Bamboo as a Building Material in Kenya

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Summary

A century ago, Kenya had 350,000 hectares of it's only indigenous bamboo "Yushania Alpina" covering the Aberdares, Mt Kenya, the Cherangani's, Mt Elgon and the Mau. Today little more than 80,000 hectares remain. Since there is no commercial value placed on bamboo and it has been widely replaced by cash crop plantations, the destruction to Kenya's biodiversity and water catchment has been immense. Preservation of the environment seems only to work if Kenya's population will be able to profit directly from it. Against this background, it seems promising to promote the use of bamboo as a building material, even though very little construction has been undertaken in Kenya yet.
The paper will give a brief overview over contemporary bamboo constructions in Asia and South America and show ways of possible adaptations to Kenya.
It will have a detailed look at the roof construction of the skills centre near Malaa, that was build in 2011/2012 in a cooperation between JKUAT, Technische Universität München and the University of applied sciences Augsburg.
Three different kind of roof structures made of the indigenous African alpine bamboo show suitable solutions for three different kinds of building size and use. A very sophisticated construction of a wide span is confronted with a very simple construction that can easily be repeated for common tasks. The determining advantage of light weight allows substantial prefabrication of structural elements, that can be manufactured with high precision under low tech conditions and be assembled on site without special equipment in quick succession. For a holistic use of the delivered bamboo the architectural design includes applications for remnant material of the manufacturing process.
The example of the skills centre project shows bamboo to be a very suitable and environmentally friendly substitute to construction materials like timber or steel in Kenya.

Keywords:

Sustainable construction; bamboo construction; resource efficiency; biogenic building materials; indigenous bamboo

Introduction

Bamboo has the highest biomass productivity of of all land plants. Depending on variety and location, between 15 and 25 tons of bamboo per hectare can be produced in a year. An average European spruce forest, on the other hand, yields only some six to eight tons of timber per year and hectar [1]. According to Liam O'Meara, head and founder of the Kenyan enterprise The Bamboo Trading Company the indingenous local bamboo even produces 40 to 60 tons per hectare and year and by far more than any tree is able to produce.

Given the fact that in many of the world‘s regions the need for wood is continually increasing, sustainable bamboo offers an alternative to tropical woods and could play a role in preserving the rain forests. Bamboo can can also play a role in in solving some of the 21st century‘s major environmental problems: soil erosion, deforestation and water scarcity. There is a Chinese saying that goes: „If you plant bamboo, you plant water“. Thanks to its finely woven roots and their capacity for storing water, the plant raises the groundwater level on a long-term basis. With this widely ramified root system bamboo stabilizes deforested mountain slopes and river banks, thereby preventing soil erosion. These diverse uses make bamboo a genuine miracle grass [1].
A century ago, Kenya had 350,000 hectares of it's only indigenous bamboo *Yushania Alpina* covering the Aberdares, Mt Kenya, the Cherangani's, Mt Elgon and the Mau. Today little more than 80,000 hectares remain. Since there is no commercial value placed on bamboo and it has been widely replaced by cash crop plantations, the destruction to Kenya's biodiversity and water catchment has been immense. Preservation of the environment seems only to work if Kenya's population will be able to profit directly from it [2].
Since 1985 the Kenyan Forestry Research Institute (KEFRI) under the direction of Bernard Kigomo has been researching on reforesting and cultivating indigenous and exotic species of bamboo in Kenya [3-8]. Since 1989 studies were made on the socio-economic potential of the use of bamboo [9]. In 1995 Kigomo published „Guidelines for establishment and managing plantations of bamboo in Kenya“ [10]. All studies and research of KEFRI suggest a similar conclusion: The potential of utilization of bamboo as a raw material from sustainable managed forests and plantations and it‘s positive side effects for rural economy, preservation of environment and wildlife as well as water catchment is not yet recognized in Kenya.
Against this background, it seems promising to promote the use of bamboo as a building material, even though very little construction has been undertaken in Kenya yet.

fig. 1 global distribution of natural bamboo resources

Contemporary Bamboo Constructions in Asia and South America

The main areas of natural distribution of bamboo are located in South East Asia, South America and Central Africa (fig. 1). But even if there is very sophisticated use of bamboo as a building material in several African countries, bamboo constructions in Africa are remarkably rare and unknown compared to Asia and South America. So from the African perspective a look at constructions built in Columbia and China might be inspiring.

In 2000, at the Expo in Hannover, Germany, the Pavilion of the ZERI-Foundation (Zero Emissions Research Initiative) was designed by the Columbian architect Simon Velez (fig. 2). The main structure was made of the Columbian bamboo *Guadua Angustifolia*. For the first time in history a building permit was given to a bamboo structure in Germany. To receive the permit, a sample construction in Columbia had to be build and was tested for stability and fire safty by German authorities. This way the various bamboo constructions of Simon Velez in Columbia was recognized by a large attendance. Simon Velez and other Columbian and South American architects are using the strong, long and very straight *Guadua* bamboo for all different kind of constructions from multi-level housing to a cathedral in Peireira through to wide span motorway bridges.

fig. 2 sample construction of the ZERI-Pavilion in Columbia

In 1994 a bridge over the river Paez near Coquiyo in Columbia was destroyed by a mudslide. The German developement worker and carpenter Jörg Stamm suggested to rebuild the bridge as a roofed bamboo construction made of local *Guadua* instead of a steel construction. In cooperation with the Institute of light weight construction in Stuttgart and the RWTH Aachen he was able to design a bridge that was not only much more cost-efficient than a steel construction, but also enabled the local community to implement the construction themselves. The bridge has an overall length of about 25 meters, a span of about 10 meters and carries a truck of two tons of weight. Continuing working with bamboo he realized a bridge in Pereira with a span of 52 meters. But his most impressive bamboo construction is the Tiga Gunung (three mountains) in Mambal, Bali in Indonesia (fig. 3). Built as a workshop and event building it covers 1200 square meters. Three about 15 meters high towers carry a suspended roof construction and at the same time form three skylights to give the interior its significant and unique architectural expression. The famous and iconic building is now used as event location and and showroom of an international jewelry. It is a very good example for how architectural design is able to promote a building material, that is locally despised as „poor man‘s timber“ to the highest acceptance and the most representative use. But the building also shows one of the most obvious problems about building with natural bamboo poles: Mostly because of it‘s joints the construction is hardly statically calculable. In the case of the Tiga Gunung building the construction proofed to be not braced enough and undulates under the load of strong wind.

fig. 3 Tiga Gunung building in Mambal, Indonesia, interior

By far most bamboo structures are designed just by the experience of the architect and not calculated by a reliable method. That‘s why in many constructions structural elements are by far over-designed and therefore disproportionate. For simple and repeating building tasks that procedure might be suitable. But even in China, India and South East Asia, where there is a tradition of building sophisticated bamboo constructions with a great variety of well-elaborated joints for thousands of years, the designing and planing process has not yet caught up with methods used in ervery day‘s practice constructing with timber, steel, concrete or brickwork.
In some cases, like the ZERI-Pavilion, stability is determined by mechanical load tests, an appropriate, but expensive way of designing structural elements. That method of defining

structural elements is most promising in constructions of a high quantity of repeating elements and without complex dependencies.

fig. 4 German-Chinese House at the Expo 2010 in Shanghai, China

Markus Heinsdorff took a very different approach designing the German-Chinese House at the Expo 2010 in Shanghai, China (fig. 4). His design combines primarily structural elements of natural bamboo poles and of laminated bamboo trusses, frames and panels. To pass German as well as Chinese building regulations, all parts of the structure had to be verified for its stability by calculation. The laminated structural elements produced in China were of very homogeneous quality, could be tested at the Tongji University in Shanghai and calculated in the manner of timber constructions, even though for the first time laminated bamboo trusses with a span of seven meters were produced. The harder part was to deal with the structural elements made of natural bamboo poles. In order to create a reliable and rather invisible joint between two poles, the common technic of steel connections implemented in concrete fillings in the outer internodiums of the bamboo canes were chosen. To optimize the compound properties between bamboo and concrete, at the Technische Universität Darmstadt an innovative concrete mix formula was invented, that not only avoided shrinking of the concrete filling, but also improved adhesion between both of the compounds. Material testing of the connections generated reliable values for static calculations [11].

Parallels of Timber and Bamboo Constructions

A century ago, timber constructions in Europe faced similar problems to bamboo constructions around the the world today. No reliable calculating methods were known, common constructions were designed by practical values and manufactured on a very handcrafted basis. For a long time timber was considered not to be a modern, durable building material and being suitable for contemporary building requirements. Like bamboo today, timber was assumed to be only useful for temporary structures.

But by continuously developing sophisticated engineering and calculating methods and by inventing a great variety of timber products timber today in Central Europe became not only a popular, reliable and modern building material, but with increasing environmental problems caused by the building sector it is valued to be the most incomparably sustainable building material in Europe. The exhibition „Building with Timber - Paths into the Future“, that was first shown in 2011/2012 in the Pinakothek of Modern Arts in Munich, explained the incredible potential of that renewable resource to a greater public. It identified timber not only as the single building material in Europe - assumed to be harvested from sustainable managed forests - available in endless amounts. It pointed out, that slightly more than one-third of the annual German timber harvest - which is about 9 % less than the annual incremental timber growth - would theoretically suffice to construct all new buildings in Germany that year out of timber [12]. A scientific study of five buildings, comparing the structures constructed of timber on the one hand and constructed of conventional construction products - largely created from non-renewable mineral, metallic or synthetic materials - came to a very clear conclusion: The only way to reduce CO2-emissions, acidification potential and primary energy consumption significantly, is to build with timber (fig. 5) [13].

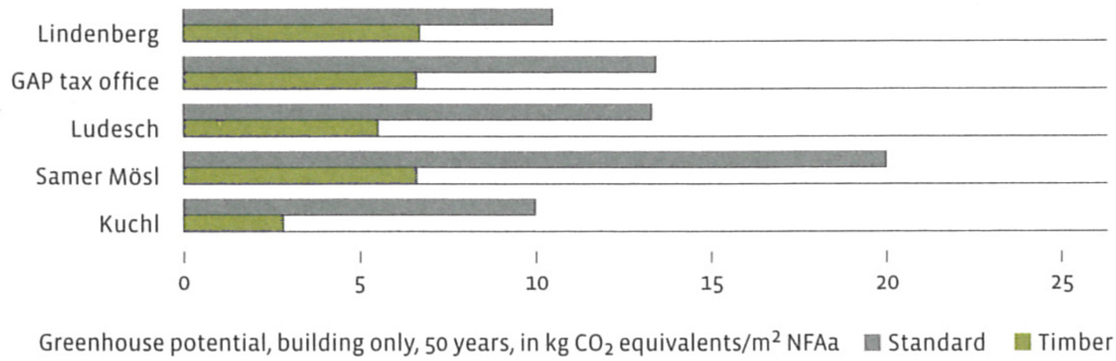

fig. 5 Greenhouse potential of timber construction compared to conventional construction at the example of five building ensembles in Germany and Austria

By growing, plants take CO2 out of the atmosphere, so any biogenic building material, bamboo as well as timber, stores carbon. That carbon stays stored in buildings for a in the best case long time. For that reason building with biogenic materials from sustainable forestry means not only less damage to the environment, but active climate protection.

Timber has proved to be a suitable building material for almost every type of building, as can be observed at the project of the office building LCT one, nine story a high rise building with a primary structure of timber (fig. 6).

fig. 6 Life Cycle Tower LCT one in Dornbirn, Austria; designed by Hermann Kaufmann Architects

Bamboo could possibly progress in an analogous way. The development of proper designing and reliable calculation methods as well as global acceptance thru a change of appreciation as a durable construction material seem to be the key to success. Like timber, bamboo is an inhomogeneous and ansiotropic material. Analogous to wood products like cross laminated panels the strategy of producing a rather homogenous material by cutting and reassembling is adapted to bamboo. Cross lamination of layers reduces it's anisotropic qualities. With laminated bamboo already a elaborate bamboo material is in many regions available and can be used in the same way as timber products. An example for that possible substitution is the project of a restaurant building in Zhoushan, China designed by Hermann Kaufmann, Wolfgang Huss and Stefan Krötsch (fig. 7). Designed as a timber construction in the first place, it was changed into a construction of laminated bamboo since high quality timber was locally not available. That change of material had almost no altering impact to the structural design.

fig. 7 Restaurant Building in Zhoushan, China; designed by Kaufmann, Huss, Krötsch

The for ecological reasons even better use of solid timber can not be easily matched by natural bamboo canes in respect of possible adaptions. While solid timber can easily be cut into suitable profiles for any structural implementation, the applicability of the hollow and round bamboo cane is limited. Interesting experiments were made in the nineteen-seventies by the Institute of light weight constructions by using battens of split bamboo canes to generate wide-span grid shells.
Since natural bamboo canes are perfect qualified for resisting forces in direction of the pole, compound elements like concrete-bamboo-compound elements seem promising. As a substitute for steel bars as concrete reinforcement bamboo is locally already quite common. The possible strategies of using bamboo for constructions can not be foreseen yet. The mentioned disadvantages compared to timber might be matched by the higher strength of bamboo fibres, but in the first place by it‘s amazing speed of growth.
At a time of scarer resources and increasing population numbers, and in conjunction with cutting-edge processing methods, bamboo represents a new, pioneering material [1].

Bamboo Construction at the Skills Centre Nairobi in Malaa

The Skills Center was build in August and September 2011 and March 2012 in a cooperation between Jomo Kenyatta University of Agriculture and Technology (JKUAT), Technische Universität München (TUM) and the University of applied sciences Augsburg as a design-build students project. It was initiated by the German NGO „Promoting Africa“ in cooperation with the Kenyan NGO „Youth Support Kenya“ to help juveniles of Nairobi's second largest slum Mathare to learn simple craftsmen skills necessary for a self-employed means of subsistence. Structural design, material testing and manufacturing prototype elements were mainly done in Munich, while preparation of the site and agreements with local authorities were done in Nairobi.
While walls and floor slabs are conventionally constructed out of the local hand-dressed natural stone and concrete, the roof construction and several other elements of the building are - for ecological reasons - made out of the indigenous Kenyan bamboo *Yushania Alpina,* harvested in the nearby Abadare mountains.
Representing the Department of Timber Construction at the Faculty of Architecture at the Technische Universität München, it would have been obvious to build a timber structure. But even if timber in Central Europe might be the most ecological building material, for Kenya, however, the situation is different: In the past the forest coverage of Kenya has been reduced from about 15% to less than 2% of the land area [2]. The pressure on the remaining forests is very high. Sustainable forestry might not always be the source of the timber available. After considering using a steel construction the design team learned about the studies of KEFRI and recognized bamboo as the most promising substitute for timber.
Experimenting with building materials was a mayor part of the design process. From the very beginning the inner logic of the architectural design was influenced and formed by the characteristics of building materials. The aim was to use materials that are locally available, ecologically sustainable and practicable for unskilled workers to be copyable for neighbor constructions. For that reason the bamboo construction uses natural canes and very efficient, but simple joints. The insect treatment is for ecological and financial reasons done with a sea salt solution. Since the location of the skills centre is quite arid, there is no damage to the

bamboo to be expected from hydroscopic effects. But way more important for the durability of the construction is the detailing. The design principal for the bamboo structure is to avoid moisture by covering, using metal roofing and natural stone walls as hard shell for the soft core of bamboo, so no part of the bamboo structure is exposed to weather. All footings of bamboo pillars are at least 30 cm above floor level to avoid splashing water contact.

Since these manners of constructive protection were quite easy to adapt from timber construction, the greatest challenge for the structural design was to find adequate methods of shaping and dimensioning the yet to us quite unknown material. The first bamboo structures that were designed did not correspond quite well with the characteristics of the material. But the course of the process, with the help material testing and prototypes of joints, reasonable constructions was developed.

One of the objectives of the exploration trip in March 2011 was to find out about availability, quality and price of the building materials needed. Since bamboo is not yet in use as a building material at all in the area of Nairobi, it was a lucky coincidence to find the only company capable of delivering the required amount of bamboo, and also to bring eight sample canes back to Munich. In this way the indigenous Kenyan bamboo *Yushania Alpina* was tested for its strength under pressure, tension and bending for the first time at the material testing office of the Technische Universität München. The results proved Y*ushania* to be of very good quality as a building material. It‘s values are similar to *Guadua Angustifolia* and in some respects equal to steel. The testing also showed that it is most important to make sure static forces are introduced properly into the walls of the hollow canes. Punctual strain cracks the bamboo cane even at little load, while immense burden can be managed by optimal load application (fig. 8).

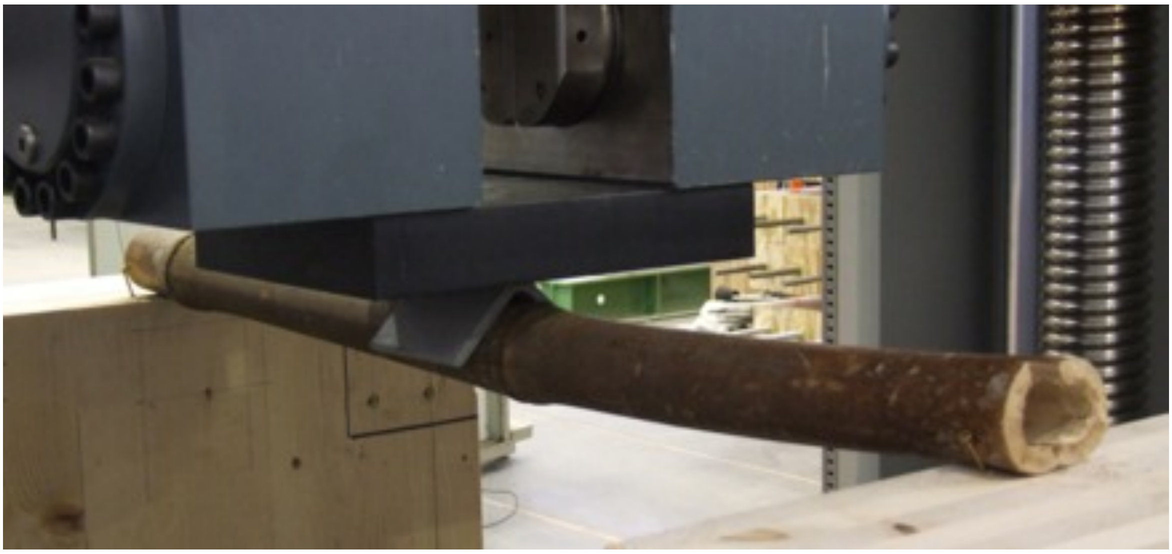

fig. 8 Material testing of samples of Kenyan Yushania Alpina at the TUM: Cracking cane by punktual strain at the support

The generated values were supposed to be base of the static calculation for the roof structure of the skills centre. To verify the calculated results, sample trusses were manufactured and mechanical load tests were made. It became apparent, that the calculation method was not appropriate for the specific kind of truss. The connections between the three bamboo canes, that form - laying on top of each other - the body of the trusses, proofed to be too flexible.

From that point on, shaping and dimensioning of the trusses as well as details and connections of the structure were developed in continuous, circular process of planning and manufacturing samples. Finally, the structure was optimized to the specific demands of broad prefabrication and safe assembling of building elements.
On site, the roof structure of all three types was prefabricated successively in negative forms in about three weeks time. Assembling of the roof construction of the workshop building was done in less than three days, at the kitchen building in about two days and at the dormitories in less than one day. This way not only safety was increased since complicated work did not have to be done in hight of the ceiling and less scaffolding was required, but also other work on the building like concreting and walling could be executed without interference. Last but not least prefabrication allowed a much higher precision of joints within the bamboo structure. The light weight of bamboo allowed prefabrication of trusses of about 12 meters in length combined with pillars of 4,50 meters in hight. The truss-pillar combination could still be carried by just two workers and be assembled by five or six workers without crane or else special equipment (fig. 9).

fig. 9 Assembling of the roof structure of the workshop building

Already by building prototypes, attention was drawn to the topic of wholesale material use. Sorting out canes suitable for the wide span truss in the workshop building out of a bunch of harvested bamboo canes leaves 70% to 90% reject. In order to be resource efficient, the concept of the skills centre was to use a cascade sorting system into types of declining quality of bamboo poles for different applications. The straightest and longest poles were used for the structure of workshop building with a span of 6,50 meters and cantilevers of 3,50 and 1,80 meters. A second quality level was used for the structure of kitchen building with a span of six meters, while the remaining material could still be used for dormitory ceilings with a span of three meters. Leftovers of the manufacturing process were recycled for auxiliary constructions like scaffoldings, or used as concrete reinforcement and for fillings of door and window shutters (fig. 10).

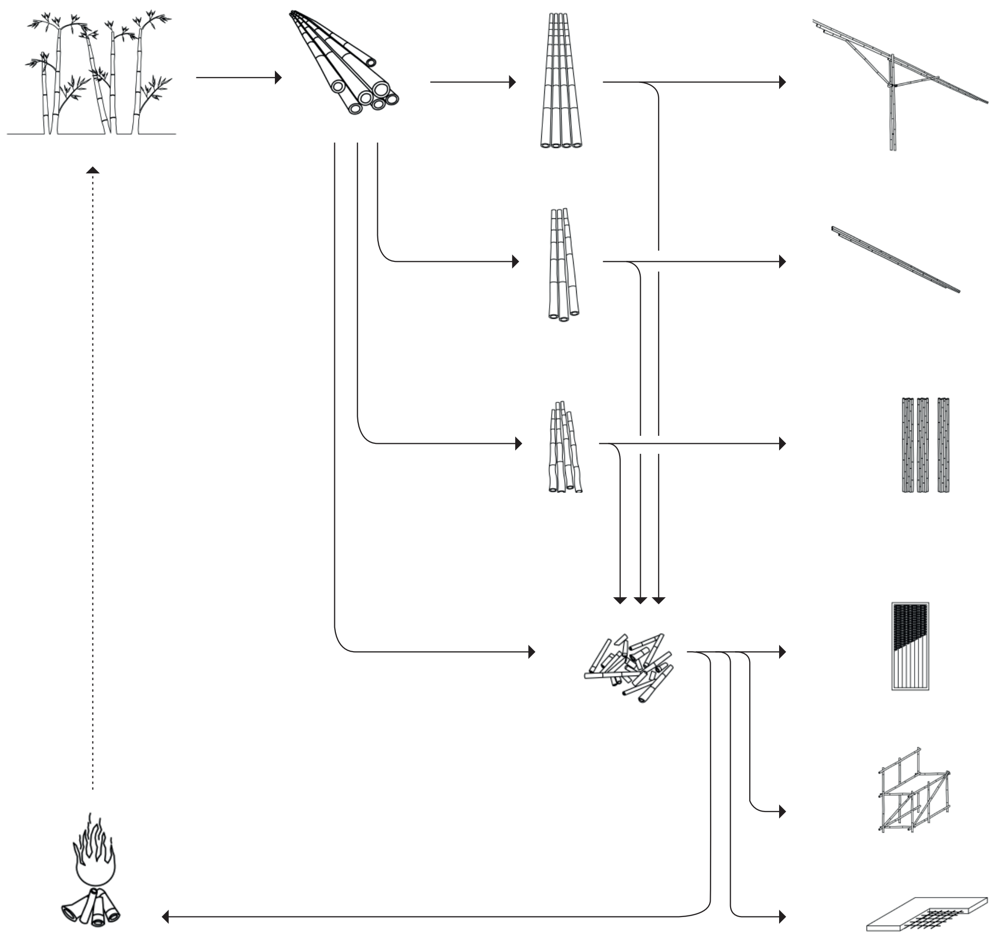

fig. 10 cascade sorting system for different types of construction elements

So already during design phase material influenced design and layout of the building ensemble. The development of very specific characteristics of roof and wall construction was integrated in the design as a synchronizing process. The architectural expression of the build ensemble relies very much of that intense relationship (fig. 11).

fig. 11 facade of the workshop buildung

Conclusion

The example of the skills centre shows bamboo to be a very suitable and environmentally friendly substitute to construction materials like timber or steel in Kenya and at the same time is much more cost efficient.
The light weight of bamboo construction allows prefabrication without special equipment. Repeating structural elements make it easier to design and to prefabricate the construction. If all parts of the bamboo structure are protected from wetness, a durable, long lasting construction can be established. Modern design for contemporary tasks can be realized.
The indigenous *Yushania Alpina* is a very qualified building material. At the same time, using *Yushania* from sustainable forestry and plantations helps to save and replant the natural vegetation. This way wildlife can be preserved, water catchment can be improved and local rural communities are able to benefit from natural, renewable resources.
Building with bamboo offers the chance for Kenya to not only utilize an important part of it‘s natural and by sustainable use endless resources, but at the same time to develop an industry within a market of high expectations.

References

[1] BAUR, M., „Bamboo - a miracle grass and material of the future“ in Markus Heinsdorff (ed.) *The Bamboo Architecture, Design with Nature*, Hirmer Verlag München, 2010, pp. 180-181

[2] O‘MEARA, L. „Bamboo in Kenya“, 2013, yet unpublished

[3] Kigomo, B.N., Kamiri, J.F. (1985). Observations on growth and yield of Oxytenanthera abyssinica (A. Rich) Munro in Plantations. E. Afr. agric. For. J. 51 (1) 22 - 29.

[4] Kigomo, B.N., Kamiri, J.F. (1987). Studies on propagation and establishment of Oxytenanthera abyssinica, Bambusa vulgaris and Arundinaria alpina in medium altitude sites in Kenya. Kenya J. Sc. Tech Series B8 (1), 5-13.

[5] Kigomo, B.N. (1988). Distribution, cultivation and research status of bamboo in East Africa. KEFRI Ecological series, Monograph No.1 43 p.

[6] Diana de Treville and Kigomo, B.N. (1992). A preliminary assessment of the Bamboo subsector and Associated semi-arid ecosystems of East Africa-In-Progress findings and Recommendations KEFRI and WINROCK International, Nairobi, Kenya.

[7] Kant, H., Kigomo, B.N., Ndambiri, J.K. (1992). Development of bamboos in Kenya. Kenya Forestry Master Plan. Forest Department; MENR, Nairobi.

[8] Kigomo, B.N. & Sigu, G.O. (1996). Establishment and growth of field trials of exotic and indigenous bamboo species in Kenya. E. Afr. Agric. For. J. 61 (3), 213 - 223.

[9] Minae, S. (1989). Socio-economic issues in bamboo production and utilization in Kenya; present and future potentials. Paper for: Kenya Forestry Research Institute. KEFRI and IDRC, Nairobi.

[10] Kigomo, B.N. (1995). Guidelines for establishment and managing plantations of bamboo in Kenya. KEFRI Occasional Management Paper No.1 31p.

[11] GARRECHT, H., SCHNEIDER, J., et al. *Connections* in Markus Heinsdorff (ed.) *The Bamboo Architecture, Design with Nature*, Hirmer Verlag München, 2010, pp. 188-191

[12] KAUFMANN, H., NERDINGER, W. et al. (ed.), *Building with Timber - Paths into the Future,* Prestel, Munich, 2011, p. 17

[13] KÖNIG, H., *Wood-based construction as a form of active climate protection* in Kaufmann, H., Nerdinger, W. et al. (ed.), Building with Timber - Paths into the Future, Prestel, Munich, 2011, pp. 18-27