COASTAL EROSION MITIGATION AND LOW COST SEA LEVEL RISE PREPARATION IN BRAZIL

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ABSTRACT

For implementation of the residential development Riviera de São Lourenco, a resort for 11,000 residential units in Bertioga, northern coast of Sao Paulo State, there was a clearing of native vegetation called *Jundu*, and in relation to such liability, nothing could be done. After the establishment of the condominium and the landscaping of the same, made mostly with *Pernambuco* Grass (***Paspalum maritimum***) and coconut trees, coastal erosion settled with the breaking of sea waves and storm surge, since landscaping did not have established conditions to ensure soil stabilization under these natural phenomena. To restore the affected portions of slopes, protect landscaping and prevent damages from sea level rise, the environmental agencies authorized only the use of organic materials, such as piles, logs, roots, biodegradable blankets, soil layers (organic layer and layer of sandy soil, extracted from the *Jundu*). The restoration project of the coast used bioengineering techniques, contemplating the use of Vetiver Grass hedgerows, sediment retainers (wattles), logs and biodegradable blankets.

Keywords: Sea level rise, Coastal Erosion, Coastal landscaping, Vetiver Grass.

INTRODUCTION

The *restinga*[(1)] and sand dunes cover about 70% of the Brazilian coast. In the South and Southeast formations they are represented by herbaceous, shrub and forest, and the latter can present species ranging from 4 m to 20 m tall, composed of tree trunks twisted and branched, sparse deformed canopy, very fragile and susceptible to disturbance. The *Jundu* vegetation is characterized by a strip between the *restinga* and the sea, including a vegetation consisting of low, twisted trees, interspersed with shrubs and herbaceous vegetation.

Back in 1977, Bertioga's coastal plain was covered in its entirety by vegetation, where the different strips were easily perceived on beach ridges. The natural vegetation of *Jundu* gave way to streets and buildings, and a big portion of cleared land was kept during a long time, waiting for real estate valuation.

The construction of a building complex in the region began in 1979. Today it has over 220 buildings, 2,500 houses in a total of over 11,000 housing units, a mall, school, golf facilities and much more, in a 4,5 km stretch of beach. Another 3 km of the beach are yet to be built.

But the construction of the condominium also included environmental awareness and strict rules were established for the use and occupation of the land. To meet the needs of sanitation infrastructure, it was implemented a system for capturing, processing and distributing water as well as a collection system, pumping and sewage treatment. To address the litter issue, it was set up an integrated solid waste management plan. It created a laboratory for environmental control, with the most modern equipment to verify the quality of water (sea water, fresh water and monitoring the sewage and drainage channels). Green areas were planned and more than 2.6 million square meters were committed for conservation (the equivalent of 263 football fields). In addition, to preserve the botanical memory of the region, a native plant nursery was built in an area exceeding 20,000 m² to produce plantings to be used in the recovery of degraded areas within condominium's limits and nearby areas.

Even with all the environmental awareness, the development of the project has lead to a major deforestation. And there were several consequences of this construction, especially in the coastal wet zone. The vegetation established as base for all landscaping of the project was Jundu's *Paspalum maritimum* known popularly as "Sweet Grass" and palm trees which have no resistance to the movement of the tides and wave impact, resulting in erosion and destruction of the landscaped area border.

In this context, soil bioengineering brought sustainable, low cost and very effective solutions to control this erosion process. Likewise, the results demonstrate the possibility of recovering the shoreline of urban areas and the benefits of preserving coastal areas for future urban planned and sustainable development. In this way, preservation of the beach area also plays an important role in the operation of urban drainage, increasing quality of sea bound flows.

This study aimed to demonstrate a model of environmental restoration at the edge of Bertioga-SP, on the Riviera de Sao Lourenco's beach, through the use of the most modern soil bioengineering technology, contributing directly to the stabilization of the marginal slope and, consequently, recovery and protection of the condominium's landscape.

(1) A ***restinga*** is a distinct type of coastal tropical and subtropical moist broadleaf forest found in Brazil. *Restingas* form on sandy, acidic, and nutrient-poor soils, and are

characterized by medium sized trees and shrubs adapted to the drier and nutrient-poor conditions.
The World Wildlife Foundation distinguishes two *restinga* ecoregions: the Atlantic Coast restingas are found in several enclaves along Brazil's east coast from Rio Grande do Norte State in northeastern Brazil to Rio Grande do Sul State in southern Brazil, covering an area of 7,900 square kilometers (3,100 square miles) that extends from the tropics to the subtropics. Its flora and fauna shares affinities with the humid Atlantic forest of eastern Brazil; the Northeastern Brazil restingas are found along the northern coast of Brazil, in Maranhao, Piaui, and Ceara states. Its flora and fauna are distinct from that of the Atlantic Coast *restingas*, with greater affinities to the rain forests of Amazonia. (Wikipedia)

SOIL BIOENGINEERING

Throughout history, traditional engineering has had great difficulty dealing with environmental issues. Intense earth-moving and the use of heavy machinery oppose to the resumption of the current environmentally friendly engineering concepts that are inspired by the forms of nature to soften the contours of land in the works (see "Landform Grading" - Gray, 2008) and the use of vegetation for protection and reinforcement of soil. (Lucena, 2008)

"Vegetation has been used in engineering for erosion control processes and as a reinforcement of civil works. The set of techniques that use this live element in engineering is known as Soil Bioengineering. "(Kruedener, 1951).

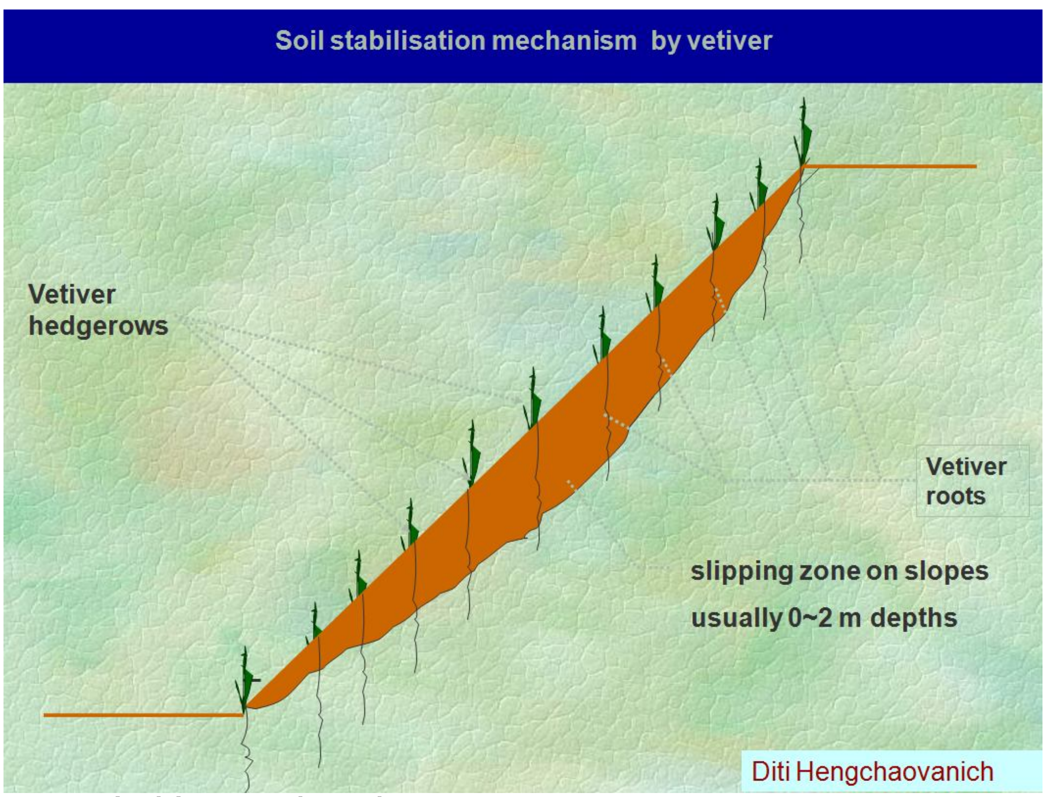

Figure 1: Soil stabilization mechanism by Vetiver
Source: Diti Hengchaovanich

Among the current techniques used to control erosion, soil bioengineering appears as the most effective, environment friendly and cheapest alternative as it uses biologically active elements in soil stabilization and sediment control practices. These elements may be vegetation and microorganisms, conjugated to inert elements such as rocks, concrete, wood, metal alloys, natural and synthetic polymers, biodegradable textiles, among others (Krüedener, 1951; Schieltz and Stern, 1996).

There is much research in the field of bioengineering in the U.S. and Europe on the erosion control of slopes on roads, water reservoirs and channels, agricultural fields, large gullies, embankments, mining, and even for urban aesthetic improvement (CEMIG , 2002; Gray and Sotir, 1996).

The first works using this technique in Europe, dating from the seventeenth century, traditionally used to control the erosion on hills and slopes, reinforcement of walls, protection of river banks on port areas, drainage channels and water supply channels. Over the past 150 years, soil bioengineering has emerged in the United States and Europe as a viable alternative for the protection of water courses and reservoirs (Durlo and Sutili, 2005).

In South America we have records of pre-Inca and Inca who were masters in the development of simple and very efficient techniques for soil conservation. The Inca technique of tying twigs, leafs and sticks, installing them on the contour lines in order to retain sediment and slow runoff, called "fajinas" (fascines), had recent technical and industrial development becoming sediment retainers called Bermalonga ® (Brazil) and wattles (USA) for similar and even broader applications (e.g. as filling material for concavities, reduction of flow speed in drainage channels, to avoid erosion in the interface of soil with any hard structure, sub superficial drainage, among others). Furthermore, we cannot fail to mention the Inca techniques for terracing and stone walls known internationally, especially through the ruins of Cuzco and Machu Picchu. (Lucena, 2008)

We can say that modern bioengineering began in 1874 with the work of Wollney, a German who conducted the first tests in research of soil and water conservation. He has truly pioneered in soil and water conservation but had his work recognized only in 1938 by Baver (USA). (Lucena, 2008)

According Schiechlt and Stern (1996) cited by CEMIG (2002), bioengineering techniques should be used as measures of protection and recovery of water bodies to supplement conventional methods of civil engineering in order to achieve greater efficiency in this type of activity. Note that, under certain conditions, bioengineering techniques can fully replace traditional methods, demonstrating even more effectiveness than these techniques.

According to CEMIG (2002) and Gray and Sotir (1996), soil bioengineering should be considered in the following actions to protect and preserve margins of water bodies:

- Conservation of natural drainage patterns;
- Conservation and maintenance of the margins of water bodies;
- Preservation of water retention areas and aquifer recharge areas;
- Establishment, development and maintenance of natural vegetation adapted to the site to be recovered;
- Sustainable management in silvicultural systems that do not promote the exposure of the soil in adjacent to riparian and seasonally inundated areas;
- System approach at all stages of the project, given the multifunctional nature of the technology.

Bioengineering techniques usually result in economic benefits to projects and are easily adapted to a variety of site conditions as it can range from the use of live construction materials alone (herbaceous, shrub and / or tree) to applications of vegetation associated with geotextiles, concrete, wood, metal alloys, organic sediment retainers (wattles), cellular confinement systems such as geocells and others. However, one should limit the use of rigid construction materials such as steel and concrete to areas / sections in which the vegetative methods prove to be inadequate to prevent erosion (Gray and Sotir, 1996).

"In places difficult to reach or inaccessible to machinery, bioengineering techniques are often the only viable alternative for execution of works of slope protection and erosion control." (Coelho, 2004).

"... Due to its low cost and relatively simple technical requirements for installation and maintenance and for landscaping and environmental benefits, these operations have a wide range of applications in the tropics, since favorable conditions to the development of vegetation occur almost throughout the year." (Golfari and Caser, 1977).

VETIVER GRASS

Chrysopogon zizanioides (L.) Roberty, syn. *Vetiveria zizanioides* (L.) Nash, a perennial grass originating from India, is used for a wide range of environmental purposes. The use of Vetiver Grass (VG) for land protection has long been practiced in tropical and subtropical countries, but its advantages (low cost, effectiveness and ease of application in soil and water conservation, land rehabilitation, embankment stabilization) only emerged in the late 1980s (Truong, 2000; Grimshaw 1997).
The Vetiver grass is a grass that does not have rhizomes. Its root system is massive, finely structured and can grow to four meters deep in his first year. This feature gives it a potential tolerance to drought and displacement by the water flows. Its stem, erect and stiff, is designed to address a relatively deep water flow. Their tolerance of dry soil covers of the high humidity, tolerates pH ranging from 3.3 to 12.5 and high levels of aluminum saturation - up to 68% - provided there is adequate availability of nitrogen, as well as the light soils the clay. It can survive in moderately saline soils and saline soils with high levels of heavy metals such as chromium, selenium, copper, zinc, arsenic, mercury, nickel, cadmium and polluted water. (Troung et al, 2008).

Figure 2: Vetiver tolerance to salinity.
Source: Paul Truong

It also has high resistance to fire, frost, traffic and heavy grazing pressure, as the new shoots develop from the underground crown. It is also resistant to pests and diseases. New roots grow from nodes when buried by trapped sediment and its crown move up when sediment is deposited, forming terraces naturally as sedimentation occurs. Its positive biotactism - potential to grow towards the next individual - allows the formation of hedgerows, rather than clumps, assuring it as a sediment filter and water spreader.

Figure 3: Vetiver tolerance to fire
Source: Paul Truong

The Vetiver grass (*Vetiveria zizanioides*) has been recommended by the World Bank since the 1980s to help control erosion, conserve soil and water in areas with few resources. (Pereira, 2006) Originated in India and recently reclassified as *Chrysopogon zizanioides*, it has been used for several purposes, from flavoring, fine fragrances, medicinal purposes, art craft, house lining and soil protection.
Regarding to soil protection in slopes and banks of water bodies, Vetiver has been used traditionally to form hedgerows retaining sediment, reducing speed and homogenizing superficial and ground water flows. Most recently, a successful technology called **GREEN NAILING** was developed to promote soil nailing using Vetiver Grass under special site conditions. Comparing to the Green Soil Nailing already used in bioengineering, when vegetation is used to protect soil surface instead of shotcrete application, when Green Nailing is applied Vetiver replaces all traditional anchoring system.

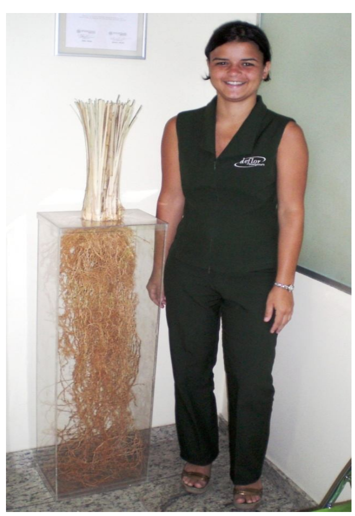

Figure 4: Roots of a young dehidrated Vetiver Grass compared to a 1.60 m tall person.
Source: Deflor bioengineering / Luiz Lucena.

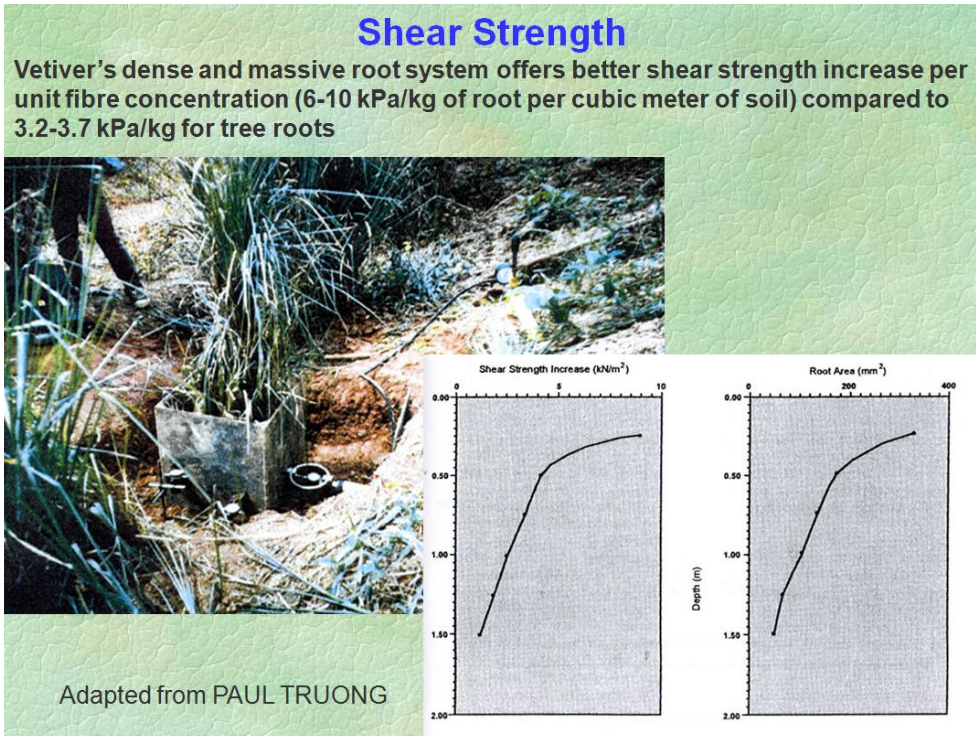

Figure 5: Vetiver shear strength resistance.
Source: Paul Truong

According to Pereira, 2006 and Troung et al, 2008, although Vetiver is highly tolerant in some extreme weather conditions, it is not very tolerant to shading what may affect the establishment of the plant in extreme cases. Therefore, Vetiver grows best in open areas, free of competition during the establishment phase.
Once introduced in degraded areas, at first Vetiver stabilizes the soil, including very steep slopes in erodible soils. Then, due to nutrients and moisture conservation, it improves microenvironment for other voluntary or seedlings to establish themselves. In this sense, Vetiver can be considered as a nurse protective plant as it facilitates the process of recolonization of the area by other plants.
Vetiver has been heavily employed in environmental protection and mitigation of soil degradation processes. Its major applications are in mining areas, to minimize risk of contamination of water bodies, in the treatment of industrial and domestic effluents, leachate control in landfills, removal of nutrients in eutrophic water bodies, protection and stabilization of slopes and banks of water bodies, among others.
Main advantages of the use of Vetiver:

- Vetiver is a low cost and easy to establish plant. It does not require maintenance after establishment, except when recommended for specific applications;
- It is not an invasive plant as it propagates only through the introduction of plantings;
- It has a dense and deep root system;
- It forms a dense, filtering hedgerow;
- It is resistant to fire;
- It develops quite well under hydroponic conditions;
- It survives long periods of draught and floods;
- It develops new roots when its crown is covered by sediments, promoting the formation of natural terraces;

- It is not host or vector for any disease or plague;
- It has great adaptability to extreme soil and climatic conditions, with annual rainfall of 300 mm to 6000 mm, temperatures from -5°C to + 50°C;
- Vetiver is easily eliminated or removed through cutting the plant down its crown or the usage of low dosages of herbicides;
- It tolerates extremes of PH and heavy metal and salt contents.
- In sodic soils, the Vetiver grows satisfactorily, provided there is good availability of N and P;
- The tensile strength of Vetiver can reach as much as 120 MPa (average is 75 MPa), with a diameter ranging from 0.2 to 2.2 mm.;
- Vetiver can be used to reinforce traditional structures used in engineering such as gabions, retaining walls, soil wrapping, soil nailing, crib walls among others;
- Maintenance costs are low in the long term. In contrast to conventional structures engineering, green technology improves when the vegetation matures. The vetiver system requires a planned maintenance program in the first two years, however, once established, is virtually maintenance free. Therefore, the use of vetiver is particularly suitable to remove the areas where maintenance is expensive and difficult. (TROUNG, P. et al, 2008)

Tensile Strength of Roots of Some Plants

Botanical name	Common name	Tensile strength (MPa)
Salix spp	Willow	9-36*
Populus spp	Poplars	5-38*
Alnus spp	Alders	4-74*
Pseudotsuga spp	Douglas fir	19-61*
Acer sacharinum	Silver maple	15-30*
Tsuga heterophylia	Western hemlock	27*
Vaccinum spp	Huckleberry	16*
Hordeum vulgare	Barley	15-31*
	Grass, forbs	2-20*
	Moss	2-7kPa*
Vetiveria zizanioides	Vetiver grass	40-120 (Average 75**)

* After Wu (1995) ** After Hengchaovanich and Nilaweera (1998)

Table 6: Tensile strength of the roots of different plant species
Source: Adapted from WU, 1995 and HENGCHAOVAMICH, 1998.

THE RIVIERA DE SAO LOURENCO CASE STUDY

SITE CHARACTERISTICS AND VEGETATION

The study was conducted in northern Bertioga-SP, in the condominium called Riviera de Sao Lourenco, between the geographical coordinates 23° 47' to 23 ° 48' S and 46° 0' to 46° 2' W (Figure 8). The current climate type of the region, according to Köppen's classification, is tropical with an average temperature above 18° C, average annual rainfall around 1,600 to 2,000 mm, no dry season and high humidity in the summers (Rossi, 1999). According to a study of IPT – Brazilian Technological Research Institute (1989), maximum annual rainfall in Bertioga reached over 2700 mm yr-1.

The relief is represented by Bertioga's smaller coastal plains, with sparse presence of marine terraces remaining from Pleistocene and present river systems are transverse and parallel to the coastline, the latter installed on small lagoons filled on Holocene.

Figure 7: Satellite image of Riviera de Sao Lourenco
Source: Google Earth

The vegetation of the beach is restricted to a few areas without beach erosion. On the faces of beach dunes, the Restinga occurs in small areas, being some of the vegetation associated with Paleolagoons. The low forest of Restinga develops in a narrow strip parallel to the sea (Souza et al., 1997).

The strip between the *restinga* and the sea, includes a vegetation consisting of low, twisted trees, interspersed with shrubs and herbaceous vegetation called *Jundu*.

In the terrestrial realm, the morphology is characterized by being established on sandy soils, highly leached and poor in nutrients. These vegetation formations are very fragile and susceptible to disturbances, which makes conservation widely dependent on the intrinsic mechanisms of plant in its community, such as the presence of

mycorrhizae, sclerophylly and character evergreen (Araújo & Lacerda 1987, Moraes et al. 1999).
The variation in salt marsh vegetation, reflected in the various vegetation types studied, is closely related to the variation of abiotic factors present in this ecosystem, such as substrate type (sand, organic), nutrient levels and salinity, water table depth, proximity to the beach or mangroves, water regime, among others (Henriques et al. 1986; Britez & Silva 2005).

THE URBANIZATION PROJECT

The complex "Riviera de Sao Lourenco" was designed along the north shore of Bertioga - Sao Paulo State. The installation of the first construction site was in 1979 with the opening of the first streets, walkways, installation of topographic marks, concrete drainage pipes, opening of the drainage channels, installation of nursery for native vegetation and the studies to water catchment and supply. At this time, the access roads were not yet ready and the trucks and machines had to reach the area by ferry, which made the work advance slowly.
The Mogi-Bertioga road was inaugurated in 1982, helping to speed the process. The Rio de Janeiro - Santos highway was inaugurated only in 1985. In 1982, there were 20 miles of streets with walkways placed, the first water treatment plant (with capacity to treat 20,000 liters per hour) was already under construction and landscaping system was well advanced, with the importation of 8,000 seedlings of coconut trees from Bahia State and their development in the nursery.
Today, the Riviera has about 50% of its area occupied: more than 2,500 houses built and / or under construction, over 220 buildings between six and ten floors inhabited and / or under construction, a segment of the Riviera Shopping Center operating at 50 stores , schools, medical and dental offices, a complete infrastructure for sanitation, and the Society of the Friends of Riviera de Sao Lourenco, a non-profit organization with over 300 employees, that organizes and administrates the hole condominium. During the initial phase of the project, vegetation removal was performed. All organic material was stored and the logs separated for future usage in parks and landscaping.

PRIMITIVE EROSION CONTROL MEASURES

Concerned about the erosion, the slopes were designed and built under the maximum inclination of 1:3 (V:H), and covered with “Sweet Grass”- *Paspalum maritimum*, a very resistant and easy to establish native grass, very commom in most of Brazil’s coastal zone, to protect soil against erosion.
However, this procedure was not efficient to promote soil protection and stability. During the storm surge that occurred in the years 1995 to 1997, sweet grass’ root system of was not deep or resistant enough to protect soil against surf and the impact of waves during high tides, resulting in the undermining of the embankment formed by *Jundu*, as can be seen in Figure 8. Several coconut trees fell down and a severe erosion process was evidenced.

Figure 8: Coastal erosion caused by storm surges and tidal changes.
Source: Luiz Lucena.

The initial solution set in 2008 was to build a rip rap using raffia bags previously filled with a mixture of soil-cement in the proportion of 12% cement and 88% soil extracted from the vegetation removal stage. The bags were conveniently arranged in the shape of pyramid and covered with a geogrid - high density polyethylene extruded plastic screen to minimize the effects of wave breaking and allowing the deposition of sand from the return of the waters in which the new vegetation was planted, resulting in an enhanced carpet and homogeneous surface ensuring stability, Figure 9.

Figure 9: raffia bags to resist surf erosion.
Source: Field, J. B. N., 1998.

Although this worked partially, it faced the inconvenience of a very low landscaping appeal for a condominium set to be the number one beach urbanization settlement in Brazil. Finally, the concerns of share holders through their Association and also from the environment authorities, who wanted a most environment friendly project for the region, lead to the studies of a new concept of beach protection and landscaping.

NEW LANDSCAPING AND EROSION CONTROL DESIGN USING VETIVER

By the end of 2008 and beginning of 2009 a new concept for the protection was designed under the responsibility of Gaia Environmental Consultants, idealized and technically supported by DEFLOR BIOENGINEERING / Luiz Lucena.
Initially it consisted in the construction of the slopes with the original geometry (1:3), using soil rapping reinforcement, sediment retainers (Bermalonga / wattles) to guarantee soil anchoring and filtering of water flows from and to the ocean and Vetiver Grass to work as energy dissipaters. Figure 10.

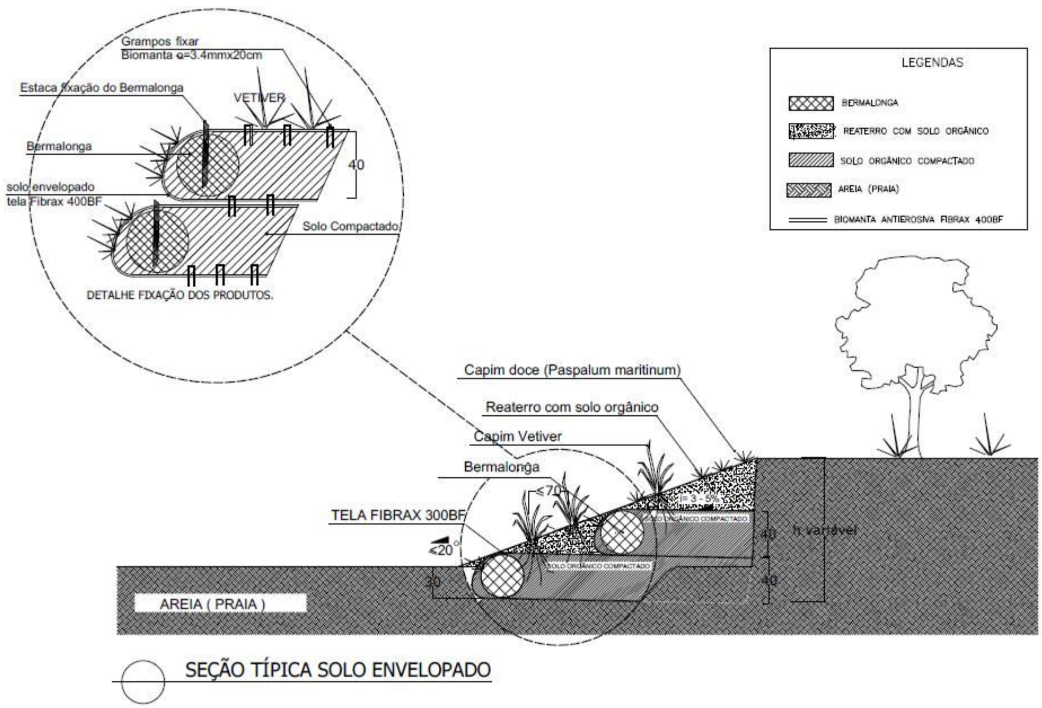

Figure 10: Project concept**.**
Source: Deflor Bioengineering / Luiz Lucena

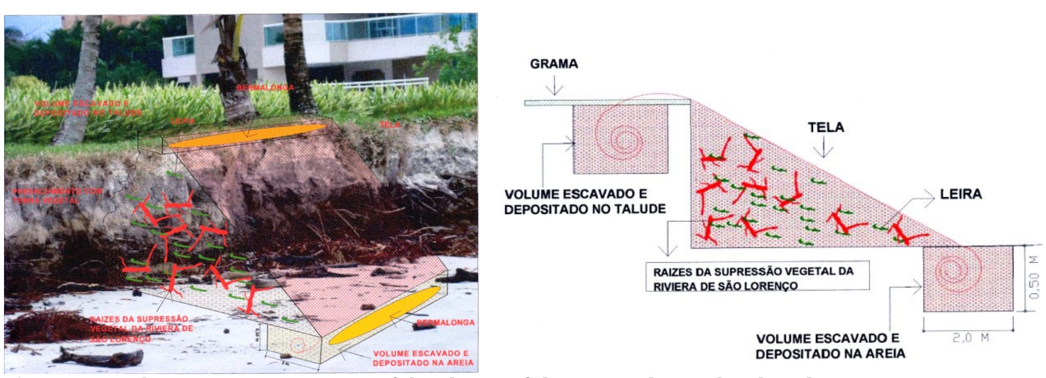

Figure 11: Schematic representation of the slopes of the project being developed.
Source: Gaia Environmental Consulting

Due to the concern regarding to sea level rise in the near future and the need to consume logs originated from deforestation process in an environmentally friendly manner, designers decided to add a wood palisade separating the sand beach from the landscaping area in order to increase security factor of the structure. The palisade was designed to use part of the wood stored during development of the urbanization project and the slopes incorporated biomass that was also stored and had to be used within the limits of the project and could not be burned according to Brazilian environmental regulations (DPRN Authorization No. 29/2005). Figure 12.

Figure 12: Final Project executed: palisade, erosion control blanket and Vetiver hedgerows.
Source: Luiz Lucena.

On June 23, 2009, the construction began according to the new project . The project was conducted in two parts: first, from June 23, 2009 until July 30, 2009. At the end of this period, government agencies hindered the release to soil preparation and therefore the second part was committed to a short delay, being held from December, 2009 until February 2010.

The restoration project included the following materials:

a. 30 cm diameter sediment retainers – Bermalonga D30;
b. 50 cm diameter sediment retainers – Bermalonga D50;
c. 400 g coconut fiber erosion control blanket – Tela Fibrax®400BF;
d. 20 cm polypropylene stakes for erosion control blanket installation;
e. Vetiver grass seedlings;
f. Tree branches, roots and other biomass material from deforestation;
g. Topsoil and sandy soil layer from deforestation;

Construction procedures:

a. Construction of a 0,30 m deep under the level of the beach sand and 3 m wide trench along limits of condominium's gardens;
b. Construction of a palisade to anchor the toe of the slope to be built using logs 0,30 m average diameter and 0,60 m long;
c. Installation of a non-woven geotextile on the bottom of the trench and behind the palisade;
d. Construction of slope fill with topsoil and biomass;
e. Excavation of trench for sediment retainers behind palisade;
f. Installation of the 0,50 m diameter sediment retainers behind the palisade, over the geotextile (toe protection);
g. Installation of the 0,30 m diameter sediment retainers on the crest of the slope (crest protection);

h. Installation of coconut fiber erosion control blanket with four polypropylene stakes per square meter;
i. Planting of five Vetiver hedgerows (7 seedlings per meter), one on the crest of the slope, one on the toe and 3 intermediate hedgerows spaced 1.5 m.

The first stage of the project, held by the Association of Friends of the Riviera de Sao Lourenco was the site preparation through the construction of the trench, palisades and deposition of organic material using heavy machinery such as hydraulic backhoe and bulldozers, as shown in Figure 13.

Figure 13: Preparation of land with the deposition of organic material.
Source: Luiz Lucena.

Figure 14: Storage of material from deforestation process.
Source: Luiz Lucena

Figure 15: Detail: palisade and slope ready for erosion control blanket installation.
Source: Luiz Lucena

Figure 16: Detail: palisade, geotextile and Vetiver.
Source: Luiz Lucena

Diameter (cm)	Weight (kg)	Average resistance				Volume (l/m)
		Tensile Strenght (Kgf/cm2)		Compression (Kgf/m)	Elongation (mm)	
		Longituginal	Transversal			
30	**7**	**250**	**120**	**3.200**	**130**	**70**
50	**20**	**660**	**320**	**8.550**	**335**	**200**

Figure 17: Specifications of Bermalonga ® D30 and D50.
Source: Deflor Bioengineering.

Figura 18: Sediment retainers 0,30 m diameter - Bermalonga® D30
Source: Luiz Lucena

Figure: 19: Trench excavation for sediment retainer installation.
Source: Luiz Lucena

Figure: 20: Installation of erosion control blanket..
Source: Luiz Lucena

Figure: 21: Beginning of Vetiver development.
Source: Luiz Lucena

SYSTEM MAINTENANCE

Biodegradable erosion control blankets and wattles are temporary products designed to work as shields to protect the ground surface, enabling time for the development of Vetiver and the recolonization of area by the native species. These degradable elements are not expected to be substituted and will integrate microenvironment chain generating colloids improving soil texture and constituting an additional supply of nutrients for the development of plants.
Maintenance of the Vetiver is an extremely simple and low cost activity, requiring only the substitution of some Vetiver seedlings during installation period (mortality rate of Vetiver is almost zero) and whenever one or more Vetiver hedgerows are bent by the hit of especially strong tide or surf events, the leaves shall be cut near the soil to allow Vetiver to grow again.

RESULTS

After unsuccessful attempts to mitigate coastal erosion through the use of a native grass and later through the construction of soil cement rip rap, the planting of Vetiver grass, associated with sediment retainers and biodegradable blanket type Fibrax® 400BF was a low cost and effective technique to control erosion and prevent landscape disturbance during strong surf and high tides. The strong and deep roots of the grass allowed it to settle in coastal sandy soil.
Vetiver has also proved its tolerance to long term exposure to salinity. In this sense, further investigation is required to verify if Vetiver roots grew fast to catch low salt water from the continental water table.
Today, after two years of the initial phase of this restoration project, there is the occurrence of recolonization of native vegetation of herbaceous and grasses and also species of fungi, which shows the quality of the recovery process of the site, with soil biodiversity and stability (Figure 22).

Figure: 22: Recovery quality indicators: fungi and several species from native Jundu.
Source: Luiz Lucena

The highest tides in Brazilian coast occur usually during the months of August and September. In September 2009, there were some sea storm surge events, leading to strong surf and wave hitting the system just one month and fifteen days after completion of installation part one. The consequence of this natural phenomenon was that the first Vetiver hedgerow was bent and recovered without maintenance.

Figure: 23: First Vetiver hedgerow bent after strong surf and wave hit.
Source: Luiz Lucena

Figure: 24: First 3 Vetiver hedgerows at the worst spot where wave hit and no soil loss observed.
Source: Luiz Lucena

Bioengineering is the technique that did not affect the local landscape design (Figure 27) and at the same time, recovered the erosions. Palm trees planted, which were at risk of falling and were unstable, are now protected by a secure system (Figure 28).

Figure: 25: Frontal view of the beach showing Vetiver completely integrated to landscaping.
Source: Luiz Lucena

Figure: 26: Before and after pictures of the Riviera de Sao Lourenco beach.
Source: Luiz Lucena

CONCLUSIONS

The proposed treatment for the urban coastal areas is a successful model. This report can constitute an informative guide for the use of the coastal strip of Jundu in future developments, as well as restoration of diversity in similar environments.

The Jundu strip once adequately handled constitutes part of the landscape and contemplative recreational areas, resulting in sustainable development, minimizing disturbance and maintaining the local biodiversity and biological chain.
Bioengineering techniques used in this project were more efficient when compared with the conventional engineering techniques tested "in situ", and ensure the effectiveness and stability of the local landscape thus representing an efficient option for coastal zone protection during high tides and as prevention of damages related to sea level rise.

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