



TU1206-WG1-015

Lisbon

TU1206 COST Sub-Urban WG1 Report

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TU1206-WG1-15**

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Subsurface and urban planning in Lisbon

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Cover image: Overview of Tagus River and Lisbon Hills from Eduardo VII Park
(<http://www.cm-lisboa.pt/viver/urbanismo/lisboa-historica-cidade-global-candidatura-a-unesco>)



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Summary

Lisbon, Western Europe's oldest city is the capital and the major touristic and economic center of Portugal.

It has about five hundred and fifty inhabitants and the higher population density of Portugal, nearly six thousand and five hundred habitants per square kilometer.

Lisbon is affected by natural hazards, particularly flooding, resulting from its morphology, occupation of ancient water streams as also to the incapacity of the old sewerage system.

The seismic activity is also a concern and during its history Lisbon has been affected by several earthquakes that caused considerable damage and produced large economic and social impacts, particularly the November 1st, 1755, earthquake ($M \geq 8$) that caused the complete destruction of its downtown area.

Superficial fills, resulting from sediments transported and deposited along ancient streams, deposited in Tagus River margins and anthropogenic materials used in urban activities, lead to a widespread distribution across Lisbon with a variable thickness and composition. Due to the importance of this matter in underground planning, several approaches have been made to model the thickness of surficial fills using geotechnical data.

Limestone, basalts, mudstones and sandstones were exploited in ancient quarries located in Lisbon. The quarries were filled with anthropogenic heterogeneous materials with variable thicknesses which create geotechnical problems.

The lack of space led to the expansion of the city to the suburbs, to the occupation of less favorable terrains and the extensive construction in the consolidated city, leading to cost increases.

To promote mitigation, a sustainable urban planning, cost reduction and optimizing the launching and completion of new projects, detailed knowledge of subsurface characteristics is a primary need. In order to achieve it Lisbon Municipality has been developing a geotechnical database to generate a 3D geological/geotechnical model.

1. Introduction

1.1. Overview

Lisbon, Western Europe's oldest city is the capital of Portugal, the major touristic and economic center and occupies a fairly limited area (figure 1). However if we analyze its history we see that the ancient occupation of the Lisbon territory was limited to a central core, benefiting from the privileged and strategic position along Tagus River as well as the rugged morphology that has provided natural conditions for the city defense over the centuries.



Figure 1 – Occupation of Lisbon territory

Many of the city's buildings are centuries old, and infrastructure is likewise aging and though the city has strong technical expertise and political will to undertake upgrades, it also faces financial constraints from the global economic crisis.

The lack of space led to the expansion of the city to the suburbs as well as to the occupation of less favorable terrains, leading to cost increases.

The solution was the extensive construction in the consolidated city, both in height and depth, in order to promote better conditions for the inhabitants (basements, underground parking and subway tunnels). However this implies detailed knowledge of subsurface characteristics, which was gathered through survey campaigns. Using this information Lisbon Municipality has been developing a geotechnical database to generate a 3D geological/geotechnical model, aiming towards cost reduction and optimizing the launching and completion of new projects.

Urban improvement projects are being developed to ensure residents that have ongoing access to services, and also to:

- Reduce the risk from natural hazards, such as seismic activity which could cripple current structures and networks;
- Reduce the risk from flooding that is also a concern in Lisbon territory, causing regular and severe damages;
- Promote and facilitate conditions to a sustainable planning and urban management with a mitigation perspective;
- Prepare the city for other threats, especially storms and other severe events brought on by climate changes;

1.2. City description

Lisbon is located in the left bank of Tagus river Estuary and covers an area of about one hundred square kilometers (85.87 Km² emerged area). It includes 24 administrative areas.

1.2.1. Social

Lisbon is the biggest city in Portugal and although it occupies 0.1% of the total area of the country, it has about five hundred and fifty inhabitants and the higher population density, nearly six thousand and five hundred habitants per square kilometer.

According to the last Population Census (2011), Lisbon is the most aged city of Portugal (23,6 % residents with more than 65 years).

The percentage of young people is very low, and the inhabitant's ratio reveals the value of 186 elderly per 100 young. The proportion of the population over 65 years has been increasing over the past twenty years: 1991 - 18.8%; 2001- 23.6% and in 2011 - 23.9%.

Daily commuting movements in the city to work or study generates income from the transport of about 325 thousand people per day. In contrast the number of residents has decreased dramatically, mainly in young and active age intervals of the population, leading to the aging of the population as well as the degradation and desertification of central areas. Health conditions have been improved over the last centuries and, as a result, citizens of Lisbon are living longer than ever.

1.2.2 Environment, land use and infrastructure

In Lisbon the ecological structure is composed by the Monsanto Forest Park and other public parks, with an area of about ten square kilometers.

In general terms, Lisbon is influenced by a temperate climate characterized by an annual average temperature of 16°C, with minimums occurring during the period between December to February (10 ° C), and maximums from July to September (20 to 25 ° C).

The total number of housing units in Lisbon is about 52.500, according to the Population Census, 2011. The buildings were mostly built at the beginning of the last century. The administrative areas of the historical center have the most degraded buildings.

Lisbon shows currently a positive tendency regarding the buildings conservation state, in which 85.9% of the buildings are in a rate of "average" to "excellent", and the percentage of buildings without need of repair reaches 54%.

Lisbon sewerage consists of an unitary and separate system, with an extension of about 8,4 Km². It is also a very aging system: 21% of the drains are from before 1919, 43% were built between 1919 and 1960, 24% built between 1961 and 1980 and the remaining are after 1980.

Traffic volume has had a significant growth between 1993 and 2003 (232 to 281 vehicles / thousand inhabitants). Recent monitoring studies indicate that the rate current status in Lisbon is about 450 vehicles / thousand inhabitants. The public transportation network ensured the access to Lisbon by train, subway, boat and bus.

1.2.3 Economy

Lisbon region is the largest and most competitive geographical agglomeration of the country, establishing strategic economic functions.

At the European level, the Lisbon Metropolitan Area is part of what is referred to as the European Atlantic Margin. It has sustained development strategies aiming the establishment of the region as an important European Atlantic gate.

The Port of Lisbon is the third largest national port, preceded by the Sines Port and Leixões and turnover approximately 11.969,000 tons of goods in 2009.

According to data released by Airports Council International Europe (ACI Europe), Lisbon International Airport, with a 10.7% percent growth in passenger traffic in 2015, integrates the Top 30 of the busiest in Europe. This Portuguese airport is in 28th position in the ranking. It should also be noted that in 2012 the Lisbon airport surpassed for the first time in its history, 15 million passengers.

2. Geological and physical geographical setting

2.1. Regional Geological setting

Lisbon is located in the Iberian West Bank and presents geological formations dated from Cretaceous to Holocene (figure 2).

The Lusitanian Basin was developed during the Mesozoic Era in extensional setting associated with the opening of the North Atlantic. It corresponds to a subsidence structure elongated in the NS direction, which evolved over four episodes of rifting interspersed with periods of regional subsidence that culminated in the lower Cretaceous. This tectonic phase lasted over 220 million years. The passage from the Lower to Upper Cretaceous, occurred about 100 to 97 million years, was materialized by a transgressive episode followed by regional subsidence.

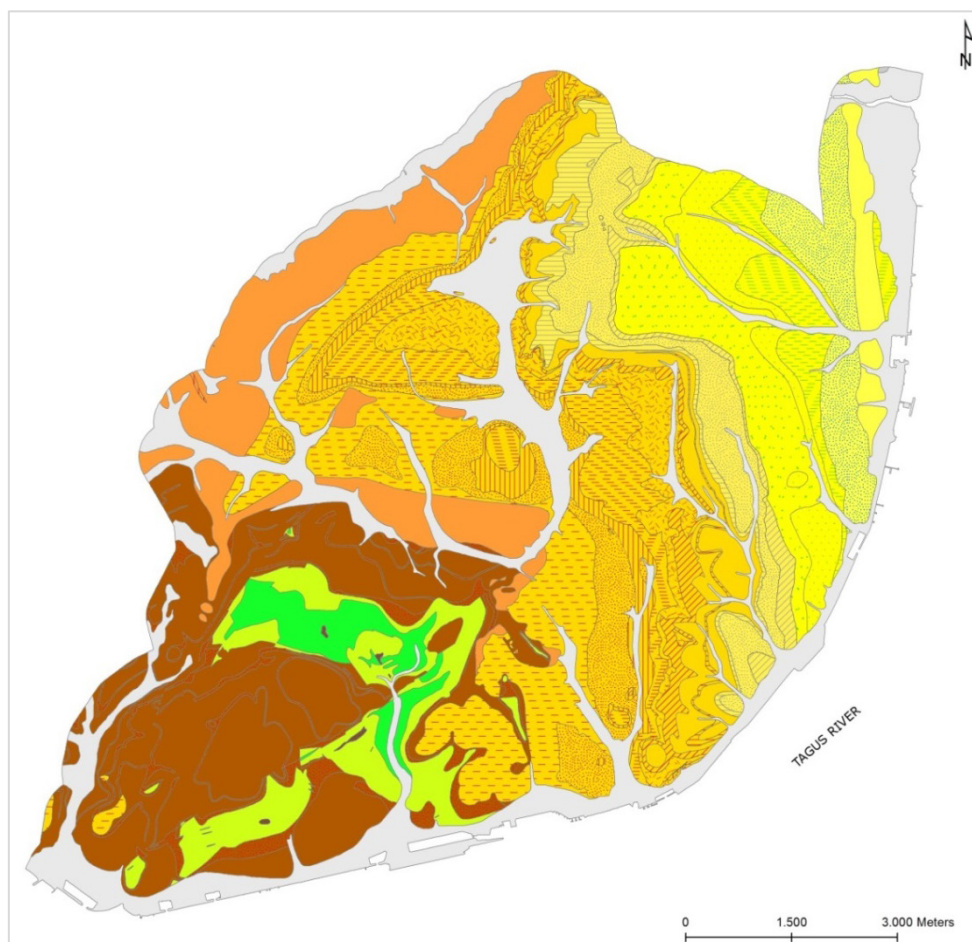


Figure 2 – Geological setting of Lisbon (green: cretaceous limestones; brown: neo-cretaceous basaltic lavas; orange: Benfica Complex - Oligocene; yellows: Miocene sedimentary series)

Lisbon was located in a marine environment with warm shallow waters, allowing the formation of marls intercalated with compact limestone layers. With the emersion of the

formed rocks, differential erosion processes occurred (chemical dissolution of limestone along fractures), leading to karst and cave formation and highlighting textural heterogeneities (Pais *et al.*, 2006).

These caves were used for Palaeolithic settlements as shelter and the silex was used for weapons, tools and flint manufacturing (Galopim, 1989). Cretaceous limestones were also explored for construction and ornamental materials and some quarries are known in Monsanto, Ajuda and Vale de Alcântara (Pinto, 2005). Building facades and Monuments, as well as sidewalks in Lisbon, are made predominantly from these materials.

In Late Cretaceous Period a volcanic event occurred in Lisbon area (≈ 65 M.y.). The intense fractures originated by plate movement allowed the installation of several conduits, chimney and dikes that conduct magma to the surface. These magma deposits covered the subjacent cretaceous formations constituting the Lisbon Volcanic Complex (Pais *et al.*, 2006). Most part of the Old Lisbon is covered by basaltic sheets, a result of effusive events, intercalated with pyroclasts from explosive events (mainly composed by ashes). Their origin was probably one single volcanic building, located in the Mafra region, higher than 2000m, with some inactive episodes showed by intercalated sediment materials.

The basaltic lavas were exploited in some quarries located in Lisbon, and applied as gravel (Pinto, 2005). They can be seen in some Lisbon street pavements. Lava and ashes alteration weathers to high quality agricultural soils, leading to human occupation of those areas since ancient times as a way of subsistence of populations. However nowadays, the urban expansion has led to the extinction of those regions in Old Lisbon.

In the Palaeogene Period (≈ 40 M.y.) an emersion phase occurred with a lack of sedimentation, caused by an intense tectonic activity which lead to relief building (Pais *et al.*, 2006). Lisbon, without Tagus river at the south, exhibited a continental sub-arid landscape, where erosion processes acted intensely.

Large volumes of heterogeneous sediments (blocks and thin sediments) resulted from the destruction of those landscapes were transported from higher areas to deposition basins by a drainage network pattern of torrential rivers (Pais *et al.*, 2006). Those basins, controlled by tectonic structures and with few connections to the sea, allowed the deposition of the thick conglomeratic series of Benfica Complex. The oxidation processes occurred in iron minerals presented in the transported sediments which causes the reddish colour, typical of an oxidant deposition environment (Pais *et al.*, 2006).

In Miocene Period (≈ 24 M.y.) and after an intense continental sedimentation phase, marine environment as established again as a consequence of subsidence, allowing the installation of Tagus Basin vestibular area - tectonic depression of NE-SW direction (Pais *et al.*, 2006). The transgressive context installed culminates in the deposition of marine sediments in the vestibular area of the Tagus River (S and SW), and river sediments to inside (N and NE),

which correspond to the Miocene series of the Lisbon region (Figure). During the next 16 M.y., sea level rises and falls several times, leading to formation of rocks typical from peri-continental and littoral environments, which correspond very characteristic sediments and fossils.

During the Quaternary there was a development and establishment of the hydrographic network as a result of a sea level drop that deposited the alluvial formations on the banks of the water streams. The presence of fluvial terraces is also evident in the topography (Pais *et al.*, 2006).

2.2. Landscape and terrain

Lisbon territory reveals a very rugged terrain resulting from structural control imposed by regional tectonics that was associated with intense fracturing, differential erosion and establishment of the water regime, lead to the city morphology as well as its occupation over time.

It is quite common to find in the literature, descriptions of Lisbon as "the city of seven hills", a reference to the hills of São Vicente, Santo André, Castelo, Santana, São Roque, Chagas e Santa Catarina, and though they gird the city when its limits slightly exceeded the historical area (Almeida, 1991), they do not fail to highlight these geomorphological aspects (figure 3).

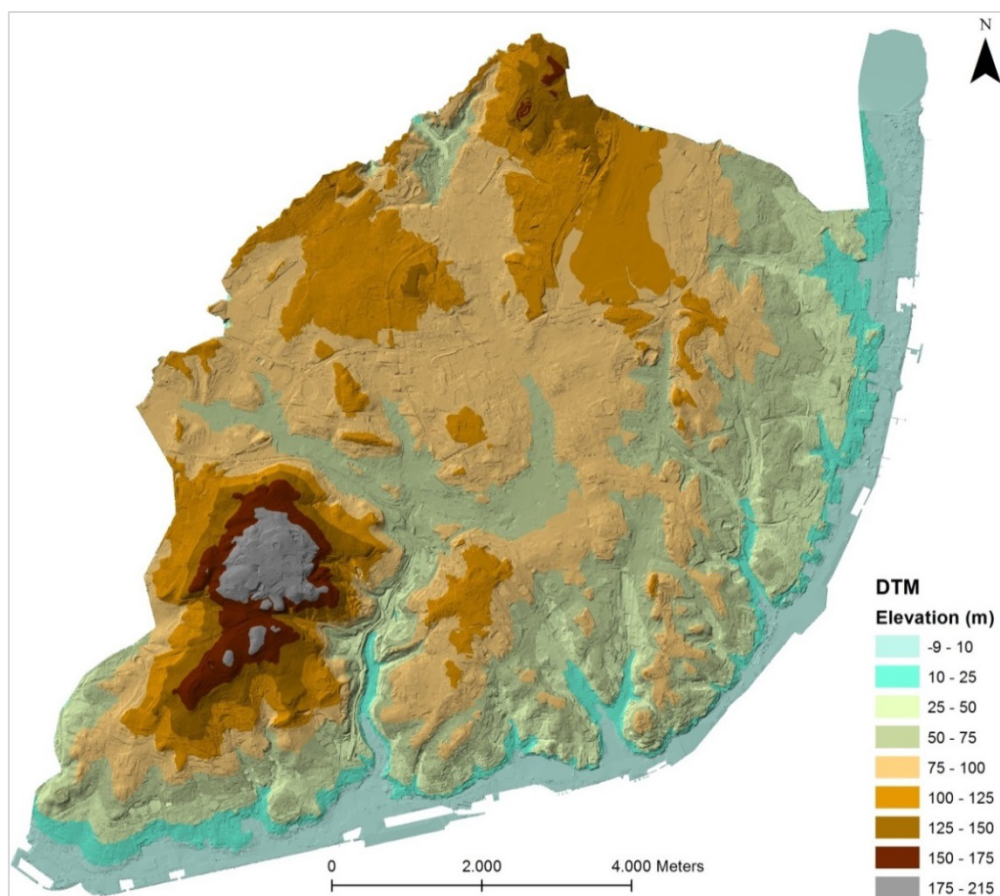


Figure 3 - Digital Terrain Model

The lower altitudes are located along the Tagus River, all along the coastline and also associated with the notch lines of subsidiaries waters.

The highest value registered is 215m and are in general registered in the north part of the city (100-150m).

3. The urban subsurface environment

3.1. Superficial fills

Lisbon superficial fills have different origins: sediments transported and deposited along ancient streams, sediments deposited in Tagus River margins and anthropogenic materials used in urban activities. This leads to a widespread distribution of surficial deposits across Lisbon with a variable thickness and composition.

Due to the importance of this matter in underground planning, several approaches have been made to model the thickness of surficial fills using geotechnical data. An example developed for downtown Lisbon is presented here (figure 4).

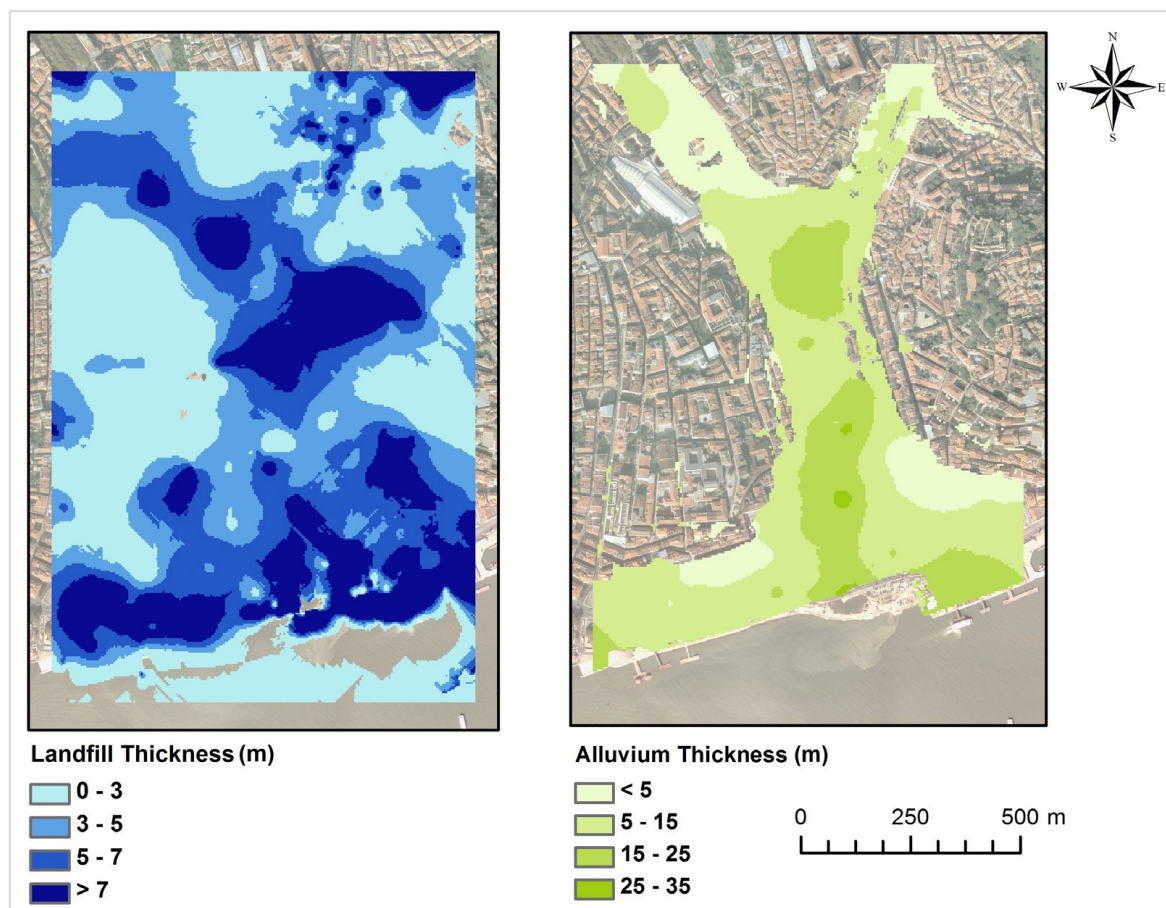


Figure 4 - Thickness of anthropogenic deposits (left) and alluvial deposits (right). (Teves-Costa *et al.*, 2014)

3.2. Groundwater

In Cretaceous formations, affected by tectonic movements, groundwater flows through fissures within the bedrock as well as through more permeable strata.

Permeability is relatively high in Cretaceous limestone and these rocks form the main aquifer system in Lisbon area.

The Miocene formations exhibit a monoclinical structure, dipping 10-15° ESE, with vertical and horizontal variations in lithology. Groundwater percolation occurs in permeability contrast areas, creating a multi-layer aquifer system.

In Alfama, Lisbon downtown, there are geological conditions for the occurrence of hot water with geothermal and medicinal properties.

This water percolates from depth along a fault system and when rises to surface, exhibit temperatures above 30°C, registered in some water points. Lisbon Municipality has recently established a partnership with other Government Institutes to promote a survey campaign to exploit these hot waters and to develop a thermal spa in this area – Projeto “Termas de Alfama” (Figure 5).

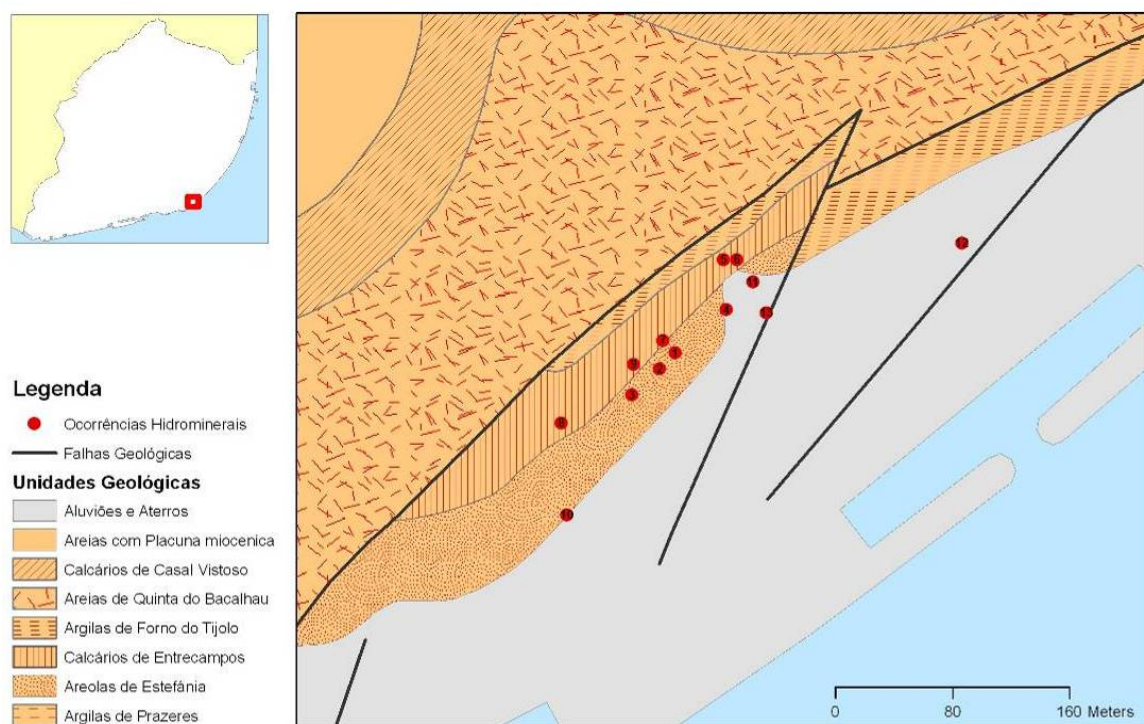


Figure 5 – Location of hot water occurrences in the Alfama area

The hydrogeological system is recharged directly as a result of precipitation and irrigation in gardens, and paved areas that remain permeable. Indirect recharge occurs as a result of leaks and losses along the water mains.

3.3.Quarrying

Limestone, basalts, mudstones and sandstones were exploited in ancient quarries located in Lisbon. Several building facades and monuments in Lisbon are made with Cretaceous and Miocene limestones. It was also used in Lisbon sidewalks. Basalts were applied in gravel and street pavements and the mudstones and sandstones were used in clay and cement industries, respectively.

The quarries were filled with anthropogenic heterogeneous materials with variable thicknesses which create geotechnical problems (figure 6).

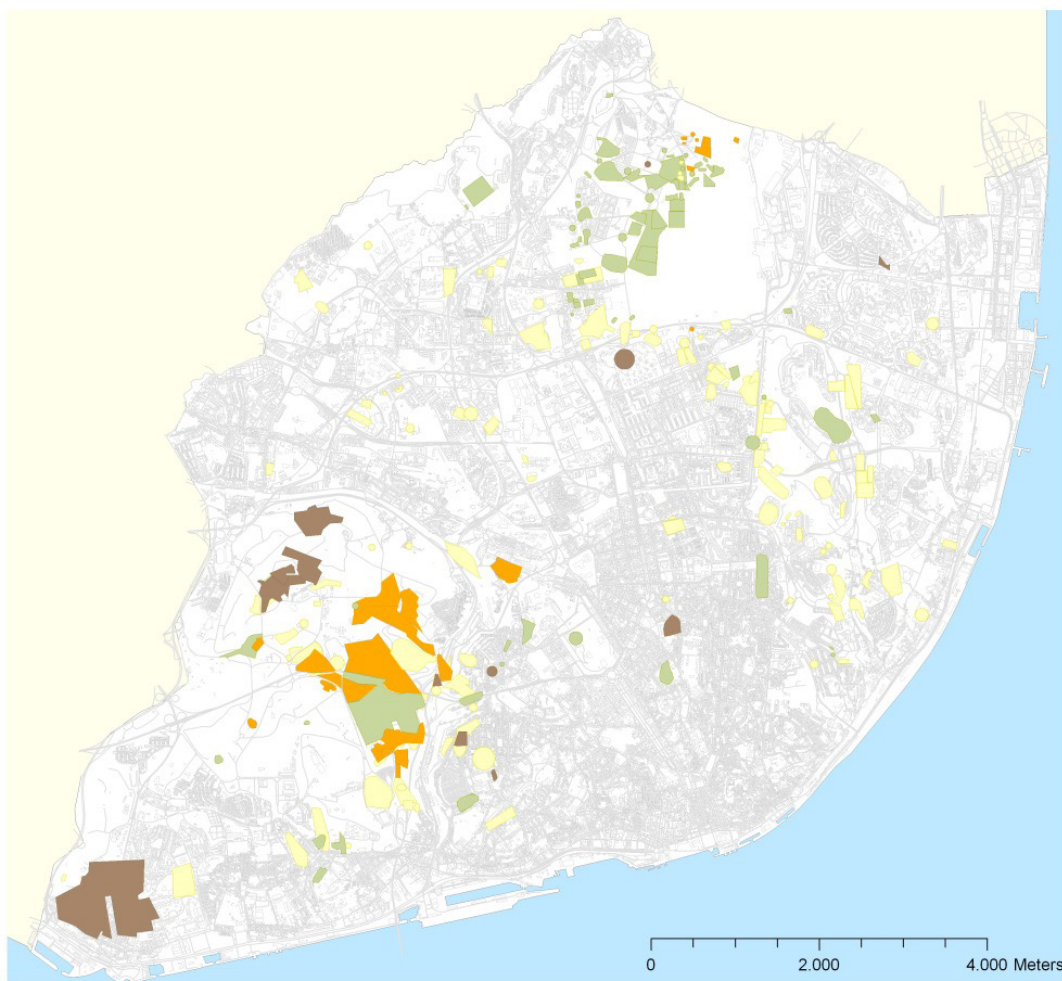


Figure 6 – Location of ancient quarries in Lisbon

3.4.Geodiversity and protection of geosites

In urban areas it is not expected to find indications of evolution and earth dynamics, mainly because of the general tendency which promotes the total occupation of the ground with construction. However, in Lisbon it is still possible to observe some outcrops preserved among buildings and roads, some of them with large dimensions that materialize several

geological formations since Cretaceous to Holocene times. The original paleoenvironments associated with the lithostratigraphic diversity presented in Lisbon area, leads to a great potentiality of the city aiming towards the preservation and dissemination of the geological heritage.

Through field work campaigns and with the collaboration of some public institutions, several outcrops were identified in Lisbon city, of scientific, educational and cultural interest. Eighteen were classified as *Geomonuments* (figure 7).



Figure 7 – Lisbon Geomonuments

- | | |
|--------------------------------------|-------------------------------------|
| G1 / G17 – Rio Seco Geomonuments | G9 – Virgílio Correia Geomonument |
| G2 – Sampaio Bruno Geomonument | G10 – Quinta do Lambert Geomonument |
| G3 – Calouste Gulbenkian Geomonument | G11 – Santa Apolónia Geomonument |
| G4 – Duarte Pacheco Geomonument | G12 – Judiaria Geomonument |
| G5/G7 – Infante Santo Geomonuments | G13 – Capitão Leitão Geomonument |
| G6 – Aliança Operária Geomonument | G14 – Eucaliptos Geomonument |
| G8 – Quinta da Granja Geomonument | G15 – Bela Vista Geomonument |
| | G16 – Parque da Pedra Geomonument |

Geomonuments were included in Municipal Planning Instruments, its accessibility and visibility was assured and description totems (figure 8) were developed. The strategy adopted involves the general public in order to proceed with the dissemination and preservation strategies.

Through ArcGIS Online services, Lisbon Municipality has created a website where the general public can access the thematic routes (figure 9).

The routes include the location of the main bus stops and subway stations as well as the sections that are made on foot.

The site can be accessed from the official website (www.cm-lisboa.pt) or through the address:

<https://cml.maps.arcgis.com/apps/MapJournal/?appid=292fa0698542496199e61a5fe32c0501>



Figure 8 – Totems layout

In April 2015, this project was awarded by the ProGeo – Portugal (The European Association for the Conservation of the Geological Heritage), with the Geoconservation Prize 2015.

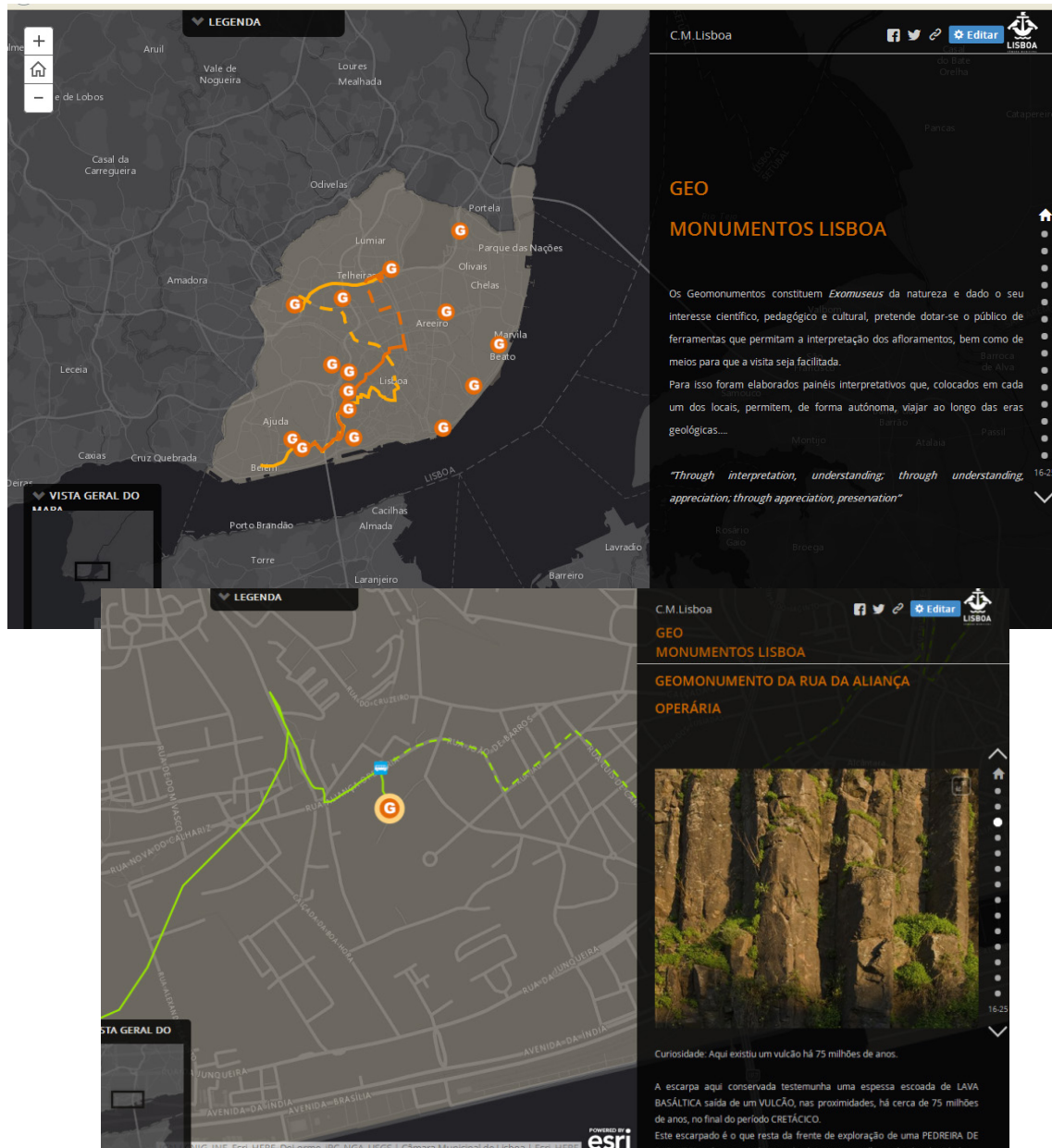


Figure 9 – Geomonuments website

3.5. Geological Hazards

Coastal inundation, flooding and earthquakes are the main geohazards with potential to impact on Lisbon city.

3.5.1. Coastal inundation

Given the proximity to Tagus River, Lisbon Municipality exhibits high potential to be affected by coastal inundation.

To promote mitigation, several measures were implemented in Lisbon Master Plan, such as the obligation to carry out hydrogeological studies and elaborate drainage plans for new buildings on the waterfront.

According to data provided by the Sea and Atmosphere Portuguese Institute, Lisbon can also be affected by tsunamis and the average estimated level reached by direct tidal effect is 5 m.

To deal with this potential hazard Lisbon wants to develop alert and warning measures.

3.5.2. *Flooding*

Due to various factors, highlighting the climate, morphology and geological characteristics, the city of Lisbon have been quite frequently affected by floods throughout the centuries. This problem increased due to dense urban occupation, whether above or underground (figure 10).



Figure 10 – Floods in Lisbon (<https://vimeo.com/132020170>)

Serious economic and social damage results from the vulnerability of the territory and Lisbon Municipality has been developing studies to identify the most vulnerable areas in order to develop measures aiming towards the mitigation of flood impacts in urban areas.

The Project is called HIDROARROIOS and aims to analyze the surface and groundwater volume accumulation, quantify the recharge (natural and artificial), water pumping that could create subsidence on the surface as well as to analyze water quality in the Arroios Stream Catchment Area.

3.5.3. *Soils Seismic Behavior*

During its history Lisbon has been affected by several earthquakes that caused considerable damage and produced large economic and social impacts. Particularly the November 1st, 1755, earthquake ($M \geq 8$) that caused the complete destruction of its downtown area.

Besides this kind of event, generated due to the slow collision of the Euroasiatic and the African tectonic plates, Lisbon can also be affected by earthquakes with moderate magnitudes, generated in Lower Tagus Valley.

Knowledge of the seismic response of the surface layers is fundamental for estimating the potential damage due to the occurrence of an earthquake.

In Lisbon Master Plan was included a Map with Soils Seismic Vulnerability (figure 11).

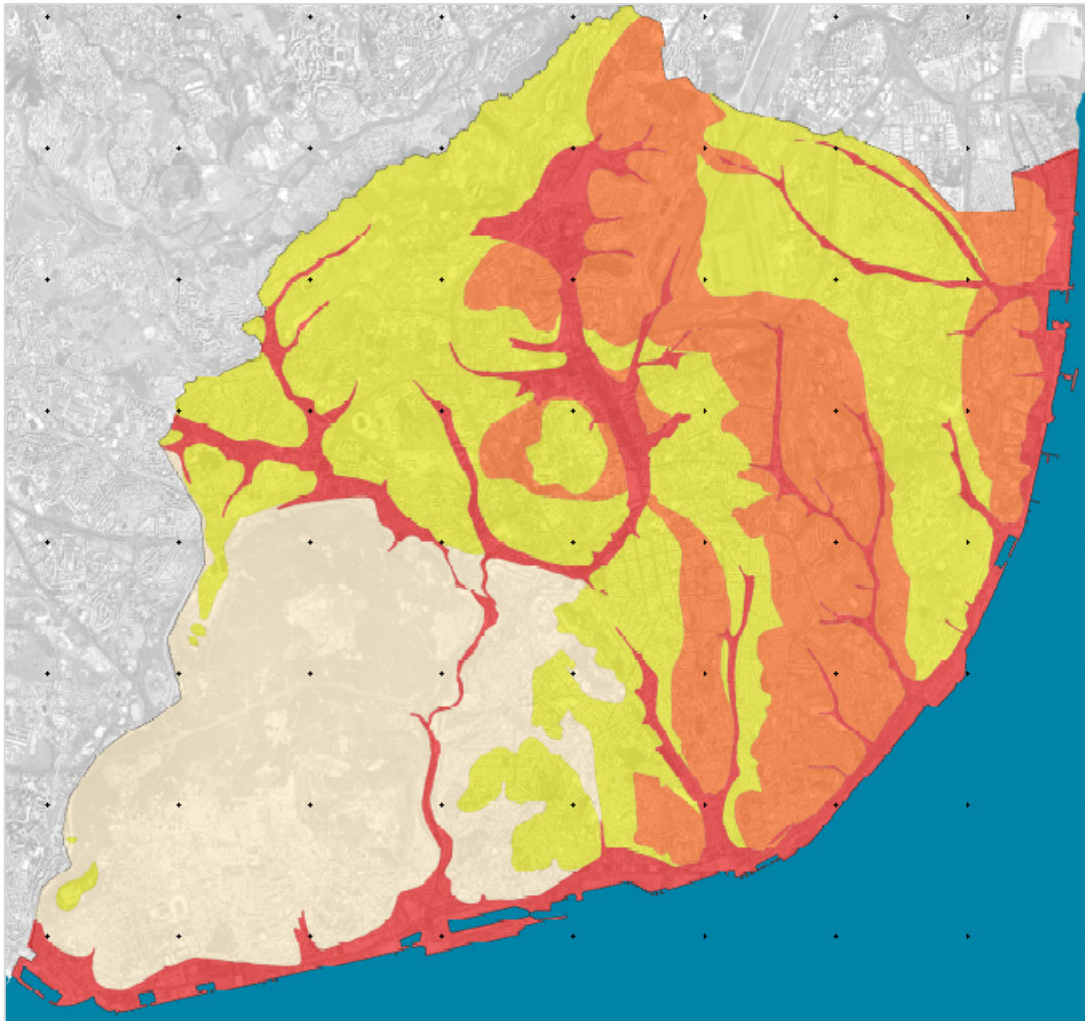


Figure 11 – Solis Seismic Vulnerability (increasing from yellow to red)

However we consider that this knowledge could be enhanced using geological and geotechnical data in order to produce micro-zonation studies. These studies are on course.

4. Subsurface information for Lisbon

4.1. GeoSIG Project

The expansion of the urban area in Lisbon, which has occurred since the last decades of the 19th century, allows the gathering of a huge volume of geological and geotechnical data usually only available in analogue format and with no internal standardization.

Taking into account the importance of this information, Lisbon Municipality initiated in 1999, in collaboration with the Lisbon Faculty of Sciences, a project aiming towards establishing a geotechnical database.

This on-going collaboration continues and in 2008 a new research project has begun, aiming towards the management of the existing information, using as basic element the Lisbon geological map and upgrading the geotechnical database.

Due to the potential of the geological / geotechnical information in Urban and Planning Management, Lisbon Municipality plans to upgrade the existing mapping and improve the tools available – Maps and Regulation.

In January 2015, Lisbon has received funding to start the GeoSIG Project - Geotechnical mapping in urban areas, which includes multiple objectives, including the development of a platform that could represent the location and the results obtained from geological and geotechnical surveys (figure 12).



Figure 12 – GeoSIG Platform

At this time about 900 reports were introduced corresponding to about 5000 geotechnical boreholes (figure 13). However many reports are in Lisbon Municipality archives.

The information obtained from these data will allow an unequalled knowledge about Lisbon subsurface.

4.2. Geological and Geotechnical Modeling

Using data from the geotechnical database, some models were developed using geotechnical parameters.

In order to evaluate the mechanical strength of different geological strata to support buildings foundations, SPT values were modeled at different depths (figure 14).

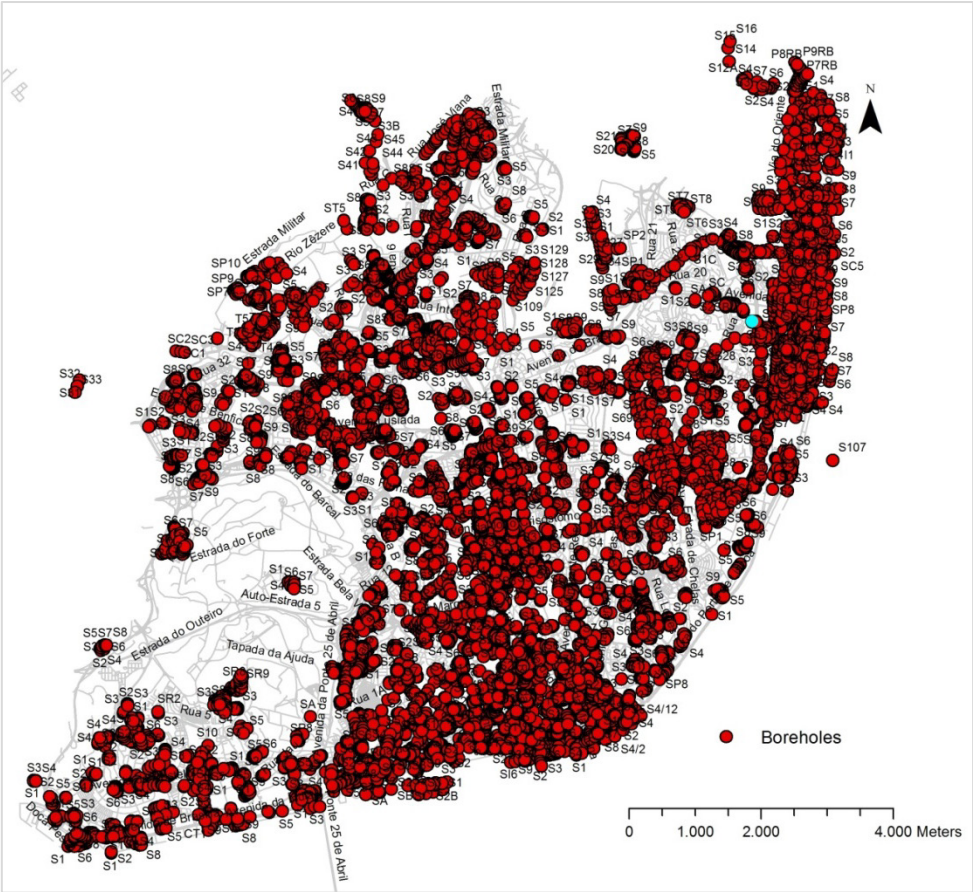


Figure 13 – Location of the boreholes – Lisbon city

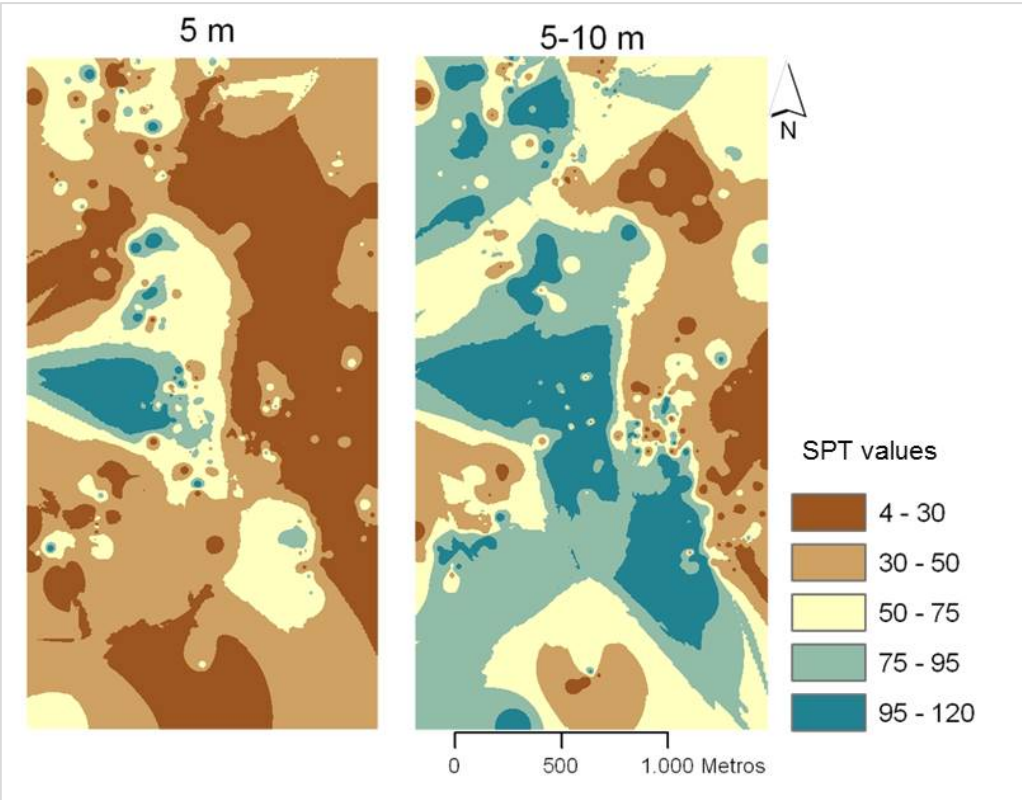


Figure 14 – SPT values at different depths

Also using geological and geotechnical data, a 3D model was developed to Expo 98 area (figure 15).

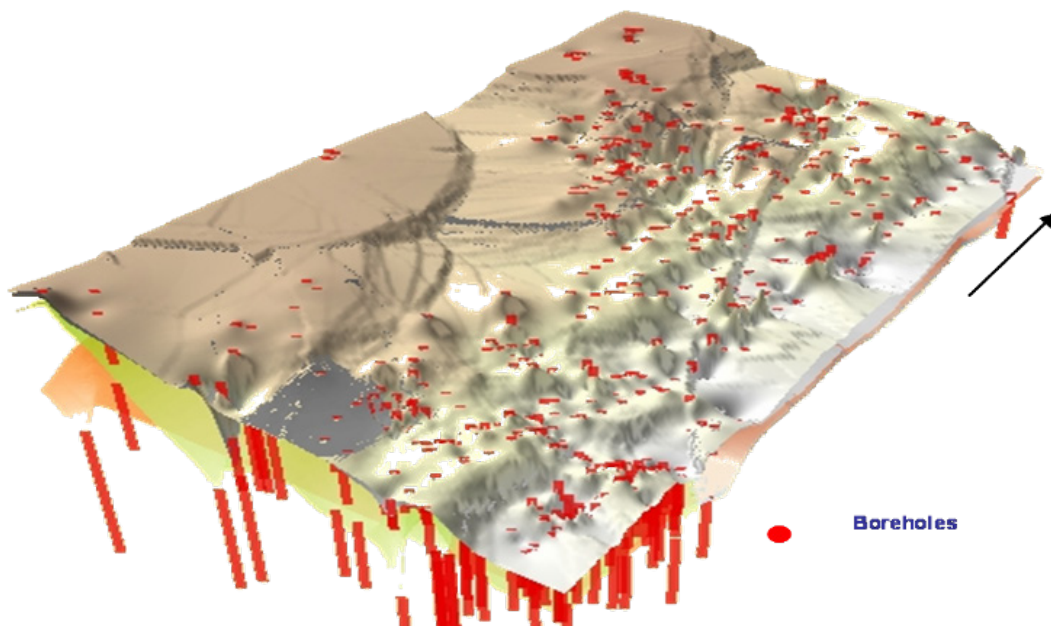


Figure 15 – 3D Model of Expo. The figure exhibit the morphology of the area

Conceptually the model will be developed according to the next schema (figure 16).

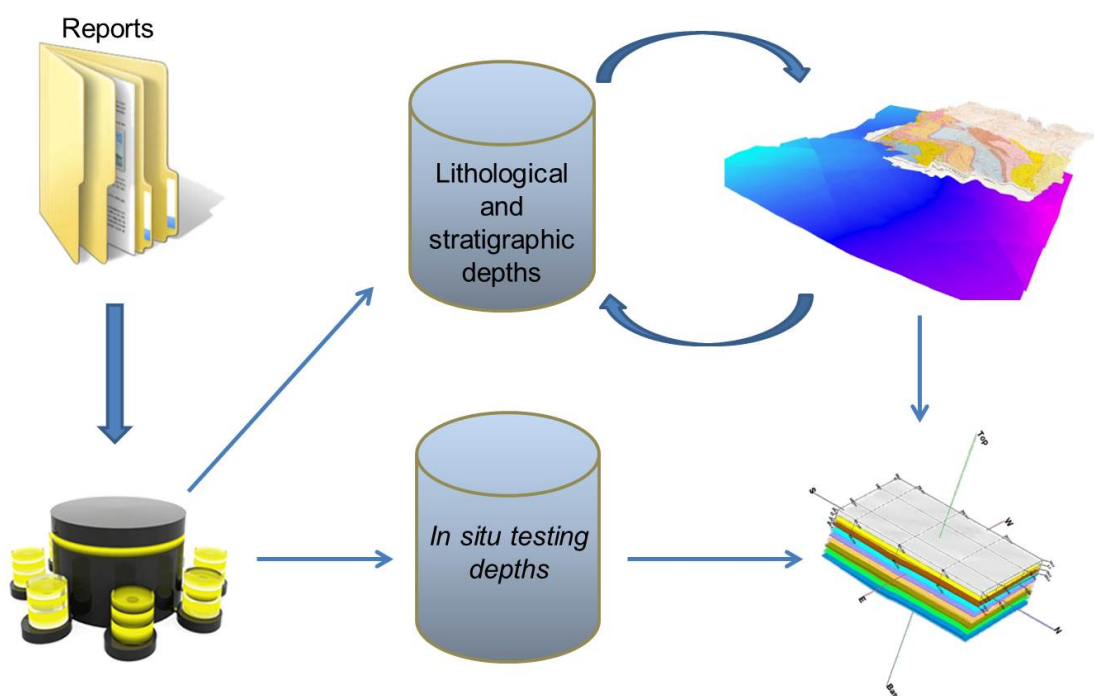


Figure 16 – Geological and geotechnical conceptual model phases

The information provided by the geological reports will be introduced in the database. Through several processes it will integrate data from lithological and stratigraphic depths in order to produce the geological model.

This model will also enable the upgrade of the information concerning to the lithology and stratigraphy.

Crossing this model with geotechnical parameters obtained during *in situ* testing, will make us able to produce a geotechnical model to Lisbon city.

At a minor scale we will apply this information in decision support aiming on an efficient territory management.

The joint effort of data standardization will allow data transfer between companies and planners, which in a nearby future, will consist of a simple and useful sharing of information.

5. Urban Planning and management

5.1. The Lisbon Master Plan (Master Plan 2012-2022)

Lisbon Master Plan (PDML), published on 30th August 2012, is a territorial planning instrument, mandatory to all public entities and private contractors, covering all municipal territory. It establishes a spatial organizational model and development strategy, urban policies and orientations to the municipal territory, soil classification and the rules and parameters to its occupation, use and transformation.

Looking back to the 1994 Master Plan, this new Master Plan represents a turning moment to the city planning. With 84% of its territory consolidated and facing a crises period, new challenges arise as how to turn Lisbon into a better and more efficient city and how to establish objectives and priorities to the city in an uncertain context.

The new Master Plan is the plan of the three R's: Reuse, Rehabilitation and Regeneration – to do more with less. It defines the development strategies, orientation and urban policies to the municipal territory, in seven major goals:

- attract more inhabitants, bringing back to the city lost residents;
- attract more business and more jobs;
- qualify public spaces;
- encourage urban rehabilitation, in priority intervention areas;
- bring back the riverfront to the population;
- increase sustainable mobility;
- promote environmental efficiency.

Add to all this, the Government's priority to bring the city and its citizens closer to the institutional power, by establishing new channels of communication, reducing bureaucracy and expedite decision processes.

5.2. Subsurface information in planning and development

In 1994, the PDML did not take into account the importance of geology, subsurface environment and resources in its planning policy.

As an increasingly awareness of the importance of these matters, the new PDML integrates initiatives and measures, through the maintenance of natural systems to promote mitigation and to reduce the vulnerability of natural and human systems against the effects from: natural hazards (floods, landslides, soils seismic vulnerability), soils contamination and climate changes, actual or expected, with the implementation of complementary solutions, for example by creating a Green Structure based on continuous green corridors, and intervention in risk areas.

The reinforcement of the city's resilience will also turns it into a more environmentally sustainable city.

The PDML also introduces several new concepts, patent in Maps and Regulation (for example figure 17), such as "Geomonuments", "Hydro mineral Occurrences", "Pluvial Water Storage Structures", "Susceptibility to Landslide", "Flood and Tidal Effect Vulnerability", "Soils Seismic Vulnerability", "Permeability index", "Soil Permeability", "Vegetal Pondered Surface", "Hydrogeology Characterization Data" and "Hydrogeology Studies", among others, aiming towards the preservation and conservation of natural heritage and environmental resources and values.

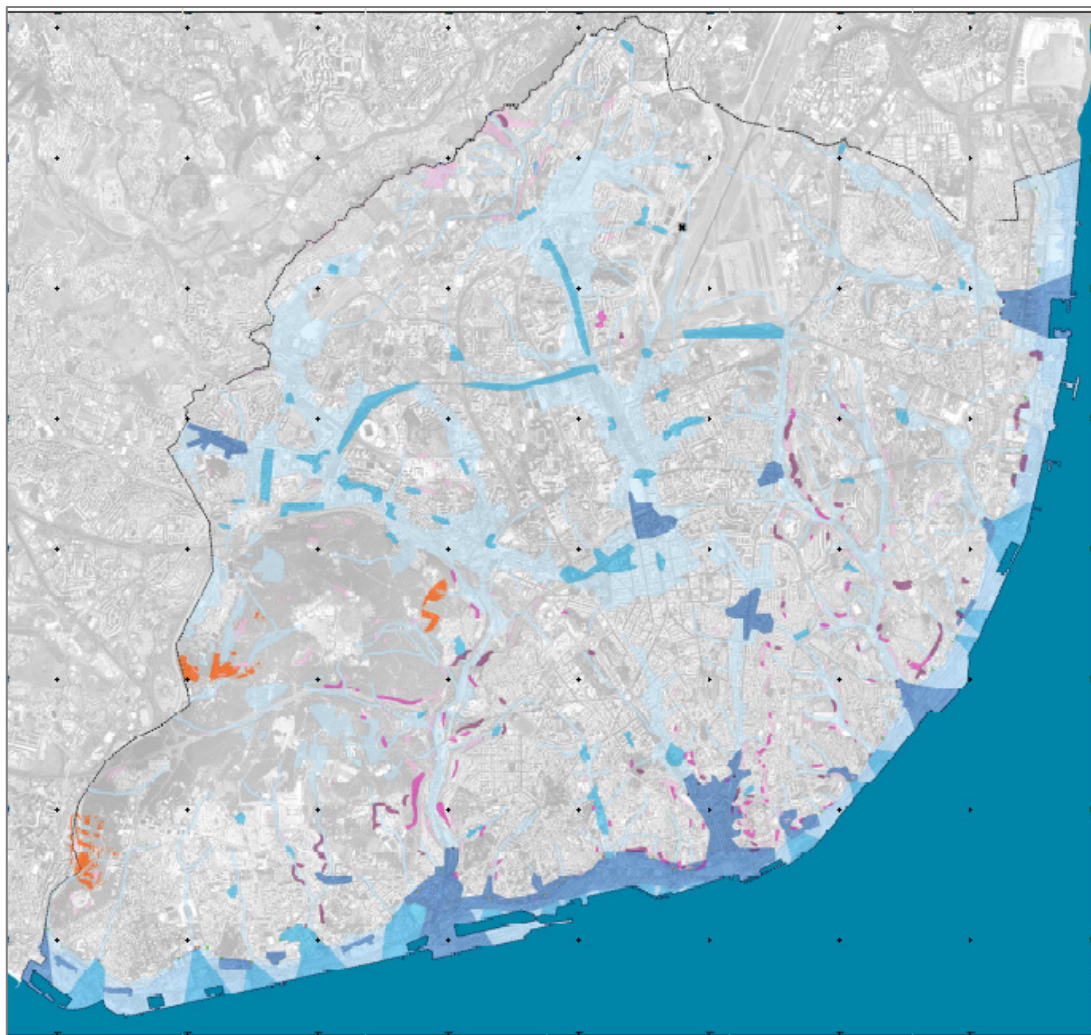


Figure 17 – Natural and Anthropogenic Hazards I - (blue – Flood Vulnerability classes; pink – Landslides Susceptibility classes; orange: fire vulnerability classes)

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