropriate ways of improving durability for Cox's Bazar, it is important to consider the following:

- The quantity of bamboo to be treated.
- The availability of treatment facilities.
- The availability of chemicals.
- The intended use of the bamboo: inside or outside.
- Any country-specific legislation.
- The transport time from harvest location to treatment facility: some treatment methods require very freshly cut bamboo.
- The budget.
- The effectiveness of the method.
- The ease of applying the method.
- The toxicity of the chemical to humans throughout the whole life of the bamboo (treatment, use and disposal).
- The toxicity of the chemical to the environment throughout the whole life of the bamboo (treatment, use and disposal).
- Impact on harvesting and productivity of bamboo clump.

### 4.2 At source/selection of bamboo

It is understood that the Shelter & NFI Sector has little control over sourcing and selecting bamboo. If any control or influence is possible, the following can be considered.

#### 4.2.1 Use more naturally durable species

As noted in Section 3 all species of bamboo are very susceptible to rot, termite and beetle attack – the difference is not considered to be significant. Therefore, in the Cox's Bazar context, *it is not considered important to select a specific bamboo type which anecdotally may have greater natural resistance – there are much more important factors which influence durability.* In addition, proper identification of

bamboo in the wild can be difficult even for specialists, and therefore communities may sometimes be mixing species and local names up anyway.

### 4.2.2 Select mature bamboo

Harvesting mature bamboo (generally between ~4-6 years old, with the precise time depending on the species and the climate) is important for the following reasons (Rabik & Brown, no date; BTSG-KFR National Bamboo Mission, 2015; Guadua Bamboo, 2017):

1. Immature (young) bamboo is more prone to insect attack and rot because some of the internal growth processes, such as silification and lignification, are not complete.
2. Old bamboo (>6 years old) may be more prone to insect attack and rot.
3. Harvesting young bamboo from a clump can reduce its productivity.

Mature bamboo is also stronger than immature bamboo.

In practice, selection of mature bamboo is generally conducted using traditional knowledge.

If possible, it is recommended to encourage the vendors to select and supply mature bamboo.

### 4.2.3 Harvesting time

There is significant traditional knowledge on the best harvesting times for durability of bamboo. These are based on harvesting when the starch and/or water content is lowest, as beetle attack will therefore be lowest. The three optimal harvesting times often reported are as follows:

1. Harvesting in the dry season (both moisture and starch content are lowest). This may be difficult to implement because it narrows down the harvest time to a small window (November to May), which means the bamboo is likely to sit in storage or in sellers' yards for long periods, significantly increasing the likelihood of deterioration by insects and rot.
2. Harvesting during "no-moon time" (a week after full moon). This is when starch content is lowest.
3. Harvesting at night, when the bamboo is using up its starch content.

Although each of these can help reduce vulnerability, (1) has by far the largest impact, while (2) and (3) are considerably less significant. Another reason why bamboo should not be harvested during the rainy season is because it can lead to damage of the young shoots growing.

Therefore, it is recommended to harvest only during the dry season. If the harvesters are traditionally also harvesting at specific times of the month and night, while this is not a priority, there is no harm in letting them carry on. It is also recommended to plan the procurement of bamboo such that there is no procurement taking place



during the rainy season. Bamboo should then be stored appropriately when it is not required (Section 4.3).

## 4.3 During storage and transport

### 4.3.1 Dispose of damaged culms

Culms damaged by beetle, termite or rot should be immediately disposed of and not mixed with healthy culms, in order not to allow insect damage to spread (BTSG-KFR National Bamboo Mission, 2015).

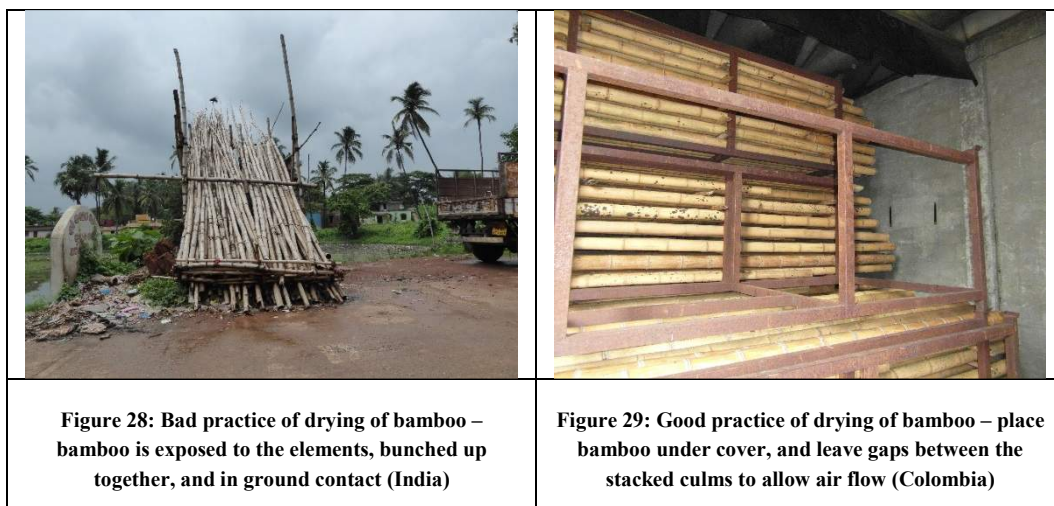
### 4.3.2 Keep bamboo dry

During storage and ideally transport, bamboo should be kept dry to reduce the risk of rot (Figure 28 and Figure 29). Bamboo should be stacked above ground, with gaps in-between the culms, allowing air flow, such that the bamboo can “breathe”. There should also be a roof covering to protect against rain and driving rain. These steps are particularly important with fresh bamboo which will have a high moisture content and therefore be particularly susceptible to rot (Section 4.4.1).

An exception is where bamboo is transported by being floated down river. This process normally lasts only a few weeks, and therefore is not long enough for rot to occur, therefore is not an issue. However, the bamboo should be properly dried after such transport.

The longer the storage or transport time, the greater the importance of keeping the bamboo dry.

Bamboo treated with boron should be kept dry during storage and transport to site, as the boron can leach out if it is exposed to rain.



### 4.3.3 Keep bamboo away from insects

During storage and transport, bamboo should be kept away from insects as best as possible. Elevating the bamboo above the ground can help reduce the risk of

subterranean termite attack. Periodic fumigation could be considered where the storage facility is particularly large. Fumigation should use chemicals which kill termites and beetles, however these can be toxic to humans and therefore local health and safety regulations should be followed, including the use of appropriate personal protective equipment such as gas masks.

## 4.4 Treatment of bamboo using traditional methods

### 4.4.1 Seasoning (drying)

Seasoning (drying) of bamboo involves reducing its water content to be in equilibrium with the surrounding air. Seasoning of bamboo reduces the risk of insect and rot attack, and also increases its strength. Seasoning is best done in a sheltered environment where the bamboo is stacked such that it can breathe. Air seasoning of large diameter bamboo may take 2-4 months, and potentially more in high humidity areas.

In Cox's Bazar, the bamboo in the shelters will effectively dry fairly quickly in-situ anyway (with the exception of the bamboo placed directly into the ground, which will rot quickly). Bamboo used for bridges will be exposed to the elements so will not be able to dry. *Therefore, there does not appear to be any value in introducing seasoning into the supply chain.*

### 4.4.2 Water soaking (leaching)

Soaking in water/leaching is a traditional method of treating bamboo that is common across the world. This method involves submerging the bamboo in water (can be flowing or stagnant, fresh or salt) for typically 2 weeks to 2 months, during which some of the sugars (starch) in the bamboo diffuses out (Figure 35 and Figure 36).



Figure 30: Water treatment of bamboo by immersion in water (India)



Figure 31: Water treatment of bamboo by immersion in water (India)

The longer the soaking period, the better (typically closer to 2 months is recommended). Leaching is normally recommended on green fresh bamboo, as it's easiest for the sugars to leach out. The bamboo that is transported by floating down the river likely has some starches leached out for free, however since this transport

only takes ~2 weeks, it's not as long as is traditionally done, so probably has limited effect.

Water soaking reduces (but does not eliminate) the risk of beetle attack, however has no significant effect on termite or fungi attack.

Water soaking is a low-cost way of slightly improving durability. *Where the refugees have access to water and other treatments such as boron are not available, water soaking can be utilised at household level scale.*

#### 4.4.3 Other traditional methods which are not recommended

Other methods not recommended for Cox's Bazar include the following:

- **Clump curing:** immediately after harvesting, leave bamboo upright in the plantation for a few days (no more than a week), with the end of the culm standing on a stone (Rabik & Brown, no date; Liese & Kumar, 2003). This technique gives the culm time to continue to use up starch and water, reducing the levels of both, and so improving natural durability a little. *Because of the additional complexity of introducing this into the supply chain, for the added minimal benefit, this is not recommended.*
- **Smoke or fire treatment:** this method involves exposing bamboo to fire or smoke for a period ranging from 30 minutes to several hours. This method works by heat treating the outer layer of the culm and applying a thin layer of smoke to the outer layer (which makes it less attractive to beetles and termites). Bamboo fibres like timber fibres become damaged at temperatures >50 degrees (Kaminski et al., 2016b; Mena et al., 2012), and therefore it is likely that this treatment method actually damages and therefore weakens part of the culm wall, even if it does provide some protection. This method also does not provide any protection to the more susceptible inner skin of the culm, which is left at risk of termite, beetle and rot attack. Finally, this method exposes people involved in the treatment to smoke and also requires the burning of wood/coal or bamboo. *Therefore, smoke or fire treatment is not recommended.*
- **Others:** other “natural” or “sustainable” methods that anecdotally provide some protection to bamboo exist. *However, these tend to have limited or unproven efficacy, and some can actually be dangerous to humans, and therefore are not recommended.*

## 4.5 Treatment of bamboo using modern chemicals

### 4.5.1 Boron

Boron is a safe to use chemical (Green Building Press, no date; System Three, 2013) which protects very effectively against beetles and termites (Kaminski et al., 2016c), and can be commonly purchased in Bangladesh as a fertiliser. It can be safely disposed of by selling the waste chemical to farmers as a fertiliser. It can also protect a little against rot in high quantities. However, because it is water soluble,

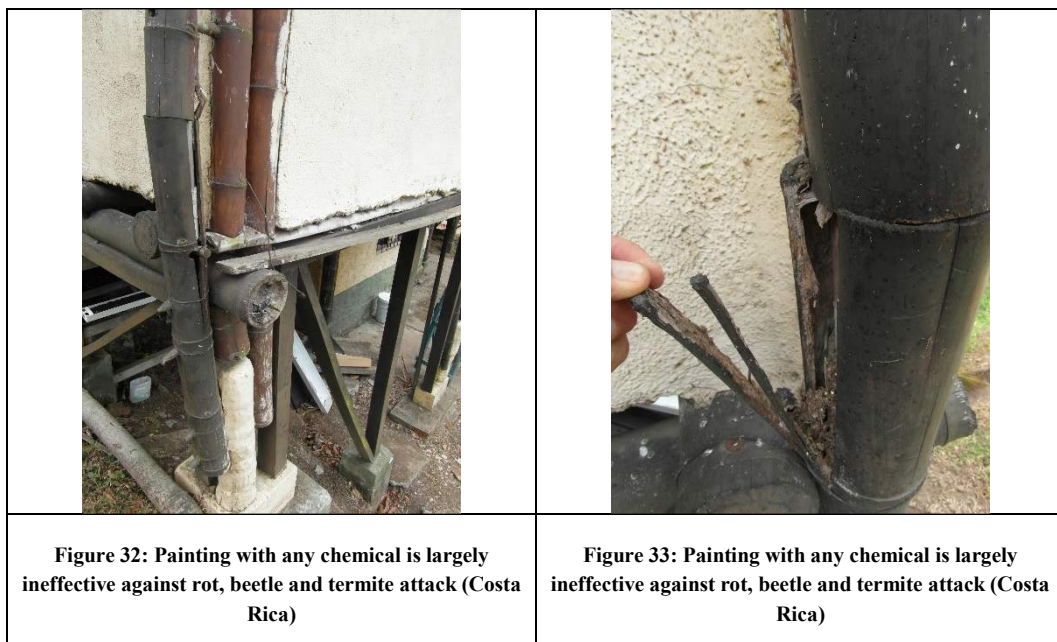
it can leach out over time if the treated bamboo is exposed to running water, such as rain. Boron is the standard method of treating bamboo internationally, and there is experience of using it in Bangladesh. Boron can also provide some protection against rot, however this protection should not be relied upon, since the boron can get washed out easily anyway.

*Boron is the only treatment chemical recommended for Cox's Bazar.* Boron treatment effectively negates the need to harvest the bamboo at a specific time, or soak the bamboo in water. By treating with boron, the lifespan of bamboo can be increased significantly (Table 4), provided that the bamboo is kept dry in service by “durability by design” (Section 4.6.1).

#### 4.5.2 Other modern chemicals which are not recommended

Other methods not recommended for Cox's Bazar include the following:

- Painting with conventional paint:** painting provides a thin layer of a water repellent coating to the outside of the bamboo (Figure 32 and Figure 33). Painting reduces the amount of water that is absorbed in light rain, however does not completely prevent water ingress especially if the bamboo splits, provides effectively no protection if the bamboo is embedded in the soil, and provides no protection against beetles or termites. Paint also deteriorates rapidly in the sun, and would therefore need to be reapplied very frequently to have any benefit.



- Painting with coal tar/bitumen/used engine oil:** this method involves painting the outer skin of the bamboo with these chemicals, which are toxic to beetles, termites and fungi, so in theory this would provide a thin outer protective barrier against them. However, this method is not recommended because of the following:
  - The method only protects the outer layer of bamboo, however since it is not possible to paint the inside, termites and beetles can still get

in, and the bamboo can also still rot on the inside. *Therefore, its efficacy is very limited.*

- Bamboo will naturally swell or shrink when exposed to water or changes in humidity. This change in size will crack the protective layer, and even small gaps allow beetles, termites and water to enter.
- Coal tar and used engine oil are known carcinogens (Koppers, 2017; HSE, 2017). The risks to the user are during application (communities will inevitably be applying this without any gloves or protection); during use (children may touch the bamboo and then eat with their hands); during disposal of leftover material (waste oil or coal tar is likely to be poured into the soil, which could make its way into drinking water or be absorbed by crops), and at end of life (old bamboo is normally burned. However burning coal tar and engine oil releases toxins).

Although widely used in the humanitarian and development sector, this method is in fact much less effective than many believe.

- **Other modern fixed preservatives:** examples include (Liese & Kumar, 2003; Lebow, 2004): copper sulphate, dispersed copper azole, copper-chrome arsenic, creosote, dursban, sodium pentachlorophenate. While some of these can be very effective, they are all either expensive, complex to apply or carry significant health risks during application and at end of life.

## 4.6 In design/construction

### 4.6.1 “Durability by design”

Durability by design involves designing a structure such that it has characteristics which improve its durability. For bamboo structures in Cox's Bazar, the key recommendations are provided below (Figure 41) – note that the same recommendations apply to all structures (shelters, community buildings and bridges):

1. Elevate and separate the bamboo frame from the ground with a good barrier, such as a reinforced concrete footing (Figure 34). This significantly reduces the risk of rot to the base of the columns, and forces subterranean termites out into the open, where their tunnels can be destroyed (Figure 17). **DO NOT CAST BAMBOO INTO CONCRETE.** Bamboo cast into concrete cannot breathe and normally rots very quickly (Figure 22, Section 4.6.2). If possible, also place a plastic sheet between the concrete surface and the bamboo frame, to act as a damp-proof membrane, to reduce the risk of the bamboo base absorbing water directly from the concrete.
2. Create a watertight roof to protect the bamboo frame below (Figure 35).



**Figure 34: Elevate and separate frame from ground using a concrete footing, with the bamboo sitting on top and bolted to it via a cast in steel plate. Ideally also place a plastic membrane between the concrete and the bamboo (Cox's Bazar)**



**Figure 35: Create a watertight roof and walls. Small overhangs are recommended to stop water running down the sides of the walls (Cox's Bazar)**



**Figure 36: Allow the bamboo to breathe inside the waterproof envelope (Cox's Bazar)**



**Figure 37: Veranda added to sides of house to protect against driving rain damage (India)**

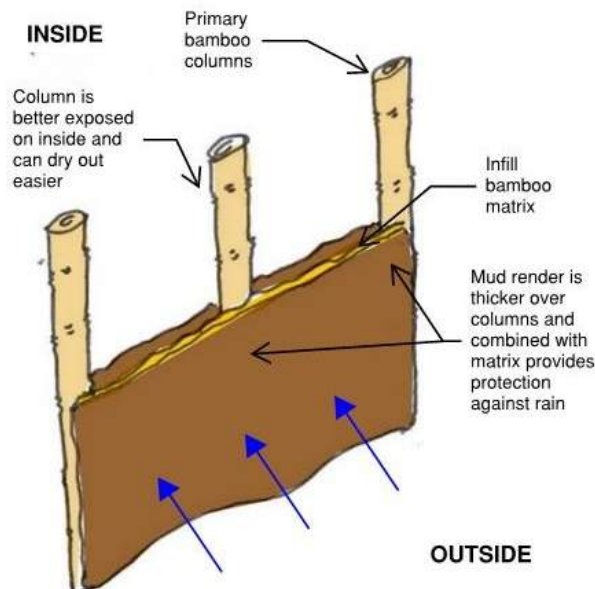


**Figure 38: Protect all exposed bamboo from driving rain, such as here using split bamboo to protect a veranda column. Note however this can hide termite tunnels. (Cox's Bazar)**



**Figure 39: Mud plaster also provides some protection, although ideally the bamboo is still able to "breathe" on the inside face. Note however this can hide termite tunnels. (India)**

3. Create as water watertight walls as possible to protect the bamboo frame inside (Figure 35). Mud plaster also provides some protection (Figure 39). Ensure the bamboo is completely protected on the outside (Figure 40), although ideally the bamboo will still be able to “breathe” on the inside face.
4. Create an overhang on all four sides to reduce the risk of wind-blown/driving rain hitting the walls (Figure 35). Too large an overhang will however increase wind loads on the structure, therefore a compromise must be made between the two.
5. All bamboo to be allowed to “breathe” inside the waterproof envelope (Figure 36).
6. Avoid water traps, particularly on horizontal beams and at connections and at the bases of columns (Figure 41).
7. Train the community to be aware of termite tunnels/shelter tubes (Figure 17), and to destroy them when they are seen (Kaminski et al., 2016c).



**Plan view of recommended matrix construction method:**

***Matrix is installed outside of primary columns***

**Figure 40: Plastering recommendations**

The following recommendations are more difficult to achieve, but can also have a good benefit:

1. Use verandas to extend the roof, reducing the amount of driving rain that hits the main walls (Figure 37). Note that verandas will attract large upward wind loads, therefore these should be designed accordingly and fixed down well. The columns supporting the edge of the veranda should be inset to reduce their exposure to rain and replaced as required.

- Elevate the building on an earth plinth, such that it is above any areas of standing water, to reduce dampness in the foundation of the building (Figure 41).

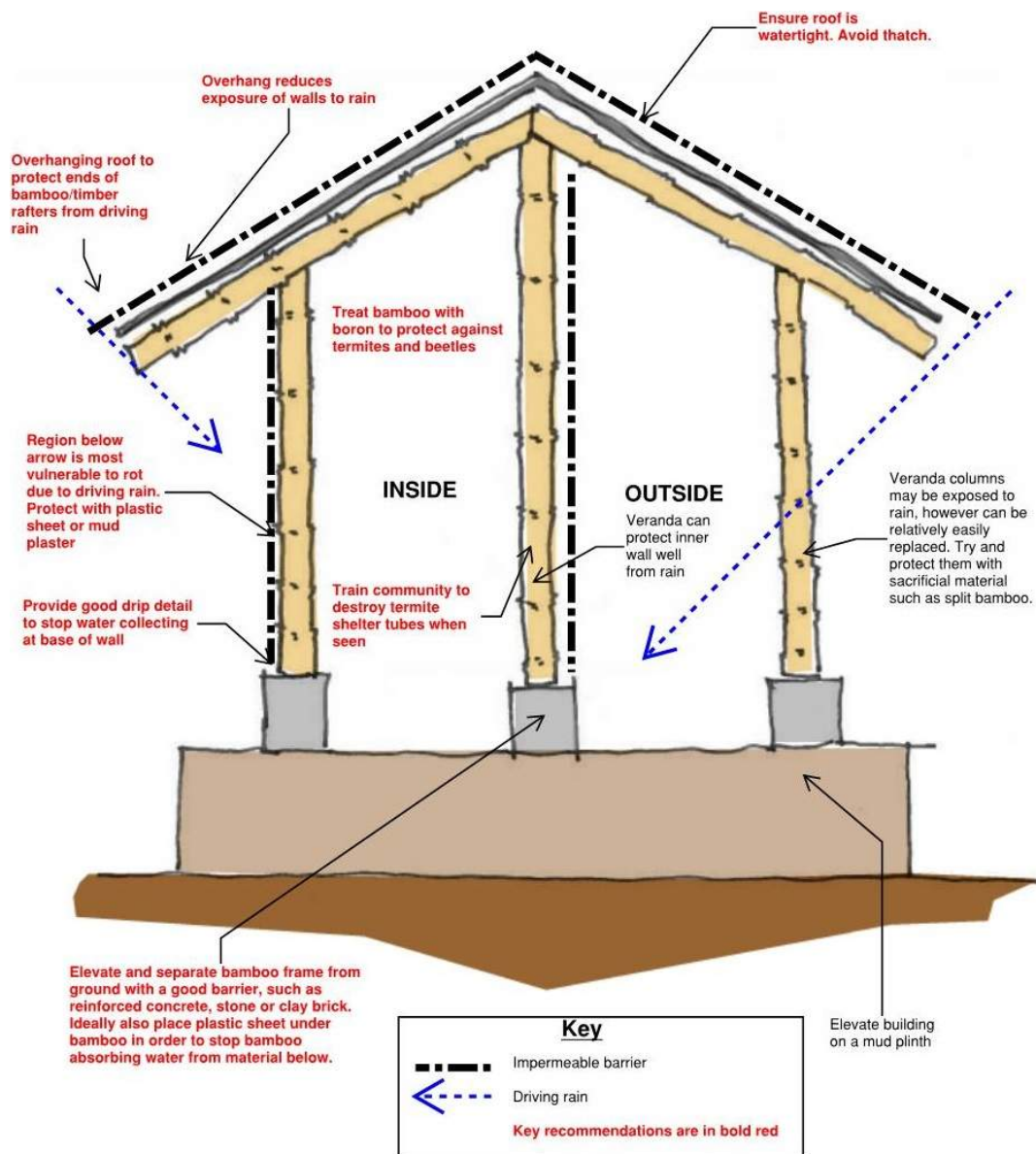


Figure 41: Summary of key recommendations for “durability by design”

#### 4.6.2 Why is casting bamboo into concrete a bad idea?

Casting bamboo into concrete is an easy way to create a quick and solid foundation. It is commonly used in humanitarian and longer term developmental contexts for these reasons. However, it is **never** recommended for the following reasons:

- Bamboo cast into concrete tends to rot quickly. When bamboo is cast into concrete it actually attracts and traps water in the following three ways, while simultaneously preventing it from breathing and drying:



- a. Water from rain that flows down the culm or from the concrete surface can trickle down into the tiny gap between the culm and the concrete.
  - b. If the culm is installed green there is already excess moisture in the bamboo.
  - c. Concrete is hygroscopic, which means it has the ability to absorb water. Concrete will therefore absorb water from the soil, further wetting the cast-in bamboo.
2. Termites can easily access the cast-in bamboo, from the top surface or through cracks as small as 0.8mm (University of Tennessee Agricultural Extension Service, 2001). Concrete is likely to exhibit cracks from temperature, shrinkage and load effects. Any termite attack will also be hidden since the bamboo is cast-in.

Casting bamboo into concrete therefore is effectively like placing the bamboo into a bucket of water.

Attempting to seal the bamboo from the water by placing it into a plastic bag, or placing the footing into a plastic bag, also generally does not work, because water can still enter by one or several of the above methods, and even small tears in the plastic can allow water to enter.

Attempting to seal the gap between the bamboo and the concrete or plastic bag also does not work, as it is virtually impossible to create such a seal.

Well-built and successful vernacular constructions throughout the world do not cast bamboo into concrete – instead, they place the bamboo frame on top of an elevated upstand of stone or concrete. Casting bamboo into concrete is a modern "innovation".

Combining painting bamboo with coal tar/bitumen/used engine oil (Section 4.5.2) with casting bamboo into concrete also generally does not work for the same reasons.

### **4.6.3 What about when bamboo is used for slope stabilisation or drainage channels?**

Bamboo is currently used for slope stabilisation and drainage channels in Cox's Bazar. This unfortunately exposes bamboo to water, reducing its design life to 0.5-1 years (Section 3.4). There are no practical or appropriate ways to improve the design life of such bamboo – as described in Section 4.5, the only method appropriate for Cox's Bazar is boron, which will wash out in running water; other fixed chemicals are very expensive and dangerous to human health. Therefore, it is recommended to simply use untreated and unprotected bamboo for slope stabilisation and drainage channels, and replace it periodically – this is likely to work out cheaper and safer in the long term (compared to expensive chemical treatment), and is what is traditionally done.

#### 4.6.4 What about bridges?

Exactly the same principles outlined in Section 4.6.1 apply for bridges. This means that bamboo bridges that are uncovered and exposed to the elements will have a very short design life, even if they are treated with boron.

#### 4.6.5 What about two-storey structures?

Exactly the same principles outlined in Section 4.6.1 apply for two-storey structures. In practice, two storey structures without a waterproof wall are considerably more vulnerable to rot compared to one storey structures without a waterproof wall, because of the following:

- The amount of driving rain that hits the lower part of the structure is much more, which in practice means that the boron gets washed out quicker, and rot is more likely.
- The edge of the second floor structure is generally exposed. Horizontal beams are considerably more vulnerable to rot because it is more difficult for water to run off them quicker, and inevitable splits allow water to enter and collect.

Therefore, two-storey structures need more consideration for waterproofing. It is recommended that all two-storey structures should have a waterproof wall.

## 4.7 Comparison between treatment methods

Table 3 presents a comparison between the various treatment methods for bamboo, how easy they are to implement, and how effective they are in different scenarios, in the Cox's Bazar context.

	Immature	Mature	Mature, water treated	Mature, boron treated	Mature, modern fixed preservative
Cost	✓✓	✓✓	✓	⚡	✗✗
Complexity	✓✓	✓✓	✓	⚡	✗✗
Health risks during treatment	✓✓	✓✓	✓	✓	⚡
Health risks at disposal	✓✓	✓✓	✓✓	✓	⚡
Protection against beetles	✗✗	✗ (natural protection)	⚡	✓✓	✓✓
Protection against termites	✗✗	✗ (natural protection)	✗	✓✓	✓✓
Protection against rot	✗✗	✗	✗	✓✓	✓✓
Likely lifespan: internal, protected from rain and moisture	✗✗ 0.3-5 years	⚡ 1-5 years	✓ 2-10 years	✓✓ 30+ years	✓✓ 30+ years
Likely lifespan: external above ground	✗✗ 0.3-4 years	✗✗ 0.5-4 years	✗✗ 0.5-4 years	✓ 2-10 years	✓✓ 20+ years
Likely lifespan: external in ground contact	✗✗ 0.3-0.5 years	✗✗ <0.5 years	✗✗ <0.5 years	✗✗ <1 year	✓ 10+ years

Table 3: Comparison between various treatment methods for bamboo, how easy they are to implement, and how effective they are in different scenarios, in the Cox's Bazar context. Note lifespan's shown are very approximate.

## 4.8 Existing bamboo structures

If any existing bamboo structures are experiencing issues with rot or insect attack, and there is a need to improve their durability, in most cases it is simplest and most

effective to demolish the building and rebuild. If this is not feasible the following can be considered:

- Retrofit the structure to incorporate as many of the “durability by design principles” as possible (Section 4.6.1).
- Spraying on boron directly onto the frame *may* reduce the risk of further insect attack, however this is much less effective compared to the methods recommended in Section 5.2.

Fumigation likely has little impact on beetles and insects already inside the bamboo.

## 4.9 Summary of recommendations

1. The two key recommendations for improving durability of bamboo in Cox's Bazar are presented below, in order of priority and impact. Both are required (introducing one does not negate the need for the other): **Incorporate durability by design, in particular the use of footings to isolate the bamboo frame from the ground, and creating watertight walls and roofs.** This is considered as *more important* as treating the bamboo, since treated bamboo will still rot quickly in the ground.
2. **Treat bamboo with boron.** The most appropriate method of treating bamboo is considered to be boron.

In addition to the above, the following are also recommended – these will have a smaller impact on durability, but are still worthwhile:

3. **Select mature bamboo.** It is recommended attempting to influence the bamboo supply chain by harvesting mature bamboo only. Harvesting immature bamboo can also reduce clump productivity.
4. **Keep bamboo away from insects during transport and storage, prior to treating with boron**
5. **Keep bamboo dry during transport and storage, both before and after treating with boron.**

If boron treatment is not available:

6. **Alternatives to boron.** If boron treatment is not possible, it is recommended to attempt to influence the bamboo supply chain by harvesting at optimal times, and then soaking the bamboo in water for 4-8 weeks, but effectiveness will be limited.

## 5 Boron Treatment

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Bamboo can be treated with boron in a number of different ways (Liese & Kumar, 2003; Kaminski et al., 2016c). All methods allow the boron to diffuse through the walls of the culm, with the aim of treating the entire thickness of the culm walls. The most appropriate for Cox's Bazar are given below.

### 5.1 Treatment chemicals

There are a number of boron-containing compounds which can all be used for treating bamboo. These compounds are slightly different in their ease of use, but they are all equally effective, and can be used interchangeably with the different methods of treatment. The compounds are normally available as fertilisers.

- Disodium octoborate tetrahydrate ( $\text{Na}_2\text{B}_8\text{O}_{13}\cdot 4\text{H}_2\text{O}$ ) (also known as the acronym "DOT"). This comes as a single ready to use compound. It is the most readily soluble of the boron-containing compounds. Trade names include "borosol" and "solubor".
- Borax ( $\text{Na}_2[\text{B}_4\text{O}_5(\text{OH})_4]\cdot 8\text{H}_2\text{O}$ ) and boric acid ( $\text{H}_3\text{BO}_3$ ). These two boron-containing compounds need to be used together, as they are only soluble when mixed. A general rule for quantities is 3kg borax + 2kg boric acid, per 45 litres of water.

**All boron-compounds are soluble and will therefore leach out when exposed to rain. It is not possible to chemically fix boron into the bamboo.**

In order to be affective, it is recommended to add boron to water such that the concentration reaches 10-12%, although lower concentrations will still likely have some affect (Liese & Kumar, 2003).

It is generally recommended to treat bamboo with boron via the methods below while it is still fresh – normally between 7-14 days after cutting – and therefore ideally the bamboo will be treated with boron immediately upon arrival in the camps. If bamboo which is less fresh is treated, the treatment methods are still likely to be relatively affective, but it is harder for the boron to diffuse through the full thickness of the culm wall

The water used for the boron treatment should be clean **freshwater**. It is possible that salt-water may interfere with the solubility of the boron (both compounds above). If there is a demand to use salt-water for boron treatment, it is recommended that a laboratory boron solubility test is conducted, to see if and how much the salt interferes with the boron's solubility, and whether this is acceptable or not (i.e. whether enough still dissolves for the treatment method to be effective).

The boron liquid can be re-used in all of the following methods, however, over time, the liquid will fill with dirt and sap, which may affect the hydrometer reading, and may interfere with the efficacy of the treatment. The liquid should therefore be periodically cleaned in the following ways:

- Filtered through a fine filter to remove dirt.

- Coagulating the sap and then removing it and disposing of it safely (Section 5.2.8).

Experienced bamboo treatment workers can advise on the best methods.

## 5.2 Treatment methods

### 5.2.1 Cold-water bath

This method involves placing the bamboo in an unheated water bath for 10-14 days, during which time the boron diffuses through the bamboo walls. After treatment, some diffusion continues. It is the “lowest tech” method and therefore the hardest to go wrong and the easiest to replicate. However, it is slow. The cold-water bath treatment method will work on both *Borak* and *Muli* bamboo. A typical treatment method is as follows:

1. Thoroughly clean outside of bamboo with brush and water to avoid adding dirt to bath, which could affect the hydrometer reading.
2. Either: pierce all nodal diaphragms by inserting a long steel reinforcing bar through the length of the culm; or drill two holes directly in each intermodal space. Both of these methods allow the boron-containing liquid to enter the inside of the culm.
3. Fill bath with water to half-way level. Mix borax and boric acid in bath slowly until dissolved. Check solution with a hydrometer – the specific gravity should be around 1.06 for a 10% concentration, or 1.07 for a 12% concentration (see Liese, Gutiérrez & González (2002) for an accurate graph of how specific gravity of a boron-containing mixture varies with concentration and temperature). The bath can be a concrete tank (e.g. an empty shrimp hatchery tank) or a hole in the ground lined with a heavy duty plastic bag or concrete, but should be protected against rain and should not leak (to avoid contamination). The bath needs a method of safely draining and disposing of the used boron liquid.
4. Place culms in bath. Weigh down culms with clean weights such that they are completely submerged. Culms require a method of removing them safely.
5. Leave culms in bath for 10-14 days. The longer the bamboo is in the solution, the more effective the treatment. The exact time should be determined by testing (Section 5.2.6).
6. Carefully remove culms, allowing them to drain excess liquid back into the bath.
7. Culms are normally seasoned after treatment, but for Cox's Bazar it is recommended to miss this step, use them immediately and simply allow them to season in service.
8. The bath liquid should be periodically filtered to remove dirt. Additional boron and water may need to be added from time to time to maintain the

concentration. A hydrometer can be used to maintain the boron at adequate levels, however as dirt and sugars accumulate in the liquid, the hydrometer reading may become inaccurate.

9. There are techniques to periodically coagulate and then remove the sap. The bath liquid may also require a full replacement after many cycles, as it may be too dirty to continue to be used, even if the sap is coagulated and the water filtered.
10. A single bath 7m long x 2m deep x 3m wide can treat 200x 6m large-diameter culms every 10-14 days (~5000 culms per year).



**Figure 42: Culms should be cleaned before placing in bath, to avoid adding dirt to bath, which could affect the hydrometer reading (Colombia)**



**Figure 43: Culms should have their nodal diaphragm pierced as shown, or alternatively each internodal region should have two holes drilled into them (Colombia)**



**Figure 44: Bamboo treatment bath using boron (Colombia)**



**Figure 45: Empty shrimp hatchery in Cox's Bazar could be used for bamboo treatment with boron (Cox's Bazar)**

## 5.2.2 Hot-water bath

This method is identical to the cold-water bath, however by heating the liquid to around 50 degrees, the boron diffuses much faster and therefore the treatment method can be sped up considerably, to around 8 hours. This is more “high-tech” than the cold-water or vertical soak diffusion method, and therefore more costly to construct, operate and maintain, and more likely to go wrong, however it is fast and likely to be more effective when conducted properly. The hot-water bath treatment

method will work on both *Borak* and *Muli* bamboo. A typical treatment method is as follows:

1. Thoroughly clean outside of bamboo with brush and water to avoid adding dirt to bath, which could affect the hydrometer reading.
2. Either: pierce all nodal diaphragms by inserting a long steel reinforcing bar through the length of the culm; or drill two holes directly in each intermodal space.
3. Fill bath with water to half-way level. Mix borax and boric acid in bath slowly until dissolved. Check solution with hydrometer. Bath should be a concrete tank (e.g. empty shrimp hatchery tank) or a hole in the ground lined with concrete. Bath needs a method of heating the liquid, maintaining the temperature correctly at 50 degrees, safely draining and disposing of the used boron liquid. Heating the liquid could be done using an electrical heating element or a solar heat exchanger.
4. Place culms in bath. Weigh down culms with clean weights such that they are completely submerged. Culms require a method of removing them safely.
5. Leave culms in bath for 8 hours. The longer the bamboo is in the bath, the more effective the treatment.
6. Carefully remove culms, allowing them to drain excess liquid back into the bath.
7. Culms are normally seasoned after treatment, but for Cox's Bazar it is recommended to miss this step, use them immediately and simply allow them to season in service.
8. The bath liquid should be periodically filtered to remove dirt. Additional boron and water may need to be added from time to time to maintain the concentration. A hydrometer can be used to maintain the boron at adequate levels, however as dirt and sugars accumulate in the liquid, the hydrometer reading may become inaccurate.
9. There are techniques to periodically coagulate and then remove the sap. The bath liquid may also require a full replacement after many cycles, as it may be too dirty to continue to be used, even if the sap is coagulated and the water filtered.
10. Assuming the bath is only used for one 8h treatment cycle per day, a single bath 7m long x 2m deep x 3m wide can treat 200x 6m large-diameter culms every 8 hours (~70,000 culms per year). If production increases to two 8h cycles per day, the same bath can treat ~140,000 culms per year.

### 5.2.3 Vertical soak diffusion (VSD)

This method involves treating the culms by placing them upright, filling the inside with the boron-containing liquid and leaving them there for 10-14 days, during which the boron diffuses through the bamboo walls (Environmental Bamboo



Foundation, 2003). After treatment, some diffusion continues (Figure 46). This method is similar in effectiveness to the cold-water bath, however has the potential for a slightly higher output rate as it is not limited by bath size or number, however is a little more complex. The VSD method can only be conducted on large-diameter culms, therefore will work on *Borak* bamboo, but not *Muli*. If the bamboo arrives cracked full-thickness, the liquid will leak and therefore this method will not work.

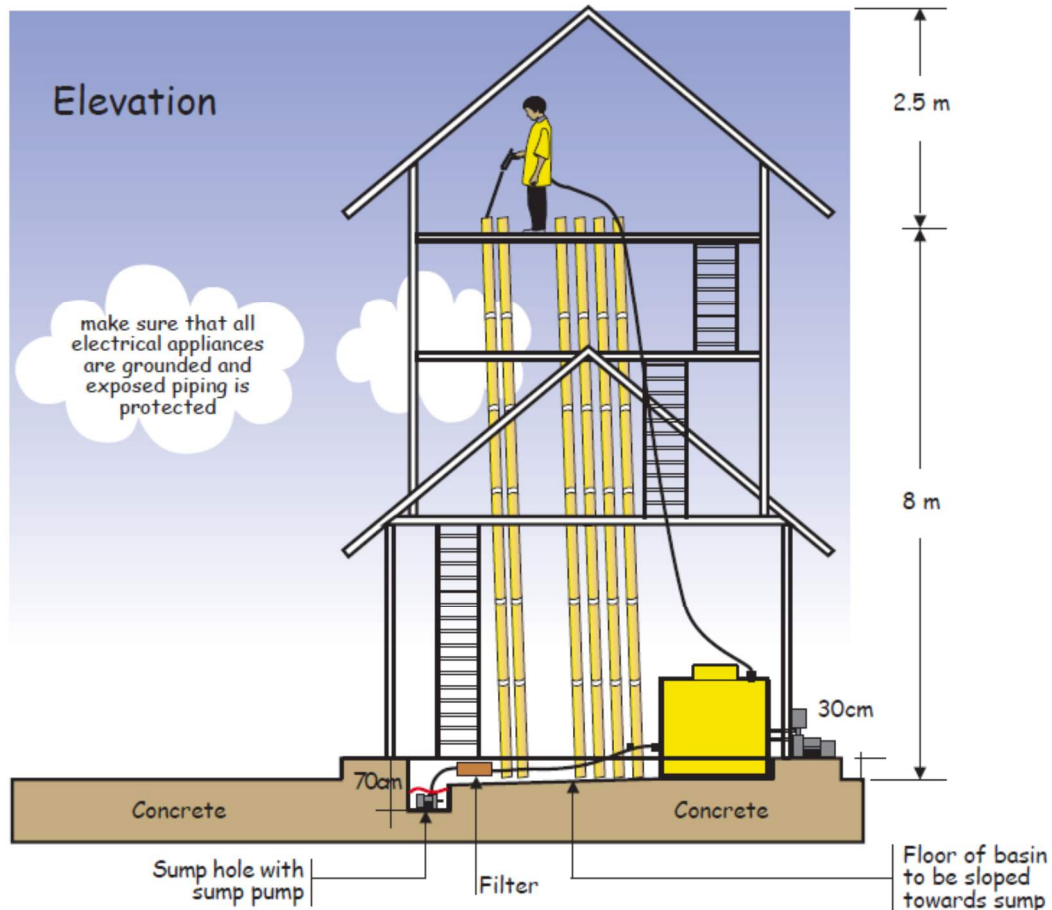


Figure 46: Vertical soak diffusion method (Environmental Bamboo Foundation, 2003)

A typical treatment method is as follows:

1. Pierce all nodes except the one at the base using an 8m long steel reinforcing bar.
2. Place culm upright.
3. Fill culm with boron-containing liquid to brim. This will require a method of holding the culms vertically, and a method of reaching the top of the culm – often a simple tower is constructed for this.
4. Leave culm vertically for 10-14 days. Periodically top-up with liquid lost due to evaporation and absorption by the bamboo. The longer the bamboo is in the solution, the more effective the treatment. The tops of the culms should be protected against rain to prevent the water inside the bamboo being diluted with rain.

5. Pierce final node, allowing liquid to drain out of culm. Collect liquid after use. Simplest method to do this is to create a concrete platform with a slope down to a sump where the liquid can be pumped from.
6. Culms are normally seasoned after treatment, but for Cox's Bazar it is recommended to miss this step, use them immediately and simply allow them to season in service.
7. Liquid should be periodically filtered to remove dirt. Additional boron and water may need to be added from time to time. A hydrometer can be used to maintain the boron at adequate levels, however as dirt and sugars accumulate in the liquid, the hydrometer reading may become inaccurate.
8. The liquid should be replaced periodically as it will become too dirty and filled with sugars to be effective. Different experience exists with this, but as a starting point assume the liquid is replaced after 20 cycles.
9. The output of a VSD facility depends on the number of culms that can be stored simultaneously vertically. Assuming a continuous production of infilling a culm every 5 minutes over 8 hours allows, 100 culms to be treated per day, which equates to 36,000 per year. This would require 1400 culms to be stored simultaneously, which requires an area of around 5m x 5m which is capable of safely storing 1400 culms vertically.

#### 5.2.4 Other methods

Other methods of treating bamboo with boron also exist, such as the “boucherie method” which involves displacing the sap and filling the culm directly with boron under pressure using a pressure vessel. These are all more complex, costly or can only be conducted within 24 hours of harvesting the bamboo, and are therefore not considered appropriate for Cox's Bazar.

#### 5.2.5 Ensuring *good enough* quality assurance

The facilities are not trying to produce bamboo which has been reliably treated to an international standard – they need to produce bamboo which has been treated in a manner that it is *good enough* to reduce the risk of insect attack, considering the refugee camp context. Therefore, the following are the key areas which should be focused on:

- **Proportion of boron in the water:** the proportion of boron in the water must be maintained at the required level, otherwise the percentage retention of the boron in the bamboo may be inadequate. The water should be routinely topped up with boron as some of the active chemical will be retained in the bamboo in each cycle.
- **Cleanliness of the water:** over time the water will accumulate dirt, soil and sugars from the bamboo. This can affect the efficacy of the treatment method and make it harder to monitor the water for boron content using a hydrometer (as it will interfere with the hydrometer's readings). It is recommended to periodically filter the water to remove contaminants.

- **How well dissolved the boron is in the water:** if the boron is not properly dissolved in the water, it will not be able to diffuse into the culm. It is therefore essential that the boron is properly dissolved at the beginning, and periodically throughout the treatment process if settlement of the boron occurs.
- **Treatment times:** optimal treatment times vary depending on the species of bamboo, how fresh it is, the temperature of the water, the concentration of the boron, and the cleanliness of the water. The treatment times provided above are based on experience. It is suggested that these should be maintained as a minimum, unless reliable experience suggests otherwise, and has been validated by testing as discussed below.

### 5.2.6 Ensuring the treatment method is effective.

Based on the published evidence and international experience to date, the treatment methods described above with boron should be effective against termites and beetles. However, because the bamboo that arrives in the camp will have a range of times since harvest, the quality control in the camp may be limited, and some of the variables such as how often the liquid can be reused is not yet confirmed, it is recommended to conduct some testing to ensure the amount of retained boron is adequate. This testing will give more confidence in the efficacy of the treatment at the beginning and moving forward, and also allow the treatment to be optimised. The testing recommended is as follows:

1. Once the treatment workshop opens, a sample of 10-20 treated bamboo pieces to be sent to an appropriate laboratory for testing for boron as follows:
  - a. Atomic absorption spectroscopy. **This is the only way of identifying exactly how much boron has managed to diffuse to each part of the culm wall.** This can be conducted at specific universities or chemical testing laboratories.
  - b. Turmeric indicator test. This is a simple way of identifying whether or not boron is present in the culm. **It is indicative and does not give a reliable way of identifying the amount of retained chemical.** The detailed method is provided in Liese & Kumar (2003). The first turmeric tests can be approximately calibrated against the spectrum tests in order to confirm the colour required.
2. Periodically (initially every 10 cycles, and later less frequently) conduct turmeric indicator test on site.

The periodic tests can be checked against the initial test to ensure the treatment is continuing to be done effectively.

Some facilities suggest adding dyes to the boron-containing water in the VSD method. The idea is that once the dye colour is visible on the outside of the culm, the boron has diffused throughout the culm wall. This method is not recommended, as dyes and boron diffuse at different rates and therefore this is not necessarily a true reflection of the efficacy of the treatment.

### 5.2.7 Safe use

It is recommended to follow the manufacturer's data sheets on safe use of boron, which may include appropriate personal protective equipment. Examples of boron data sheets include System Three (2013).

### 5.2.8 Safe disposal

In high concentrations, boron can cause health problems in humans, and can damage plants. However, in low concentrations boron is an essential plant mineral, and used routinely as a fertiliser. Waste boron liquid must therefore be disposed of properly – it cannot simply be poured into the soil, river, or sea. This is particularly important in Cox's Bazar where the refugees obtain potable water sources from surface water and wells of varying depth and quality. Two safe disposal methods are suggested:

1. Sell waste liquids and solids to local farmers who can then dilute it down to use on their fields. This would require ensuring the farmers know how to use the fertiliser properly and not excessively.
2. Use a managed reed bed or similar system to naturally use up and break down the boron, in a similar way to how they are used to treat grey-water sewage.

## 5.3 Summary

Table 4 presents a comparison between the three different possible methods of treating bamboo with boron in Cox's Bazar. Each of the methods have their own advantages and disadvantages, however generally:

- If mainly Borak is to be treated, the culms are generally not cracked or damaged, and very large scale treatment is required, VSD may be the preferred solution, since little infrastructure is required, and the rate of production is high.
- If both Borak and Muli are to be treated, and/or the culms are generally cracked, then one of the bath methods will be more appropriate:
  - If lower production is required, or there are enough empty tanks to fulfil production requirements, then the cold-water bath method is probably adequate.
  - If high rates of production are required, or there are insufficient empty tanks to fulfil production requirements, then the hot-water bath method is likely to be the most appropriate.

	Cold-water bath	Hot-water bath	Vertical soak diffusion
Initial cost	✓	✗	✓
Running cost	✓	⤵	✓
Complexity	✓✓	⤵	✓
Speed of treatment	✗	✓	✗
Typical number of culms treated per day	✗ 15-20	✓✓ 200-400	✓✓ 100+ (easy to scale up)
Effectiveness	✓	✓✓	✓
Can both Borak and Muli be treated?	✓✓	✓✓	✗ Only Borak
Can cracked bamboo be treated?	✓✓	✓✓	✗

Table 4: Comparison between the three different potential methods of treating bamboo with boron in Cox's Bazar

## 6 Common misconceptions

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The following are a number of common misconceptions regarding the durability and treatment of bamboo, which are especially pertinent in the context of Cox's Bazar.

1. *Painting bamboo with coal tar/bitumen/used engine oil and placing it in the soil is effective against insects and rot.* This method is ineffective against preventing insects and rot – the toxic chemicals only provide a thin layer on the outside of the bamboo, however the inside is unprotected and normally still decays relatively rapidly. See Section 4.5.2 for more information.
2. *Casting bamboo into concrete is effective against insects and rot.* This method is ineffective against preventing insects and rot – concrete is porous and termites can still enter. The concrete also prevents the bamboo from “breathing”, leading to rot. See Section 4.6.2 for more information.
3. *Once bamboo is treated with boron, it can be exposed to rain.* Boron treated bamboo cannot be exposed to rain because the boron gets washed out.
4. *Only a small roof overhang is required to protect bamboo from rain.* Rain in the tropics does not fall vertically – with wind it can quickly soak a wall protected by only a small overhang.
5. *The type of species of bamboo greatly affects its durability.* Different bamboo species do have different levels of durability. However, based on the published evidence to date, selecting a species because it is anecdotally known to be more durable has far less effect than treating the bamboo or keeping it dry. It has been observed for example that the Muli in the camps is experiencing less beetle attack than the Borak. However, this is not necessarily a conclusive test of natural durability – the Muli might have been better seasoned before arrival, or alternatively all of the Muli might be mature, compared with the unseasoned and immature Borak that is arriving. Nonetheless, the Muli remains very vulnerable, even if less beetle attack has been observed to date.

## 7 Further Reading

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The following documents are recommended for further reading on bamboo and the durability and treatment of bamboo:

- Technical Note Series: Structural use of bamboo – Part 1: Introduction to bamboo: A general introduction to bamboo (Kaminski et al., 2016a): [https://www.istructe.org/journal/volumes/volume-94-\(2016\)/issue-8/structural-use-of-bamboo-part-1-introduction-to-b](https://www.istructe.org/journal/volumes/volume-94-(2016)/issue-8/structural-use-of-bamboo-part-1-introduction-to-b).
- Technical Note Series: Structural use of bamboo – Part 2: Durability and Preservation (Kaminski et al., 2016ab): [https://www.istructe.org/journal/volumes/volume-94-\(2016\)/issue-10/structural-use-of-bamboo-part-2-durability-and-pr](https://www.istructe.org/journal/volumes/volume-94-(2016)/issue-10/structural-use-of-bamboo-part-2-durability-and-pr).
- Humanitarian Bamboo Guidelines: General guide on using bamboo in humanitarian contexts (Humanitarian Bamboo, 2009): [http://humanitarianbamboo.org/wp-content/uploads/2018/03/IFRC\\_SHELTER\\_2009\\_hmntrn\\_bmbooDv2-1.pdf](http://humanitarianbamboo.org/wp-content/uploads/2018/03/IFRC_SHELTER_2009_hmntrn_bmbooDv2-1.pdf).
- Technical Brief: Bamboo Preservation Guide: A general guide on bamboo preservation (Practical Action, n.d.): <https://answers.practicalaction.org/our-resources/item/bamboo-preservation>.
- Vertical soak diffusion for bamboo preservation: A detailed guide on the VSD method for bamboo preservation (Environmental Bamboo Foundation, 2003): <http://www.bamboocentral.org/index1.htm>

## 8 Further Information

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This Technical Guidance Note has been prepared by Arup at the request of the Shelter & NFI Sector as a contribution to the humanitarian response.

For further information please contact: **sebastian.kaminski@arup.com** or **international-development@arup.com**



## 9 Disclaimer

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1. This guidance is provided for information purposes only. Anyone using this guide must satisfy themselves regarding the application of statutory requirements, local building regulations, codes, insurance certification or other requirements or recommendations relevant to the location where and materials with which they plan to build. Examples of local conditions that will change the design include climate (flooding, temperature variation, insects), soil mechanics (foundations), seismic characteristics (earthquakes), chemicals and legislation regarding inclusive safe access (including emergency egress for fire).
2. This guidance is provided on an “as is” basis, without representation, warranty or indemnity of any kind. To the maximum extent permitted by applicable law, Arup disclaims all representations or warranties – express, implied, statutory or otherwise – including (but not limited to) implied warranties of fitness for a particular purpose, accuracy or validity or completeness of information, merchantability, title, quality, and non-infringement.
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4. Construction is an inherently risky activity. You must ensure you have adequate skills to safely assemble (and disassemble) shelter buildings. You must procure advice from a competent person if there is any doubt as to your own competence to design, assemble, adapt, commission or disassemble emergency shelter buildings. Such advice can be readily obtained from professional architects, engineers, and builders.

## References

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Amer, J. (1992) A Note on the Taxonomic Problems, Ecology and Distribution of Bamboos in Bangladesh. In: *Bamboo Science and Culture – the Journal of the American Bamboo Society*, 9, pp. 1-7.

Antonelli, A. (2002) *Termites: Biology, Prevention and Control (EB0787)*. Washington, US: Washington State University

BRE (1999) *Termites and UK Buildings: Biology, detection and diagnosis – Digest 443 Part 1*. Bracknell, UK: BRE.

BTSG-KFR National Bamboo Mission (2015) *Manual for establishment and management of bamboo plantations*. [ONLINE]. Available from: [http://nbm.nic.in/PDF/Manual\\_Bamboo\\_Plantations.pdf](http://nbm.nic.in/PDF/Manual_Bamboo_Plantations.pdf). (Accessed August 2017).

Climate-data.org (2018) *Climate Cox's Bazar*. [Online]. Available from: <https://en.climate-data.org/location/56253/>. (Accessed October 2018).

Environmental Bamboo Foundation (2003) *Vertical soak diffusion for bamboo preservation*. [Online] Available from: <http://www.bamboocentral.org>. (Accessed November 2014).

Green Building Press (n.d.) *Boron, our Health and the Environment*. [Online] Available from: <http://www.greenbuildingpress.co.uk/archive/Boron.php>. (Accessed November 2014).

GuaduaBamboo (2017) *Bamboo Species*. [Online]. Available from: [www.guaduabamboo.com/species](http://www.guaduabamboo.com/species). (Accessed August 2017).

HSE (2017) *Used Engine Oil*. [Online]. Available from: [www.hse.gov.uk/mvr/topics/oil.htm](http://www.hse.gov.uk/mvr/topics/oil.htm). (Accessed August 2017).

Humanitarian Bamboo (2009) *Humanitarian bamboo: A manual on the humanitarian use of bamboo in Indonesia*. [Online]. Available from <http://humanitarianbamboo.org/>. (Accessed October 2018).

Janssen, J. (2000) *Technical Report 20: Designing and Building with Bamboo*. Beijing, China: INBAR.

Kaminski S. (2013) Engineered bamboo houses for low income communities in Latin America. In: *The Structural Engineer*, 91 (10), pp. 14–23.

Kaminski, S., Lawrence, A. & Trujillo, D. (2016a) Technical Note Series: Structural use of bamboo – Part 1: Introduction to bamboo. In: *The Structural Engineer*, 94 (8), pp. 40–43.

- Kaminski, S., Lawrence, A., Trujillo, D. & King, C. (2016b) Technical Note Series: Structural use of bamboo – Part 2: Durability and Preservation. In: *The Structural Engineer*, 94 (10), pp. 38-43.
- Knaak, K. (2006) *Holzurm anobium punctuatum*. [Online]. Licensed under CC BY-SA 2.0. Available from: [https://commons.wikimedia.org/wiki/File:Holzwurm\\_anobium\\_punctuatum\\_in\\_hole.jpg](https://commons.wikimedia.org/wiki/File:Holzwurm_anobium_punctuatum_in_hole.jpg). (Accessed September 2018).
- Koppers (2017) *Safety Data Sheet: Coal Tar Roofing Pitch*. [Online]. Available from: [www.chemadvisor.com/Koppers/Database/koppers\\_na/msds/00228/00228355000220003.PDF](http://www.chemadvisor.com/Koppers/Database/koppers_na/msds/00228/00228355000220003.PDF). (Accessed August 2017).
- Lebow, S. (2004) *Alternatives to chromated copper arsenate for residential construction. Research Paper FPL-RP-618*. Madison, WI: U.S: Department of Agriculture, Forest Service, Forest Products Laboratory.
- Liese, W., Gutiérrez, J. & González, G. (2002) Preservation of bamboo for the construction of houses for low income people. In: *Bamboo for Sustainable Development*, pp. 481-494.
- Liese, W. & Kumar, S. (2003) *INBAR Technical Report 22: Bamboo Preservation Compendium*. Beijing: INBAR.
- Mena, J., Vera, S., Correal, J. & Lopez, M. (2012) Assessment of fire reaction and fire resistance of *Guadua angustifolia kunth* bamboo. In: *Construction and Building Materials*: 27, pp. 60–65.
- Practical Action (no date) *Technical Brief: Bamboo Preservation*. Rugby, UK: Practical Action.
- Rabik, A. & Brown, B. (no date) *Towards Resilient Bamboo Forestry*. Bali: Environmental Bamboo Foundation.
- Ridout, B. (1999) *Timber Decay in Buildings: The Conservation Approach to Treatment (Guides for Practitioners)*. UK: Historic Scotland.
- Shelter / NFI Sector (2017) *CXB Shelter Sector Market Assessment*.
- Steel, T. (2005) *Fungus on Log in Garston Wood*. [Online]. Licensed under CC BY-SA 2.0. Available from: [https://commons.wikimedia.org/wiki/File:Fungus\\_on\\_Log\\_in\\_Garston\\_Wood\\_-\\_geograph.org.uk\\_-\\_313089.jpg](https://commons.wikimedia.org/wiki/File:Fungus_on_Log_in_Garston_Wood_-_geograph.org.uk_-_313089.jpg). (Accessed September 2018).
- System Three (2013) *Material Safety Data Sheet: Board Defence*. [Online]. Available from: [https://www.systemthree.com/reslibrary/msds/Board\\_Defense\\_MSDS.pdf](https://www.systemthree.com/reslibrary/msds/Board_Defense_MSDS.pdf). (Accessed November 2014).

University of Tennessee Agricultural Extension Service (2001) *Subterranean Termite Control, PB1344-3M-4/01*. [Online]. Available from: [http://trace.tennessee.edu/utk\\_agexdise/15/](http://trace.tennessee.edu/utk_agexdise/15/). (Accessed November 2017).



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