

ECO-CONSTRUCTION AND INFRASTRUCTURE

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Abstract - An attempt is made in this paper to give a holistic point of view of eco-construction and infrastructure especially with regards to the choice of non-conventional materials and technologies, which are used not only in developing countries, including Brazil, but as well in industrial countries. Eco-construction and infrastructure become more and more important in our world with the growing concern about the use of non-renewable materials. Even a normal citizen becomes concerned with his environment. It is not the task of the engineer to pass his awareness of what could become a bleak future for generations to come but to give the options existing in construction. Non-conventional materials are introduced which might be the answer to a worldwide quest for eco-construction and infrastructure such as soil, bamboo and composites reinforced with vegetable fibers. Their efficiency, effectiveness, impact, relevance and sustainability are considered and discussed.

Keywords: Non-conventional materials, composite, bamboo, vegetable fiber, energy

1. Introduction

The construction industry is one of the most polluting on earth. On the one hand housing is still urgently needed as there are millions, alone in the developing world, without homes, and on the other hand there is the feeling that construction has to stop. Cities have grown beyond their limits, have sprawled in all directions, which not only create problems with transport, refuse, energy- and water-supply but as well have invaded eco-systems and valuable green space necessary for agricultural use (Thompson, 2000). Nature has suffered irreparable damage. The consequences become more and more evident: droughts, heat waves, forest fires, polluted air and waters, which together result in human sacrifices. Crops fail; there is a lack of drinking water, lack of water in the reservoirs for energy generation etc. Armed conflicts around the world contribute even more to the human misery.

At this point it does not lead anywhere blaming the industrial countries because they cause more pollution in the nature of their activities. Waiting for them to clean up, thinking that they have the means to do so, does not resolve the problems either. Everywhere, actions need to be taken to try to reverse the present state. Rio 92 and Rio+10 had created a forum where the environmental problems were presented and discussed. Various other national and international events disseminated on-going research projects. Now steps need to be taken to implement the results of these projects.

The whole construction process has to be revised starting with the location and the choice of materials to the different production processes. The answers are there already but they are followed by only a few. The few research centers make hardly a difference. These topics need to be taken up and supported by governmental agencies, NGOs, private enterprises and industries. Eco-construction and infrastructure need to be part of regular university courses.

Before starting to build new housing one should look at the existing already. It has been a trend recently, and this worldwide, to abandon the old city center and build at the periphery of the city getting further away from the center and its commercial activities. Property developers attract people to a newly developed area with the prospects of a better life; especially families with small children welcome a bigger house with garden and very often with a swimming pool. But often infrastructure does not accompany the development. Especially water and waste water can become a great problem to a point that drinking water has to be delivered in tanks and waste water is released into the local stream without any previous treatment. Often the new home can turn into a nightmare without water and open stinking sewer running amidst the newly built area.

The city center in contrast loses its population; houses fall beyond repair and soon are not fit for habitation. This could be amended; the city could step in with some actions such as incentives for owner-occupier or taking over abandoned houses, restore them and rent them out to low-income groups.

A greater number of the population commutes to work everyday and where there is no efficient public mass transport system, people, who can afford it, take to cars; and mostly one person per car. Modern life style requires many appliances to make life more comfortable: heating when it is cold, air conditioning when it is hot, apart from all the other devices, which “improve” life. Tolerance hereby becomes zero. In some countries, as soon as heating is turned off, air conditioning is switched on. Old methods of improving temperature indoors are forgotten. Thicker composite soil-fibers walls of older houses proved to be efficient in the past. Green roofs or Soil fiber roofs used in Asia, as insulation, can improve the temperature inside and outside buildings considerably and is of pleasing appearance. Systems of the antiquity such as underground streams and interconnected airshafts or wind catching towers as were used in Persia (Iran) very efficient to cool houses and palaces even in the desert.

Wind, sun and water can be harnessed to create energy. Large hydraulic power generating installations do not always meet the expectation. It nearly always leads to changes in the ecosystem if not even climatic changes. Solar energy not in its modern sense but as a non-conventional heating, especially in tropical countries, could supply most of the energy needed. Wind, existing near the sea and in the mountains, could be changed to electric energy. Plans are on the way that green energy makes up 5% of the energy supply in Washington, DC (Journal of Civil Engineering, 2003).

As eco-structures can be seen those constructions which are in harmony with the surrounding, which do not violate the environment neither through the chosen building materials nor through construction methods. Ideally this includes all types of construction: houses, apartment buildings, schools and roads, even factories to a certain extent. The use of industrial materials should not be the first choice. Renewable and non-polluting materials should ideally be considered first. This conscientiousness does not come naturally, especially after decades of being subjected to a marketing, which promoted only industrialized building components. The use of non-conventional materials and techniques should be included in every engineering curriculum so that the young engineer, like a doctor of medicine, will exercise his profession in the best of his knowledge and conscience.

2. Materials

Since Rio-92 a lot of research has been carried out at many research organization around the world in the development of ecological materials. In the 70ties local energy saving materials such as rice husk ash, soil-vegetable fibers, cement composites reinforced with vegetable fibers, bamboo as well as renovated ancient technologies started to be investigated by

scientists and researchers in order to substitute industrialized materials which are highly polluting and high energy demanding in their production. Although proven technically and scientifically that the newly developed non-conventional materials and technologies are superior to the conventional materials they are not used in large or medium scale projects.

There is an intense on-going search for non-polluting materials, which consume little energy in their production and/or utilization. Attention of researchers has turned to materials such as vegetable fibers including bamboo, soil, mining, industrial and agricultural wastes for engineering applications. New cements using all types of wastes are being developed and used for the production of composites reinforced with vegetable fibers around the world in a global effort to find a substitute for health hazardous asbestos cement which is prohibited by law in industrialized countries and used in most of developing countries with low cost.

To overcome the serious construction problem in Brazil and other developing countries in the world, several successful research programs have been carried out since 1979 at PUC-Rio (Ghavami et al 2001). The results are being propagated through the ABMTENC (Brazilian Association of the Science of Non-Conventional Materials and Technologies) and implemented in other universities using indigenously available local materials such as bamboo, vegetables fibers (Toledo Filho et al 1999; Savastano Junior et al 2000), soil, quick lime, and cement mortars in the production of new structural elements such as bamboo space structures, corrugated sheets made of cement mortar composites reinforced with bamboo pulp, sisal and coconut fibers, soil-fibers composite for load bearing walls and concrete elements reinforced with bamboo.

Although with the accumulation of technical data concerning the developed materials and structural elements obtained from the research programs, they are not yet systematically used in large scale in civil construction. Although these materials have proved to be very efficient as substitutes for industrialized materials they are not yet topics to be discussed by the committees for the elaboration of national norms.

Bamboo is one of the materials well suited for construction. It presents a tremendous economical potential, as it reaches its full growth in only a few months and its maximum mechanical resistance in a few years, besides the fact that it occurs in abundance in tropical and sub tropical regions of the globe. The energy necessary to produce 1m^3 per unit of stress projected in practice for materials commonly used in civil construction has been compared with that of bamboo. It was found that for steel it is necessary to spend 50 times more energy than for bamboo. The use of bamboo is attractive as a substitute for steel, especially when considering the relation between tensile strength and specific weight of bamboo, which is six times greater than that for steel. Although, having been used intensively in South America by the natives for centuries, European colonizers did not know the potentials of bamboo. Systematic studies have been carried out on bamboo for more than two decades in order to develop methodologies for its application in space structures and as reinforcement in concrete and other types of structure, considering their safety and durability.

3. Building Components

The simplest building component is stone. It is extremely durable and has been used for thousands of years. Soil, transformed into walls and burned bricks, has as well been known as building material since origin of mankind. Houses with loam and vegetable fibre reinforced walls are known to have survived hundreds of years. Modern versions of mud houses are being constructed in France, Germany and Mexico (Minke 1995); in addition to those built with ancient technologies in some African countries. Today soil can be mixed with different admixtures and formed into bricks, which do not necessitate firing. This material is extremely

economic as frequently soil from the very building site can be used in the brick manufacturing and in this way transport costs are cut. They are well suited for external and internal walls and safe for construction of up to 6- storey houses.

Bamboo is a ready made building component (Dunkelberg 1985, Lopez 1978). It may take only 3 years for a culm to grow and be ready for use in contrast to timber where the fastest growing tree (Eucalyptus) needs 10 years to grow. A further advantage of bamboo is that it does not need to be replanted. Once cut it will grow again and again. The rhizome can be thought of as an underground factory.

Bamboo was found to be used nearly for anything. Indeed there are thousands of applications. In the Department of Civil Engineering of PUC-Rio bamboo has been studied for almost 25 years (Ghavami 1988 and 1995; Moreira 1991). It has been studied for application as a construction component.

3.1 Bamboo as a structural component

In order to include bamboo as a structural material in civil construction, the behaviour of some elements, such as slabs, beams and columns of concrete substituting steel with bamboo have been studied during the last two decades. One of the main problems in using bamboo as a reinforcing bar or permanent shutter in conjunction with concrete are the dimensional changes due to water absorption. To produce an efficient treatment for perfecting adhesion between bamboo and concrete, a water repellent treatment should be considered beside introducing roughness on the surface of bamboo in contact with the concrete. Figure 1 shows half bamboo culms, treated with Negroline and sand, or SIKA32-Gel which work as permanent shutters and also as reinforcement for the concrete slab.

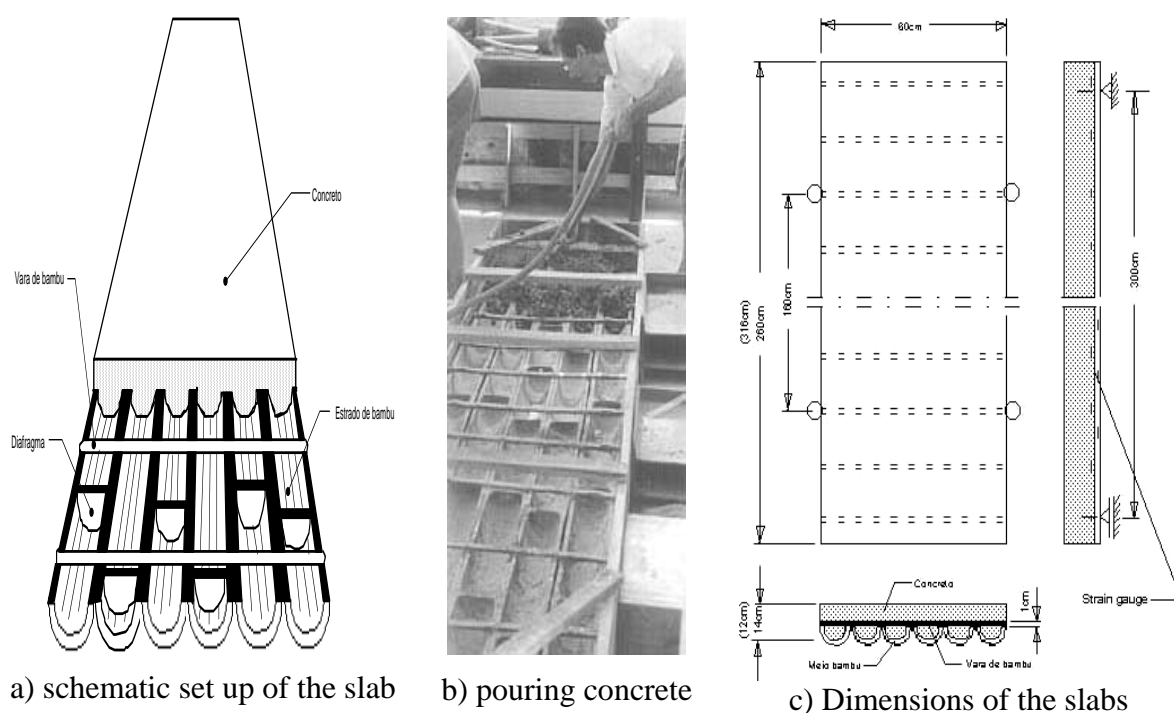


Figure 1: Concrete slabs reinforced with bamboo permanent shutter forms

The viability of a Double Layer Grid Space Structure, DLGSS, using whole bamboo culms was investigated (GHAVAMI, 1981). Among the various different types of joints considered, the pin ended joint has been studied in detail both theoretically and experimentally (MOREIRA,

1991). In Figure 2, the general view of the DLGSS during the test and the detail of one of the pin ended joint is shown.

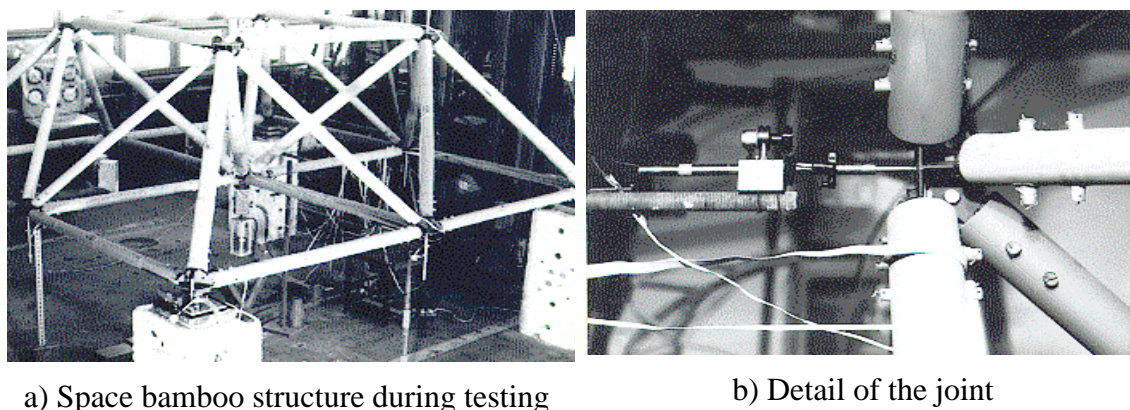


Figure 2: Double layer Bamboo space structure

The structural component has been developed recently in a concrete column reinforced with bamboo segments of the *Dendrocalamus giganteus*. As can be seen in Figure 3 it can work as permanent shutter and one economises the finish (Ghavami 2001).

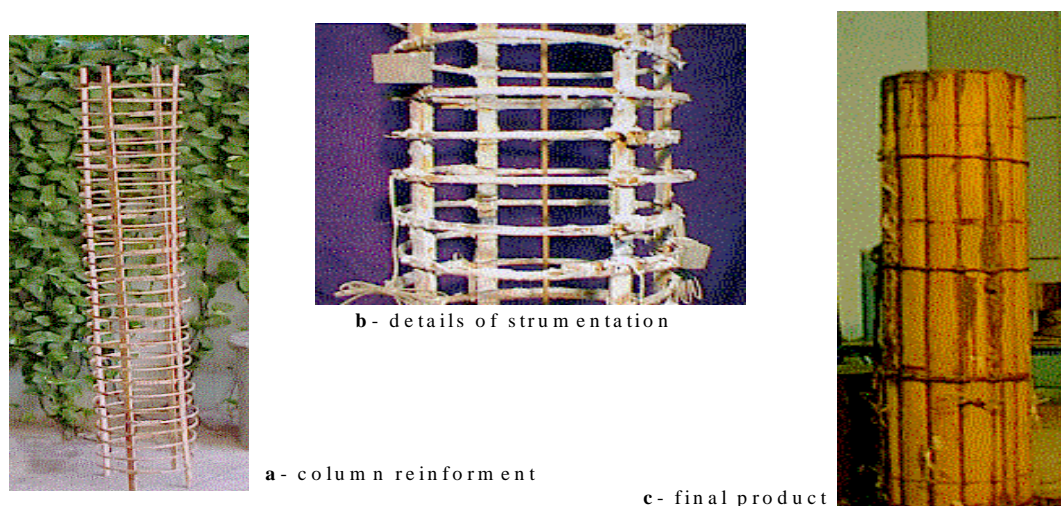


Figure 3: Bamboo rods as reinforcement for concrete column

Further, tiles made of mortar cement with vegetable fibre reinforcement have been fabricated and tested at DEC-PUC. Different composites have been developed. Coir, sisal, bamboo chips and pulp were used as admixtures. These tiles have shown to be of good resistance and durable even when exposed to extreme conditions.

4. Recycling of inner city structures

Throughout history consecutive governments and private organizations took care to preserve monuments and public buildings such as palaces, theatres, schools, hotels or just beautiful estates handed over to the state by the impoverished rich as maintenance became too costly. Somehow, it was not understood that poor men's houses as well was part of the cultural heritage handed down to us.

Recycling living space in the inner city makes sense when one considers all facilities already existing in the center of the city. Those facilities such as museums, theatres, cultural centers

and restaurants are used during the week fairly well by the thousands who work there. But at the weekends most are closed for lack of users.



a) View of Lapa: the new and the old center (studycase highlighted)



b) Typical housing at Rua Senador Pompeu: mansions, cortiços (study case highlighted) and two storey houses.

Figure 4 Locations of constructions

In the following an example of recycled housing, located in the center of Rio de Janeiro (shown in Figure 4), is presented. It is planned to recuperate about 500 houses in the heart of Rio, which is considered the start of a new era. It should be seen as an attempt to not only create housing in the inner city area but as well to preserve public memory of an area which once buzzed with activities and then fell into disuse. In a special housing project some selected historical houses in bad repair were restored in the most economical and ecological way and at the same time adapted to present day standards to provide comfortable living conditions for their inhabitants.

The traditional plan of a building (shown in Figure 5) in the center was narrow and long and this house, as most from the same era, suffered from lack of ventilation and natural light. Its rooms were accessed through a narrow internal corridor. After some years of being abandoned, it was found on the verge of collapse with its structure and roof already jeopardized. Its internal finish as well was decayed and damaged by infiltrations. All hydraulic and electrical installation were improvised and presented health risks. There were some families still living on the premises for more than 10 years in precarious conditions.

The house, acquired by the local government, was a pilot project of rehabilitation, starting in 1996. After conclusion in 1997 the old inhabitants, who had the option to become owner-occupier with a help of a financing program, were able to return and by having optimized space five more families could be housed. This example united various common situations in relation to urban housing regulations where greater liberty was allowed with regards to necessary adaptations of the norm.

The second case presented a specific situation as the building was listed as a historical heritage. The “cortiço” in the Rua Senador Pompeu was included in the rehabilitation project in 1996 after criteria of its recuperation and adaptation had been defined to restore it to its original use. It is one of the last surviving examples of the urban reforms dating from the end of last century. This building complex consists of a main part in the form of a 2 storey town house and a rear part formed by 38 rooms arranged along an oblong internal patio. Beside the rooms all facing the patio there are two shops in front at street level as can be seen in Fig. 5.

In both cases, restoration had as objective to improve the housing condition through structural reinforcement, substituting the deteriorated elements and replacing the hydraulic and

electrical installations in accordance with actual norms. Internal re-dimensioning was carried out only when it was necessary. The architectural design was preserved in both cases.

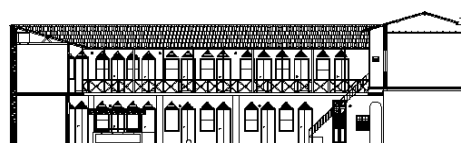


a) The Sobrado before and after restoration

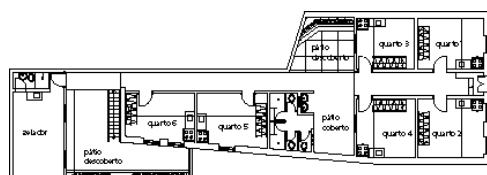
b) The Cortiço before and during restoration



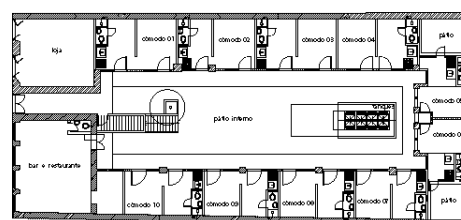
façade



internal façade



plan at street level



plan at street level

Figure 5. Building components

Generally, all dwellings in Rio de Janeiro followed the same building methods. Materials used were solid burnt bricks, clay, mortar, pigmentation from the soil and agglomerates of quick lime mixed with whale oil for the paints, burnt roof tiles of half semi circular profile or French type. Fragmented rock and solid bricks were used for the structural walls; non-bearing walls were made of stuck or “taipa”. The floor consisted of a wooden frame with wooden floor boards. Timber was used for internal and external structures as well for door and window frames, wrought iron for balcony and window details. The roof structure was executed in timber in a scissor truss system.

Restoration work consisted of substituting the deteriorated parts when necessary. For example the taipa walls beyond repair were substituted by brick walls, replacing the rotten roof beams and recuperating roof tiles or substituting depended on the state of the structure. The wood framed and finished wood flooring were substituted with pre-cast slabs when repair became impossible. It must be mentioned that there are no restrictions with regards to internal materials in listed structure as the complex value is considered and not the monument value. Therefore, economical and durable materials were adopted whenever it was possible.

One might say “what are 500 recuperated houses when thousands are needed? “ Perhaps it appears little, but considering that these recuperated houses serve as models for what could be done in every city. Surely there are houses worthwhile restoration in São Paulo, Salvador, Ouro Preto, Toronto, London or Calcutta?

5. Final Remarks

The understanding of eco-construction and infrastructure has undergone changes over the years. First attention was given to the issue of non-renewable resources and how to reduce their impact on the environment. Now emphasis is placed on more technical issues such as the use of renewable and thus non-conventional materials in construction and technologies with energy related design concepts.

In this paper, it is shown that the implementation of NOCMAT could be well succeeded when by applying an evaluation framework, which should be seen by all concerned parties as a way to learn and improve their integrated action in a systematic form. This is possible when the efforts are made to build social, political, economic, environmental, cultural and technical indicators for innovative projects, which are designed to serve the real needs of decision makers at local, state and federal level.

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References

- Dunkelberg, K., IL-31: *Bamboo as a Building Material*, Institut of Leicht-Flächentragwerke, Universität Stuttgart, 1985
- Ghavami, K. *Structural Concrete Elements Reinforced with Bamboo*, Asian Journal of Civil Engineering and Housing, Vol 2, No. 2, pp. 97-110,
- Ghavami, K., *Ultimate Load Behaviour of Bamboo Reinforced Lightweight Concrete Beams*, Cement and Concrete Composites, 17(4) Elsevier Science Ltd. England, pp 281-288, 1995
- Ghavami, K., *Application of Bamboo as a Low-cost Construction Material*, Bamboos current research, Kerala Forest Research Institute and IDRC, Cochin, India, pp. 270-279, 1988
- Journal of Civil Engineering, "Alternative Energy reduces Fossil Fuel Use", Oct. 2003, Vol. 73, No. 10, p.33
- Lopez, O.H., *Nuevas Tecnicas de Construcion com Bambu*, Estudios Tecnicos Colombianos Ltda. 1978
- Minke, G., *Experimentelles Bauen*, Ökobuch, Gesamthochschule Kassel, 1995
- Moreira, L.E., *Desenvolvimento de Estruturas Treliçadas Espaciais de Bambu*, MSC. Thesis, PUC-Rio, 1991
- Savastano Junior, H, Warden, P.G. Coutts, R.S.P., *Brazilian Waste Fibres as Reinforcement of Cement-based Composites*, Cement and Concrete Composites V.22, pp.379-384, 2000
- Toledo Filho, R.D., Joseph, K., Ghavami, K., England, G.L., *The Use of Sisal Fibre as Reinforcement in Polymer and Cement based Composites*, Brazilian Journal of Agricultural and Environmental Engineering, Vol. 3, No. 2, pp.245-256, 1999
- Thompson, D., *Asphalt Jungle*, Time Magazin, vol.155, No. 17, 2000.