ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Construction and Building Materials xxx (2008) xxx–xxx

Construction and Building MATERIALS

www.elsevier.com/locate/conbuildmat

One laminated bamboo-frame house per hectare per year

Katleen De Flander *, Ronald Rovers

Urban Environment Group, Wageningen University, Wageningen, The Netherlands

Received 26 July 2006; received in revised form 2 January 2008; accepted 4 January 2008

Abstract

This paper presents an outline of a quantitative analysis that demonstrates the global potential of bamboo as a "modern" construction material. The underlying goal is to contribute to a real shift in resource management by focussing on renewable resources in general and on the high brow, modern use of bamboo as an alternative for construction products such as concrete, brick and (hard)wood in particular. The analysis illustrates how laminated bamboo-frame building could be a direct alternative for wood-frame building, bamboo having a great advantage in yearly yield per forest area compared to wood. Current and potential bamboo resources in Colombia are posed against required material volumes for constructing a model house, resulting in a practical and realistic view on bamboo's global potential on lowering the environmental impact of the built environment.

Keywords: Bamboo; Laminated bamboo; Renewable resources; Construction materials; Innovation

1. Introduction

At the base of this paper stands the concern about the vast resource consumption and the ever-growing environmental consequences of the built environment. Building and building-related activities are the largest consumers of resources, whether it will be materials, capital or energy [1]. However, resources have a limit. So far, those limits have not been met but with current consumption patterns and a growing world population, resources and land to harvest these resources are becoming increasingly scarce. There is a need to a real shift in resource management based on reduction and the use of renewable resources. Bamboo, one of the fastest growing renewable resources in the world, could play a major role in a society shifted for a balanced resource use.

Thanks to its great strength, flexibility and versatility, bamboo culms have been widely used in housing and for other construction purposes. Bamboo provides pillars, walls, window-frames, rafters, room separators, ceilings and roofs for houses. Beautiful and intriguing constructions can be found world-wide.

In spite of this, if we discuss the significant impact that the use of bamboo can have in sustaining building and construction by lowering the environmental impact in using natural resources, we need not discuss for example an improved joint originating from tradition. Then we need to discuss high level products from bamboo, processed for easy use and meeting many conditions set by modern standards. This means re-inventing the archetype by placing the raw bamboo in a different context of high-tech product, or even low-tech but processed for a standardised use. Compare it with wood: there are some beautiful constructions made from fresh cut trees, however, the real use of wood is in a processed way: standardised (low-tech) sawn products like planks, beams, etc, and also highly processed (high-tech) wood such as laminated beams, sometimes even pre-stressed. If bamboo is to become a global product and fulfil a significant role in the use of natural resources in building and construction, it needs to become easy to use, standardised and competitive. Bamboo needs to be accepted as an alternative for concrete, bricks, plastics and wood, by using it in modern innovative construc-

* Corresponding author. Tel.: +32 11 650543.
E-mail address: katleendeflander@gmail.com (K. De Flander).

0950-0618/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2008.01.004

tion products such as façade panels, floor tiles and laminated structural elements (Fig. 1).

This is not only valid in the 'western' or 'industrialised' world. With a billion people world-wide living in bamboo houses, you could think that raw bamboo has proven its great potential as a material source in construction from low-grade temporary shanties to exclusive, architect-designed mansions. However, the issue of acceptability remains. There seems to be a subconscious tendency that rejects bamboo as a construction material as something associated with poverty, marginality, and lower-class status [2–4]. In many bamboo-countries, the prestige of owning a modern cement or even wooden house has replaced the desire to build with bamboo and goes even so far that people paint bricks on the walls of their bamboo dwelling [2]. As for other commodities, the use or non-use of bamboo as a construction material is related to processes of social differentiation. Consciously or unconsciously, consumers make decisions about their purchases based upon their identity or the identity they wish to project or communicate to others. By buying certain commodities, and others not, people construct difference, i.e., difference in representing inclusion or exclusion to certain social groups. Housing is one of the most visual representations of social status and therefore, of social differentiation [5]. And although through the course of history the use of bamboo has changed not only quantitatively but also in 'who' built with the material, for instance in the last decade the extreme rich have used bamboo, the majority of these billion people living in bamboo houses are found on the lowest end of the economical ladder. When people get more wealthy, experience shows that they want different houses, different materials, more appealing to their view of modernisation, of wealth. Raw bamboo is not part of this view; raw bamboo is old, reminding of poverty. The only chance to avoid communities reaching economical growth from massively moving to the use of for instance concrete is to create a new bamboo with the same properties these individuals are looking for when leaving the traditional bamboo behind.

Undoubtedly, the traditional use of bamboo is more sustainable than the here described modern, industrialised use of bamboo and will continue being used by local

Fig. 1. From round bamboo to bamboo strips ('latas') to laminated bamboo beam/column. Source: Juan Ayala.

Fig. 2. Scandinavian wood construction development. Archetype wood construction – farm Norway (left); Archetype modern wood-frame construction – Norway (middle); Modern residential multi-story wood-frame construction in Lahti, Finland (right). Source: Ronald Rovers (left, middle); Wood Focus Finland, Photographer: Voitto Niemelä (right).

Please cite this article in press as: De Flander K, Rovers R, One laminated bamboo-frame house per hectare per year, Constr Build Mater (2008), doi:10.1016/j.conbuildmat.2008.01.004

ARTICLE IN PRESS

Fig. 3. Bamboo construction development. Archetype traditional bamboo construction – Philippines (left); Modern plastered bamboo house – Colombia (middle); Innovative standardised bamboo building products. Source: Unknown (left); Katleen De Flander (middle, right).

experts and individuals. However, raw bamboo will often not survive once communities reach a certain level of wealth.

Going back to the comparison with wood, original wood construction was based on the use of the rough material, and only partially treated for joints. Over the years, wood construction has developed into standardised sawn products and lately in laminated and endless production technologies. The professionalizing of wood-based construction developed parallel with more demand in quality and safety. This became a barrier for wood, since for instance fire protection prevented the construction of multilevel houses and apartment blocks. Only recently, research has overcome these barriers and now wood-frame construction can come to full growth, as in the example from Scandinavia (Fig. 2). More and more multilevel residential buildings are constructed. Bamboo could and should go through a similar process: from basic rough culm construction via partially treated one-level-housing construction to a modern all-purpose construction material which can provide the properties demanded by, e.g., energy efficiency and safety standards (Fig. 3).

2. Quantitative analysis bamboo's potential

2.1. Objectives and approach

This paper is based on the goal to contribute to a real shift in resource management by focussing on the high brow, modern use of bamboo for construction products. Therefore its main objective is to demonstrate the global potential of bamboo as a "modern" construction material. Bamboo products that serve as an alternative for other materials such as bricks, concrete and plastics and as a direct competitor for (hard)wood products in daily building practice.

The following quantitative analysis illustrates how a new building technology 'laminated bamboo-frame building' could be a direct alternative for wood-frame building, bamboo having a great advantage in yearly yield per forest area compared to wood. Current and potential bamboo resources in Colombia are posed against required material volumes for constructing a model house, resulting in a practical and realistic view on bamboo's global potential on lowering the environmental impact of the built environment.

2.2. Practical delimitations

Before starting this analysis, some practical delimitations have been set:

- The first delimitation is to limit the potential to one species of bamboo and the available/potential resources of this species in one country. The chosen bamboo species for this report is *Guadua angustifolia*[1] a native Colombian bamboo species, and its growing region the 'Eje Cafetero'[2] in Colombia (Fig. 4). *Guadua angustifolia* has a great potential for construction purposes and industrial development thanks to its outstanding physical and mechanical properties [6]. From now on we will talk about *Guadua angustifolia* as Guadua or Guadua-Bamboo.
- The second delimitation is that for the comparison between a bamboo-frame and a wood-frame house we will work with the same material volume of respectively

[1] Guadua, a genus established in 1822 by the German botanic Kunth, unites approximately 30 species that are distributed between 23° North in Mexico and 35° South in Argentina. Guadua grows natural in all Latin American countries with the exception of Chile and the Caribbean Islands. Guadua grows in diverse habitats from 0 to 2800 m.a.s.l. The species *Guadua angustifolia* stands out within the genus because of its physical-mechanical properties that make it an excellent structural material and was selected as one of the 20 bamboo species in the world with a great potential for development. It also stands out because of the size of its culms that can go up to 30 m in height and 25 cm in diameter. *Guadua angustifolia* grows naturally in Colombia, Ecuador and Venezuela but has been introduced in other countries and continents. Its elasticity and capacity to absorb energy make the species ideal for seismic resistant constructions. In spite of its multiple uses and applications, little added-value has been given to this resource and its interference in the national economy is minimum. It only carries out a more evident role in local economies like the one of the coffee area in Colombia or the coastal region of Ecuador. (Ximena Londoño, 2004)

[2] The 'Eje Cafetero[2]' (coffee belt) in Colombia is the country's coffee growing region situated in the inner valleys of the Colombian Andes where the size and abundance of Guadua is unequalled.

Please cite this article in press as: De Flander K, Rovers R, One laminated bamboo-frame house per hectare per year, Constr Build Mater (2008), doi:10.1016/j.conbuildmat.2008.01.004

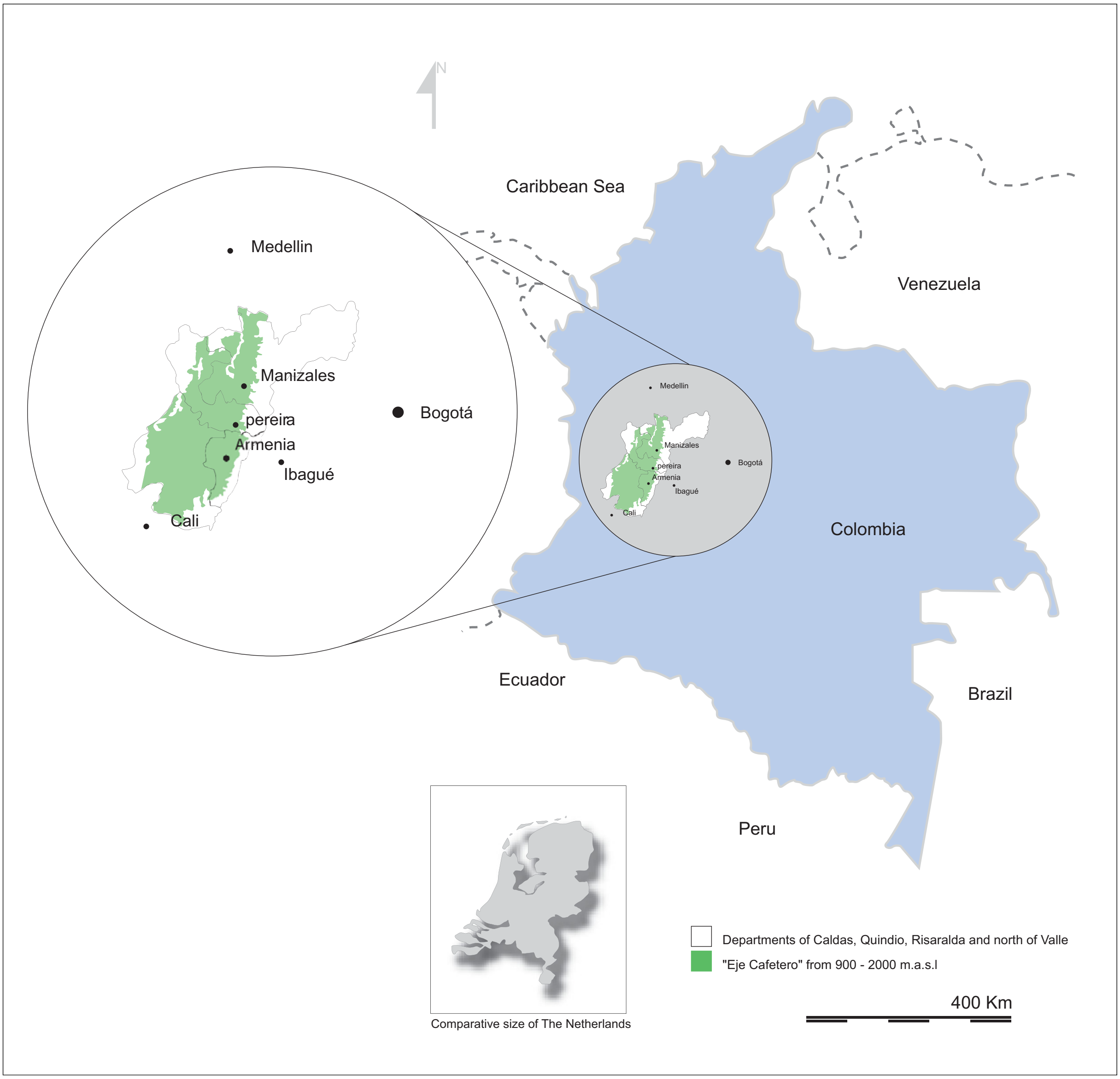

Fig. 4. 'Eje Cafetero' situated in Colombia and comparative size of The Netherlands. Source: Juan Ayala.

wood and bamboo. Early research shows that laminated bamboo could have a comparable structural performance as wood in this kind of constructions. However, research is not yet mature enough to make detailed calculations for frame strength (2004). Therefore, for this research, similar frames from bamboo as for wood are assumed. In the future it is likely that the section of the laminated bamboo beams and columns could be further reduced if adjustments to the type of gluing and orientation of the bamboo strips are made.

2.3. The volume of wood or Guadua-Bamboo necessary to construct a certain model house

This one-family house (Fig. 5) constructed in timber-frame has a total floor area of 175 m^2. The walls, roofs and first floors are constructed in timber-frame. The out-

Fig. 5. Model house used for this exercise. Source: Horemans houtskeletbouw nv, Meeuwen, Belgium.

Fig. 6. Leftovers during the production process can be used for various other purposes. Source: Juan Ayala.

side walls are constructed in brick because of urban planning prescriptions. The volume of CLS wood used for its timber-frame is 13.7 m^3, in volume CLS per floor area this is 0.078 m^3/m^2. This will be the reference house for the quantitative exercise. According to the second delimitation, an equivalent volume of 13.7 m^3 is assumed for the structural frame in both wood and Guadua-Bamboo.

2.4. Annual net yield of 1 ha Guadua-Bamboo forest area

Because of the optimal quality demands for the production of laminated beams and columns, only the best parts of the Guadua-Bamboo are used and there is a great margin set for imperfections. This is why there is a big difference in volume/ha compared with studies that calculate a general yield of Guadua-Bamboo. The parts of the Guadua-Bamboo harvest that are not used for the production of Guadua strips ('latas') and the leftovers during the production process (Fig. 6) can be used for a range of other purposes and products such as chip board, particle or fibre board, handicraft articles, tooth picks, bamboo charcoal, paper, etc. to name only a few. Of course this asks for a good organisation of the residuals of the process but in principle, there is no waste product.

Below calculations from Jörg Stamm [7] are made for a 'normal natural guadual'[3] in the 'Eje Cafetero'. The following steps are taken in the calculation of the volume of Guadua per ha per year for the production of laminated Guadua beams or columns:

- A 'normal natural guadual' counts 5000/6000 culms of 10–12 cm diameter per ha.
- Of these 5000/6000 culms, 25% can be harvested each year. This brings us to 1250 culms of 12–14 m length/year.
- For the production of 'latas', only the first 9–10 m are used: 3.1 m 'cepa'[4] and 6.2 m 'basa'[5] (the rest can be used for other purposes such as 'esterilla'[6].
- It is assumed that 250 of the 1250 culms are useless to produce 'latas' because they are damaged, curved, etc. (These can be used for other purposes.)
- From the remaining 1000 culms (3000 of 3.1 m), using calculations made in a Colombian production unit, a net of 21.3 m^3/ha/year brushed 'latas' can be derived. With a deduction for imperfections of 15% one can count with 18.1 m^3/ha/year perfectly brushed 'latas'.
- Laminated boards, beams and columns need a second brush after the process of lamination, which reduces the net volume (of 21.3 by m^3/ha/year) with an average of 30% to 15 m^3/ha/year.
- This equals the need for the volume of the reference house, and therefore one can now say approximately that: 1 ha of bamboo = (produces) 1 bamboo-frame house (175 m^2) each year.

2.5. Annual net yield of 1 ha wood forest area

To give a comparison of the net volume of laminated Guadua-Bamboo products and lumber that can be obtained from 1 ha of respectively Guadua-Bamboo and wood, the data for wood is still required. This data turned out to be very hard to find and could not be obtained in a simplistic manner because they depend on multiple factors, making it hard to give a solid comparison figure. However, some available statistics were used to get some answers:

[3] Guadual: Forest mass that occurs naturally with large regenerative power in which the dominant specie is Guadua.

[4] Cepa: Base part of the Guadua culm (with a length of about 3 m) which has the largest diameter. Due to its shorter internodes this part of the culm had the greatest resistance.

[5] Basa: Part of the Guadua culm above the 'cepa' (with a length of about 8 m). This part of the Guadua culm knows the most commertcial uses due to its intermediate diameter.

[6] Esterilla: Flattened (unrolled) Guadua culmn often used as wall covering.

Table 1
Lumber recovery per ha per year for Canadian lumber in British Columbia (BC)

Lumber BC (lumber recovery/year) rough green lumber (m^3/ha)	40 years rotation	125 years rotation (m^3)	400 years rotation (m^3)
94	2.35	0.75	0.24
200	5	1.6	0.5
401	10	3.2	1

Source: Katleen De Flander based on information from Council of Forest Industries (COFI).

Table 2
Logs to lumber[a]

Products	Process	Volume (m^3)	Co-products
Logs		100	
	Sawing		
Rough green lumber		63	+10 m^3 of sawdust and 27 m^3 of wood chips
	Drying		
Rough dry lumber		60	
	Planing		
Surfaced dry lumber		45	+15 m^3 of shavings and trim

Source: Katleen De Flander based on information from Bruce Sundquist, 2003. Forest and land degradation: a global perspective. (http://home.alltel.net/bsundquist1/df7.html).

[a] Data from M. Milota – CORRIM, 2002 (Consortium for research on renewable industrial materials, www.corrim.org) are comparable: Of the volume of rough dry lumber entering the planing process, 86% leaves as lumber. The major co-product is shavings. Combining 86% recovery at the planer with 56% recovery at the sawmill gives an overall yield of approximately 50% for planed lumber from logs.

Table 1 gives an overview of the range of lumber recovery per ha per year, taking into account the range of rotation ages.

These figures are valid for 'rough green lumber' recovery. However, we want to know the volume of 'surfaced dry lumber'. Table 2 gives an overview of the necessary steps:

2.6. Comparison annual net yield of 1 ha Guadua-Bamboo and 1 ha wood forest area

The combination of the new figures for 'surfaced dry lumber' as 71% of the volume of 'rough green lumber' and the range of rotation ages (taking the same data for British Columbia from COFI) can be compared with Guadua as in Table 3.

Keeping in mind the great variability in range of lumber recovery and rotation years and the difficulty to find hardly available figures for wood, one can see that a Guadua-Bamboo forest has a much bigger output of net material per ha per year than wood. From Table 3 one can derive that a wood plantation with an average wood recovery of 142 m^3/ha and 40 years of rotation age can provide material to construct 10 reference houses every 40 years, which is an average of one house every 4 years. The Guadua forest on the other hand produces enough material to construct one house every year. As becomes clear, one of the great advantages of bamboo over wood is that the forest can be harvested each year.

Table 3
Surfaced dry lumber recovery per ha per year compared with Guadua-Bamboo

Lumber British Columbia (lumber recovery/year) surfaced dry lumber (m^3)	1 year rotation (m^3)	40 years rotation (m^3)	125 years rotation (m^3)	400 years rotation (m^3)
66.7 (=71% × 94 m^3/ha)	NA	1.67	0.53	0.17
142 (=71% × 200 m^3/ha)	NA	3.55	1.14	0.36
284.7 (=71% × 401 m^3/ha)	NA	7.12	2.28	0.71
Guadua (net recovery products/year)				
15	15 m^3	NA	NA	NA

NA: not applicable.
Source: Katleen De Flander based on information from COFI and Bruce Sundquist, 2003.

2.7. Current Guadua-Bamboo resources in Colombia

The next logical question is finding out how many Guadua-Bamboo resources exist currently in Colombia? Morales and Kleinn [8] made an inventory of the existing *Guadua angustifolia* in the 'Eje Cafetero' in Colombia. This inventory was realised in 2002 by the CATIE[7] in the frame of the Guadua-Bamboo project.

The process of making an inventory becomes more important when dealing with a very fragmented natural resource such as Guadua. You can find Guadua dispersed on the borders of rivers and small streams, but also in small patches not associated with water sources, fragmented and dispersed in the 'Eje Cafetero' of Colombia. The majority if the guaduales grow natural. However, in the last years there has been a growth in the cultivation of Guadua in plantations for commercial purposes.

The map below shows the area of study located in the 'Eje Cafetero' of Colombia, in the departments of Valle de Cauca, Quindio, Risaralda and Caldas. The area was selected based on a digital elevation model of the region in which the areas with elevations between 900 and 2000 m.a.s.l. were chosen (Tolima was excluded for logistic reasons). The reason for this is that at these elevations, Guadua has the best growing conditions in the 'Eje Cafetero'. The total area of study was 1,029,524.77 ha (this is 1.7% of the total Colombian territory).

The objects of study were all the Guadua patches in this study area with a minimum of 0.3 ha (Guaduales smaller than 0.3 ha are not commercially attractive, nor interesting for forest management application).

Some results of the study:

[7] CATIE: Centro Agronómico Tropical de Investigación y Enseñanza – Costa Rica.

Please cite this article in press as: De Flander K, Rovers R, One laminated bamboo-frame house per hectare per year, Constr Build Mater (2008), doi:10.1016/j.conbuildmat.2008.01.004

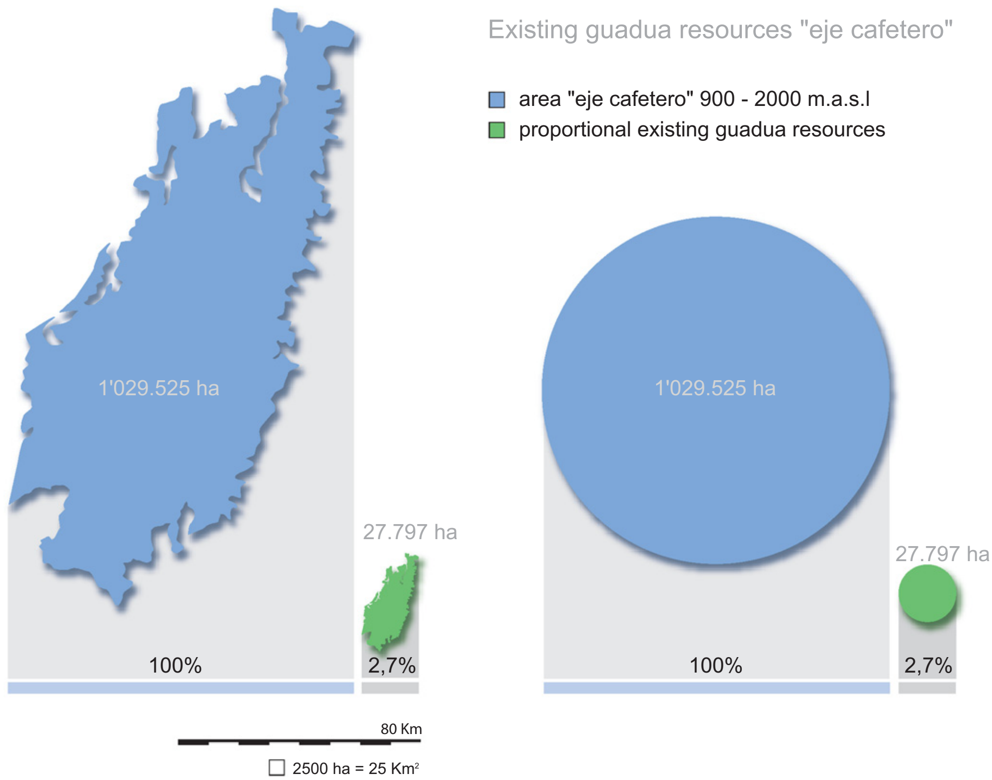

Fig. 7. Existing Guadua cover in the Eje Cafetero. Source: Katleen De Flander and Juan Ayala.

– The estimated effective area (not the projected crown) of Guadua is 2.7% which is 27,797.2 ha in the area of study of 1,029,524.7 ha.
– The average size of the Guadua patches is 2.9 ha.
– 95% of the delineated Guadua patches are smaller than 10 ha, which means a great fragmentation of the different guaduales in the region.
– The average density of Guadua culms per ha is 6940.
– The average diameter of the culms is 10.8 cm.

Fig. 7 represents the existing Guadua resources in proportion to the total area of the Eje Cafetero (900–2000 m.a.s.l.).

Table 4 translates this current potential of raw material in a potential volume of finished laminated products for bamboo-frame construction and a number of potential reference houses, assuming for a moment that all available bamboo is used for this purpose.

Table 4
Potential # products and houses with full use of current Guadua-Bamboo cover

Area of current Guadua-Bamboo[a] 'Eje Cafetero' (ha)	Volume of potential products at 15 m^3 per ha/year[b] (m^3)	# potential model houses at 13.7 m^3 per house/year[b]
27,797	416,955	30,435

[a] Source: Morales and Kleinn.
[b] Source: Katleen De Flander.

2.8. Potential Guadua-Bamboo resources in Colombia

The project of Sustainable Forest Management[8] in Colombia made a preliminary zoning for Guadua with the objective identifying the potential areas where the species could be developed. Table 5 gives the results of this study extended by some additional columns to be able to make comparisons.

Note that these are figures per department from a different source than the previous calculations of the 'Eje Cafetero' by Morales and Kleinn. The figures from column 3 and 4 show that the percentages of actual Guadua cover in these departments are very low. The average percentage of coverage (0.53%) is here obviously much lower than the percentage of Morales and Kleinn (2.7%) who limited their area of study to the central 'Eje Cafetero' with a size of only 1,029,524.7 ha where Guadua grows in optimal conditions.

The figures in the last two columns show a big potential to establish Guadua plantations. Nevertheless, it is necessary to make a zoning with greater detail to be able to make political, economic and technical decisions related to the promotion of the cultivation and management of this species with greater certainty [9].

[8] Study to define technical and methodological criteria for the inventory, arrangement, zoning and sustainable management of the Guadua resources in the Eje Cafetero, Tolima and Valle del Cauca. Ministry of Environment – Project of Sustainable Forest Management in Colombia.

Table 5
Existing and potential Guadua cover per department

Department	Area department[a] ha)	Current area Guadua[b] (ha) natural + planted	Current Guadua/total area department[c] (%)	Area of potential development of Guadua[d](ha)	Area potential development of Guadua/total area department [c] (%)
Caldas	788,800	6195	0.79	241,657	30.6
Quindio	184,500	8348	4.52	95,055	51.5
Risaralda	414,000	4130	1.00	200,304	48.4
Tolima	2,356,200	4221	0.18	697,217	29.6
Valle	2,214,000	8392	0.38	604,500	27.3
Total	5,957,500	31,286	0.53	1,838,733	30.9

[a] Source: www.colombia.com/colombiainfo/departamentos.
[b] Source: Guadua Para Todos. 2004. In: Organización de la Cadena de la Guadua, caracterización de eslabones, actores y procesos, first edition, April 2004. (Slightly different figures are found in other sources.)
[c] Source: Katleen De Flander.
[d] Source: Proyecto de Manejo Sostenible de Bosques en Colombia (Moreno, 2003).

Fig. 8 translates this potential of raw material in a potential number of model houses per department.

This maximum situation of potential Guadua-Bamboo cover is very far from the current situation and will also be never reached in reality because of strong competition for land use. However, these numbers do give a clear view of the great potential the region has in developing their Guadua-Bamboo resources and transformation possibilities. Even if only 10% of the potential Guadua-Bamboo area is reached, this means that every year 200,000 reference houses could be constructed.

3. Conclusions

The fundamental goal of this paper is to facilitate the use of this fast-growing renewable resource out of its cur-

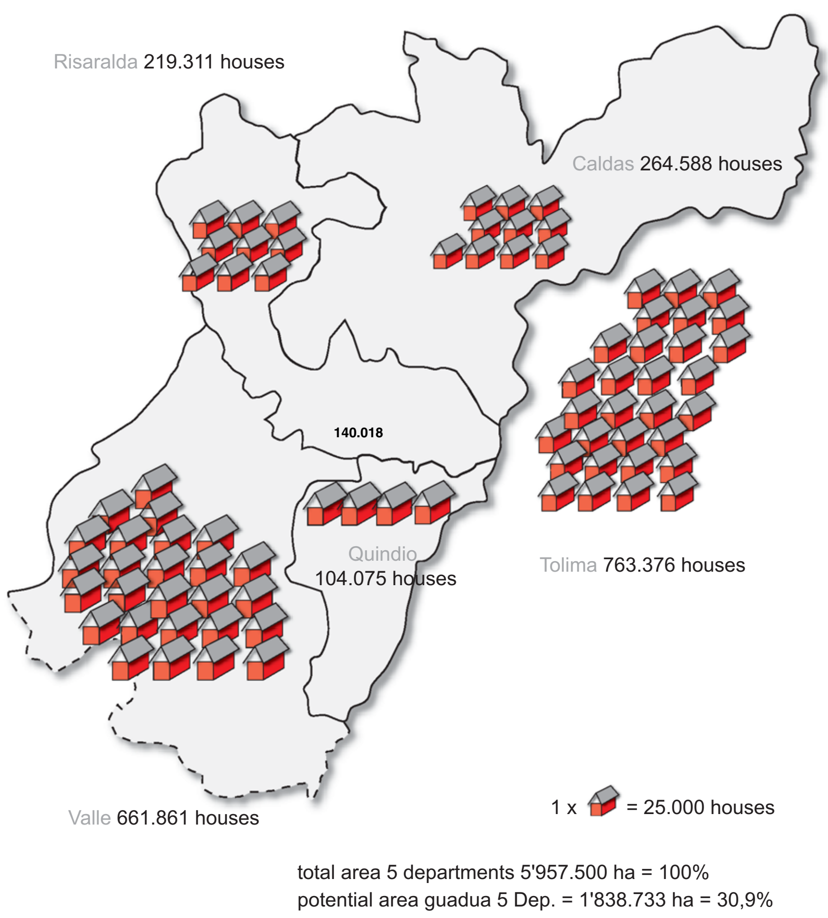

Fig. 8. Potential # reference houses per department with full potential Guadua-Bamboo cover. Source: Katleen De Flander and Juan Ayala.

rent experimental and special interest status and into the mainstream, by focussing on the high-tech products from bamboo, processed for easy use and meeting modern standards. Comparable with the development of wood-based construction, bamboo needs to go trough a similar process of professionalisation.

The quantitative analysis presented in this paper aimed at demonstrating the global potential of laminated bamboo-frame construction as an alternative for concrete and brick and as a direct competitor for wood-frame construction. Because of its fast-growing quality and the fact that a bamboo forest can be (partially) harvested every year, bamboo has a great advantage in yearly yield per forest area compared to wood. As demonstrated, one laminated bamboo-frame house of 175 m^2 can be constructed from 1 ha of bamboo forest each year, leaving still a great amount of bamboo material to be used for secondary products.

This paper looked into the potential Guadua-Bamboo resources of Colombia, and could draw conclusions that even if only 10% of the countries potential Guadua forest area is reached 200,000 laminated bamboo-frame houses (175 m^2) could be constructed each year. Knowing that the growing regions of bamboo are widespread globally, the potential of bamboo as a mainstream construction product is greatly enlarged.

If we compare this potential with the construction market of The Netherlands for example, with a current number of around 60,000 new-built houses per year and with an estimated market share of timber-frame dwellings of about 5% (and growing), we could say that laminated bamboo-frame houses could easily replace these 3000 timber-frame houses and/or even better, take over part of the other non-bio-based mainstream construction materials such as concrete and bricks.

The life of new structural elements in laminated bamboo is still very young. A great deal of research has to be done to improve the production process, which will have a positive effect on the structural properties of the elements and on the annual yield per ha. However, these construction products already encompass a very promising future. Next to the fact that they are ecologically sound, they are now standardised and easy to use.

It should be noted here, that so far the view developed in this paper has not found so much support. To the knowledge of the authors, the first pilot project in laminated bamboo-frame construction still has to be realised. It is hard to understand why the focus in the "bamboo scene" stays with the use of rough culms, and hardly any research goes into standardising and developing industrialised and modern products from bamboo, and this while the latter is the most promising approach for a successful global bamboo future.

References

[1] Laul Anil, The quest for the ultimate building block. Sustainable Building. No. 2-2002; 2002. p. 10–3.

[2] Gutierrez Jorge A. Structural adequacy of traditional bamboo housing in Latin America. International Network for Bamboo and Rattan (INBAR) Publication; 2000.

[3] Moran J. Visión y proyecciones de la industria de la construcción y de otras industrias a base de Bambú en América Latina. Paper presented at the international symposium Guadua 2004, Pereira, Colombia; 2004.

[4] Arce-Villalobos, Oscar Antonio. Fundamentals of the design of bamboo structures. Doctoral Thesis, TU Eindhoven; 1993.

[5] Pigg, Stacy Leigh. Inventing social categories through place: social representations and development in Nepal. Comp stud soc hist 1992;34:491–513.

[6] Londoño Ximena. La Subtribu Guaduinae de América. Paper Simposio International Guadua 2004, Pereira, Colombia; 2004.

[7] Stamm Jörg. Proyecto Latas y Laminados de Guadua. Informe Final Proyecto U.T.P.-GTZ; 2002.

[8] Morales D, Christoph Kleinn.Inventario de las existencias de *Guadua Angustifolia* en el Eje Cafetero de Colombia. Paper presented at the international symposium Guadua 2004, Pereira, Colombia; 2004.

[9] Moreno R.D. Proyecto Manejo Sostenible de Bosques en Colombia. Area Piloto Eje Cafetero – Tolima – Valle del Cauca. Conformación de los Núcleos Forestales Productivos de Guadua, en el departamento de Risaralda. CARDER (Corporación Autónoma Regional de Risralda); 2003.

Please cite this article in press as: De Flander K, Rovers R, One laminated bamboo-frame house per hectare per year, Constr Build Mater (2008), doi:10.1016/j.conbuildmat.2008.01.004