Post-earthquake report on bamboo structures and recommendations for reconstruction with bamboo on the Ecuadorian coast
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The International Bamboo and Rattan Organisation (INBAR) is an intergovernmental organisation established in 1997, which has 41 member states and is dedicated to promoting the social, economic and environmental development of bamboo and rattan.

INBAR plays a unique role in finding and demonstrating innovative ways of using bamboo through projects to protect environments and biodiversity, alleviate poverty and facilitate responsible trade throughout the supply chain. INBAR connects a global network of partners from the government, private and not-for-profit sectors in over 50 countries to define and implement a global agenda for sustainable development through bamboo and rattan.

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Quito, November 2016
Executive summary

In Ecuador bamboo is an abundant material that has traditionally been used over the centuries in both formal and informal housing in the coastal regions. Bamboo can be used to build very sustainable, low-cost structures for formal housing. When bamboo structures are well designed and well built, they can be used as earthquake-resistant housing, as has been observed after several earthquakes in Latin America.

This report describes the potential for bamboo to be used more widely in Ecuador (and in other countries) to build low-cost housing. Topics covered include the high tolerance of bamboo to earthquake loads, how homes can be built from bamboo to make them earthquake-resistant, and how to ensure that homes built from bamboo have lasting durability. The report also covers the availability of bamboo supplies and how these might be improved.
1. Introduction

1.1 Report objective

The objective of this report is to present information collected after the earthquake in Ecuador on April 16th 2016, specifically regarding structures built of bamboo. Key information is presented on bamboo structures in the context of the earthquake and the subsequent reconstruction. This is followed by information on the availability of this resource in Ecuador. By way of conclusion, recommendations on the effective use of bamboo in the post-earthquake reconstruction process and the development of good practices in general are put forward for consideration.

This report was prepared in collaboration with the following stakeholders:

- The International Bamboo and Rattan Organisation, (INBAR) – an intergovernmental organisation established in 1997 which currently has 42 member countries. INBAR’s mission is to improve the wellbeing of producers and users of bamboo and rattan in the context of a sustainable resource base for bamboo and rattan, by consolidating, coordinating and supporting strategic and adaptive research and development.
- The UK Earthquake Engineering Field Investigation Team (EEFIT) – a joint venture between industry and universities set up in 1982. EEFIT’s principal activity is conducting field investigations after major earthquakes and reporting their conclusions to the engineering community.
- The Arup group – an organisation founded in 1946 that operates as an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services.
- Shelter Cluster – this is an Inter-Agency Standing Committee (IASC) coordination mechanism, focused on the Housing Sector, that provides people affected by natural disasters and internally displaced people affected by conflict with the means to live in safe, dignified and appropriate shelter.
- ULEAM – La Universidad Laica Eloy Alfaro de Manabí [Civil University Eloy Alfaro of Manabí].
- The Ecuadorian Army Corps of Engineers.
- PUCE – La Pontificia Universidad Católica del Ecuador [Pontifical Catholic University of Ecuador].
- AIS – La Asociación Colombiana de Ingeniería Sismica [The Colombian Association of Earthquake Engineering].
1.2 Context

1.2.1 Earthquake on April 16th 2016 on the Ecuadorian coast

On April 16th 2016 at 18:58 (local time) the northern coast of Ecuador was struck by a magnitude 7.8Mw earthquake. The epicentre was located 29km to the south-south-east of the city of Muisne, in the north of Manabí province, at a depth of approximately 19km.

Ecuador’s coastal provinces were the worst affected. In Manabí the most extensive damage occurred in the cities of Pedernales, Bahía de Caráquez and Manta. The collapse of structures during the earthquake and its aftershocks killed around 650 people in this province.

The earthquake on April 16th and subsequent aftershocks of up to 6.8Mw caused damage to a large number of homes. According to a report on April 22nd 2016 by the United Nations Office for the Coordination of Humanitarian Affairs, over 1,125 buildings were destroyed and over 829 buildings, including 281 schools, suffered damage. There are also 25,376 people living in communal shelters.

According to the latest information update, 35,198 buildings have been assessed as being unsafe or of limited use (MIDUVI, (Ministerio de Desarrollo Urbano y Vivienda) [Ministry of Urban Development and Housing], July 15th).

According to the UN Office for the Coordination of Human Affairs, more than a million people were affected, reconstruction work is ongoing and local residents are trying to recommence their productive activities.

Figures from INEC (Instituto Nacional de Estadística y Censos) [National Institute of Statistics and Censuses] show that around 35% of all homes in the Manabí province are made of timber and bamboo. Information from surveys carried out in the shelters with affected families shows that 30% of families interviewed lived in a timber or bamboo house. There is a larger proportion of houses made from timber and bamboo in rural areas.

The tragedy provided several lessons on building systems and the importance of establishing conditions that reduce the vulnerability of people living in areas of seismic activity.

This study has been set up with the aim of establishing parameters which allow:

- Analysis of the behaviour of bamboo in the affected areas, taking into consideration its traditional use in the local area.
- Determination of building principles that provide better safety in the event of serious natural disasters.
- Outlining of strategies that can reduce people’s vulnerability.
Some key data:

- As of July 21st there have been more than 2,256 aftershocks from the earthquake, 40 of which have been of a magnitude greater than 5.
- Over 230,000 people have been classified by the State as “affected”.
- Over 11,000 displaced people are still living in temporary shelters without basic services.
- So far a total of 9,375 families have been identified and notified that they will receive government grants. This includes 7,113 families in Manabí and 1,181 in Esmeraldas.
- The programme plans to build around 4,500 homes, predominantly in urban and peri-urban areas, by the end of 2016.
- Around 35,000 homes are classed as destroyed or damaged, leaving around 140,000 people without adequate housing.

As of July 15th, MIDUVI has assessed and classified 24,692 buildings in urban areas and 10,506 in rural areas as having collapsed, needing demolition or being unsafe (Shelter Cluster, 2016a).

1.2.2 Risk of earthquakes in the coastal region of Ecuador

Seismic phenomena in the region are the result of the interaction of large plates which form part of the Pacific Ring of Fire. Since the beginning of the 20th century, Ecuador’s coastal region has been hit by several earthquakes with moment magnitudes greater than 5.0. The epicentre of the 2016 earthquake is located at the extreme south of the 400-500km long rupture area from the 8.8Mw event in 1906 that caused a tsunami, killing hundreds of people (Franco et al., in press). Closer to the epicentre of the 2016 event, a 7.8Mw earthquake occurred in 1942, 43km south of the recent April earthquake, and a 7.2Mw event occurred in 1998 near to Bahía de Caráquez.

The degree of vulnerability of housing to earthquake damage depends on the following factors: seismic risk in the area, type of soil, and the strength and behaviour of the structure.

The entire coast is considered to be at high seismic risk and could be hit by earthquakes of considerable magnitude at any moment. However, specific studies on seismic activity allow areas of higher seismic risk to be more accurately pinpointed.

The type of soil, its resistance and the level of the water table can change the movement of soil in an earthquake, and can increase or decrease the level of ground movement. As a general rule, construction on firm, dense or rocky soil is preferable, while soil which is highly saturated with water should be avoided. Therefore it is strongly recommended that a geological soil analysis should be carried out before starting construction.

The resistance of houses to seismic movements depends on the type of structural system used to resist the inertia forces produced during the event. In other words, the structure must be designed to withstand the horizontal loads experienced during an earthquake. To achieve this, shear walls or cross-bracing elements can be used.
Although the seismic risk in the area cannot be changed, the effect of soil type can be mitigated by careful choice of site and a suitable geological analysis, and the building can be suitably designed to withstand the loads produced during an earthquake.

### 1.2.3 Potential of bamboo as an alternative for housing construction

Bamboo provides a construction solution that meets the requirements of the situation: seismic area, soil of low bearing capacity, urgent need for construction and limited financial resources. Bamboo is also highly sustainable, on account of its low carbon footprint and other beneficial qualities (Kaminski et al., 2016b).

From a technical and economic perspective, bamboo is undoubtedly an alternative material for housebuilding that is completely adapted to our area of study. Its local availability as a raw material is a guarantee of low cost and its physico-mechanical properties are ideal for coastal areas with high seismic risk. Despite these two essential qualities, the use of bamboo in housing is still minimal and it is associated with low quality self-build homes. Bamboo now needs to regain its role in the construction world as a quality, cost-effective and sustainable material.

Along with adobe [mud bricks] and bahareque [construction technique similar to wattle and daub, also known as quincha], bamboo is one of the traditional building materials still in use today. It is cheap and readily available as it can be found in local communities. These days the bamboo structures in the area of study are generally “self-build” or are built by bricklayers and carpenters with little training, because the current construction technique is simple and does not require complex tools.

In Ecuador the species most commonly used for construction is Guadua angustifolia Kunth, which is also known as “Guadua” or “Caña”. Another species which is also used is Dendrocalamus Asper, known as “bambú gigante” [giant bamboo]. In this report all of the species used in construction are referred to generically as bamboo.
2. Design and construction of bamboo housing

2.1 How does bamboo behave in earthquakes and wind?

Earthquake and wind loads are relatively similar in that they both effectively apply a horizontal load to the building that has to be transmitted down to the foundations. The key differences are:

- Earthquake loads are proportional to the self-weight of the structure, while wind loads are independent of this.
- Earthquake loads are cyclic, which can cause fatigue failure of connections.
- There is greater uncertainty over the magnitude of earthquake loads, so it is possible and acceptable for these to cause some damage, provided the damage is produced in a controlled manner. No damage should occur under wind loads.

It is a common misconception that bamboo as a material somehow performs “miraculously” well in earthquakes and strong winds. In fact, as an individual element, it possesses several brittle failure modes which could affect its behaviour under earthquake and wind loads. Historically traditional buildings made of bamboo and bahareque have performed well in earthquakes for two key reasons (Figures 1 and 2):

- The lightweight nature of bamboo (high strength-to-weight ratio), which results in a light building overall.
- Its ductility (essentially the capacity to absorb energy) in connections and joints, especially when nails are used. This has been observed after earthquakes in vernacular buildings built using techniques such as bahareque, which normally use joints with metal nails (Kaminski, 2013; Franco et al., in press; López et al., 2004). Some of the energy is also absorbed by cracking of mud renders in traditional bahareque dwellings.

Figure 1: Traditional bahareque house after the El Salvador earthquake in 2001. Damage is limited to mortar falling off, while the structure remains intact and safe.

Figure 2: Traditional bahareque house after the El Salvador earthquake in 2016. Damage is limited mainly to mortar falling off, while the structure remains intact and safe.
2.2 Existing houses with bamboo construction

Bamboo housing in Ecuador can be grouped into two general types:

1. Informal huts (Figure 3). This type of housing is generally used by people with a very low income and consists of a timber or bamboo frame with split or open bamboo (split cane or bamboo laths) for the walls. This type of housing is mainly found in the coastal region.

2. Semi-formal or formal bahareque house (Figure 4). This type of vernacular construction typically consists of a timber or bamboo frame, clad in a matrix of split or opened bamboo, laths, canes, twigs or timber strips, which is then covered with a mud-based mixture, sometimes with straw added for extra strength. This type of housing can be found both in the sierra and on the coast.

Unless otherwise indicated, all references to existing bamboo houses in this report refer to both construction types described here.

In the 2001 census Manabí province had 93,550 bamboo houses, and in the 2010 census this figure had decreased to 88,744. The total number of bamboo houses in Ecuador in 2001 was 254,152 while in 2010 there were 329,416, which represents an increase of 75,264 houses.

<table>
<thead>
<tr>
<th>Provinicial Capitals</th>
<th>Provincial Capitals 2001</th>
<th>Provincial Capitals 2010</th>
<th>Increase/Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guayaquil</td>
<td>No. of houses 40055</td>
<td>No. of houses 60521</td>
<td>Increase of 20,466 houses (20.4%)</td>
</tr>
<tr>
<td></td>
<td>39.80%</td>
<td>60.20%</td>
<td></td>
</tr>
<tr>
<td>Portoviejo</td>
<td>No. of houses 15792</td>
<td>No. of houses 14,218</td>
<td>Decrease of 1,574 houses (5.2%)</td>
</tr>
<tr>
<td></td>
<td>52.60%</td>
<td>47.40%</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Bamboo houses in the provincial capitals Guayaquil (Guayas) and Portoviejo (Manabí) (Ubiedia, 2012).
2.3 Factors limiting the development of good building practices using bamboo in Ecuador

Bamboo has acquired a negative image as a “poor man’s timber” for two main reasons: it is susceptible to degradation by rot or attack by insects, and it is widely used in informal self-build houses.

However, since the earthquake there is a general tendency in the affected areas to re-evaluate bamboo as a material which can save lives. Around 68% of the families interviewed while living in refuges as a result of their homes being lost or made uninhabitable by the earthquake believe a timber or bamboo house to be the safest option for their future home.

Until recently bamboo was not recognised under the Ecuadorian building regulations (NEC) as a material suitable for structural use and this has held back innovation and the development of projects using bamboo. There are some exceptions, such as the research being carried out by the architect Jorge Morán at the Universidad Católica de Guayaquil [Catholic University of Guayaquil], who is a world-leading pioneer. However, the recent approval of the NEC-SE-GUAD-UA (Norma Ecuatoriana de la Construcción- Seguridad Estructural- GUADUA) [Ecuadorian Building Regulation-Structural Safety-GUADUA] provides a technical basis for developing projects using bamboo as a structural material. This opens up the possibility of developing better building practices. Approval of the regulation also brings benefits for people wishing to build a bamboo house who need to apply for grants to finance the construction.

Although design proposals exist for bamboo buildings, there is a shortage of skilled labour in Ecuador specialising in bamboo construction. This is in contrast to the large quantity of material suitable for construction, some of which is exported to neighbouring countries such as Peru.

2.4 Common deficiencies of bamboo structures

The most common deficiencies of existing bamboo structures can be summarised as follows (Kaminski, 2013; Franco et al., in press; Kaminski et al., 2016d):

1. Lack of a structural system capable of withstanding earthquake and wind loads: all buildings need shear walls or bracing to withstand earthquake and wind loads, and many of the existing bamboo structures do not have these.
2. Poorly connected elements: the connections are typically the weak points in a structure, and many existing structures use traditional weak joints.
3. Untreated or incorrectly treated bamboo: bamboo is very susceptible to termites and beetles, which are both very common in Ecuador, and so it needs to be treated to protect against these insects. Many existing bamboo structures use untreated bamboo, or bamboo that has been treated with ineffective chemicals.
4. Details which compromise durability: bamboo is very prone to rot and so must be kept dry throughout its lifespan. Many existing bamboo structures are not designed to protect the bamboo from rot.
5. Inadequate maintenance: since bamboo is susceptible to rot and attack by termites and beetles, houses made from bamboo generally need more maintenance than other types. However, owners frequently cannot afford the maintenance or are unaware of its importance.

6. Harbouring insects: traditional bahareque is prone to harbouring insects, especially the “kissing bug” or “chinche” as it is known in Latin America. This small biting insect can transmit the T. cruzi parasite that causes Chagas Disease, a potentially life-threatening illness that is estimated to currently affect 6-7 million people worldwide, mostly in Latin America (OMS, 2016).

Points (1) and (2) can be addressed by means of good design and good construction of bamboo buildings (Section 2.5) Points (3) and (4) can be addressed by means of good design and treatment (Section 2.6) Point (5) can be dealt with by good maintenance (Section 4.3). Point (6) can be addressed by ensuring a clean environment and crack-free walls in the interior of the home, avoiding mud-based mortar and avoiding straw roofs.

2.5 Designing earthquake-resistant structures

Recommendations for designing structures that can withstand earthquake and wind loads (Figures 5 and 6) are as follows:

- Keep the structure as light as possible, by keeping ceiling and floor finishes to a minimum and designing an efficient structure with light walls.
- Ensure that there are regular, uniformly spaced reinforcing walls in both orthogonal directions and that these are broadly symmetrical on both sides of the building throughout the entire elevation of the building.
- Ensure that columns are continuous from the roof to the ground - avoid transferring column loads.
- Loads must be transferred through joints using support bearings wherever possible, since this gives a stronger, more rigid and more reliable load transfer.
- Provide simple, robust foundations that effectively tie together the columns and lateral load stability system.
- Provide strong connections using bolts and internodes filled with mortar.
- Provide vertical tension ties to resist overturning of the frame and the structure.
- Longer eaves.
- Collectors or guttering, located on the lowest part of the roof, and downpipes to collect rainwater.
- Channels to collect water on the upper and lower slopes. These channels made of blocks or soil-cement allow water to be collected from the downpipes on the roof and from further up the slope.
- They allow water to be channelled away into larger collection tanks or into street gutters and drains.
- This solution requires determination and effort from the community.
Figure 5: As with any structure, a bamboo house needs a structural system that is designed to withstand horizontal loads caused by earthquakes and wind. This can be provided by bracing or shear walls.
2.6 Designing for durability

2.6.1 Causes of decay

Bamboo lacks natural toxins and so has no natural resistance to decay (Janssen, 2000). In addition, its typically has thin walls mean that a small amount of decay can cause a significant percentage loss of structural load capacity. The two main causes of decay in bamboo are: attack by beetles (Figures 7 and 8) and termites (Figures 9 and 10) and fungal attack (Figures 11 and 12) (Kaminski et al., 2016c; BRE, 2003).
Post-earthquake evaluation and recommendations for reconstruction with bamboo on the Ecuadorian coast.

Figure 7: Beetle damage in bamboo, Ecuador - exit holes are clearly visible

Figure 8: Beetle damage in bamboo, Colombia - exit holes are clearly visible

Figure 9: Severe termite damage to timber and cane in traditional bahareque, El Salvador

Figure 10: Severe termite damage in bamboo, Costa Rica

Figure 11: Fungal damage, splitting and bleaching of boron-treated bamboo exposed to sun and rain after around 10 years, Colombia

Figure 12: Rotting of bamboo in walls, Costa Rica. Note the visible mould at the bottom of the walls due to splashback of rainwater from the roof
2.6.2 Protection against decay

The most effective ways of protecting bamboo from decay are by building with dry treated bamboo and by adopting appropriate design and detailing (Figure 13), as follows:

1. Bamboo should be kept dry throughout the lifetime of the structure, which can be achieved by:
   - Always covering it with a watertight roof with a good overhang to protect against driving rain.
   - Providing good drip details and avoiding water traps especially at the base of walls and columns. This will prevent rot and will also decrease the rate of beetle and termite attack.
   - Protecting external walls with a waterproof layer. Single-storey bamboo buildings are likely to suffer less rot damage than multistorey buildings, because in general less of the wall is exposed to rain (Kaminski, 2013).
   - Ensuring that the building can always “breathe”. For example, any cavities in the wall should have ventilation holes to allow air to circulate, especially any which form external walls. The bamboo must also never be cast directly into masonry or into concrete foundations as this will prevent it from “breathing” and make it much more likely to rot, even if the bamboo is coated with bitumen or a similar chemical product.

2. The bamboo should be separated from the ground with a good barrier, preferably a concrete ground slab, which forces termites out into the open.

3. Buying dry treated bamboo from the outset.

Due to the high risk of attack by drywood termites and beetles found in Ecuador, structural bamboo must be treated with preservative if a reasonable design life is required. Although this will slightly increase the initial cost of the bamboo, it will reduce the overall life cost of the structure.

<table>
<thead>
<tr>
<th></th>
<th>No preservative</th>
<th>Treated with boron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior</td>
<td>2–6 years</td>
<td>30+ years</td>
</tr>
<tr>
<td>Exterior isolated from the ground</td>
<td>0.5–4 years</td>
<td>2–15 years</td>
</tr>
<tr>
<td>Exterior in contact with the ground</td>
<td>&lt;0.5 year</td>
<td>&lt;1 year</td>
</tr>
</tbody>
</table>

Table 2: Approximate length of time before bamboo will need to be replaced in warm areas of Ecuador with a risk of termite and beetle attack.

The length of time bamboo will last before it needs to be replaced will depend on the environment in which it is used and the treatment type. Table 2 gives the approximate lifespan of bamboo in warm areas of Ecuador and clearly indicates why it should be treated and also why it should preferably only be used in a dry internal environment. Note that the variation in lifespan depends on the prevalence of termites nearby.
2.6.3 Treatment options

Traditional treatment options

Several simple traditional preservation methods are commonly used in developing countries (Liese and Kumar, 2003). However, these are not recommended as their effectiveness has not been scientifically proven and some may be harmful to humans. There is undoubtedly a need for research to assess the effectiveness of the traditional preservation methods.

Treatment with boron

In almost all cases, boron is the most appropriate chemical treatment for bamboo (Liese and Kumar, 2003), and has a good track record (Kaminski, 2013). Boron is cheap, which makes this very effective treatment affordable. However, since the treatment is water-soluble elements treated with boron cannot be used externally where they are exposed to rain. Boron is widely available in Ecuador as a fertiliser and simply needs to be dissolved in water.

There are several methods for treating bamboo with boron, including: modified Boucherie, bath/soaking, vertical soak diffusion (Environmental Bamboo Foundation, 2003) and pressure vessel (Liese and Kumar, 2003; Kaminski et al., 2016c).

2.6.4 Summary of design recommendations for durability

Figure 13: Recommendations for detailing a bamboo house to protect against rot and attack by insects (Kaminski, 2013 and Trujillo et al., 2013)
2.7 Ensuring good quality construction

Use of skilled labour is essential to ensure high quality structures. Ecuador has highly skilled professionals with experience in bamboo construction, who might be described as specialist carpenters for bamboo structures. Although they are few in number, the knowledge is there and can be shared.

It is important to support the development of practical and theoretical knowledge relating to bamboo construction in order to have a skilled workforce for building work.

2.8 Case study of a bamboo house built using modern techniques

One highly recommended bamboo construction system is “engineered bahareque” (Figure 14). Engineered bahareque is an improved form of vernacular construction that takes the traditional structural system of bahareque and improves it, using modern materials, knowledge, and construction techniques. Engineered bahareque generally consists of reinforced concrete foundations supporting a reinforced masonry upstand that elevates the timber and/or bamboo structural frame. An organic matrix of cane, small diameter bamboo, bamboo laths, or bamboo mats is nailed to the frame, and galvanised steel chicken mesh is nailed to the matrix to act as reinforcement. The walls are then finished with cement mortar render to form solid walls. The roof is normally constructed from fibre-cement or clay tiles.

Figure 14: Characteristics of modern well-designed engineered bahareque housing: details of walling system.
Engineered bahareque houses have been used successfully in various countries around the world, including: Costa Rica, Colombia, Ecuador, El Salvador, and the Philippines (Figures 15-20). When properly designed and built, they have demonstrated their effectiveness as an affordable, safe, and durable form of housing which is resistant to environmental hazards. Engineered bahareque has significant potential in many countries around the world where bamboo grows, especially Ecuador, and is particularly suited to one and two-storey housing units.
Engineered bahareque housing is safe to build and uses no toxic chemicals, can be constructed by the beneficiaries themselves, does not require significant maintenance, and has been shown to be very popular with beneficiaries in many case studies. It can provide a hygienic, safe, durable and thermally comfortable home.

INBAR recently published a design guide for engineered bahareque (Kaminski et al., 2016d), which can be found on their website http://www.inbar.int/. Further information on engineered bahareque has been published by Kaminski et al. (2016a).
3. Availability of bamboo in Ecuador

3.1 Bamboo production

The native bamboo Guadua angustifolia, and other introduced species such as Dendrocalamus asper and on a smaller scale Phyllostachys aurea, can be an ideal material for earthquake-resistant construction when a technical approach is used.

The commercialisation of bamboo begins on the farm where the producers sell “en pie” (standing) or “cortada a filo de carretera” (ready cut at the roadside). The farmers value bamboo on their farm for its uses, its commercial value and the environmental services it provides, mainly the protection of water sources. They prefer to cut their canes themselves to sell “at the roadside”, so they can get a better price (approximately an extra $0.5 per stem) and also to ensure their bamboo grove is properly looked after. According to the farmers, when a buyer takes responsibility for harvesting he over-exploits the plot and does not cut correctly, so the bamboo grove takes longer to recover. These buyers transport the material to collection centres in cities in the sierra or coastal regions, or take them to warehouses in Huaquillas to be sold to Peru at a better price.

3.1.1 Where is the resource?

Bamboo as a resource is found throughout the whole of Ecuador. The main types of bamboo used for construction (Guadua angustifolia and Dendrocalamus asper) grow at elevations up to 1500m (the ideal range for plantations is between 400m and 1200m).

Ecuador has a wide range of types of bamboo producer. Figure 21 indicates the distribution of producers by production volume in different areas of the country. This shows that in most provinces including Manabi the bamboo supply is in the hands of small producers.
There is no accurate record of the area covered with bamboo in Ecuador, but various studies have been carried out, mainly on G. angustifolia and D. asper which are the two species most commonly used in construction. From these studies, Añazco 2015 shows that the country has a total of 14,984.59 ha of bamboo, of which 8,908.43 ha (60%) are natural bamboo groves and 6,076.16 ha (40%) are plantations, with 67.69% planted with G. angustifolia, 32.17% with D. asper and the remaining 0.14% with species such as B. vulgaris and P. aurea.

It is worth noting that these areas of bamboo described do not include native bamboo species such as those from the genus Chusquea, of which there are 18 species in Ecuador. Although these are not commercially important they are widely used in rural areas of the sierra to build agricultural infrastructure and provide ecosystem services. It is estimated that including the other native species would easily double the figure quoted for the area of bamboo.

3.1.2 What condition is the resource in after the earthquake?

According to interviews with bamboo producers in the main production areas in Manabí, such as San Plácido and 24 de Mayo, demand for bamboo has increased considerably. This has resulted in an increase in the price of bamboo, particularly in the supply centres and to a lesser extent at farm level.

As previously mentioned, when the bamboo is sold “en pie” the intermediaries harvest all the stems, causing deterioration of the bamboo grove. Moreover, many of the stems are soft and do not yet have the physico-chemical properties required for durability and structural strength.

Studies carried out using satellite images show a reduction of 4% in the area of bamboo over the last 5 years in the Portoviejo river basin. A possible increase in demand needs a technical intervention to prevent the harvesting process from adversely affecting the bamboo grove.

According to bamboo producers interviewed who use technical management on their plantation and sell treated bamboo, the demand for their product has not increased. This is due to a lack of knowledge regarding the correct use of bamboo for construction, which means that many people buy fresh, untreated bamboo from warehouses which do not guarantee that the bamboo is sufficiently mature to be used in construction.

These producers say that although there are extensive controls by the authorities, in areas such as Pedro Vicente Maldonado several intermediaries have purchased bamboo groves and have harvested by clear-cutting, without any authority controls.

3.1.3 What is the availability of bamboo groves to produce guaranteed raw materials for reconstruction?

There is sufficient capacity in the existing stocks of bamboo in Ecuador to supply raw material for the planned building projects, taking into account that around 500 stems per hectare per year can be obtained.

The annual demand for bamboo for other activities is around 20,903,800 stems (Table 3), which includes the ongoing national demand for construction.
Taking into account the registered area of bamboo harvested under technical parameters, there are 7,500,000 stems of guadua available per year. This figure indicates that there is unmet demand, which is causing over-exploitation of both natural bamboo groves and plantations.

The bottleneck is not at the production stage but at post-harvest, since bamboo culms must undergo a treatment and drying process to make them suitable for construction, and this takes around a month and a half. Another factor in addition to the time required for this process is that there are currently not enough preserving centres capable of producing bamboo suitable for construction to meet the growing demand.

3.1.4 What actions can be taken to improve the supply of bamboo?

Despite the unmet demand, the few existing producers who use technical management on their bamboo say it is difficult for them to sell their product compared with a bamboo stem bought from a warehouse with no guarantee of quality. A bamboo stem that has been treated and dried ready for construction can cost up to 6 times more because of the labour costs, the required infrastructure, low production volumes and the price of the preservatives used to treat the bamboo.
Due to the difference in price, people with no experience in bamboo construction prefer to use the cheapest material without recognising the risks involved in using construction materials of unknown quality. This also threatens the conservation of bamboo groves, since the price paid by a typical intermediary is very low and so many farmers choose to replace their bamboo groves with other more profitable crops.

Consequently large-scale awareness-raising campaigns are needed to educate people about the properties that make bamboo suitable for construction. It is also important to formalise the sector in order to map bamboo groves more accurately and have control of bamboo prices throughout the entire supply chain. Once producers see the benefits of growing bamboo and using technical management on their plantations the area planted with bamboo will increase.

### 3.1.5 What is the projected capacity for the next few years?

As has been previously observed, the growing demand and indiscriminate cutting of bamboo puts bamboo groves under great pressure, mainly in the coastal provinces. If measures are not taken to formalise the sector and improve sales channels, especially at local level, the area of bamboo in Ecuador will decrease.

Conversely, the Amazon region has large areas of bamboo G. angustifolia which have not been exploited or received any form of management, mainly due to their distance from the coastal provinces where demand is highest.

Experts believe the approval of the new building regulation for bamboo will considerably increase demand and price, so important work must be done on technical improvements to increase the capacity at each link in the chain where bottlenecks arise: crop management, treatment and drying.

### 3.1.6 Who are the stakeholders in this system?

According to Añazco 2015, the commercialisation of bamboo is seen as a “system” in which there is interaction between the ecosystem of “natural bamboo groves” and the agro-ecosystem of “plantations”. Five macro stakeholders are involved in these two arenas: producer, intermediary, haulier, collection centres and end consumer.

Each of these has different characteristics and commercialisation channels depending on the situation in their local area or the target market.

At present the bamboo sector is a major source of jobs. According to Añazco 2015 approximately 600,000 people are directly involved in the sector nationally. Table 4 shows the percentage of stakeholders involved in each link of the bamboo supply chain.
3.1.7 What actions can increase the availability of dry treated bamboo?

As previously discussed, the availability of dry treated bamboo is very limited compared with the demand. In spite of this, businesses that produce it say that because of a lack of understanding people prefer to buy fresh and often immature bamboo from warehouses.

Strategies follow two approaches: the first involves the possibility of increasing the number of processing and treatment centres, while the second is to encourage the technical management of existing bamboo groves, along with a forestation plan which increases the number of hectares of this species with sustainable harvesting criteria.

Formalising the market and raising awareness of the importance of the quality of bamboo used for construction will increase the demand for bamboo produced under technical management.

The high import costs of the preservatives used can be reduced if people are encouraged to work together to identify opportunities; for example, the cost of these supplies can be reduced by buying in bulk.

3.1.8 How is the price distributed among the stakeholders?

The price of bamboo at the farm gate has stayed the same for over 6 years. Intermediaries pay $1 per cut cane, while producers who manage their plots and sell their product directly to treatment centres get a better price. Prices in the warehouses vary with the seasons, since the cost of extraction increases in the rainy season and varies between $3.25 and $3.50, according to the warehouse owners and intermediaries who were interviewed.

Demand increased considerably in the first few days after the earthquake since bamboo was widely used to build refuges and to prop up houses that had suffered damage. In the small warehouses in large cities in the disaster area, increases of as much as $1 per stem were recorded.
It is worth mentioning that the majority of warehouses also sell timber, which also saw a large increase in demand, but unlike bamboo timber is in short supply in the affected provinces.

From an environmental perspective bamboo is a useful resource which can reduce the deforestation of other species. For managed plantations the farm gate price is around $3, while the price of dry treated bamboo varies between $1.25 and $2 per linear metre of bamboo.

In order to make changes to the current bamboo situation, work needs to be done on all links in the chain and with all of the construction stakeholders in both the public and private sectors. Any deficiencies at a given stage in the process can affect all of the following stages.

One specific action to break this trend and improve the supply chain is to “build” demonstration settings using appropriate technology and high quality materials. With this in mind, governments such as Pichincha, Napo, Santo Domingo de Los T’sáchilas, Península de Santa Elena, Manabí and Esmeraldas are changing their position and adopting measures which will allow diverse uses in different areas. Meanwhile, some businesses have invested in areas of cultivation while others are showing an interest in manufacturing products with added value such as paper or bamboo laminates.

It is important to find and communicate with all of the initiatives, communities, technicians, private individuals, professionals, institutions etc. currently involved with or interested in bamboo because they have a key role in achieving an overall improvement in the use of bamboo.

“To use guadua for productive and environmental purposes, we can manage bamboo forests appropriately to improve their yield or grow bamboo crops specifically for these purposes. In a managed bamboo forest, culms can be harvested after 4-6 years, whereas in cultivation the recommended age for harvesting is between 5 and 7 years. Up to 1,400 culms per hectare can be obtained each year. With planned management of guadua groves there will be continuous harvests without the need to replant...” “This is why the availability of guadua combined with its quality and size make it a resource with great potential for making hundreds of products...”

Although bamboo is a non-timber forest product, the same products can be made from bamboo as from timber. In the industrial manufacture of boards, high density timber, beams, and bamboo laminates the bamboo undergoes a series of processes designed to increase its strength and physico-mechanical properties. Thus, using modern technology, bamboo timber with better mechanical properties and greater durability is created. This allows new areas of use to be opened up for sustainable environmental development.
4. Conclusions and recommendations

4.1 Encourage good practices (incentivise, document, disseminate)

In Ecuador there are old structures that use bamboo as a structural material. There are also contemporary practising architects who specialise in the design and construction of bamboo structures. It is important to raise awareness of good practices, both historical and new, for the benefit of the construction sector.

4.2 Formalise construction

Formalisation of construction processes in urban areas is needed to ensure citizens’ wellbeing. For example, it is common to see extensions on existing structures where a lack of proper assessment and planning leads to a risk situation.

In rural areas a way of improving construction practices must be found. This can bring about benefits such as improving the structural safety of housing and prolonging its useful life, thus avoiding waste of resources (material and financial). Obviously rural areas can be difficult to access, and so a strategy adapted to this reality must be found. For example: construction training (reference: Shelter Cluster initiative - see Appendix 1).

4.3 Maintenance culture

Unfortunately the importance of maintaining structures is generally underestimated. This may be a consequence of the promotion of industrial products as “maintenance-free”. Whatever the reason, if a maintenance culture existed at some point, it has gradually been lost in modern times. Maintenance is key to ensuring a long useful life in bamboo structures. However, it is important not only for the durability of structures but also as a way of helping to keep alive the knowledge of the techniques used.

Frequency of maintenance depends on the house’s level of exposure to the effects of weather: the effect of the sun, humidity, wind, salinity, degradation of the protective film and the level of structural demand on the culms. To ensure the durability of the construction the condition of the structure needs to be checked for defects such as those caused by fungi, termites, humidity, crushing or splitting, and the affected structural elements must be replaced where necessary.

4.4 Theoretical and practical training for skilled labour

There is a group of professionals in Ecuador who specialise in design and construction with bamboo, but the group is currently small considering the potential construction volume. The construction of high quality buildings requires skilled workers who are familiar with the material and know how to use it to achieve the desired result.
4.5 Improve implementation of building regulations

When building regulations are applied they help to ensure a safe product which meets quality standards. Improving the implementation of the regulations means that architects, engineers and builders need to know the regulations and know how to correctly apply them. In addition it is important for some form of check to be carried out not only on the paper design but also on the finished construction.

4.6 Ensure quality materials on site

Good materials are needed for a safe and durable structure. As the industry producing bamboo for construction develops there must be a guarantee that the products supplied meet the quality standards. The properties that bamboo must have in order to be considered suitable for construction are described in the NEC-SE-GUADUA.

Although some of the properties of material suitable for construction can be checked on site, others are impossible to determine at that point. For example, the type of drying process and the type of treatment carried out can be difficult to check. A certification system with periodic checks on plantations and bamboo processing centres could help to formalise compliance with quality standards. In other words, quality control should exist in both processes: production and construction.

4.7 Summary of findings for consideration

- Engineers and architects in the region would benefit from a broader understanding of seismic design criteria and good practices for working with bamboo.
- Improving the application of building codes and better controls in the use of construction systems would greatly benefit the region by ensuring quality in the design and construction of buildings.
- Builders (construction workers and foremen) would benefit from training in the use of local raw materials.
- The general population would benefit from being reminded of the importance of carrying out maintenance on their houses, especially if the house contains timber or bamboo.
- Formalising the supply chain may benefit producers who grow bamboo using technical management.
- There would be an increase in the number of new job opportunities in the affected areas.
- Safe and comfortable housing built from local materials can encourage innovation in earthquake-resistant construction systems.
5. Further reading

**Shelter Cluster Guidebook**
Shelter Cluster is the coordinating body of the Housing Sector in Ecuador. It is led by MIDUVI, supported by the International Federation of the Red Cross (IFRC) and has 16 participating agencies who are trained and interested in supporting activities to provide temporary and emergency relief housing in the affected areas.

In their efforts to provide an organised response after the earthquake, Shelter Cluster worked in coordination with housing stakeholders to ensure that people who needed shelter provision received help quickly and were given appropriate support.

Building principles and details were developed in collaboration with INBAR for construction professionals and non-professionals to support an improved construction culture and to avoid reproduction of errors in the reconstruction process, including construction using bamboo. Further information on other construction techniques can be found at: http://sheltercluster.org/response/ecuadorearthquake-2016. In the appendix we present the results of this joint effort, focused on guadua and bamboo.

**Information on engineered bahareque**
Information on the engineered bahareque construction system can be found online at www.inbar.int and has been published by Kaminski et al. (2016a and 2016d).

**Technical guides on designing with bamboo**
A series of articles on designing with bamboo-in-the round have recently been published in The Structural Engineer magazine (Kaminski, 2016b and 2016c). Three further articles on the design of elements and connections will be published in the near future.

**Norma Andina para diseño y construcción de casas de uno y dos pisos en bahareque encementado** [Andean Regulation on the design and construction of one and two-storey houses using engineered bahareque]
This recently published building code provides guidance on the design of engineered bahareque structures (INBAR 2015).

**Manual de construcción sismo-resistente para viviendas de uno y dos pisos con bahareque encementado** [Manual for earthquake-resistant construction for one and two-storey houses with cemented bahareque]
This illustrated guide provides guidance on the design, capacity of shear walls and examples of details. It is useful for understanding concepts and details. (Prieto et al., 2002).

**Código NEC-SE-Guadua – Estructuras de Guadua (GaK)**
[NEC-SE-Guadua Code – Guadua Structures (GaK)]
This Ecuadorian regulation which is about to be published gives detailed methods for the design of bamboo elements, types of joints and details on engineered bahareque (Ministerio de Desarrollo Urbano y Vivienda [Ministry for Urban Development and Housing], in press)

This guidebook uses diagrams and photographs to demonstrate step-by-step how to use Guadua angustifolia, in a technical and efficient way, using the Peruvian Regulation E.100 on Bamboo, to build earthquake-resistant, comfortable, safe and durable buildings.
6. References

- INBAR (2013) El bambú, una alternativa innovadora para la diversificación y generación de ingresos locales rurales: promoviendo la gestión de conocimiento sobre bambú en Ecuador, Colombia y Perú. INBAR-EU-CFC, Quito.


- Post-earthquake evaluation and recommendations for reconstruction with bamboo on the Ecuadorian coast -
- Post-earthquake evaluation and recommendations for reconstruction with bamboo on the Ecuadorian coast -
In Ecuador bamboo is an abundant material that has traditionally been used over the centuries in both formal and informal housing in the coastal regions. Bamboo can be used to build very sustainable, low-cost structures for formal housing. When bamboo structures are well designed and well built, they can be used as earthquake-resistant housing, as has been observed after several earthquakes in Latin America.

This report describes the potential for bamboo to be used more widely in Ecuador (and in other countries) to build low-cost housing. Topics covered include the high tolerance of bamboo to seismic load, how homes can be built from bamboo to make them earthquake resistant and how to ensure that homes built from bamboo have lasting durability. The report also covers the availability of bamboo supplies and how these might be improved.

In collaboration with:

**INBAR**
**INTERNATIONAL BAMBOO AND RATTAN ORGANISATION**

**Post-earthquake report on bamboo structures and recommendations for reconstruction with bamboo on the Ecuadorian coast.**