Integration of Landscape Reclamation and Design in a Mine Tailing in Cartagena-La Unión, SE Spain

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Abstract**—**Mine waste hills, in other words mine tailings, especially heavy metal accumulated ones are the subject of environmental problems and pending questions for local communities and administrations. In order to find a sustainable solution for the problems and gain these problematic areas back, new functions have to be brought out for them, but initially environmental risks have to be reduced or eliminated. Traditional solutions used in mining areas such as excavation and backfilling works are not feasible and appropriate because of the high amount of pollutants and the big volume of polluted soil of mine tailings. Therefore some negative effects of former mining activities can be minimized by creating a native vegetation cover which can also serve in the process of metal immobilization, called phytostabilization. This study explores how an optimal landscape design can be developed for a mine tailing by considering the process of phytostabilization as a reclamation technique, and how reclamation efforts can be integrated in the landscape design by taking into account not only the scientific considerations and also cultural and human aspects.

Keywords**—**Landscape design, mine tailing, phytostabilization, reclamation

I. INTRODUCTION

THE most significant of the issues that arise from the length of mining operations is the inability to fill the metal mine pits back in, if it takes a hundred years to dig the ore out, it ought to take about the same amount of time to fill it back in, assuming the use of similarly sized equipment [1]. Mining activities had been under operation for more than 2500 years in southeast Spain and have generated high amounts of sterile materials accumulated in pyramidal structures called mine tailings or tailing ponds, characterized by strong acidification processes, high salinity, scarce or null vegetation and especially accumulation of heavy metals [2]. Heavy metals are natural components of soil and they cannot be decomposed in simpler forms nor be destroyed. They are not always toxic pollutants but all heavy metals are potentially toxic if their concentration exceeds an upper limit [3]. Reintroduction of a vegetation cover can achieve immobilization of metals, stabilization, pollution control, visual improvement and removal of threats to human beings [4]. In the initializing of plant colonization, incorporation of organic amendments into contaminated mine soils has also been proposed as feasible, inexpensive and environmentally solution practise, as generally such wastes can improve soil properties [5]. Besides, spontaneous vegetation itself may contribute to metal immobilization processes through biological activities in the production of organic matter [6], which is seen an emerging technology called phytostabilization.

Phytostabilization is a phytoremediation technique. Phytoremediation is to remove, stabilize, or detoxify hazardous pollutants in soil which is also known as green remediation, botanical remediation or eco-remediation [7]. Remediation of polluted sediments and soils is possible by means of eco-remediation which is due to its lasting operation, sustainability, efficiency, affordability and landscape attractiveness [8]. At sites contaminated with metals, plants are used to either stabilize or remove the metals from the soil and ground water through different mechanisms. Phytostabilization is one of those mechanisms used for the stabilization of metals, and defines as the use of metal tolerant plant species to immobilize heavy metals through absorption and accumulation by roots, adsorption onto roots, or precipitation within the rhizosphere, but not in plant tissues, thus reduces the mobility of the contaminant and prevents migration to the ground water or air, and it reduces bioavailability for entry into the food chain, prevents erosion and spreading of pollution, creates a new ecological condition in the area. Using metal-tolerant species for stabilizing mine spoils also could provide improved conditions for natural attenuation [4]-[9].

There is a growing evidence that phytostabilization can facilitate the restoration of mining degraded land [10]. Because in so heavily contaminated soils, like in Cartagena-La Unión Mining District, removal of metals using plants would take an unrealistic amount of time, so that phytostabilization can change metals to a less bioavailable form; exposure of livestock, wildlife and human can be reduced [11].

Phytostabilization needs to use native plant species which are found in the tailings, appropriate to the specific conditions of the areas. Also these native plant species can prevent the introduction of non-native and potentially invasive species that may result in decreasing regional plant diversity [12]. For creating a self-sustainable landscape in post-mining areas, utilization of natural plant species is also important. Thus, new ecological conditions can be created in the area.

However, finding solutions for environmental problems is not only a technical problem; also it requires an understanding of the environment as a social, economic and natural system, among people [13]. According to [14] when one works for a very long time in environmental issues, particularly in reclamation, one begins to realize that environmental problems are created and defined not only by science, but also by our culture. We immediately set about measuring the problem and the potential of its fix, somehow leaping from a culturally defined problem to a scientifically defined fix. While all this measurement, this science is necessary, it is not sufficient to fully address the real landscape in which we live. We need to address the underlying culture as much as the science, particularly in the places with significant public access or visibility. We inherit the sum of all the previous cultural decisions made about this landscape, and we address those we choose to address. That decision can be a cultural decision, but too often we neglect the cultural side of the solutions: the arts. [14] suggests that the vast array of environmental-reclamation science and technology is not sufficient, that the degraded environments we address are cultural artifacts as much as they are problems for science, and that we must address these with the full range of the arts and humanities, as well as the sciences, if we are to be effective. It also should not be forgotten as [15] highlights in the key concepts of design strategies which belong to AMD&ART “arts can be found in the process not just in the form”.

While this study explores the problems related to reclamation and new land use of a mine tailing, on the other hand integration of these components (solutions or solution processes for reclamation efforts and the new identity or the new recreational potential of the area) in a recreational area is trying to be achieved in a landscape conceptual design.

II. MATERIALS AND METHODS

The study area was described with its natural, cultural characteristics and negative effects on the environment and human. The procedure was explained with the considerations which were taken into account in the creation of a conceptual landscape design.

A. *Case Study Description*

The mine tailing which is the subject of our study area is located in Cartagena-La Unión Mining District, one of the post-mining areas in Iberian Peninsula, in which intense metal mining activity had been under operation for more than 2500 years. The activities were ended in 1991. Mining district is located in Murcia Province, southeast Spain (Fig. 1) and covers 50 km^2, including five population nuclei with around 20.000 total populations.

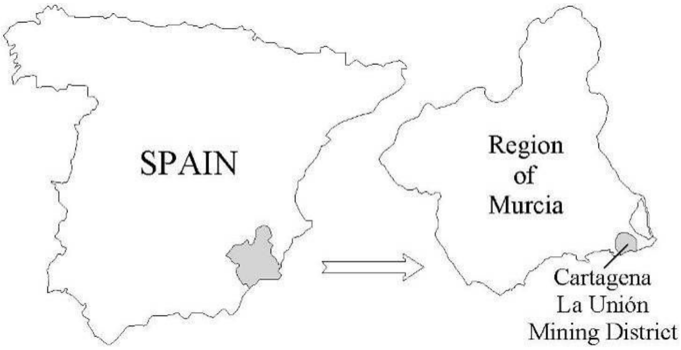

Fig. 1 Cartagena-La Unión Mining District

The surroundings of the mining district have a population of more than 200.000 inhabitants, including the city of Cartagena and the rest of its Municipality. During the summer, the population dramatically increases because of tourists who come to the Mar Menor Lagoon (one of the most important lagoon of the Mediterranean) and Mediterranean Sea beaches.

In the north agricultural areas, in the west petrol refinery, in the south Mediterranean Sea, and in the east and north-east respectively newly emerging resorts, golf areas and Mar Menor Lagoon are located. The altitude of the district is between 0 and 500 m above sea level. The climate is semiarid Mediterranean, long warm summers and short moderate winters with mean annual temperature of 18ºC and mean annual rainfall of 275 mm.

Formation of the area and regional climate conditions determine a natural flora adapted to drought and high temperatures which are only found only in hills and small sites that contain small formations of pine trees (*Pinus halepensis*) and groups of typically Mediterranean brushes with xerophytic characteristics. Some of the thicket plant species are endemic in this zone such as *Tetraclinis articulata* and therefore have a high botanic interest [16].

The mines constituted the only economic activity during hundred of years for local people. This reason has conditioned the socio-economic situation of this council that was tied to the up and downs of the mining activity throughout the years. In spite of this “monocultural” character, economic alternatives to mining were not proposed by successive governments. Mining-dependence caused a lot of population fluctuations with a decline from 30.000 citizens in 1900 to 13.900 in 1991 when the mining activity ceased. These aspects left a strong mark in the idiosyncrasy and character of La Unión's citizens [16].

In 1955 the Government prohibited the mining companies from dumping wastes on the ground to form mining tailings. Nevertheless, with the recurrent torrential rains typical of the Mediterranean climate, the tailings that remain in the mountains continue to be eroded and washed into the lagoon [16]. As a consequence, these mine soils which have scarce or null vegetation due to very poor properties of soil such as extremely low organic matter, and most of the natural vegetation formations are degraded due to the atrophic use of the soil. While unvegetated tailings have been exposed to eolian dispersion in the semiarid climate conditions of the region, on the other hand for a long time, these mine residues have been transported downstream during periods of high rainfall and runoff; as a consequence the pollutants have migrated long distances.

The environmental impacts of the long history of mining activities in southeast Spain include large areas of soils characterized by strong acidification processes, high salinity and accumulation of metals. These mining activities have generated high amounts of wastes for many years; the wastes are accumulated in tailing ponds. Throughout the area there are around 80 mine tailings (Fig. 2) which contain materials of high Fe-oxyhydroxides, sulphates, and potentially leachable elevated contents of heavy metals (mainly Zn, Pb, and Cd) due to extreme acidic conditions.

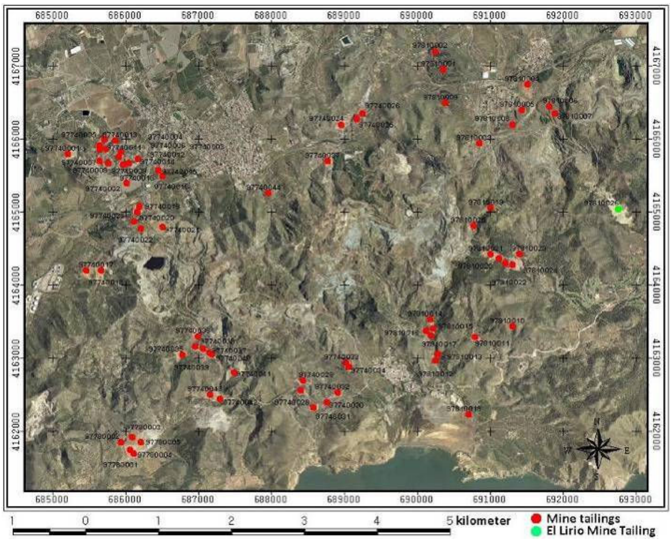

Fig. 2 Cartagena-La Unión mining district [17]

It is also possible to see some deleterious examples related to the public safety. For example in the year 1972, the mine tailing Brunita collapsed due to the strong rainfalls, spreading the materials in nearby areas and killing one person [18]. Some of the mine tailings are more than 20 m in height and cover an average area of 40.000 to 80.000 m^2, are unstable and difficult to eliminate. Close to two children school, one acid mine tailing was reported with high concentrations of zinc, lead and arsenic [16]. Because of the waste from mining operations was discharged directly into the inner part of the bay for more than 30 years, polluting the Mediterranean Sea for a radius of several kilometers, Portman Bay was reported the most contaminated bay in the entire Mediterranean by [19].

We selected among those one tailing pond called El Lirio (Fig. 3) close to newly emerging resorts in a scenery location and covers a 2.5 ha of the district. Environmental problems resulting from the unvegetated structure of the tailing, and public safety concerns especially due to its proximity to the settlements and its some appropriate conditions for being a recreational area such as topography, location and views, made this area a critical case study, where the resolution advisories have to be brought out immediately in the context of ecological and sustainable considerations.

Fig. 3 El Lirio mine tailing (Original, 2010)

B. Procedure

Natural, cultural, geophysical, biological, and geochemical characteristics of the landscape were analyzed. These characteristics are all important for the reclamation process, for the new function of the area and for being able to see the interactions between the reclamation process and the new function of the area which are wanted to be integrated in a landscape design.

According to the field experiment (Fig. 4) which was established on the area in 2004, the effects of different amendments on the plant colonization and their successful results such as recuperation of some soil properties were noted in several studies [20]-[21]-[22]. By the help of these previous and ongoing studies; application of marble mud and pig slurry and development of phytostabilization techniques were suggested in order to realize the reclamation and landscape design of the area.

Especially because of the soil reclamation priority the phytostabilization plantation design was wanted to be determined. In a metal-mining area, in order to be able to plant phytostabilization plant species, available heavy metal distributions have to be known. Available heavy metals constitute one of the most important factors which directly effects growth of the plant, since they are the fraction of metals that can be uptaken by plants.

Fig. 4 The field experiment in El Lirio mine tailing (Original, 2009)

In the measurement of available metals, diethylentriamene pentaacetate (DTPA) was used in the ratio of 1:2 soil-extractant [23], and measurements were carried out using atomic absorption spectrophotometer (AAnalyst 800, Perkin Elmer).

Analyzing the heavy metal distribution maps, in other words distribution of pollution, can help in the determination of land uses such as places which need phytostabilization measures, which can be used as an experimental area, which can be used for public requirement, etc.

The land use decisions were given after the assessments of heavy metal distribution maps. Due to the priority of plantation because of the soil reclamation efforts, after choosing the contaminated areas for phytostabilization objectives, landscape design suggestions have been made for the rest of the area in the context of conservation and incorporation of the history and culture.

Distribution maps (Fig. 5) were prepared using Arcview 3.1 in which metal concentrations were used as input data. (Fig. 6)-(Fig. 7)-(Fig. 9) were made in Autocad 2008.

III. Result and Discussion

Figure 5 shows the distribution of available heavy metals in El Lirio tailing. It is possible to see 9 different level polluted areas according to their context for each element (Zn, Pb, Cd).

With respect to the soil plant toxicity thresholds that are showed in Table I [24], Zn is not toxic in the 1 level of the area and is partially acceptable in 2 level, but in the rest of the mine tailing, Zn is approximately from 1.8 to 19 times higher than the toxicity threshold. Pb is not toxic in the 1, 2, 3, 4, and 5 levels of the area. However, Pb toxicity from 6 to 9 levels of the area reaches until 3 times more than the threshold. With respect to Cd amount, it is not toxic in 1, 2 and 3 levels of the area, is partially acceptable in 4 level, whereas in the rest Cd toxicity threshold is ranging from 2.5 to 8.3 times.

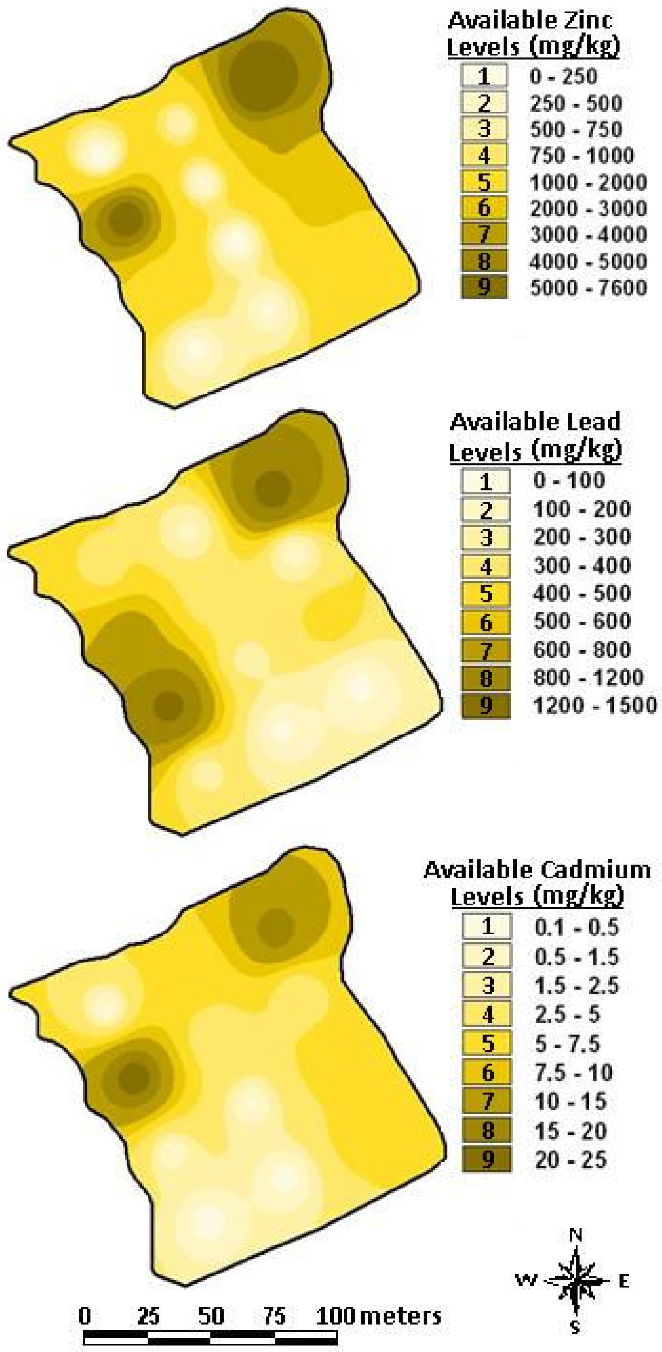

Fig. 5 Spatial distributions of available metals (Arcview 3.2)

Metal	Zn	Pb	Cd
Soil plant toxicity threshold	400	500	3

Table I Metal toxicity threshold (mg/kg) [24]

With regards to these gradual changes in distribution of available heavy metals, density of phytostabilizion measures can be separated into graded ranks. In Figure 6 toxic amount distribution of metals and the zones under toxic limits can be seen. In some zones only one element is toxic, whereas in some two or all three elements are.

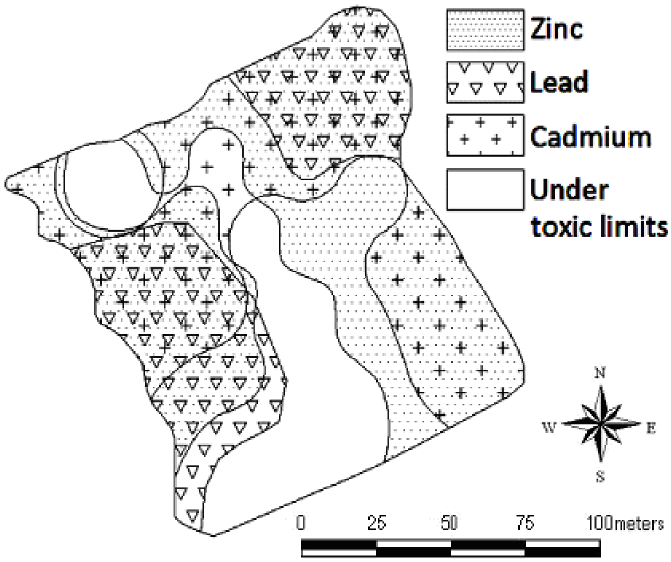

Fig. 6 Distribution of metals above toxicity thresholds (Autocad 2008)

In the plot experiment which is previously mentioned related to effects of different amendments on plant colonization, marble mud ($CaCO_3$) was used for immobilising metals, removing them in a mineral form such as carbonates or indirectly oxi-hydroxides as a consequence of increasing soil pH, and for creating better conditions for plant development. In order to add nutrients and organic matter; pig manure and sewage sludge were applied and according to the results of the experiment the better conditions were obtained from the pig manure amended soil. This initial incorporation of amendments has promoted the microbial activity and establishment of vegetation, which remains after 5 years of application. This vegetation cover includes some native species of the area: *Zigophyllum fabago, Piptatherum miliaceum, Dittrichia viscosa, Phragmites australis, Helichrysum decumbens, Sonchus tenerrimus.* Eventhough after the application of amendments these spontaneous plant species colonized in the plots without seeding, some plant species are suitable for phytostabilization process. In order to continue to observe their effects in the most polluted and therefore more problematic soil conditions, we suggest establishing experimental areas in these most polluted parts of the mine tailing. Figure 7 shows a proposed design of the experimental area which is inspired from Mel Chin's Revival Field [25]-[26].

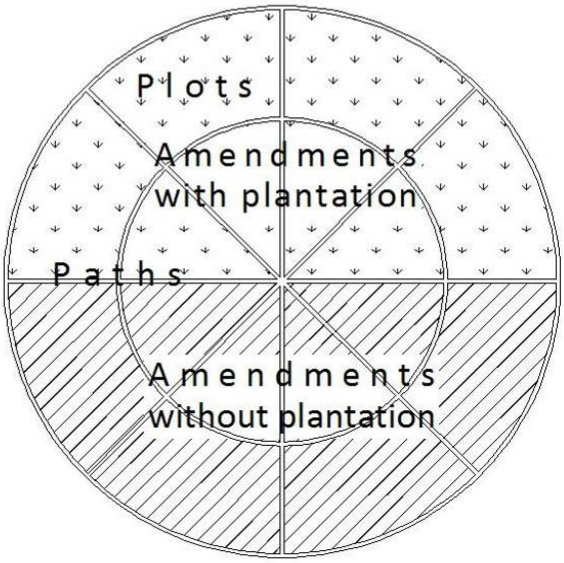

Fig. 7 Proposed design of experimental areas (Autocad 2008)

Revival Field (Fig. 8) is an example which shows that public art can also serve as a venue for experimental installations. It is possible to see the collaboration between artist and scientist in Mel Chin's Revival Field. He developed the project proposal in collaboration with USDA agronomist Rufus L. Chaney, an 18.2 x 18.2 m remediation project built on a landfill in St Paul, Minnesota. It was an art-science work that explores how plants can safely remove compounds from contaminated soils and was the first replicated field test conducted as an art installation in the US. Chin selected plants to remove toxins from degraded land and arranged them into a bulls-eye shape, surrounded by industrial fencing. At the time, little was known about the effectiveness of phytoremediation, and both research efforts and money were scarce. The project helped to confirm the effectiveness of the technique Thus, in addition to showing the role art can play in generating research with cultural meaning; his efforts also represent an alternative route to funding urban ecological experiments. Chin sees his work in two forms: as a formal planting on the landscape and as a complex series of 'systemic sculptures' that occur as the plants and roots act on the contaminants in the soil [25]-[26].

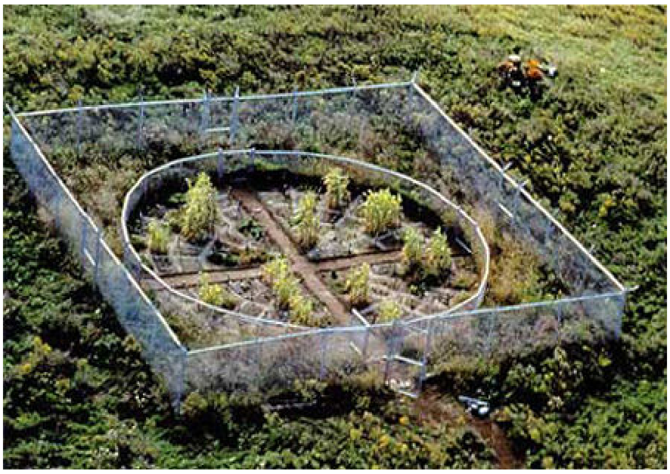

Fig. 8 Mel Chin's Revival Field [27]

In our study area, by the help of these experimental areas, the suggested phytostabilization technique in the most polluted zones of the area, can be diversified such as the places only with amendments without seeding, the places with amendments and with seeding, different plant species, etc.

The aim is to minimize the negative effects of the mine tailing by creating a landscape design which brings a new sustainable function to the area as shown in the Figure 9, presents the ideal concept design of El Lirio mine tailing.

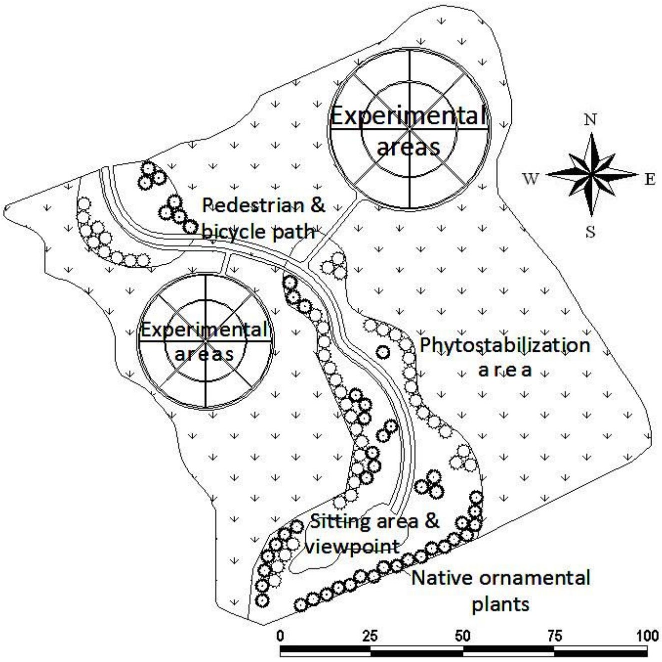

Fig. 9 Proposed design of El Lirio mine tailing (Autocad 2008)

According to the design we suggested using for the public only the area which is under the thresholds of toxicity. Visitors are not allowed to enter to the phytostabilization areas because of the maintenance requirement of phytostabilization process. They can see the phytostabilization areas through the walk way and they can enter to the surrounding circulation of the experimental areas in order to see the experimental plots. Surroundings of the no-entry areas were closed by using fences and in several places with native naturally grown ornamental plants, by allocating spaces which allow seeing inside sufficiently. Through on the both sides of the walk way and in the surrounding way of experimental areas, design process of the mine tailing and phytoreclamation explanation panels (Fig. 10) will take place. Several antique mining tools or their sculptures can also be organized among the both sides of the walk way. Their information panels have to be included too.

Fig. 10 Phytoreclamation explanation panels [28].

In experimental areas which are located in the most contaminated areas of the tailing, investigations related to the improvement of the technique will be carried out.

Besides phytostabilization plantation, the use of native ornamental plant species was suggested in non contaminated areas for several aims such as increasing attraction, redirecting of visitors, creating a barrier between the places for visitors and no-entry places, etc.

Parallel to the walk way also there will be a bidirectional bicycle path which is separated from the pedestrians´ with a plant cover border in order to provide the safety of both pedestrian and cyclist.

At the end of both ways (walk way and bicycle path), in the south of the area which is the most scenic place, sitting area will be located. In sitting area pergolas and/or gazebos can be used.

All the material to be used in the area will have to be resistant to water and climatic conditions.

In order to ensure the security of both public and the reclamation processes, throughout the implementation precautions have to be pursued by several ways such as employments of watchmen.

IV. CONCLUSION

The present work shows that if the environmental risks can be minimized, recreational activities can be developed in a mine tailing. Integration of reclamation efforts and recreational activities, based on the safety of both environment and public, can be realized by the help of appropriate landscape design suggestions.

Use of amendments and phytostabilization plant species can reduce the environmental risks of the area, by immobilizing heavy metals, their spread to the surroundings and by preventing erosion. Once these conditions are obtained, prominent value of the area can be featured by landscape design, in our case the didactic and educative value of the phytostabilization, experimental areas and mining culture can be used as a prominent value in the recreation area in order to increase public awareness and knowledge about environmental issues and challenges, this educative value should enable people to gain an understanding of how their individual actions affect the environment [13]. Also educational and academic institutions can use these new investigation opportunities as environmental education tools.

Conceptual design of El Lirio mine tailing can help to develop a theorical design approach for the rest of the tailings in Cartagena-La Unión Mining District. As noted by Swaffield (2002) in [29] "theory can also evolve from practical experience". Although this design is not an implementation yet, it is an approach for implementation and creation of more approaches would be useful for the creation of the practical design.

Instead of creating new recreational areas, instead of destroying natural or virgin lands more and more, if we can give a value to the ones which we have already started to destroy, we can discard the potential problems of today and the future by transforming a waste land to a new functional and sustainable area which can serve for the requirements of the public.

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