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REGENERATION AND RESILIENCE PROCESS IN AN URBAN AREA

THE BELLAS ARTES DISTRIC OF CARACAS

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A Neida y Salomón,
mi amá y mi apá.

A Leo,
por creer en mi.

"..., en fin, en Venezuela hay que inventarlo todo ¡Qué maravilla!

Ciudad de Panamá, abril 2017"

Carlos Cruz-Diez

Summary

Urban resilience - defined as the ability to positively adapt to stresses and trasform towards sustainability - has been receiving increasing attention in recent years. It focuses mainly on three different kinds of risks, depending on climate change, natural disasters and terrorism. In this thesis we analyze the resilience of an urban area surrounding the Anauco river in Caracas, Venezuela, focusing on the first two kinds of hazards. The Anauco river is currently buried down, representing a threat during the periodical floods that afflict the city. It is also the central element of an abandoned neighborhood filled with slums, and a hotbed of delinquency. The main problems of the 1970s project, that included Anauco's channeling, are poor planning towards future events, and the lack of an organic design. We propose an architectural project that could make the area resilient through the daylighting of the Anauco river. We also analyze the urban, financial and social opportunities deriving from a wider requalification project including the edification of an urban market area.

CONTENT

Chapter I

INTRODUCTION

This chapter provides the context and rationale behind the idea of this thesis work, its contribution with an overview about state-of-the-art literature, and a brief description of the designed solution.

The concepts and techniques introduced in this chapter will be illustrated more in depth in the following ones, briefly described in the “Roadmap” section.

Context and motivation

Caracas, capital of Venezuela, is located along the Guaire river in the northern part of the country. It lies on the Ávila mountain between 760 and 1140 m a.s.l. and has an estimated population of around 3 million inhabitants. Despite the architectural avant-garde of some districts, the city shows signs of urban and social decay. Some of its areas are periodically afflicted by floods whose aftermath is exarcebated by poor design choices in the management of the water system. In fact, rivers are of paramount importance for Caracas. Its stream system is formed by twelve main waterways flowing North to South, from the Ávila to the Guaire. Rivers have always been fundamental in the development and expansion of the city. In particular, during the last 50 years, they have been channeled to obtain new building areas that could respond to the rapid growth the city was experiencing. Occupation of the areas surrounding the buried streams, modifications in the permeability of soil, and lack of maintenance, transformed the channeled rivers to liabilities.

Resilience is a modern approach for planning and reshaping urban spaces so that they can expand and face adverse events, while mitigating the associated risks. There exist a number of possibilities to ensure resilience. In the context of flood mitigation, green and blue infrastructure design is the most widely applied technique. Daylighting instead involves the removal of the superstructures covering the stream, returning it to its natural state.

In this thesis, we examine the case of the Anauco river, originating in the Cordillera de la Costa, 1897 m a.s.l.. Most part of the river, comprised between the Avenida Pantéon and the Avenida México, was channeled during the 1970s modernization effort to create new residential areas and to build the subway, and supports the Paseo Anauco, a pedestrian boulevard. The lack of an organic planning lead to the decay of the surrounding area, now filled with slums, and a hotbed of delinquency. From an environmental point of view, any concern about potential future natural disasters was made. The poor maintenance during the latest decades, caused the partial obstruction of the buried pipe, which instead of draining excess rainwater, makes floods even more destructive.

Limitations of the study

This thesis work is subject to some limitations. The available bibliography is not extensive and in some cases it is outdated. In particular, the hydrogeological studies are not updated or they are only available on-site. The current political and economical situation of Venezuela does not allow direct access to the area subject to this requalification study, nor to potentially useful official documentation.

Therefore, in the grey infrastructure analysis, we did not use GIS tools, that would need the unavailable data, but alternative software in order to compute quantitative parameters (area of the river bed, length, flow, slope) with some approximation.

Objectives

_ Understanding the interconnections between Caracas' urban development and the natural context in which the city evolved since its foundation.

_ Analyzing Caracas' stream system, focusing on the Anauco river as a case study to describe the current setting and the urban and environmental issues around it.

_ Assessing and verifying the risks posed by the Anauco river to the urban context in which it flows, and proposing a risk-mitigation plan based on the concepts of urban resilience.

_ Studying the Anauco river as a significant part of the urban context in the city of Caracas, and evaluating the application of urban resilience concepts in the realization of a requalification project of the affected area.

_ Realizing an architectural project proposing the reintrepretation of an already-existing open market in the Bellas Artes neighbourhood, taking into account the analysis of environmental and urban peculiarities.

Roadmap

Chapter 2 - Resilience process offers an introduction about resilience in urban requalification, especially in response to floods.

Chapter 3 - Caracas illustrates the history and development of the city, focusing on its tight relationship with the valley it resides in.

Chapter 4 - **Caracas, ciudad de las aguas** analyzes the hydraulic system of the city and makes an account of the latest extraordinary flooding events and their consequences.

Chapter 5 - A case study: the Anauco stream assesses the risks posed by the river, analyzes its grey infrastructure and proposes a resilience-oriented urban project composed by blue infrastracture, green infrastructure, and daylighting of the Anauco.

Chapter 6 - **Design explorations** focuses on a smaller area, with the requalification of an already-existen open market, in attempt to redevelop and reconnect the site to the rest of the urban fabric.

Chapters 7 - Conclusions summarizes the problem, the achievements and the flaws of the implemented solution, and proposes a possible scenario for future developments.

Chapter II

RESILIENCE PROCESS

In the past, urban projects often did not take into account the peculiar context in which they were realized, thus becoming inappropriate to the continuous transformation of the urban landscape. Nowadays, local characteristics, needs, and prospective evolutions are an integral part of the whole architectural design process. Among the main concerns, the environmental one is of primary importance. Climate change, in fact, heavily shapes our way of life and the development of cities. Rising temperatures, due to heat islands, and pollution, partly due to the lack of sustainable mobility plans, impact the quality of life on a short-term basis, and feed themselves causing worse disasters on a longer scale. In turn, natural disasters, such as floods, periodically destroy human lives, activities, and urban settlements. Thus present-day urban projects are required the ethical responsibility of working on a multi-scale perspective, keeping in consideration the countless subtle interactions occurring in a complex metropolitan environment.

The resilience concept includes the characteristics described above for a multi-scale project. They provide a potentially complex system, such as a city, the ability to receive internal and external abuses without a suffering complete failure.

Resilience

In general terms, the concept of resilience refers to the capacity of a system or organism to assume flexibility in certain extreme situations and overcome them. Crawford Holling in 1973 developed the term of resilience for ecosystems as “complex systems that have a tendency to instability” and how they have the ability to absorb changes and endure.

Since then, the term has been applied to a number of different fields, among these urban planning and architecture.

According to UN-Habitat - the United Nations programme working towards a better urban future, whose mission is to promote socially and environmentally sustainable human settlements development and the achievement of adequate shelter for all-resilience refers to the ability of any urban system to maintain continuity through all shocks and stresses while positively adapting and transforming towards sustainability. Therefore, a resilient city is one that assesses, plans and acts to prepare for and respond to all hazards, either sudden or slow-onset, expected or unexpected. By doing so, cities are better able to protect and enhance people’s lives, secure development gains, foster and investible environment and drive positive change. (UN-Habitat, 2018)

According to Pollo (2015) the concept of resilience can be illustrated through two main concepts, mitigation and adaptation, both referring to a global scale. Mitigation of the effects of climate change is tightly related to the concept of adaptation, since strategies that allow coexisting with the effects of climate change and avoid even more catastrophic scenarios are needed.

Resilience and the urban requalification

Green infrastructure and resilient landscapes

A green infrastructure is an integrated system composed by urban parks and natural areas, green boulevards, greenways, sustainable mobility, and in general all those elements that can make life in a city sustainable.

Green infrastructures have their bases in a multi-scale approach with attention to the analysis of ecological and cultural patterns, and

LOOKING AROUND

Green Infrastructure

by Edward T. McMahon

Does your community have a long-range transportation plan? How about a plan to upgrade and expand the airport, sewage treatment plant, storm water facilities, fiber optics cables, or other community utilities? Most growing communities have such plans, but many of these same communities have no plan to preserve their essential life sustaining natural infrastructure.

Webster’s *New World Dictionary* defines infrastructure as “the substructure or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends.”

Just as growing communities need to upgrade and expand their gray infrastructure (i.e. roads, sewers, utilities), so too, they need to upgrade and expand their “green” infrastructure – the network of open space, woodlands, wildlife habitat, parks and other natural areas, which sustain clean air, water, and natural resources and enrich their citizens’ quality of life.

According to Charles Little, author of *Greenways for America*, the concept of green infrastructure began 130 years ago with Frederick Law Olmsted, Sr., the designer of New York’s Central Park as well as Boston’s Emerald Necklace. “No single park,” Olmsted believed, “would provide people with all the beneficial influences of nature.” Instead, parks should be linked to one another and to surrounding residential neighborhoods.

Likewise, more than 60 years ago the South African Wildlife Society recognized the importance of connections to maintaining the continent’s wildlife. By the 1960’s, U.S. ecologists had become believers in the need to create an “integrated conservation system” that protects wildlife while maintaining natural landscape processes.

Both of these concepts – Olmsted’s linking chains of parks, and ecologists’ linking conservation areas to counter habitat fragmentation – have come together in planning for systems of green space.

In recent years, there has been a growing awareness by local and state governments of the need to plan for green infrastructure. In his Inaugural Address in January 1999, Maryland Governor Paris Glendening said, “Just as we must carefully plan for and invest in our capital infrastructure – our roads, bridges and waterlines, we must also invest in our environmental or green infrastructure – our forests, woodlands, streams and rivers. Just as we must carefully plan for and invest in our human infrastructure – education, health services, care for the elderly and disabled – we must also invest in our green infrastructure.”

The concept of green infrastructure represents a dramatic shift in the way local and state governments think about green space. In the past, many communities assumed that open space was land that had simply not been developed yet, because no one had filed a subdivision plan for it. This view was reinforced by the legal and philosophical framework of our land use system which assumed that land was a commodity to be consumed.

Communities that planned for open space primarily thought about preserving land for parks. And these parks were often viewed as a community amenity, an extra, even a frill. Likewise, until recent years, most open space preservation efforts were site-specific in their orientation: develop a park here, protect a natural area there. Today, however, a growing number of communities are recognizing not just that green space is a basic community necessity, but that it should be planned and developed as an integrated system.[1]

TRENDS INFLUENCING THE PROCESS

What are some of the trends that are causing this shift to a systematic, green infrastructure approach to open space planning?

Greenways can give kids a safe place to walk or ride a bike.

• **Landscape Fragmentation** – Increased urban sprawl has caused the rapid fragmentation of land, particularly on the fringes of major metropolitan areas. Citizens have reacted to this trend by demanding that policymakers take steps to preserve open space and channel growth.[2]

• **Federal Water Quality Mandates** – Clean water standards mean that natural drainage systems have become more important as urban waterways and wetlands are protected.

1 In 1991, the National Recreation and Park Association joined forces with the American Academy for Park and Recreation Administration to publish *Park, Recreation, Open Space and Greenway Guidelines*. The report noted that economic, demographic, technological and development trends over the past decade had profound implications for open space planning – and required a change in “our entire philosophy of planning for parks and open space” to encompass a “systems approach.”

2 According to the U.S. Department of Agriculture’s recently released *1997 National Resources Inventory*, the loss of farmland and other open space to development has more than doubled in recent years. Between 1992 and 1997, the rate of loss grew to 3.2 million acres a year.

PLANNING COMMISSIONERS JOURNAL / NUMBER 37 / WINTER 2000

Fig. 01. Planning commissioners journal / nunmer 37
Winter 2000 . Pag. 1.

processes, expressed in urban units – preexisting neighborhoods, quarters, and similar areas - and conforming to the landscape mosaic (Forman, 1995).

According to Moreno (2013), the concept of green infrastructure should be developed through “a strategic approach for the conservation of the landscape and its components of natural and cultural value”, taking into consideration that this approach must be within the framework of sustainable plans initiatives for the improvement of the territory. Therefore, the impacts generated by urban expansions, substitution of soils, ecological fragmentation and destruction of habitats must be considered (McMahon, 2000).

Green infrastructures and resilient landscapes are tightly related. Moreno (2013) names two concepts, linked to the need of establishing planning strategies that could address resilience management in the territorial urban context, being able to generate different opportunities for social, cultural and economic development at the local level. The first concept is competitiveness, thought from a systemic point of view, to give strategic functions to certain nodes and to territorial actors able to establish differentiation and specialization actions, in a direct relation with common objectives at a communal, regional and national level. The other concept is solidarity, based on the relationships between actors and components at a geographical and functional level, above all the capability they have of establishing exchange networks in order to build a dynamic matrix of diverse elements.

What does a green infrastructure look like?

According to McMahon and Benedict (2001), “green infrastructure encompasses a wide variety of natural and restored native ecosystems and landscape features that make up a system of “hubs” and “links”.”

This representation can be seen in the graph by Florida Greenways Commission (fig. 2).

Hubs are the main part of green infrastructure networks, representing the origin or destination for wildlife and ecological processes. Hubs can be of any kind and dimension, for example reserves, managed native landscapes, working lands, regional parks and preserves, community parks and natural areas. Community parks and natural areas, smaller parks where natural and ecological processes are protected or restored, are important because they are situated in urban contexts.

Links are the connecting elements of the system and allow the green infrastructure to function. They can be different in dimension, function and ownership; for example landscape linkages, conservation corridors, greenways, greenbelts and ecobelts. Conservation corridors are linear protected areas, as rivers or stream corridors, which act as biological ducts for wildlife. They may also provide recreational opportunities.

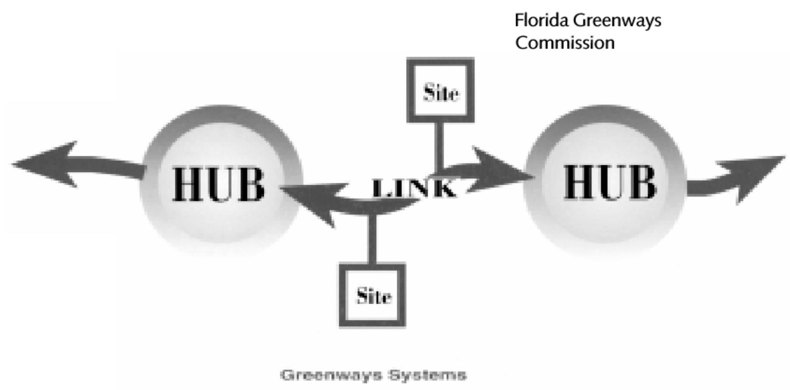


Fig. 02. Florida Greenways Commission (1995).

Analysis at multiple scales and green infrastructure

A multi-scale analysis is necessary for a green infrastructure development and action plan, which identifies and analyses urban gaps focusing on their potentials for integration and connection (Forman, 1995).

The Green Infrastructure approach has a fractal structure, with elements from the continental scale, as large transnational corridors, that contribute to guarantee the conservation of the species favouring long-term genetic flows, to smaller elements that have a value for biodiversity and the provision of ecosystem services at the local scale. A Green Infrastructure is a very effective management tool performing several functions at various scales, considering and integrating the multiple connections and interactions that are essential in the environment. This multi-scale structure must be reflected in the design and conception of the Green Infrastructure as an ecologically coherent network, and implies the search for an articulation between the different actors and levels of competencies that overlap in the territory.

The analysis, thus, seeks to configure the green infrastructure as an articulated network that guarantees the provision of ecological, cultural, social and/or aesthetic services that contribute to the resilience of life systems and the general well-being of people, communities and economies (Moreno, 2013). Identifying and analysing different open spaces of the territory as urban green areas, wild areas, productive areas, water corridors, brownfields, borders and risk areas, highlights their potential connectivity and complementarity with different functions at different scales. In fact, according to Lovell and Taylor, the essence of a Green Infrastructure is its multifunctionality. It can meet multiple needs simultaneously: ecological, productive (economical) and cultural functions, but unlike the concept of sustainability, this concept is a sum of functions and not their intersection.

Re-naturalization

Re-naturalization is an important part in the realization of a green infrastructure, through the reuse of man-made spaces, such as abandoned areas, industrial sites, or parking lots.

> *This term is at present used in the spheres of urbanism, architecture and nature conservation. “Re-naturalization” (or ecological restoration when it is planned), is a process of modification of a portion of space, a built-up area, a block, a quarter, a plot, a landscape or a territory, via the extension of occupation by natural elements – flora, fauna, surface water flows, morpho-dynamic activity etc. This mutation can, however take on different forms. (Pech, 2004)*

Pech refers to how the process is realized through mutations, naming two cases. The first one, where the Re-naturalization happens through a natural ecologic process after a previous artificialization phase. For example, as it occurs on abandoned plots of land which begin to re-naturalize by themselves after years of abandonment. On the second case, more common in urban environments, renaturalization tends to be based on the use of nature as a decorative element that is also functional to the urban system. Pech claims that spontaneously re-naturalized spaces, can be sources of tensions on the urban environment, mainly because they could foster the return of wild animal species.

In urban settings, spontaneous Re-naturalization occurs in abandoned spaces, or in areas that could lead to a great impact on the context, where spatial ordering policies have been developed and adapted to the characteristics of each place. In both cases for urban areas, Pech mentions that “Re-naturalization is written in a project”.

In urban areas or in industrial wastelands, spontaneous Re-naturalization is increasingly seen as the creator of new ecosystems, interpreted as islands of biodiversity in the urban fabric (Muratet et al., 2007). In most cases, the processes of re-naturalization are carried out without ties to the natural geographical context, thus leaving the newly created areas without autonomy, and generating high maintenance costs.

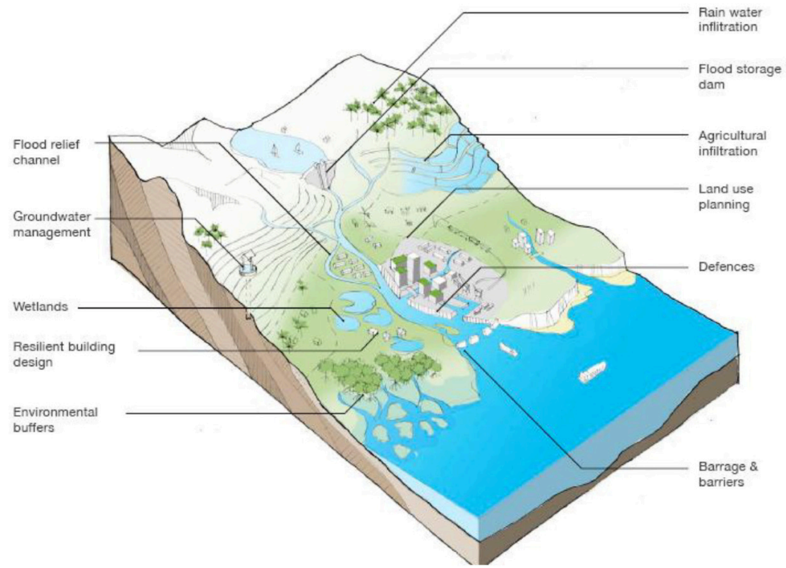
The counterpart presented by Pech is in the framework of a sustainable urbanism, where “the sustainable city must integrate nature by defining naturalness as the capacity of a mean of self-sustaining, thanks to a biodiversity of natural cycles”. This may justify that re-naturalization processes in a city can provide the so-called “eco-systemic services” (“eco-systemic” usefulness), for example, reduction of floods by drainage, reduction of heat island phenomena, urban dust capture in the vegetable coverage. Re-naturalization in city can also impact the social sphere, creating through the re-natured spaces a series of exchange opportunities between different urban realities.

Resilience in flood management

Risk and resilience concepts

All the different definitions of risk can be characterized by some common aspects: the uncertainty of future, its potential impact or its perceived value, and the relation to a preferred outcome. The concept of resilience is strongly related to risk, because it measures the capacity of a system for “bouncing back” to an equilibrium, or its robustness before it is forced from a stable equilibrium to another. The relation between risk and resilience is important from the sustainable development point of view.

Thus, resilience is the ability to develop along a preferred trajectory, defined in accordance to human values and expectations. Plans for the future use of urban areas may span over a long-term period of time, during which the city changes continuously. Resilience becomes one of the main characteristics of a city if it is able to anticipate, recognize, adapt and learn from previous disturbances, changes and disasters.



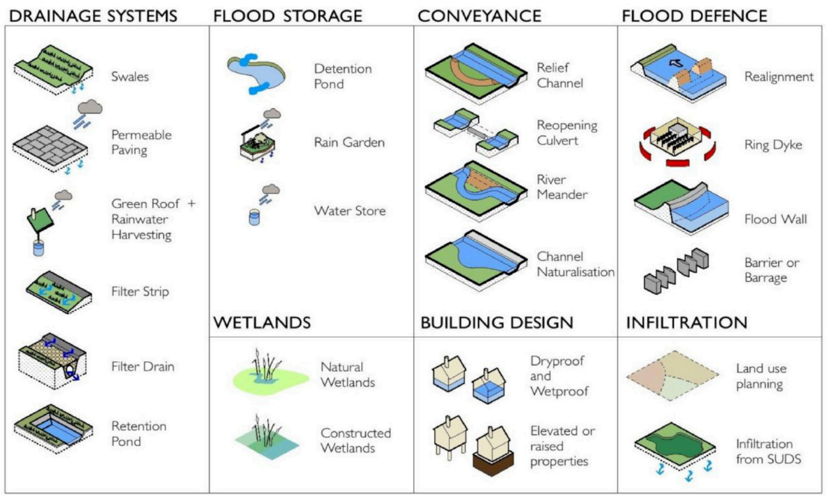


Fig. 03. BACA Architects

In conclusion, sustainable development means risk management, and resilience is the ability to do so in a complex and dynamic context.

Flood resilience and strategies

Flood management aims to evaluate and minimize flooding risk and to prepare a fast recovery with the lowest disturbance and cost possible.

Long-term strategies are needed for a cost-effective and rapid flood management. The objective is a quick recovery and restoration to good living conditions. Sustainability is important from an economical as well as a social and environmental point of view. Climate change is becoming a threat to many cities, which according to the European Flood Directive ratified in 2007 after a series of disastrous floods, should immediately act in order to prevent economic damages and to avoid an increase of dangerous events for citizens. Cities should not wait for a large-scale catastrophe or flood event: the creation of resilient cities is a long-term process and should not be based only on recent experience.

Traditional urban drainage systems are designed for 10-year recurrence period rainfalls, to avoid huge dimensions of the pipes they rely on. Bigger events are deliberately allowed to happen with selected areas inundations. Even with 100-year recurrence period rainfall, the probability of exceeding critical conditions during a 50-year period is 40% (Sörensen, 2016) . The European Flood Directive highlights that risk of failure is always non-negligible, independently from the chosen period.

Green-blue city concept

In the most recent years, climate change has caused an increased risk of flooding, especially in the cities. Flooding can impact the social, economic and environmental systems. Nowadays, in many cities the proportion of areas with flood risk is high. Increasing frequency

and magnitudes of intense precipitation events in future decades are predicted to increase flooding and damages incurred. Cities with a high range of urbanisation and economic growth have problematic areas where the consequences of flooding are especially severe. Thus, there is a demand for new and innovative research that can help reduce the probability and/or consequences of urban flooding while helping cities become more resilient and able to adapt to new flood risks imposed by climate change (Wilby, 2012).

Innovative methods for flood risk management aim to reduce the use of already existent drainage systems, the so-called “grey infrastructures”, by using natural measures. These integrate the natural water cycle with urban design and development needs, taking also into account the consequences of climate change. The grey infrastructure has a reduced adaptability to such consequences, and it does not consider the natural water cycle. The novel Blue-Green proposal instead is a water-sensitive urban design approach (Lawson, 2014), trying to adopt a holistic point of view. Water-sensitive urban design is defined through the integration of different disciplines of engineering and environmental sciences with urban design.

The blue-green infrastructure

A Blue-green city aims to recreate a naturally oriented water cycle while contributing to the amenity of the city by bringing water management and green infrastructure together (Lawson, 2014). The hydrological and ecological assets of the urban landscape can represent a novel tool to deal with flood events. Taking advantage of the hydro-geological features of an anthropized area to limit and prevent adverse events, leads to the creation of a blue-green infrastructure.

Blue-green cities may generate a multitude of environmental, ecological, socio-cultural and economic benefits when the urban system is in both flood and non-flood state. With a correct design, a system of blue-green infrastructure can reduce the risk of surface water inundation during a flood event, in addition to being cheaper than conventional infrastructures. In a non-flood state, a blue-green infrastructure can bring different environmental benefits including reduction in the urban heat island.

Blue-green infrastructures can also contribute to the ability of cities to mitigate and adapt to climate changes, and is frequently a key component of economic regeneration projects to improve the liveability of urban environments.

Daylighting

The development of urban areas with the construction of new buildings, parking lots, roadways and similar infrastructures, often requires the redirection of waterways in order to gain buildable surface area. In attempt to protect such areas from flooding, the redirected streams are then covered or buried, and channeled into artificial drainage systems.

These modifications can cause unintentional environmental consequences, such as the degradation of surrounding habitats, and above all an increased risk of flooding of downstream regions.

The process of removing the superstructures covering the stream, and returning it to its original state, is called daylighting. Besides the aesthetic advantages, the re-established river provides significant economic and environmental co-benefits, such as channeling the accumulated rainwater to provide flood management.

Also, downstream flooding can be greatly reduced thanks to daylighting. In fact, it makes available a larger area for the water to flow, thus increasing the duration of the event and reducing peak flows during floodings. With the daylighting process, also choke points can be eliminated, where streams were forced into underground channels.

Siting considerations and costs

The first problem to be taken into account before starting a daylighting project, is whether or not there is enough room for the channel, that has to be wider than the buried one to guarantee a natural and stable flow.

Existing infrastructures, buildings and underground utility lines might be challenging, especially in dense urban areas, for the construction of a channel. In fact, the cost of moving them is very high, pushing towards the realization of larger revitalization projects that include daylighting. The renewed area can then be capitalized on, thanks to the daylighted stream and the amenities it creates.

A second problem concerns soil type and channel materials: the cost of a properly designed daylighting project depends greatly on them.

The removal of the pipes for waste water is a very complex and labour-intensive work. It requires expensive and heavy equipment, and skilled experts in a wide range of fields, such as engineering, landscape design, earthmoving, and hydraulics. A 2000 study by the Rocky Mountain Institute (Pinkkhan, 2000) estimates a cost of around 3000 EUR per meter of daylighted stream, setting the cost of an average daylighting project upwards of 300000 EUR. Although costs might be reduced through donations and volunteer labor for some of the tasks, state funding is fundamental.

Besides the initial construction costs, also maintenance is to be considered. During the first years following the daylighting process, in fact, the channel and bank need lots of maintenance before they become stable. Therefore, budgeting for personnel and additional plants is fundamental during this phase, but the costs become significantly lower in after years.

Co-benefits of the strategy

Once a buried stream is daylighted, it transforms from a liability into an asset. The financial and social opportunities are countless, from setting amenities for recreational and physical activities, to moving freights, thus increasing the value of the surrounding areas. From an environmental point of view, open streams are very useful in lowering the level of pollutants, such as excess nitrogen and phosphorus. This helps creating a better habitat for fish and improves the quality of drinking water. The sewage system gets some relief thanks to open rivers, that can divert stormwater and store floodwater. Moreover, the costs required by these benefits are lower than those needed to maintain traditional grey infrastructures, such as culverts.

The Cheonggyecheon river: a case study

A striking example of daylighting, leading to the transformation of a large section of the city, is the one involving the Cheonggyecheon stream in Seoul. The 2010 project consisted in the restoration of the buried waterway to a more natural state, with the removal of a highway and the creation of a linear park. Construction works lasted 5 years, over a 0.5 Km^2 area in Seoul's central business district, which prior to the daylighting used to be bisected by the aging elevated highway, with the river buried under the street level. The linear park on both sides of the restored river alternates natural landscaping to highly designed sections, that daily attract thousans of visitors and raised property values. Besides the economical effects, the park drew also a number of environmental benefits. It reduced pollution, helped lowering summer temperatures with respect to adjacent neighborhoods, and increased biodiversity.

The case study analyzed in this thesis is the Anauco river in Caracas, one of the most important waterways in the city, comparable to the

Fig. 04. Cheonggyecheon river transformation. Online source: www.onuhabitat.org.mx

Cheonggyecheon river in many ways. It is buried underground, with a pedestrian street above (the Cheonggyecheon used to be buried beneath an automobile artery, because of the larger riverbed), in a similarly dense urban area. The surroundings of the Anauco river show the same urban decay as in the Seoul case, despite the fact that it flows through a more peripheral area of the city. Thus, a similar project might bring the same benefits and prosperity to the capital of Venezuela, together with the control and mitigation of the periodical floodings that damage the area where the Anauco flows.

Fig. 05. The restored Cheonggyecheon stream.
Photograph: Jack Malipan Travel Photography/Alamy.
The Guardian.

Fig. 06. A girl playing in the waters of the Cheonggyecheon stream in downtown Seoul. Photograph: Park Ji-Hwan/AFP/Getty Images.
The Guardian.

Chapter III. CARACAS

Valley and city

Caracas valley belongs to the Coastal Mountain Range and is approximately 15 km away from the Caribbean Sea, separated from it by the Ávila National Park . The city is embedded within the valley and traversed by the Guaire river, which is almost 35 km long. The city is constituted by five municipalities which, in turn, are part of two different federal entities, Capital District (Libertador Municipality) and Miranda State (Baruta, Chacao, El Hatillo, and Sucre Municipalities). All these municipalities make up the Metropolitan Area of Caracas. The city spreads through narrow hills and valleys, connected by mountain passes and a complex water system. The rivers, having their heads at the Ávila and disgorging into the Guaire river, develop a "structured system based on axes spreading in North-South direction" (Sansone, 2013) which are distributed through the whole city. The valley, small and irregular, covers an area of 833 Km^2, and has a variable altitude between 870 and 1043 m a.s.l. in the urban area, and around 900 m a.s.l. in the historic quarter.

There is a close relationship between the structure of the city and the environment. In an article published in 2011, Antonio de Lisio provides "historical series to allow the interpretation of development and evolution of the interrelation between the built environment and the natural one" which show that Caracas has its own peculiar conditions, which have codified its evolution and urban development.

According to De Lisio, the explanation of how a city has occupied its geographical framework may be understood through the analysis of its own spatial evolution. This way, we can see how the city has transformed its natural environment, according to the different "urban uses".

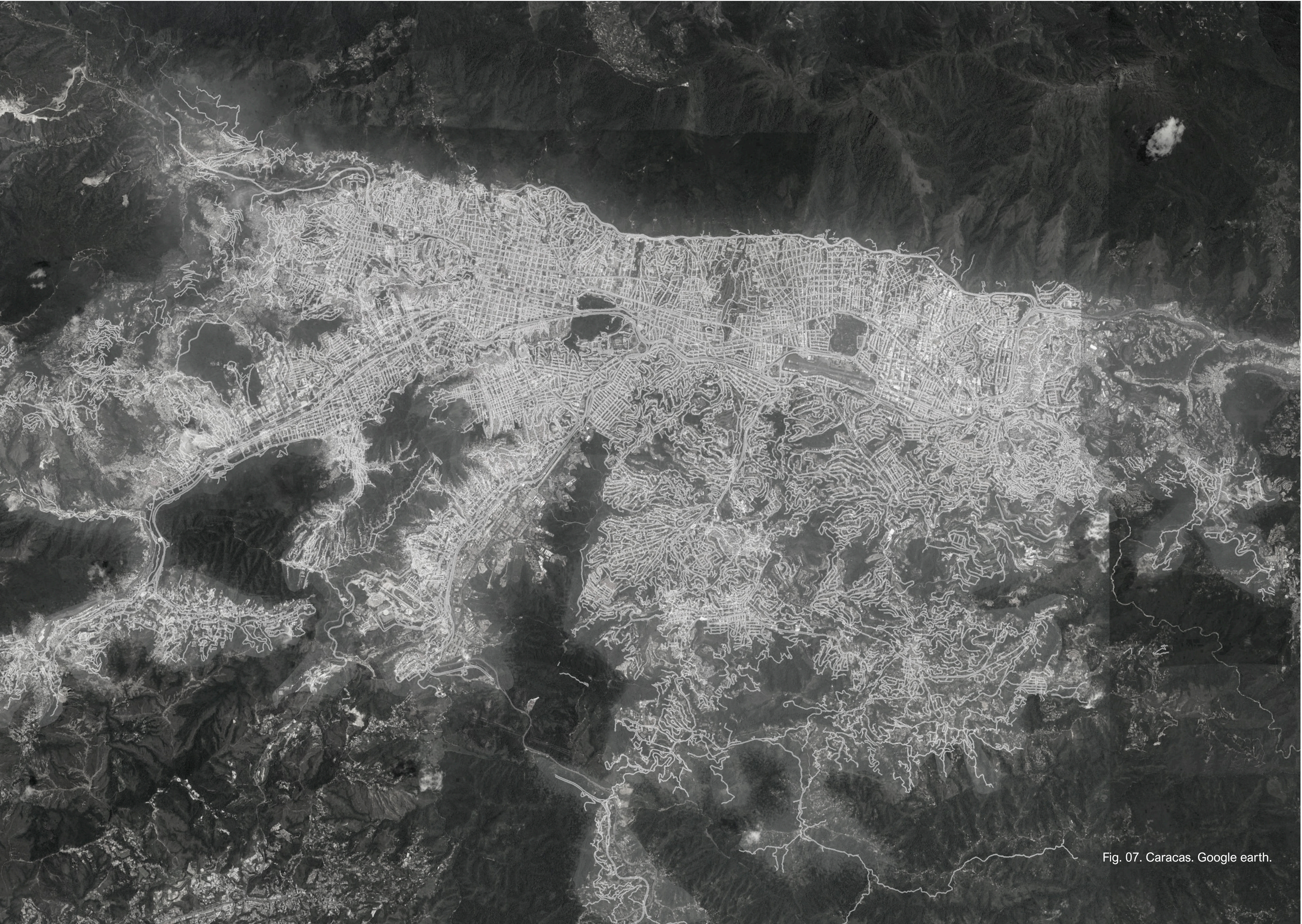


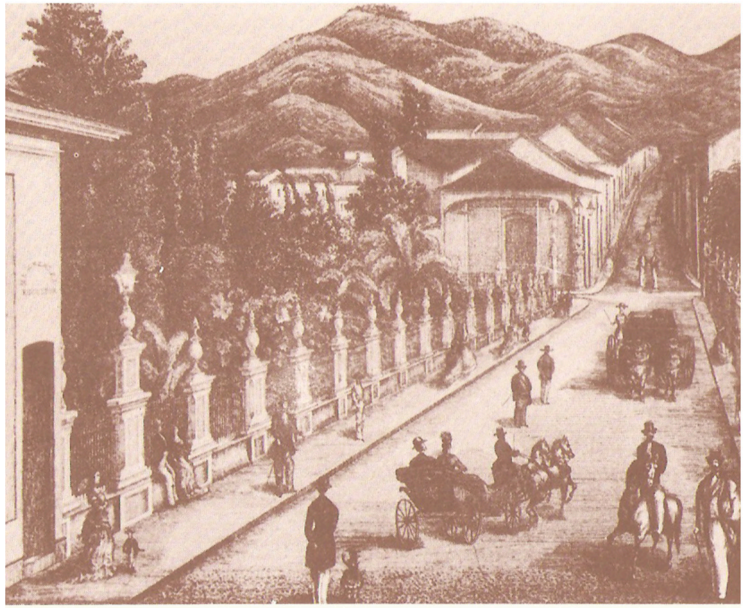
Fig. 07. Caracas. Google earth.

In the case of Caracas, the expansions took place in different steps, more intensely during the first two hundred years between 1578 and 1772, when the surface of the city grew from 130 to 2326,7 ha, which represents an increase of 5,3 times in its territorial extension. Such expansion never stopped but slowed down until the early years of the 20th century.

In 1772, Caracas spread just over 300 ha, and barely had two bridges, which, according to De Lisio, had increased to seven by 1801. In 1889, 33 bridges were recorded, 14 over the Caraota river, 13 over the Catuche, 2 over the Guaire, 1 over the Anauco, and the last one over the Cienfuegos. By 1906 the number of bridges had increased to 43 (Morales, Varely, Vallmitjana, 1990).

Thus, one of the main characteristics of the 20th century is the building of bridges over the waterways, which according to De Lisio represent "the best indicators of Caracas' expansion capacity over a natural environment". The natural environment of Caracas is characterized by the presence of rivers and streams which were one of the fundamental features taken into account by the "general provisions" of the Spanish Colony, a sort of guideline for the development of the city, inspired by the Laws of the Indies.

In this century the city started an "overflow process of its urban pattern towards the San Francisco Valley" (De Lisio. 2001) that means an increase westbound. Such development happened according to the traditional patterns established by the Laws of the Indies. The urban pattern coexisted with the existing waterways in the western part of the city, the Catuche and Caraota rivers. In the eastern part instead, where the Anauco river is located, the urban pattern used to be more loose, with the Anauco bridge only, that created a connection with an area mainly dedicated to agriculture. This configuration can be observed on the 1936 Monumental Map of Caracas by Ramon Sosa (fig. 9).



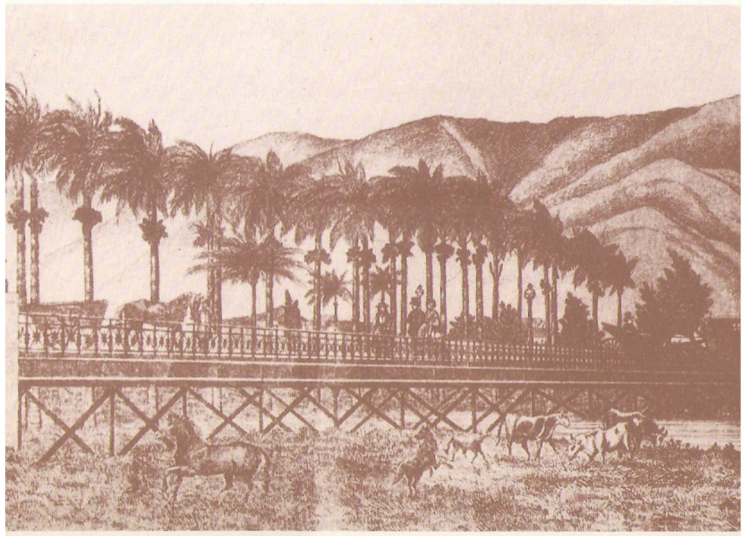


Fig. 08. Ramón Bolet (approx.1877). Curamichate bridge. Drawing by Ramón Bolet Peraza. Litography de Neum

On a 1936 map, “usos actuales del plan regulador de Caracas” (current usage of the regulatory plan of Caracas), which would have been used for the making of the Rotival plan, the zoning for agricultural use East of the Anauco can be observed. There, the river represented a very distinct limit in the firsts 350 years since the foundation of the city.

In 1939, the northeastern part of the Anauco was marked as an agricultural zone, since there was a large coffee plantation. A few years later, due to the huge demographic increase reached by that time, the area was switched to residential use. Maurice Rotival was commissioned the design of the new residential area. He planned the new San Bernardino Residential Complex with the idea of the “Garden City”, which includes the implementation of an organic urban pattern that breaks away with the original checkerboard of the city.

The Anauco river transformed from being a limit to a major urban event, a dividing line which contrasts two urban phenomena with completely different activities, uses, needs and densities.

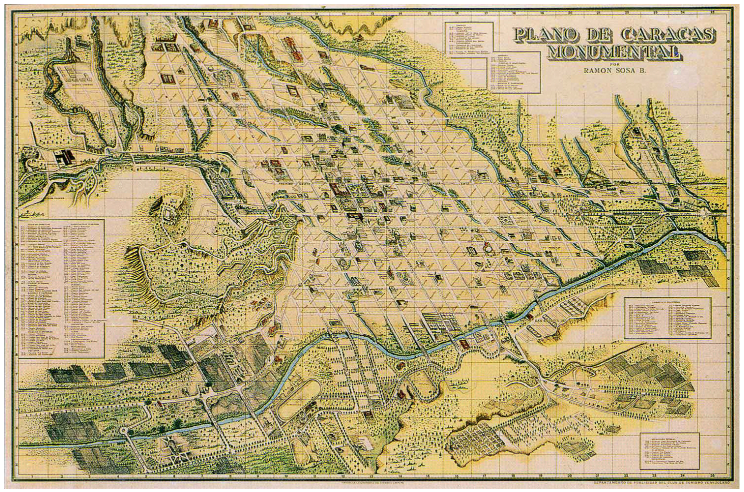


Fig. 09. Monumental Map of Caracas by Ramon Sosa B., 1936

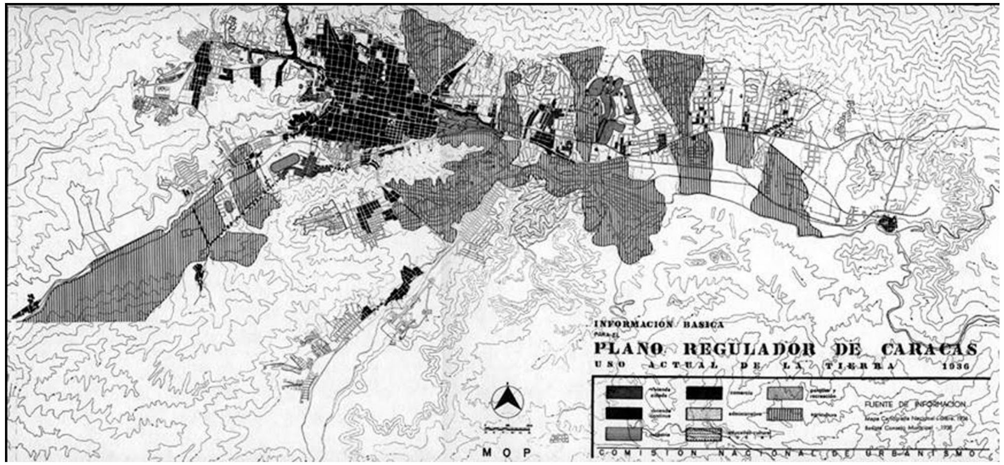


Fig. 10. Current land usage, 1578. Plano regulador de Caracas.

Fig. 11. La Sultana del Ávila. Photo: @andre.z on flicklr

The Valley: definition and environmental description of the Valley of Caracas.

The valley is by definition a low area of land between hills or mountains, typically with a river or stream flowing through it (Oxford Dictionaries). The valley of Caracas, defined as a "geographically complex area with a large diversity of landscapes and climates" (Urdaneta, 2013), is a system of narrow valleys and hills that are connected by mountain passes and heads of rivers, extending over 180 km^2. The two main guidelines of the valley, defining the lighting and temperature conditions of the city, are East-West and Southwest-Northeast.

In the Northern part of the Valley of Caracas, a large mountain range with a high probability of landslides and flooding is located. Moving towards South, between 1100 and 1500m there is an intermediate mountainous area, of soft rocks prone to turn into clay that erodes and creates massive landslides (Urdaneta, 2013). Such phenomenon is worse during the most intense rainy period, between June and November. This intermediate area mostly corresponds to the barrios (slums) in the western part of the city. Caracas' water system has been overshadowed by its uncontrolled expansio, which led some urban structures to be settled too near to the riverbeds. This caused vulnerabilities within the interested areas, both in the slums and in the more formal settlements.

Urban development of Caracas

From Caracas of the "laws of the Indies" to the current city conformation

In 1567, Caracas city emerged with an urban structure determined by the Law of the Indies, a grid configuration composed by 25 650x650 m blocks, as shown in the 1578 map by Juan de Pimentel (fig. 12). The most relevant factor in the initial settlement was the location between the Caraota and Catuche rivers, which represented an advantageous spot for the city, that would be surrounded by mountains, rivers and streams. Such location was not only favourable in terms of protection, but also for leveraging natural resources. The same map legitimates a De Lisio statement, as anticipated beforehand, that "The bridge was important during the urban occupation and sprawl", since it allowed "to cross the waterways".

The waterways in Caracas represented marked limits, which started to be overcome thanks to bridges and new roads, that started playing an important role in the urban propagation of the city. This phenomenon was more than ever present since the second half of the 20th century, during the so-called first modernization of Caracas, under the administration of Guzman Blanco, during which "The development was noticeable due the infrastructure and the road transportation" (De Lisio 2011).

Between 1948 and 1958, "la modernidad Caraqueña"

According to Herrera, Caracas' true modern era began after the second half of the 20th century. As stated in the 2013 article by the author, "The true modern physical and morphological urban era of Caracas emerged during Perez Gimenez dictatorship (1951-1958), under the motto Progress and Development".

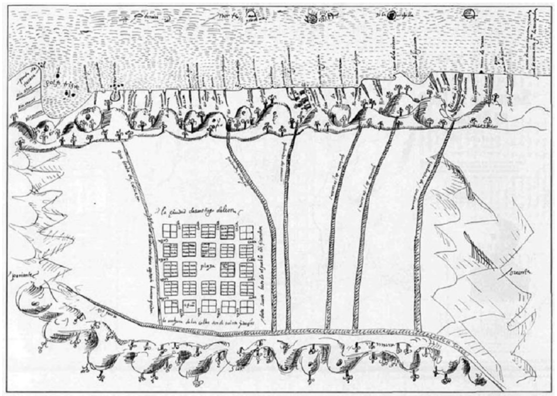


Fig. 12. First map of Caracas by Juan Pimentel. 1578.

This was a period of huge economic development because the country was starting to benefit from the oil revenues. However, several authors point out that the true modern era of Caracas starts, as discussed above, during the previous Guzman Blanco's mandate, but it is only under Perez Jimenez when the modern era started to be visually recognizable, and the city extended its territory (Herrera 2006).

Factors that contributed to the growth of the city

During the 1950s, Venezuela was experiencing a huge development, which allowed the creation of a city master plan in 1951, 13 years after the Monumental Masterplan of Caracas was published. The 1951 plan was created in order to respond to a need of organization of the city, following an urban collapse. It was meant to face the fast population growth and the unregulated expansion. In fact, according to Goycoolea Prado (2013) "The city had gone beyond the original municipality limits and it was growing towards the main valley".

Between 1940 and 1950, the urban expansion reached values of 130 ha and 6,14% of population growth per year. In the years 1950-1971 the expansion grew significantly, reaching 419,1 ha/year (Negron, 2001; De Lisio, 2001), almost four times with respect to the previous decade. Such expansion was reflected in an "important program of public works conducted by the government showed in the cement production which grew from 40000 to 600000 metric tons". During the same period of time the diffusion of electricity increased by six times, and tyre production was ten times higher (Herrera, 2013).

Fig. 13. Autopista Francisco Fajardo
Online source: temporadista.com

Fig. 14. El Paseo los Ilustres in 1958, in the background the Hospital Universitario de Caracas. Online source: temporadista.com

Fig. 15. El comercio Torres Simon Bolívar BBC -1955
Online source: temporadista.com

Fig. 16. Urban development of Caracas.
Prepared by the author.

Chapter IV. CARACAS, CIUDAD DE LAS AGUAS

Metrology and hydrology of the area

Climate in the valley of Caracas is affected by the trade winds from North-Northwest and from Southwest, by its position in the Intertropical Convergence Zone (ITCZ), and by the topografy of the Ávila mountain. Caracas valley lies around a latitude of 10° 30' in the Northern emisphere and inside the Intertropical Convergence Zone, that causes an unstable climate. Moving towards the Equator, the winds from North and Northwest become prevailing upon the valley, as well as in the whole country. Yearly precipitations, according to Cajigal and La Mariposa meteorological stations, reach 834,8 mm and 891,2 mm, respectively. In both stations, the amount of rain is equally distributed during the months in the rainy season, from May-June to November. The average monthly temperature, according to the same stations, is around 21 °C.

Guaire river flows through the Caracas Metropolitan Area to reach the Tuy river in Miranda state. Its basin spans over 655 Km^2. Its tributaries are the San Pedro, Macarao, El Valle, and Guairita en Baruta rivers, the reservoir Represa Mariposa, and some minor streams from the Southern face of the Ávila mountain.

The riverbed slope ranges from 9 m/km at its head to 2 m/km at its mouth, in La California Sur en Petare. (JICA, 2015)

Caracas water system

As a consequence of its urban expansion, the urban area of caracas' stream system now includes 12 main watercourses - quebrada Seca, quebrada Canoas, quebrada la Florida, quebrada Caroata, quebrada Catuche, quebrada Anauco, quebrada Honda, quebrada Maripérez, quebrada Chacaito, quebrada Sebucán, quebrada Agua de Maíz, quebrada Tócome, and quebrada Caurimare. Currently, they are in precarious conditions and in many of them represent security hazard for the city. In general, the stream system is oriented north to south, that is, the streams come down from the ávila mountain, flow through the caracas valley and have their mouth into the guaire river, which is the most important one in the city.

From the founding of Caracas, its streams have always been obligatory references in the growth of the city. The first drawing of "Santiago de León de Caracas" dates back to 1578 (fig. 12), in which the urban pattern can be observed, in the form of a grid divided into twenty-four blocks grouped in four lots, as it was the norm in the Hispanic cities of the Indies. The natural elements, the Ávila, the Guaire river and the streams, can be easily clearly identified.

Current situation of the "Quebradas de Caracas"

As already discussed, the streams were a fundamental component of Caracas' design. Nowadays, they are recognized by multiple studies as areas at high risk of flooding (Sansone, 2013). There are multiple causes to this, mainly due to Caracas' expansion process that included the unregulated occupation of the areas surrounding the streams and in the hills, and the modifications (redirection and burial) made to the streams especially in the modern era, that modified the degree of permeability of soils.

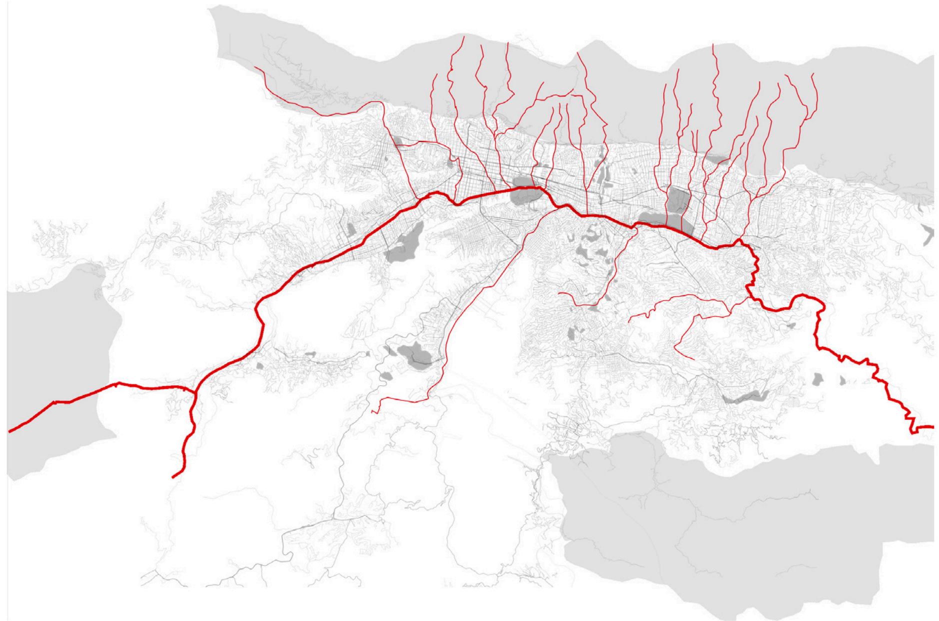


Fig. 17. Caracas water system.
Prepared by the author.

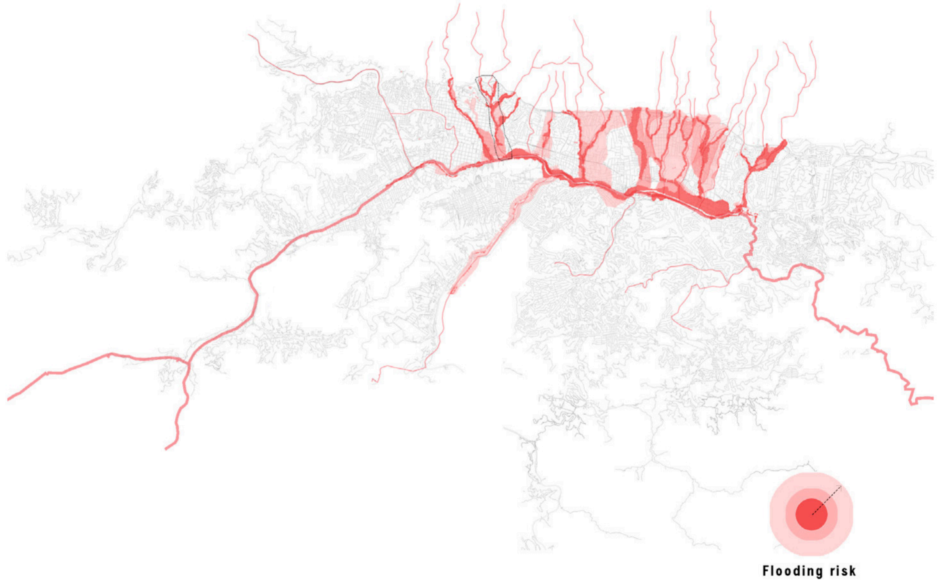


Fig. 18. Flood risk map, prepared by the author based on
Disaster Resistant Caracas: Urban Planning Student Studio. 2001.

During the last 50 years the city has been subjected to the channeling of part of its streams. In the beginning, the channels were planned to be open-air. After the canalization instead, some of them were buried for long stretches, and private and public structures were built upon and near them (Sansone, 2013).

One of the most extreme cases is that of the quebrada anauco. The urban stretch of the river, entirely canalized, is around 3 km long, of which more than 1.2km have been completely buried. The covering process began in 1977 as part of the Caracas metro project (parque central station).

Fig. 19. Quebrada Caraota, Caño Amarillo (Caracas / Venezuela). Photograph: Johnny Gomes. Online source: https://www.flickr.com

Risk and the streams

In the investigation on the basic disaster prevention plan in the metropolitan district of Caracas , carried out by the Japan International Cooperation Agency (JICA) in 2005, a summary has been made of the most important natural disasters since its foundation:

> *Caracas has several experiences of large-scale earthquakes since its history began in the XVI century. The biggest was the one that hit the city in 1812, when around 2,000 people lost their lives. The most recent occurred in 1967, where approximately 1,800 buildings collapsed, and 274 people died. Therefore, Caracas has the possibility of suffering an earthquake of the magnitude of those of 1812 or 1967.*
>
> *Caracas also has a history of frequent sediment disasters. In December 1999, Caracas suffered a torrential rain caused by the cold front that arrived from the Caribbean Sea and debris flows were generated in the mountain streams of Catuche and Anauco. This killed about 100 people. Another similar debris flow occurred in February 1951. Therefore, Caracas will have the possibility of a debris flow such as that of 1951 or that of 1999 in the future. (JICA, 2015)*

The study mentions that the preventive administration of disasters in the Metropolitan District of Caracas is defined by the Organic Law for Civil Protection and Administration of Protection issued in 2001. It defines the responsibility of Civil Protection and how it can behave at the national level and in the metropolitan area of Caracas. According to the same study, the Civil Protection has the responsibility to develop a disaster prevention plan for Caracas, but until the publication of the study, this plan had not been carried out. To date, it has not yet occurred at the Metropolitan District of Caracas scale nor at a national level.

The urban development of Caracas during the XVI century took place between the streams Catuche and Caraota, then the city continued to develop eastward in the areas of the alluvial fan of the streams Anauco, Chacaito and Tocomé. The phenomenon of debris flows and floods in Ávila presented more than twenty times since the XVII century, causing serious damage (PREVENE, 2001).

The two major natural disasters of 1951 and 1999 in Caracas were similar in terms of weather conditions, with the presence of a cold front that reached the North of Venezuela from the Atlantic Ocean, according to the study on the basic prevention plan of disaster in the metropolitan district of Caracas. However, the cold front of 1951 caused a heavier rainfall than in 1999.

In 1951 the precipitation observed by three main meteorological stations is described as follows:

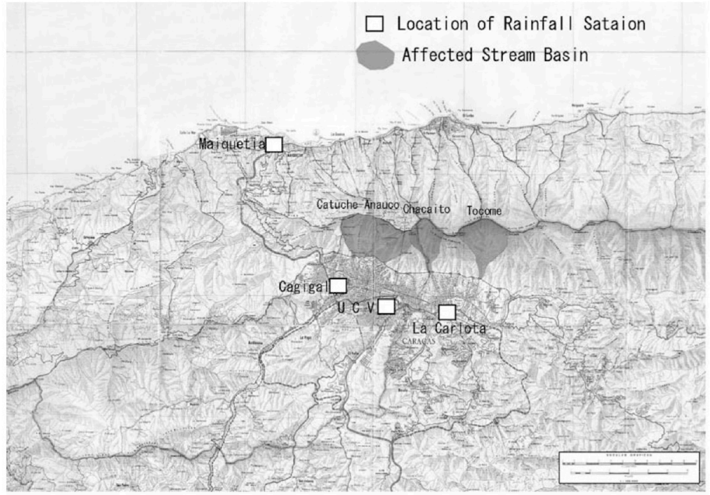
> *The maximum daily rainfall was 193,0 mm in Maiquetía in the coastal area, 72,9 mm in Cajigal and 36,2 mm in the UCV in the Valley of Caracas. With a poor description of the rainfall in Ávila, being the main cause of floods and debris flows.*

In 1999, rainfall on the Southern slope of the Ávila mountain was in the range of 100 to 350 mm, as reported by the United States Geological Survey Service through the satellite image of the total precipitation during the days 14-16 December 1999 (fig. 20).

The damages caused in 1951 were registered mainly in the Western part of the metropolitan area, from the Anauco to the Tocomé stream. In 1999 the greatest damages were registered mainly in the same area, corresponding to the Caraota, Catuche, Anauco, Chacaito and Tocomé streams.

The Catuche and Anauco streams are surrounded by about 2000 buildings. As a result of the 1999 event, the rate of destroyed buildings was 22% and 32% respectively (JICA, 2015). This is an indication of how inadequate the urban fabric is, and of the need for risk mitigation

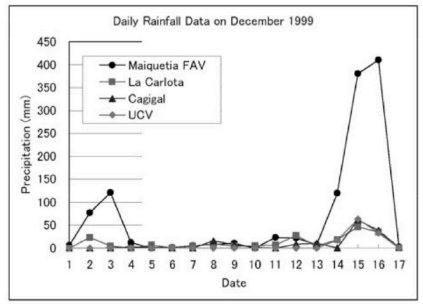
and prevention in the area.



Rainfall Stations which operated at the event of December 1999

(mm)

date	Maiquetia FAV	La Carlota	Cagigal	UCV
1	6.0	0.0	0.3	–
2	77.3	23.2	0.0	–
3	121.2	4.7	0.9	–
4	11.8	0.0	2.8	–
5	0.0	6.7	1.8	–
6	1.1	0.6	0.6	–
7	5.0	3.8	0.0	–
8	8.1	9.0	16.0	–
9	10.4	3.9	7.3	–
10	0.0	5.0	1.9	–
11	23.2	6.8	0.3	–
12	21.8	28.1	8.6	–
13	7.1	4.0	10.8	–
14	120.0	18.6	0.6	17.5
15	380.7	46.2	61.5	63.7
16	410.4	34.9	38.6	32.8
17	2.9	0.6	1.5	–
sum	1207.0	196.1	153.5	114.0



Daily Rainfall Amount at the event of December 1999

Maiquetia	Cagigal	UCV	La Carlota
1560 years	4 years	5 years	1 year

Return Period of the Daily Rainfall in December 1999

Fig. 20. Daily rainfall amount during the event of December. 1999. United States Geological Survey Service

Chapter V. THE ANAUCO STREAM

The Anauco stream is born at the top of the Ávila mountain, it flows in North-South direction until it arrives at the Guaire river. Along its route, in Caracas' urban area it crosses San Bernardino, La Candelaria and El Conde neighbourhoods. The area of the basin is 14.63 Km^2, of which 79.5% in the wild and 20.5% urban. The average slope is 13.6%, but it

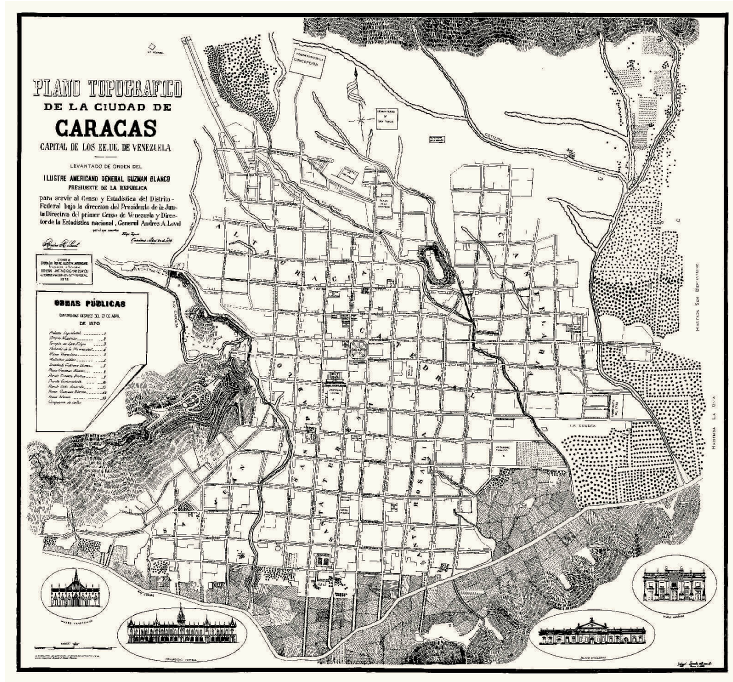


Fig. 21. Map of Caracas, 1874. Drawing by Estevan Ricard

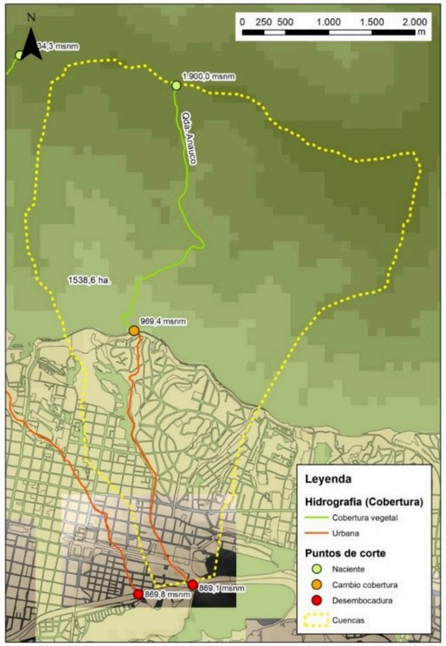


Fig. 22. Riverbed, path and isopleths of the Anauco river. Análisis de áreas vulnerables por crecidas extremas en el área metropolitana de Caracas. November 2015

is only 2.6% in the urban area. The approximate length of the stream is 7.5 km, of which 53,5% within the city. The Anauco stream is buried in a channel for a large part of its length, approximately 1,5 km, in the urban area (Sansone, 2013).

The northern part of the urbanized area crossed by the stream is occupied by San Bernardino neighbourhood, which is almost entirely residential. In the lower middle part there is La Candelaria, with a high density and high commercial and tertiary activities. Closer to the Guaire

Fig. 23.Anauco Stream.
Source: ALEXIS CORREIA

river instead, El Conde neighbourhood is found, that includes a large residential, commercial and cultural complex called Parque Central.

Caracas river system is fundamental not only as an important medium for the environment, but also for the spatial organization of the city. In the lowest part of the valley, towards South, the Guaire river receives all the streams originating in the northern side of the Ávila mountain. The waterways represent limits and ruptures in the expansion of the city. In chapter II it has already been shown how the Anauco enforced the first physical limit in the expansion of the city, and more specifically of the colonial urban grid. At that time, it separated a largely agricultural area on the eastern riverside, from a urban one on the West.

Since the colonial times, the Anauco has transformed from being only a limit, to an important urban feature thanks to the diversification in the land use.

Nowadays, the Anauco could represent an opportunity for a project based on the concepts of resilience and blue-green infrastructure. In fact, it lies within an important urban context, flowing in the city center, with a high density, and characterized by a high risk of flooding. By applying the concepts of blue infrastructure and green infrastructure, it is possible to help the area becoming more resilient and able to face new events of flooding caused by climate change.

Why the Anauco stream?

During the the flood of December 1999, there were four active weather stations working in and around the valley of Caracas. It has been reported that during the event of 1999, the Catuche, Anauco, Chacaito and Tocomé streams were the most affected by the rainfall. Among them, the Catuche and Anauco suffered debris flows in the urban area below the Cota Mil. (JICA, 2015).

Fig. 24. Flooding around Catuche and Anauco streams. 1999.
United States Geological Survey Service

The Anauco stream as a risk

To draw the consequences of the 1999 disaster, JICA conducted an interview between the 1st and 2nd week of June 2003 in order to obtain information on the condition of the sediment flow in Caracas during the 1999 event.

The Anauco stream upstream

During the December 1999 flood in the Bambù sector (marked with 1 on fig.25), the deposition of sediment reached the second floor of the houses.

As happened also with the Catuche stream, in the case of the Anauco the peak of the flood was during the afternoon on December 15, 1999. From 7 pm until 11 pm, there were two peaks of the water level. The latter was the maximum. Moreover, according to the interview, before the 2nd peak, it was heard the roar of the water that was flowing in the sewer.

The Anauco stream at half-stream

This locality (number 2 on fig. 25) is located between the confluence of the Cotiza stream with the Anauco, and the Avenida Panteón. This part of the stream is narrow and is made of an open concrete channel. In December 1999, little sediment and debris had been transported there from the destroyed houses from upstream. The houses located along the riverside were affected in their foundation by erosion.

The Anauco stream downstream

This locality (number 3 on fig. 25) lies between the Avenida Panteón and the Avenida Mexico. Unlike the upstream sectors, this stretch of the stream is channeled through all its length. The new surface over the channel is used as a pedestrian street. In 1999 the sediment flow overflowed the sewer reaching the surface, turning the overlying street into a stream. The avenida Anauco and the Avenida El Parque, parallel to the flow, suffered a 1-metre flood. Before arriving to Avenida México, flood marks on the walls of the buildings were clearly recognizable, 2 m above the street, even in 2003. This means that the duration of the flood was considerable. (JICA, 2013).

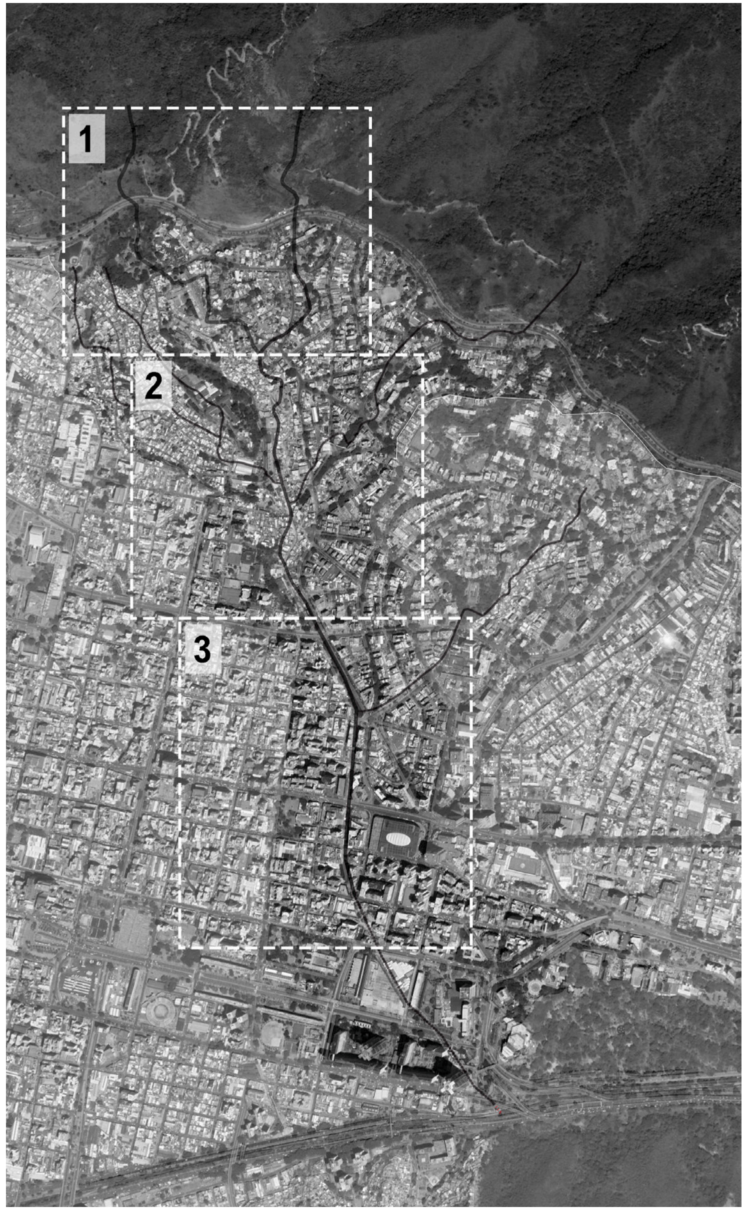


Fig. 25. Analysis of the area surrounding the Anauco Stream. Prepared by the author.

Paseo Anauco

In 1977 the Anauco stream was channeled and buried by a state-owned company, called Simón Bolívar, as part of a larger plan aimed at building the Parque Central metro station. The project was carried out in sections, with the participation of several sub-contracting companies. This caused technical problems when joining the built stretches, mainly in the construction of water collection systems, because each sections had not been built adopting the same criteria.

> *"... The canalization and interment of the Anauco stream ... shows the diversity of urban agents involved in the problem of sanitation in the city ... The execution of the work was made by bidding by sector, to private companies, each sector was assigned a different company, four sectors, four companies" (Marcano, 1981).*

In the first section from South, part of the construction of the Parque Central Center, two channels were built to collect sewage water separately from surface runoff. This mixed system proved to be useless, because in the upstram sections only one channel had been built for water collection.

At the end of the construction works, the surface, which is nothing more than the concrete footprint of the Anauco stream, began to be used as a pathway, called Paseo Anauco. Along the years, some small interventions were made, such as the installation of benches. However, none of the proposed projects that had some relevance to the urban scale was ever executed (Castellano, 2017), despite the interesting possibilities such a large area can inspire, to be improved itself and to enrich the city.

As soon as 1984 (Castellano, 2017), the paseo Anauco became an abandoned element in the middle of the city, as it is still today. Moreover, since the 1999 flood, it also proved to be a constant risk. (Instituto Metropolitano de Urbanismo Caracas, 2015).

Fig. 26. Anauco Stream.
Prepared by the author.

Fig. 27. Anauco stream. Online source: aporrea.com.

Fig. 28. Anauco stream. Online source: aporrea.com.

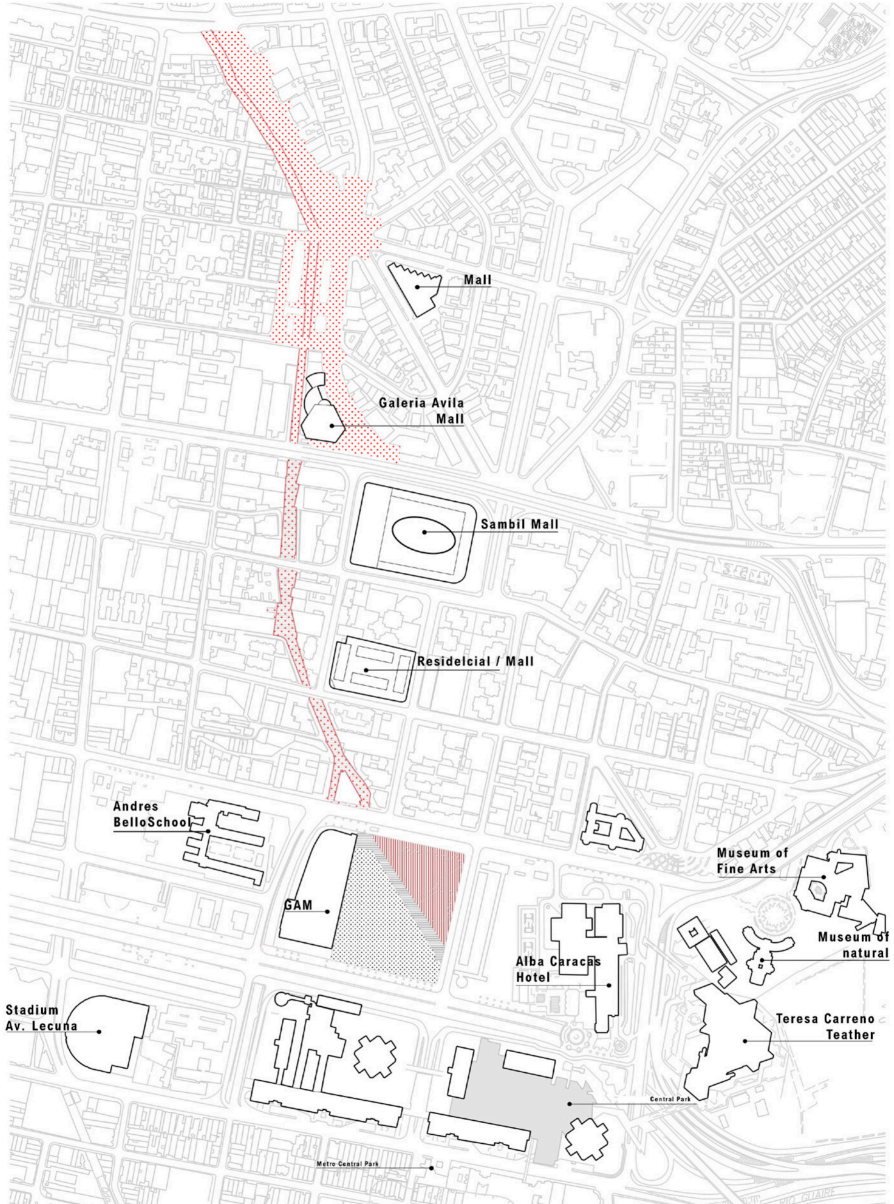


Fig. 29. Plan of Anauco stream.
Prepared by the author.

Analysis of the grey infrastructure

Grey infrastructure includes all the assets - pipes, pumps, ditches, and detention ponds - that provide the services required by society, such as transportation, stormwater management and wastewater treatment.

Such systems require to be engineered and continually maintained, and often need to be upgraded. Increasing urbanization, higher stormwater volumes, and decaying pipes put an increasing strain on these systems.

Measuring the water flow

In the drawing on fig.30, the first section a-a' is the one near the Northern part where the river is channeled only (not buried), while the subsequent five sections (A-A' to E-E') have been considered along the subterranean part of the Anauco. The sections have been realized based on the technical drawings by Castellano Diaz.

The account of the 1999 flooding event provided by JICA, lets us simulate the flood sections due to an extraordinary flooding event, such as the 1999 one. Using these simulated flood section as a starting point, some fundamental data, that were useful for the hydraulic verification have been derived. In order to realize the longitudinal sections (fig. 31), Google Earth has been used, which let us get the approximate section along the whole length of the river. Starting from this map, it was possible to estimate the slope of the river both in the urban area and in the extra-urban one, which in turn was useful to calculate the flow rate.

The flow rates in the six sections on fig. 32 were computed using the Manning equation. Each resulting flow rate, indicated by the symbol Q, is written near the corresponding section. Starting from these results, it is possible to estimate the approximate magnitude of the flooding event that will be useful for the project proposal.

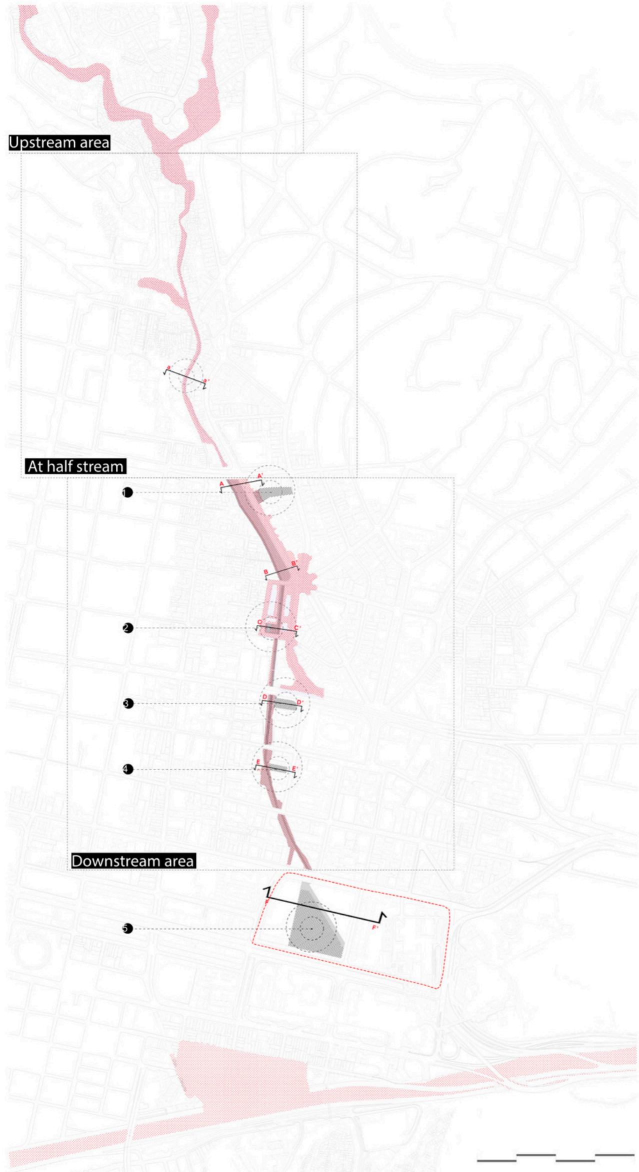


Fig.30. Hydraulic verification of the Anauco river in the area corresponding to the paseo Anauco. Prepared by the author.

Territorial Section

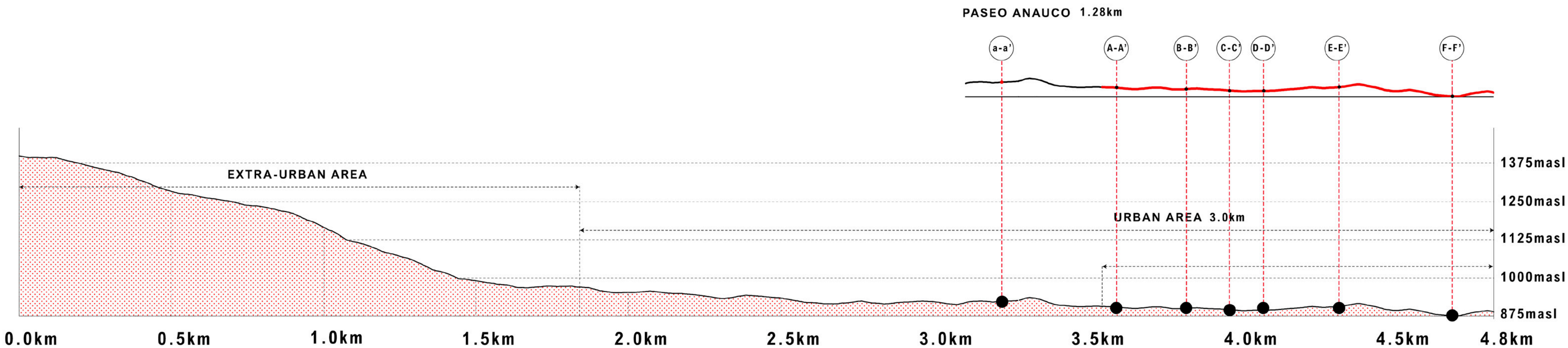


Fig.31. Territorial section. Source: Google Earth. Prepared by the author.

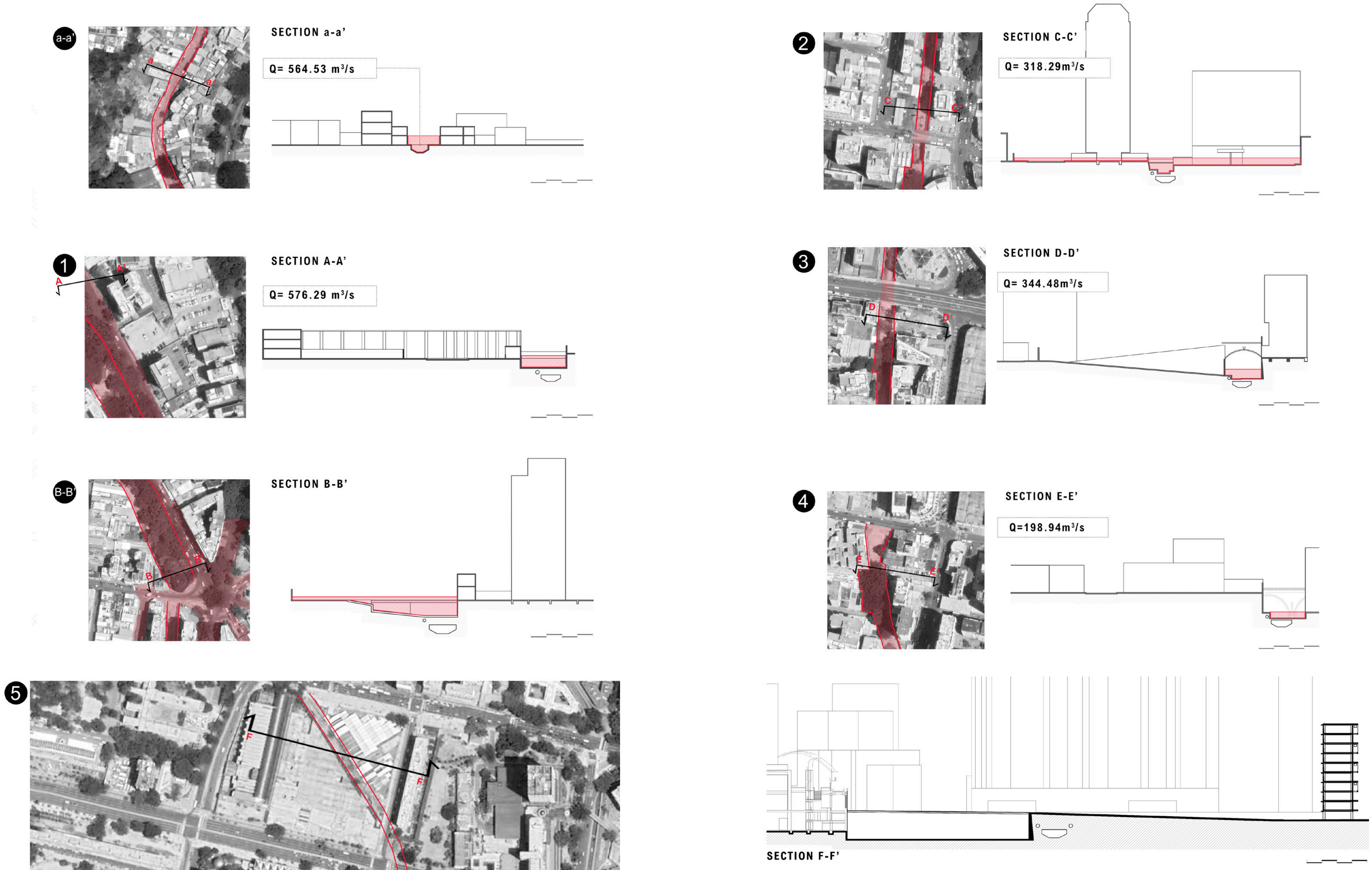


Fig.32. Six sections of the Anauco stream and their flow rates.
Prepared by the author.

Computing the river flow - Manning equation

The Manning equation is the most commonly used equation to analyze open channel flows. It is a semi-empirical equation for simulating water flows in channels and culverts where the water is open to the atmosphere, i.e. not flowing under pressure, and was first presented in 1889 by Robert Manning. The section of the channel can be any shape - circular, rectangular, triangular, etc. The units in the Manning equation appear to be inconsistent; however, the k value has hidden units in it to make the equation consistent. The Manning equation was developed for uniform steady state flow. In reality, no flow is uniform and steady. However, for an individual channel reach, the assumption is reasonable.

$$Q = VA \qquad V = \frac{k}{n}\left(\frac{A}{P}\right)^{2/3} S^{1/2}$$

Eq. 1. Manning equation.

Q is the discharge (flow rate).

V is the average velocity in the pipe, culvert, or channel.

A is the flow area of the pipe, culvert, or channel.

k is a unit conversion factor. k=1.49 for Imperial units (feet and seconds), k=1.0 for SI units (meters and seconds).

n varies with the roughness of the pipe, culvert, or channel. The higher the n, the rougher the material.

P is the wetted perimeter which is the portion of the circumference that is in contact with water.

The ratio A/P is also known as the hydraulic radius, R_h.

S is the downward (longitudinal) slope of the culvert.

Results table

	Section a-a'	$Q_{Manning}$
A	43. 97 m^2	564.53 m^3/sec
P	20.15 m	
Rh	2.18 m	
S	0.036	
n	0.025	
	Section A-A'	**$Q_{Manning}$**
A	70.387 m^2	576.30 m^3/sec
P	30.13 m	
Rh	2.34 m	
S	0.025	
n	0.034	
	Section C-C'	**$Q_{Manning}$**
A	46.913 m^2	318.30 m^3/sec
P	26.622 m	
Rh	1.76 m	
S	0.025	
n	0.034	
	Section D-D'	**$Q_{Manning}$**
A	46.385 m^2	344.50 m^3/sec
P	22.984	
Rh	2.02 m	
S	0.025	
n	0.034	
	Section E-E'	**$Q_{Manning}$**
A	30.658 m^2	198.94 m^3/sec
P	18.6 m	
Rh	1.65 m	
S	0.025	

Fig.33. Flow rates.
Prepared by the author.

As already explained, for the calculation we mainly consider the area corresponding to the Paseo Anauco. The data for the calculations was derived using as a starting point the flood section simulated by JICA. The resulting estimate is 0.0025 for the average slope S, and 0.0034 for the roughness factor n in the sections from A-A' to E-E' (fig. 30). While for the special section a-a', that is upstream the Paseo Anauco, we consider S=0.0036 and n=0.0025, since the slope is higher but there are less obstacles with respect to the paseo area. B-B' section has been excluded in these calculations, since it tends to overflow very soon during rainfalls, occupying a large irregular area along the Avenida El Parque, for which we do not have exact data. Here is where a considerable amount of water is dispersed, explaining the huge difference in the resulting $Q_{manning}$ between sections A-A' and C-C'.

Urban proposal

Response to risk

In the hypothesis of a large rainfall, in the area towards the North of the river, a large flow arises which is not supported by the current grey infrastructure. This phenomenon worsens towards the bottom of the valley, where the grey infrastructure is more invasive but damaged.

As a response to such events, we propose the creation of expansion areas that could provide a more robust management of inundations and similar extraordinary events, like the 1999 one.

The urban strategies leveraged in this thesis work are oriented towards the creation of mixed spaces like floodable squares, with a focus on the area corresponding to the urban stretch of the Anauco stream.

During the adopted 2-step approach at first, we identified the most suitable areas to be transformed into expansion basins. In the subsequent phase, we considered the possible development of those areas as public spaces during the dry season.

We identified 5 areas that are reasonably suitable to be flooded. They are mostly parking lots of different extent and altitude.

Risk control

We present a project proposal designed through the simulation of an inundation event. In the provide section views, we show simulations under different settings, and the intervention possibilities in order to increase the river cross section. The most relevant portion of the architectural project work, is located in the Southern area that is divided into two sectors by a diagonal. One of these is abandoned and exploitable to be inundated.

Daylighting

One of the intervention options for the urban area under exam, can be the application of the daylighting concept. That is, the radical removal of the concrete pavement covering the Anauco stream. This would allow the removal of the obstruction represented by due to the grey infrastructure, solving the rainwater collection problems and the subsequent floods caused by the 1970s projects.

The sectors to be revitalized are located in a very dense urban area, surrounded by buildings, distinct urban fabrics, and public transport routes. Thus, the application of daylighting is challenging and can be hampered by some limitations, especially because of the costs for the removal of the existing infrastructures.

Therefore, the daylighting techniques could be integrated into a larger urban and economical revitalization project, that would capitalize on the high land cost of dense urban areas such the one under exam.

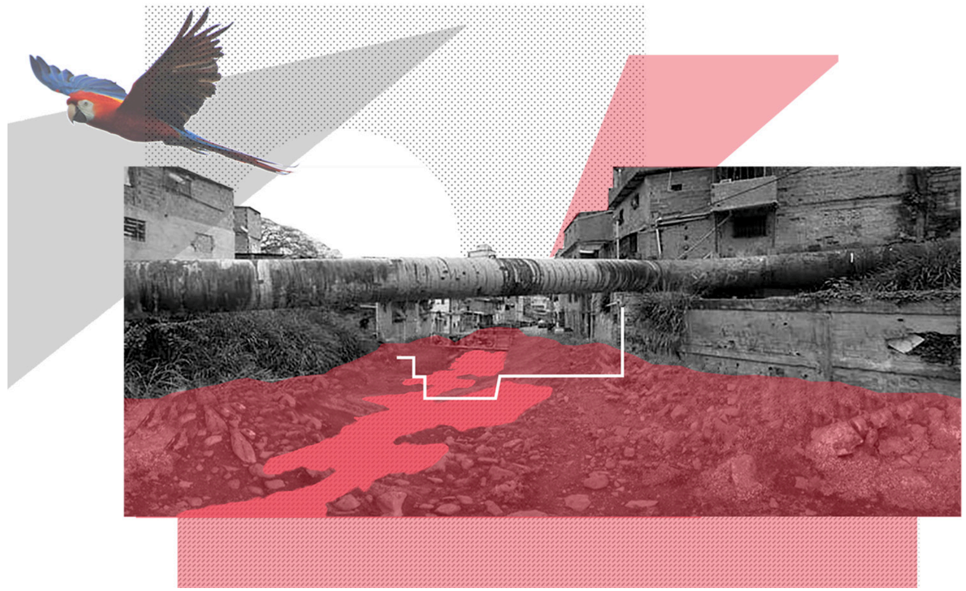


Fig.34. Prepared by the author.

Blue infrastructure

The project of a blue infrastructure allows the definition of some spaces for water management in the urban area. Such spaces are designed to allow a better penetration of rainwater towards the floodable basins in anticipation of catastrophic events.

A complete network has been designed according to the blue infrastructure concept. It grants a reduction of flooding risk, and control during minor events.

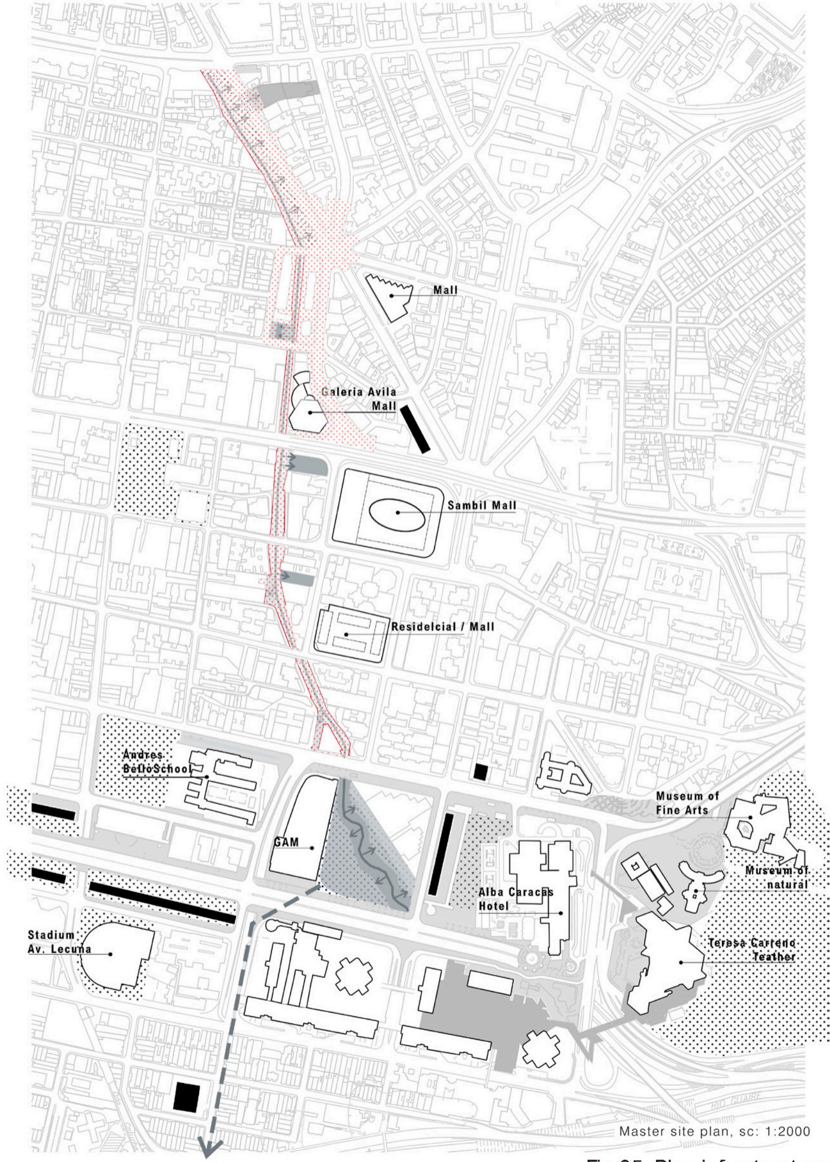


Fig.35. Blue infrastructure.
Prepared by the author.

Expansion basins

Five areas (fig. 36 - 37) have been identified that could be flooded in case an extraordinary event like the 1999 one happened again. These areas have different altitudes and extents, and are mostly used as parking lots. The most important among them is located in the southernmost region of the paseo Anauco. It is split in two parts by the channelled river crossing it diagonally, and it is abandoned, thus exploitable to be inundated.

Fig.36. Floodable areas.
Prepared by the author.

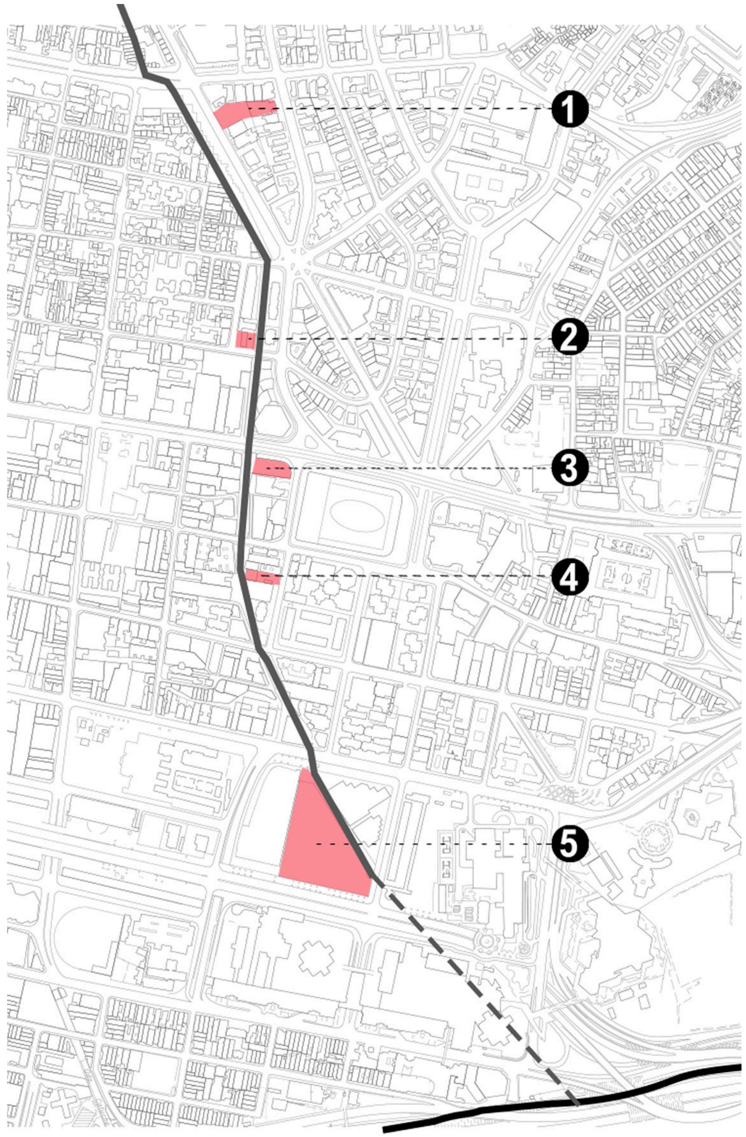


Fig.37. Floodable areas.
Prepared by the author.

Draining surface

Increasing the draining surface through the removal of the entire surface of the river. Currently, the covered area of the stream is 18945.17 m^2. The draining can be 80 % of the total area, that is, 15163.33 m^2, leaving 20 % for accommodating connection systems and sustainable mobility.

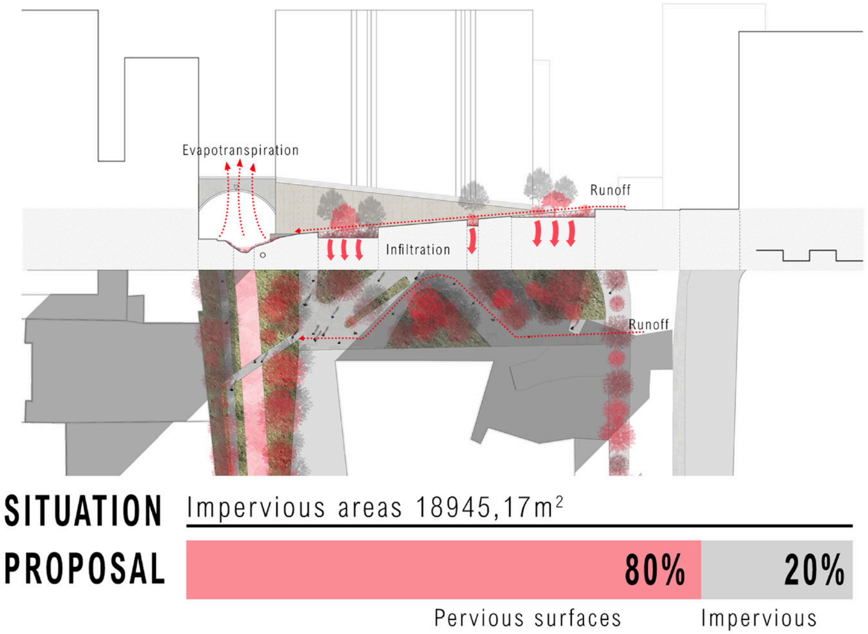


Fig.38. Water square.
Prepared by the author.

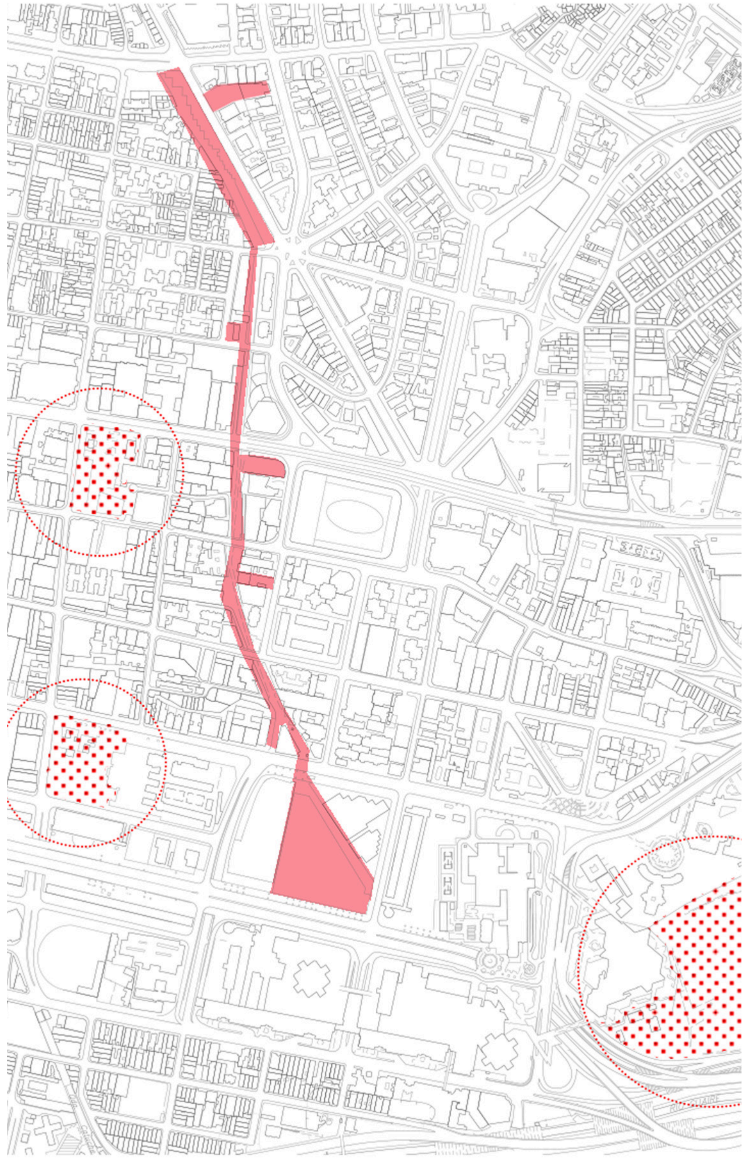


Fig.39. Drain surface. Prepared by the author.

SPILLWAY

In a first draft of our proposal, we planned the creation of a retention well in the larger area of the project, in the Bellas Artes district. However, the calculations showed that the capacity of that area was not enough for the proposal to be effective. We decided then to follow a recommendation given by an "Análisis de áreas vulnerables por crecidas extremas en el área Metropolitana de Caracas" (Analysis of vulnerable areas due to extreme floods in Caracas Metropolitan area) published in 2015, and to direct the water directly to the Guaire river through the creation of a spillway (figg 40-41).

The study recommends an intervention to decrease the flow towards the Anauco stream, and redirect it directly to the Guaire river, since the river banks are compromised and do not allow the enlargement of the river bed.

The spillway, dimensioned with the Manning equation (Eq. 1), should have a cross section of at least 70 m^2 in order to obtain $R^{2/3} \times A = 198.5$ m^3 that is more than the required 191.0 m^3.

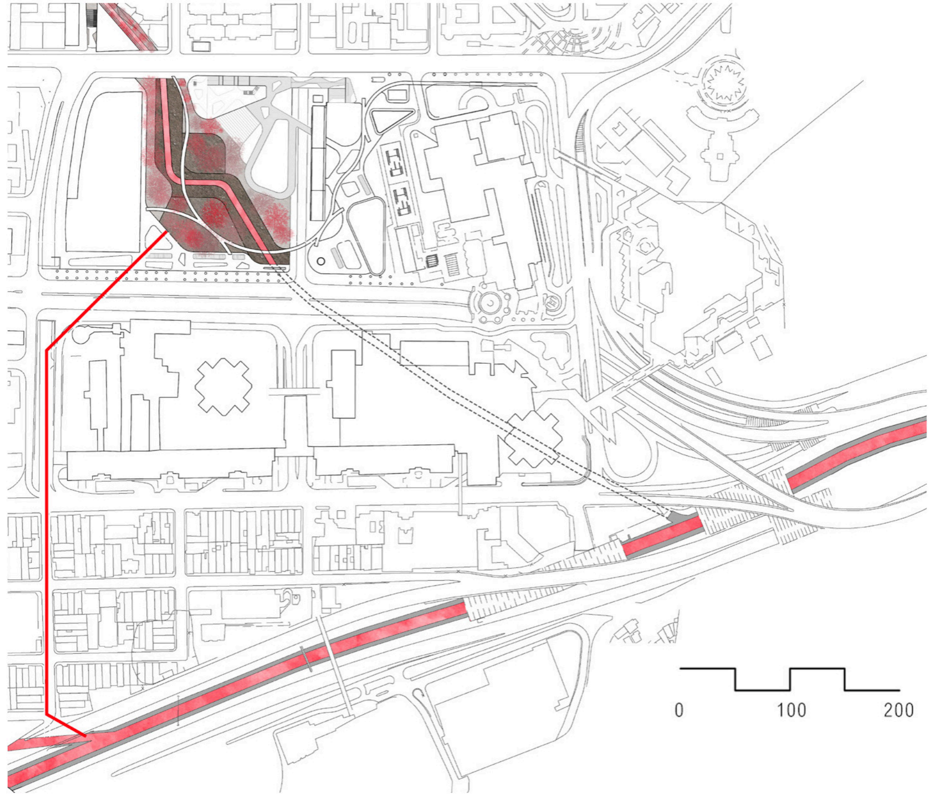


Fig.40. Spillway diagram. Prepared by the author.

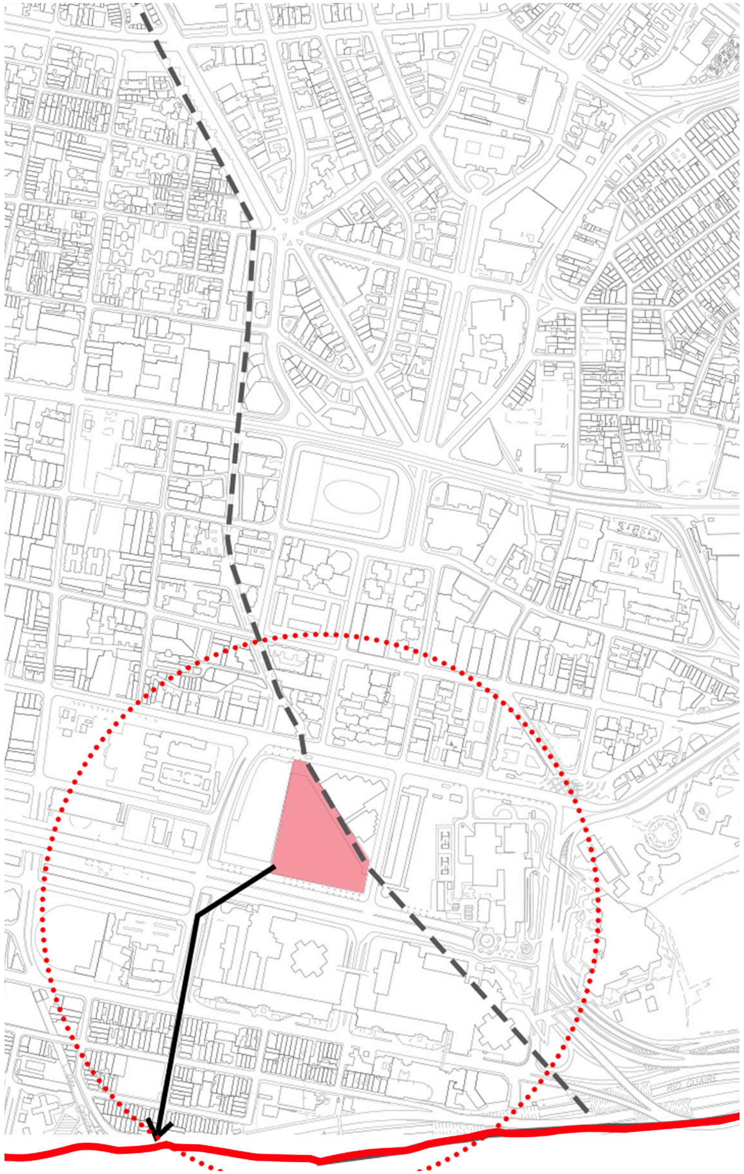


Fig.41. Spillway diagram. Prepared by the author.

Green infrastrutture

The green infrastructure proposal lets us develop a project that brings economical, social and environmental opportunities in different areas of the urban context. It starts with the identification of all the key-elements of the urban fabric that in the following let us design a schema for the green infrastructure.

It is in this sense that the Anauco stream is defined as a link between all the hubs, that is the already existing spaces and the new ones that are defined in the proposed green infrastructure.

In the area under exam, we can identify three main hubs and the already existing Los Caobos park (fig. 42), linked along the Anauco stream through the integration of sustainable mobility. The three hubs host the proposed expansion basins. The northernmost ones incorporate the floodable areas with already existing public spaces, such as La Candelaria square that during the dry season is enriched by the nearby natural area of the empty basin. The southernmost hub instead, where the project for the open market is located, represents a connection point between Los Caobos park and the recovered naturalized area of the Anauco.

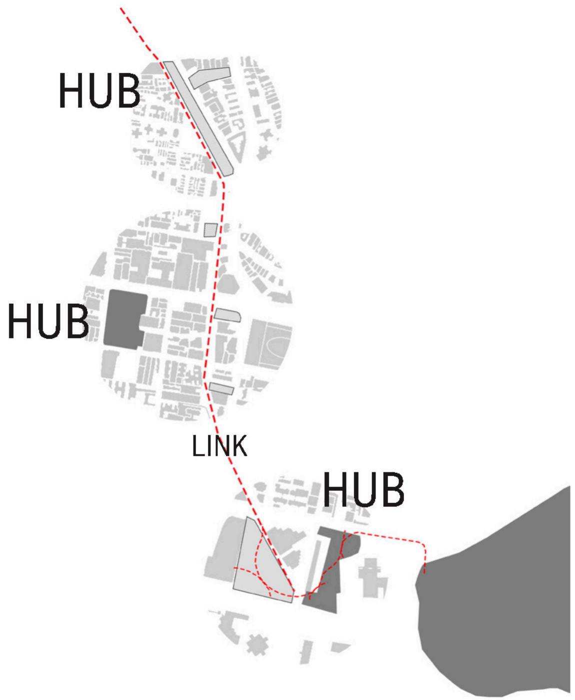


Fig.42. Green infrastructure. Prepared by the author.

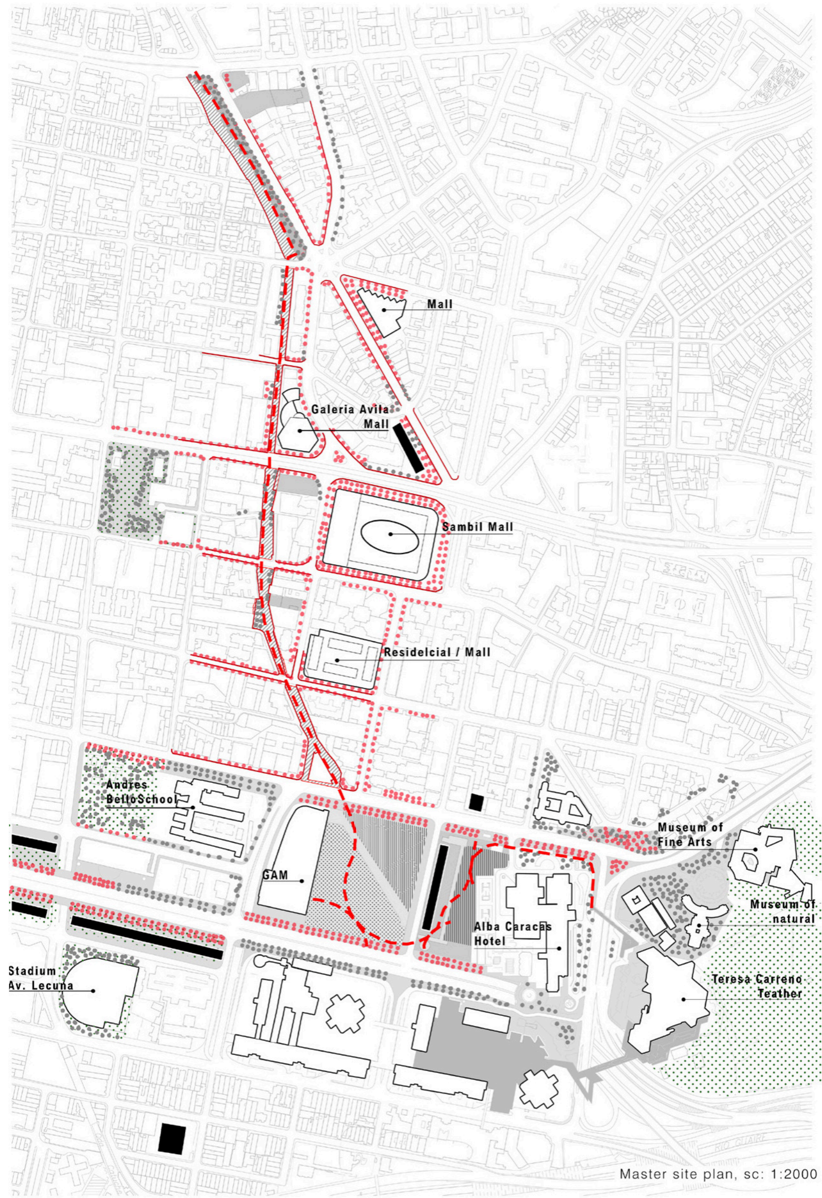


Fig.43. Green infrastructure diagram. Prepared by the author.

Naturalisation

The collage helps us figure out the hypotetical scenario that could arise from the implementation of a green infrastructure. The solution can be applied to multiple areas along the river, helping their renaturalization where the grey infrastructure is not too invasive.

Fig.44. Naturalization collage.
Prepared by the author.

Integration

The green infrastructure allows the integration of sustainable mobility (fig. 45), that creates alternative connection in the urban area. It also allows to protect endangered local flora, that in turn offers the opportunity to create a high impact sustainable system

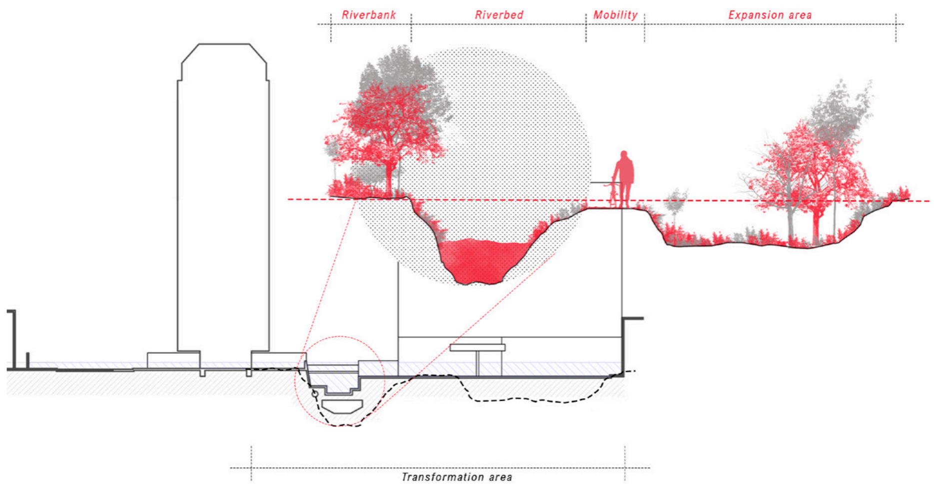


Fig.45. Mobility diagram.
Prepared by the author.

Urban rain garden

A rain garden is an area that has been excavated at shallow depth and containing native flora appropriate to its usage. Rain gardens are designed to collect rainwater running over waterproof surfaces, like roofs, streets, and sidewalks. Rain gardens are an alternative solution to traditional and expensive pipelines and treatment system, for reducing the amount of rainwater entering the sewers.

Most of the places we live in are surrounded in waterproof materials. When it rains in these areas, rainwater cannot penetrate the soil, thus dragging pollutants to rivers and lakes. At the same time, it might cause floods and erosion. Rain gardens provide beautiful areas where rainwater has a chance to restore the natural balance of the soil, filtering up to 99% of the pollutants the rain collects (United State Department of Agriculture, 2011), thus keeping water reserves cleaner.

In this project, we propose the creation of a rain garden in the southernmost expansion basin (fig. 20). The total area of the project, around 14000 m^2 wide, is divided in two parts by a diagonal corresponding to the buried Anauco stream. In the Eastern part an open market is located, while the Western one is an abandoned area. The latter is already excavated at a 10 m depth, since it was planned to be a square, never realized, as part of the 1990s project of the Galeria de Arte Nacional (GAN). Therefore, we propose to form it as a terraced rain garden, with a number of distinct areas on different levels.

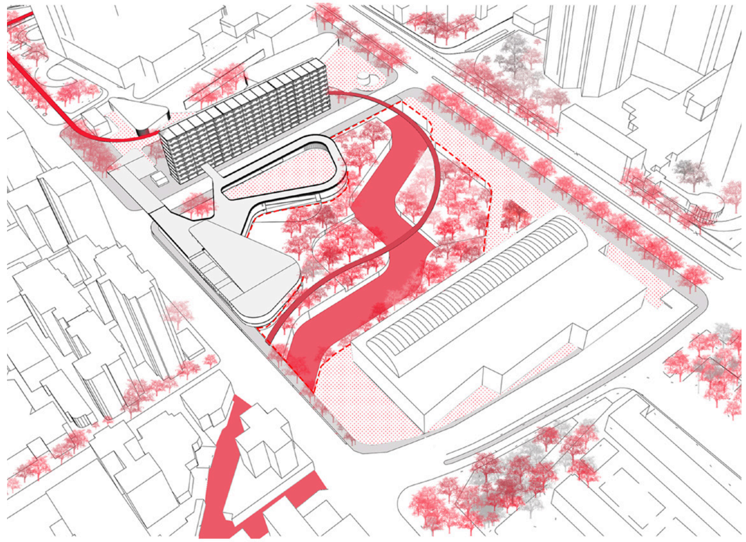


Fig.46. Rain garden
Prepared by the author.

Chapter VI. DESIGN EXPLORATIONS

The context

The avenida Bolívar is the most important street in Caracas. It has been involved in a number of projects since the 1938 Plan Rotival, a project by Henry Prost, Jacques Lambert and Maurice Rotival. It was realized between January and March 1939 under the direction of Prost. The project focused on the renovation of the city and the development of its places of particular value. The avenida Bolívar was designed to be the most important axes of the city also from a visual point of view. In this approach it is very clear the influence of Haussman in Paris.

The Rotival plan was not well received by the Venezuelan authorities. Anyway, Rotival was hired again in 1951 to revisit the 1939 proposal.

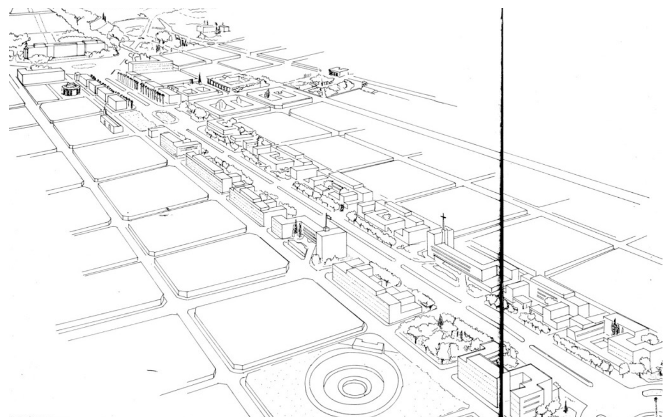


Fig.47. Rotival masterplan

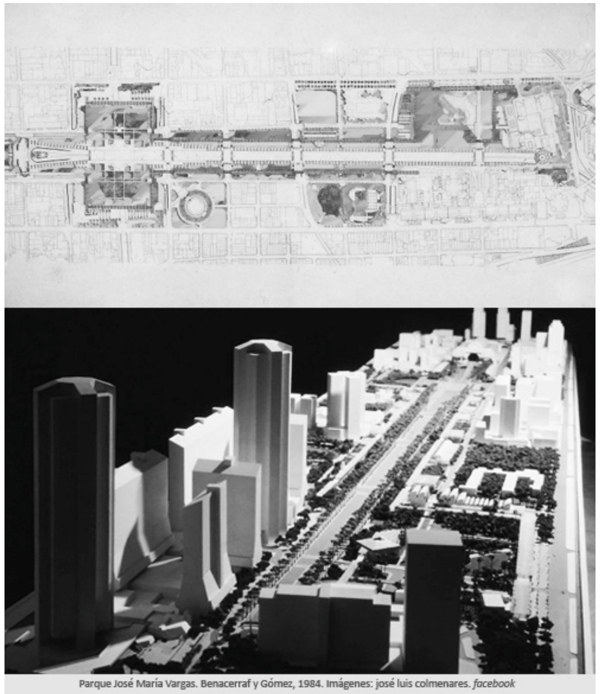


Fig.48. Parque José María Vargas.
PROPUESTAS IN_CONSULTAS
https://sancheztaffurarquitecto.wordpress.com

In 1984 the development plan began for the realization of a urban park in the surroundings of the avenida Bolívar. The park, named after José Maria Vargas, extends along 1,5 km along the avenida. The project has never been completed. Only part of the envisioned structures were built, that still define a rich urban context. In 1986, the construction of the Palacio de Justicia and the Cristobal Rojas school began. The sidewalks were finished in 1987, and in 1988 the Plaza Aérea in the Parque Central complex, the Teresa Carreño theatre, and the Hilton Hotel (now Alba Caracas hotel) were completed. That year, the construction works slowed down significantly, and in some cases stopped completely. Proceres Civiles square was inaugurated in 1989, and in the same year

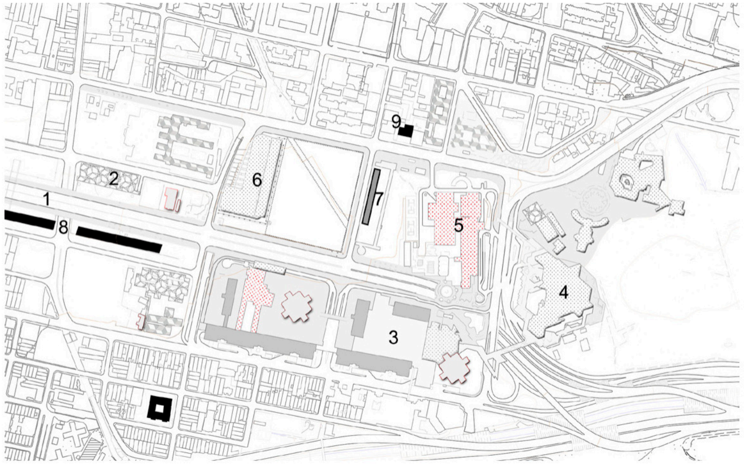
the construction works began on the Galería de Arte Nacional (GAN). Three years later, the Palacio de Justicia was completed and the GAN building site stopped. It started working again 1997, when the Museo de la Estampa y el Diseño Carlos Cruz Diez was opened to the public. In 1999, the construction of the GAN stopped again.

A 2003 decision to dedicate 3000 m^2 of the land for organoponic crops, completely changed the form of the project. In 2005, the works on the GAN started again, so that a year later a first part was inaugurated.

In 2010, the Government proposed the creation of a "misión Vivienda Venezuela" - part of a national social housing project – which incorporated new architectural typologies in the spaces of the Vargas park. The population overgrowth caused by such intervention, completely modified the context and the urban dynamics of the area.

Fig.49. Hotel Caracas Hilton.
Photograph: VENEXILE networks tumblr blog

Context development



1. Avenida Bolívar
2. Escuela Cristobal Rojas
3. Plaza Aérea in the Parque Central complex,1988
4. Teresa Carreño theatre, 1988
5. Hotel Alba Caracas
6. Galería de Arte Nacional (GAN)
7. Misión Vivienda Venezuela Bellas Artes
8. Misión Vivienda Venezuela Avenida Bolívar
9. Misión Vivienda Venezuela

Fig.50. Misión vivienda Bellas Artes building.
Source: biomorgoth, on Flickr

Fig.51. Misión vivienda Bellas Artes building.
Source: biomorgoth, on Flickr

AN IMPORTANT URBAN VACUUM

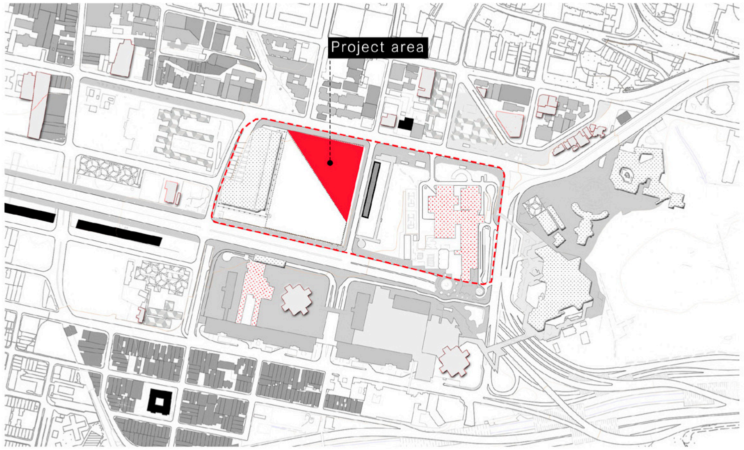


Fig.52. Urban area diagram.
Prepared by the author.

The total area of the project, around 14000 m^2 wide, is divided in two parts by a diagonal corresponding to the buried Anauco stream. In the Eastern part an open market is located, while the Western one is an abandoned area. The latter was planned to be a square, never realized, as part of the 1990s project of the Galeria de Arte Nacional (GAN). Therefore, the whole area, that was part of the Vargas park project, has been for many years an urban vacuum next to the GAN.

The latest project by the Venezuelan government involving the piece of land under exam, was announced in 2008 and has now stopped. The proposal, named Plaza del Alba square, aimed at solving the spatiality of the area by maintaining its configuration in two triangles. The Eastern one was planned to become a green area, while the other should have been a paved square with underground facilities dedicated to cultural activities and art exhibitions.

It was not possible to find more in-depth information about this project, apart from the architectural drawings published by the government magazine Operación Ciudad n. 19.

Fig.53. Canalization of the Anauco stream.
Source: www.metrodecaracas.gob.ve

Fig.54. GAN square. Project by Carlos Gomez de Llarena
Source: Ricardo Stand

Fig.55. Plaza del Alba project.
Source: Magazine Operación Ciudad n. 19

Ignoring the risk

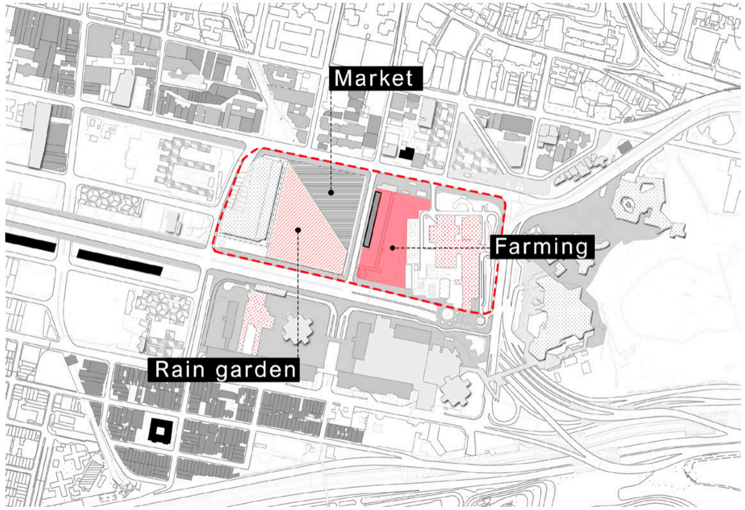
It is disturbing and preoccupying that of all the previous projects we analyzed that involved the area under exam, none takes into account the risks and the environmental implications deriving from the 1970s canalization of the Anauco stream. There are no environmental considerations in the Rotival Plan, nor in the Vargas park project, and not even in the Plaza del Alba project.

Fig.56. Canalization of the Anauco stream.
Source: www.metrodecaracas.gob.ve.

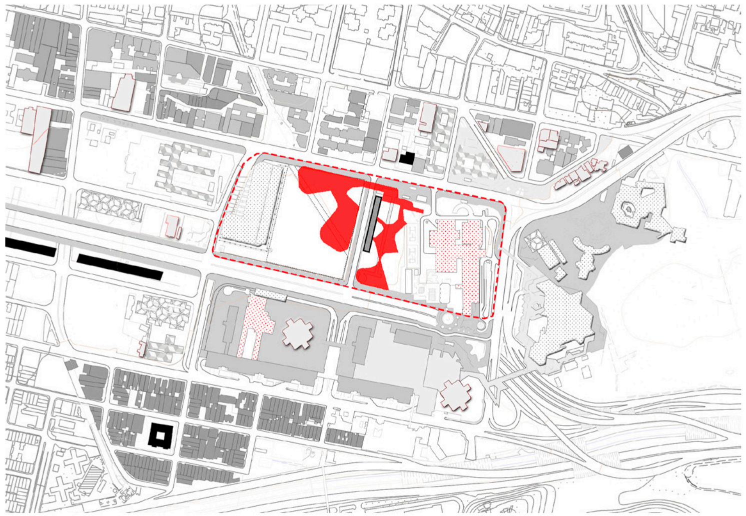
Urban proposal to recuperation

The architectural project is based on five different urban strategies. The first one concerns the occupation of voids through the creation of a mosaic of activites (p.113, top), showed in the masterplan (pp.116-117). The second one is the integration with the existent. The new architectural typologies of the misiòn Vivienda are connected to the rest of the urban context through the creation of public spaces (p.113, bottom) and economic activities that revitalize the area. A practical and visual integration is achieved also with the creation of a footbridge connecting our architectural project to the Parque Los Caobos and the Plaza de Los Museos, the cultural areas of the city. The footbridge (p.114, top) represents also an opportunity to boost sustainable mobility, another important objective of this thesis work. The footbridge starts from an already existing short footbridge between the Teresa Carreno theatre and the Alba Caracas hotel. Then it enters the project area, surrounding the market area and roughly following the path of the Anauco river. It descend to the ground in a number of places, integrating with the rain garden and granting access to the surrounding points of interest. The fourth approach is the regeneration of the ecosystem, thanks to the creation of new green areas, in particular the one we configured as a rain garden (p.114, bottom). The final approach regards the reinterpretation of the existent, through the requalification of the Mercado Popular de Bellas Artes (p.113). Our attempt is the formalization of an activity that was initiated by the Government in the 2000s as a temporary installation, without a proper spatial configuration, therefore it has not allowed the correct fullfilment of the business.

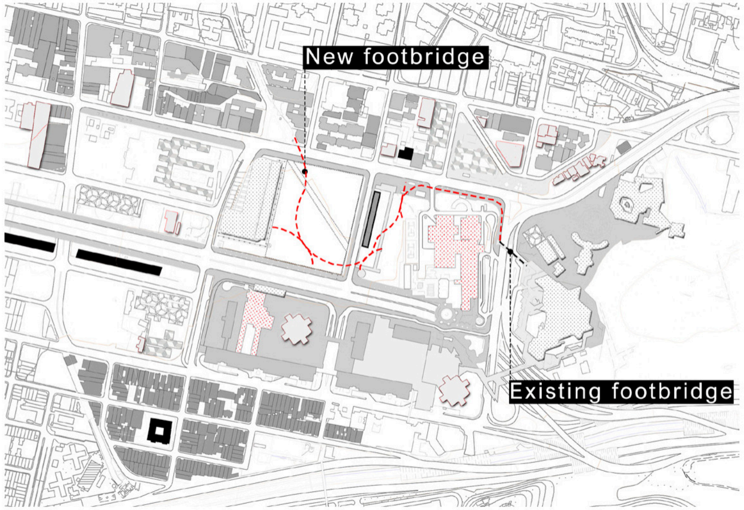
Mosaic of activites



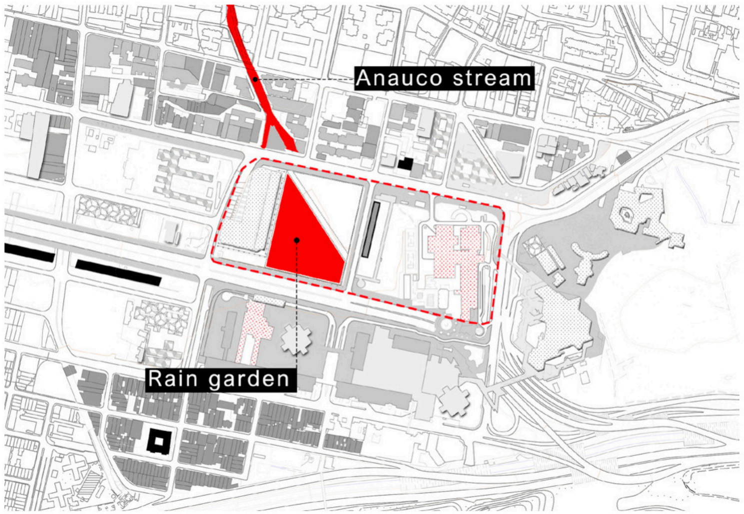
New public spaces



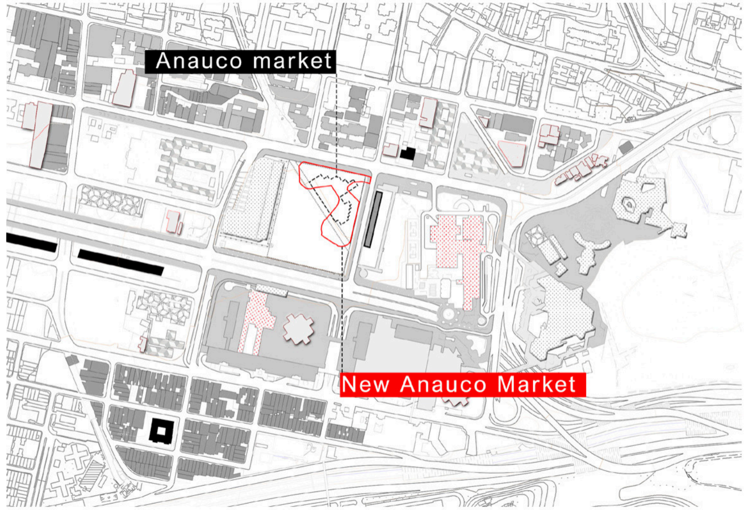
Footbridge



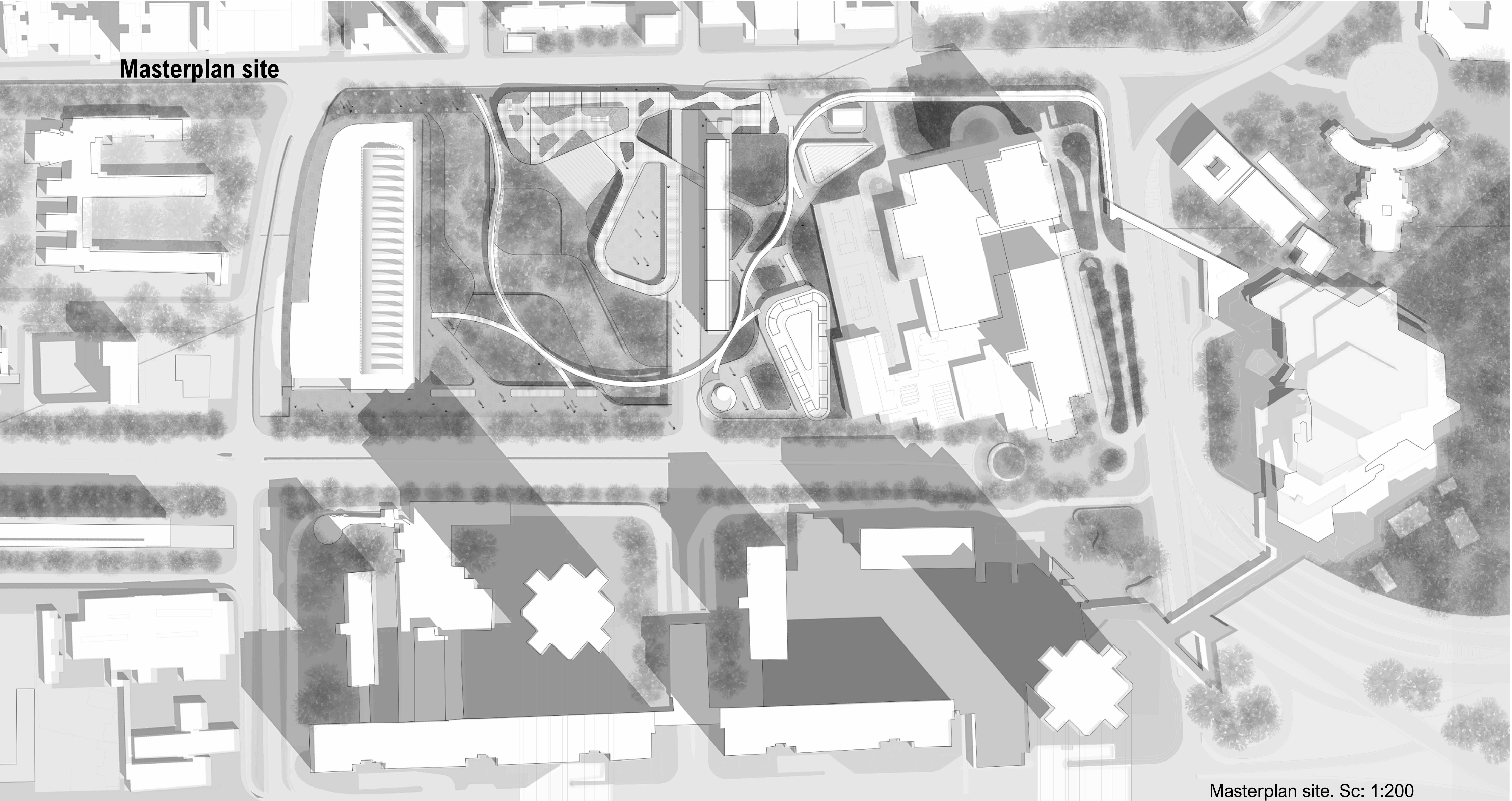
Regeneration of the ecosystem



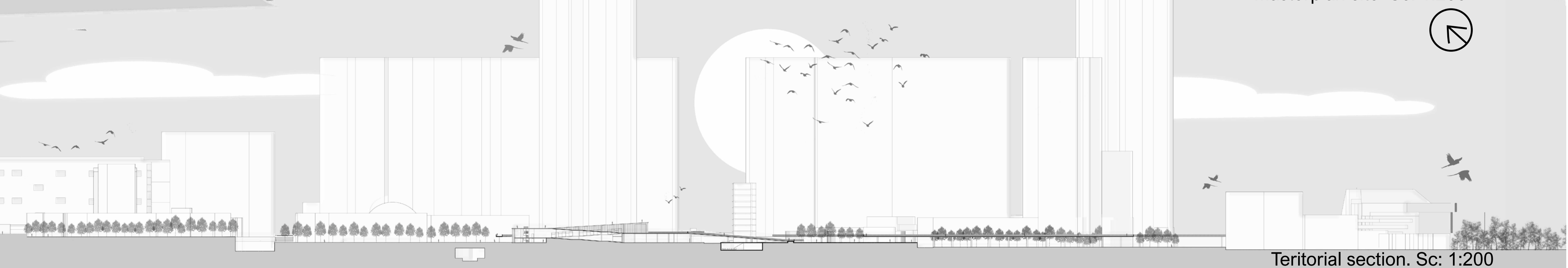
The reinterpretation of the existent



Masterplan site



Masterplan site. Sc: 1:200



Teritorial section. Sc: 1:200

An architectural reference: el Mercat dels Encants

We drew inspiration for our project from El Mercat dels Encants in Barcelona, the city's biggest market designed by Fermín Vásquez Arquitectos in 2013. The group did not want the market to resemble a shopping center, and had as a main objective the preservation of the "openness" of the street and of the already existing market. Therefore their design is a continuous space, wall-less, with ramps looping around the whole structure and giving access to the upper floors.

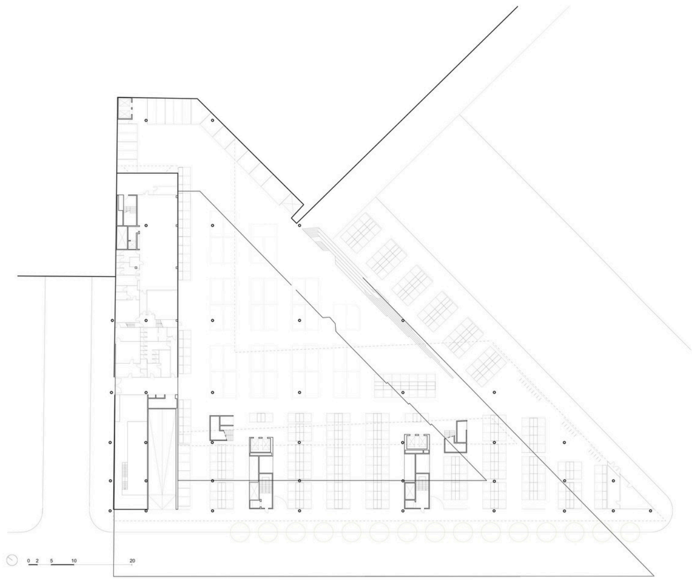


Fig.60. Mercat dels Encants.
First floor plan. b720 Fermín Vázquez Arquitectos
Source: archdaily.com

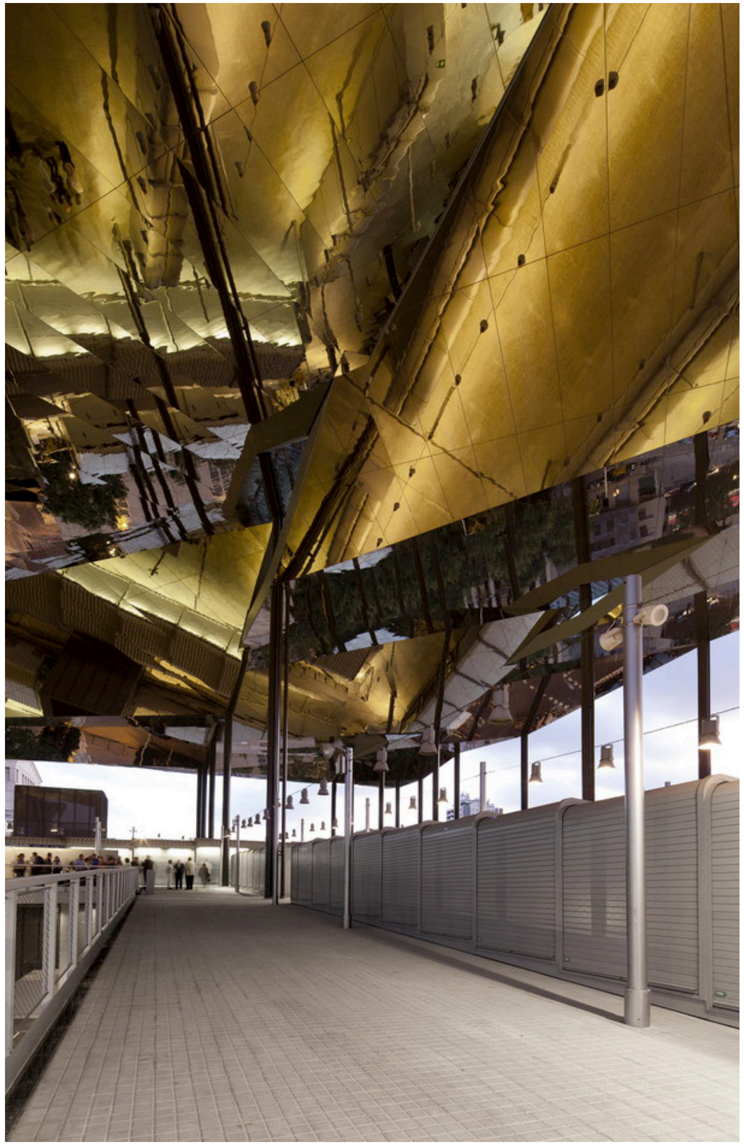


Fig.61. Mercat dels Encants. b720 Fermín Vázquez Arquitectos.
Photograph: Rafael Vargas
Source: archdaily.com

Project proposal: el Mercado Anauco

We designed the Mercado Anauco project (fig. 62), developing on a 13400 m^2 area. We configured it in two distinct sections. The first one corresponds to an open periodic market, which hosts temporary market stalls and street vendors, and can also be used as a polyvalent square for public activities. Around this space, permanent commercial spaces are located, that can be destined to cafés, restaurants and similar activities.

The other section of the project is enclosed in a permeable structure composed by vertical elements. It acts as a brise-soleil, that reduces heat gain by deflecting sunlight. It also allows natural ventilation of the internal area. It hosts the permanent market, structured as two superimposed ramps in which we arranged 132 stalls for the commercial activities.

Above the whole area, encompassing both the open market and the permanent one, there is a public space. The ramp creates a connection to the metro station, from which it departs, gradually raising to the public space on the rooftop terrace.

The whole structure is made of reinforced concrete in the lower levels, that is, the bearing structure of the underground floor with the parkings, and of the ground floor. The upper level supporting the ramp and the rooftop terrace is made of steel.

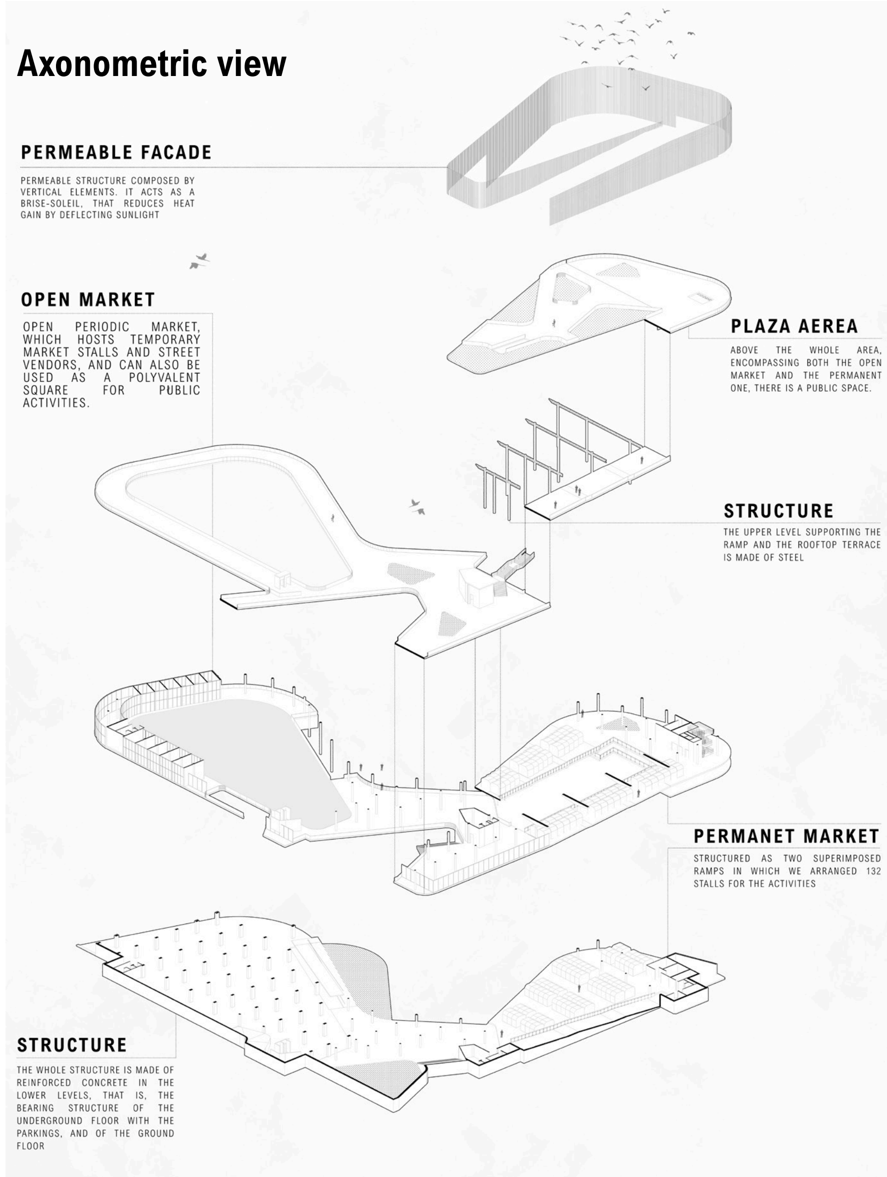
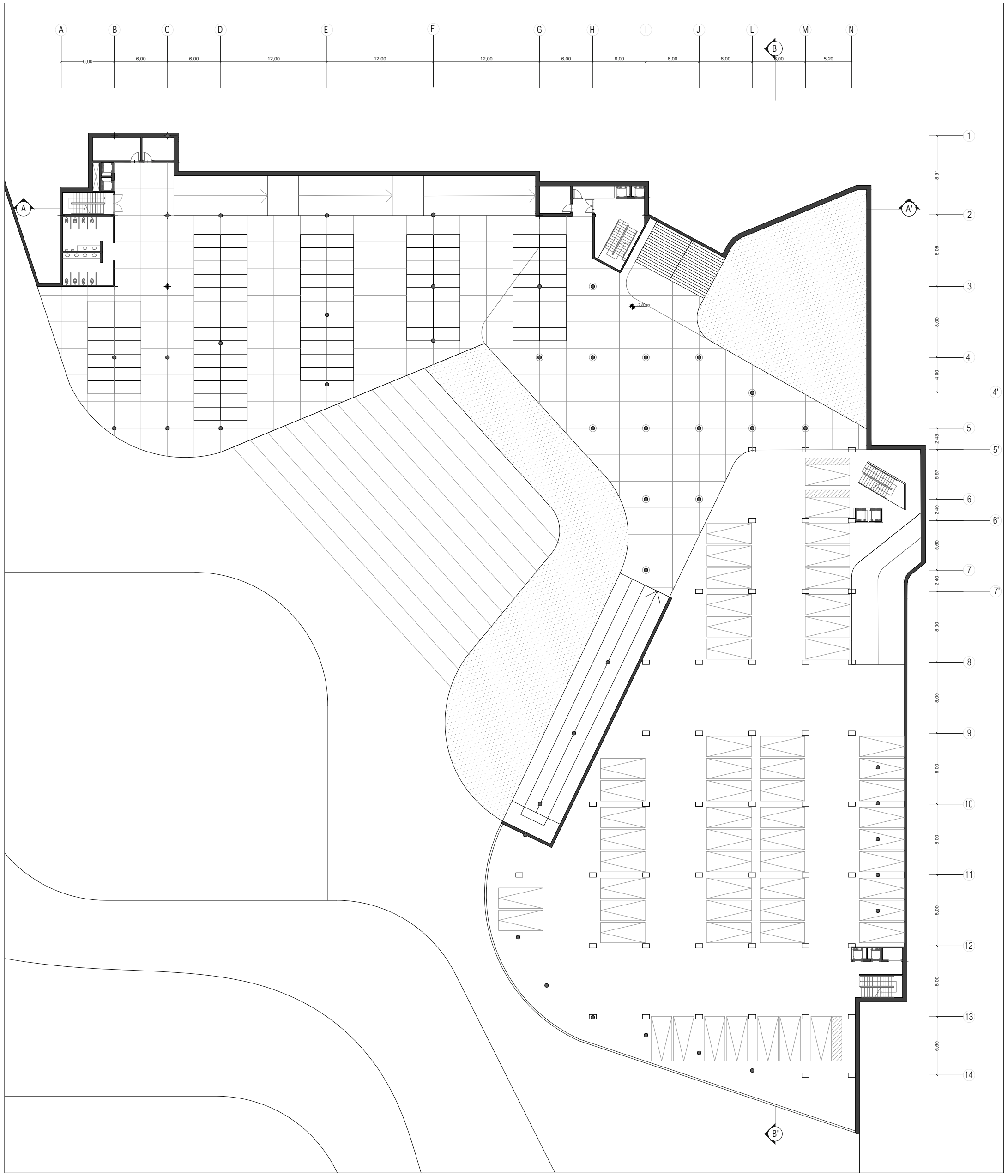
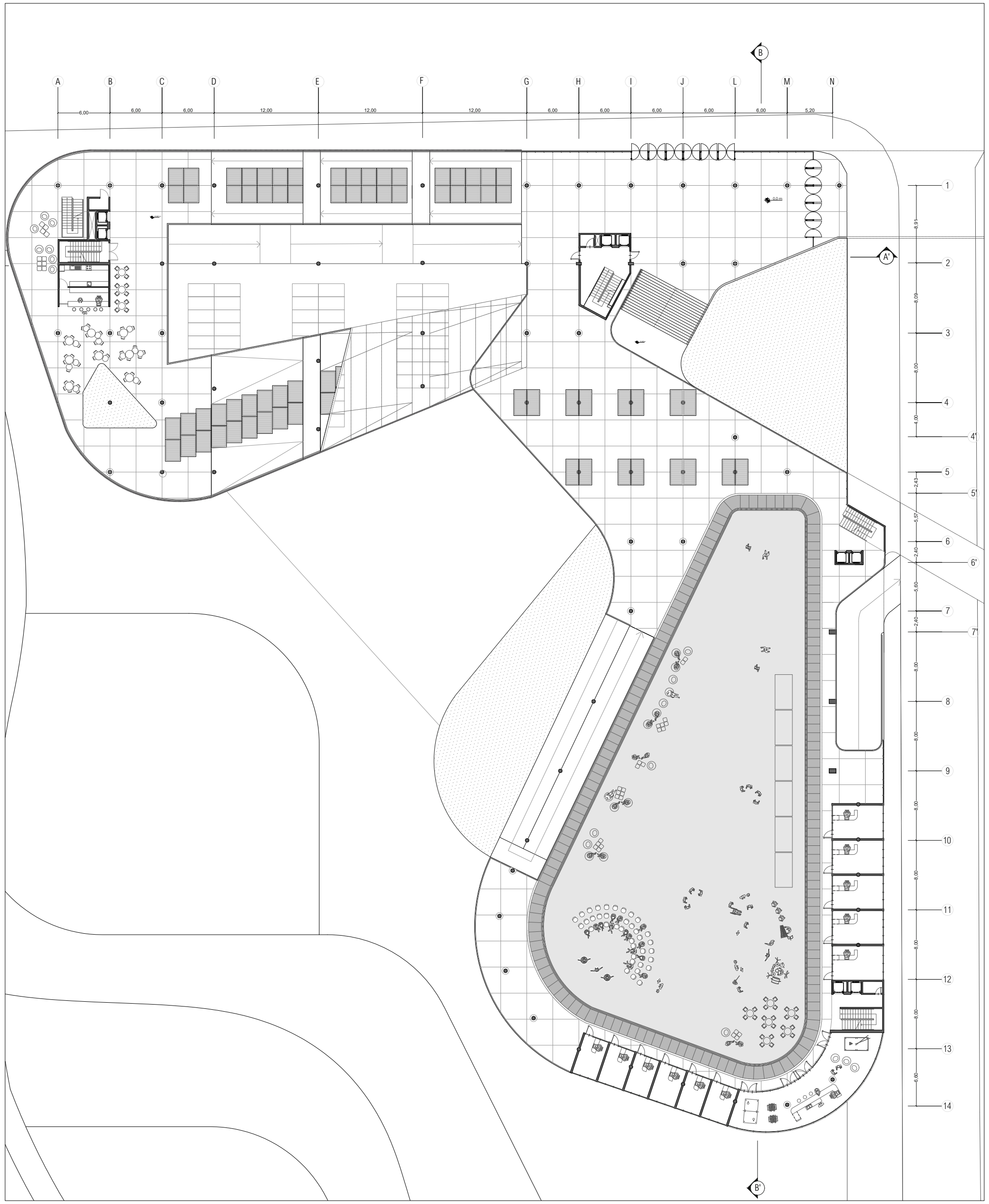


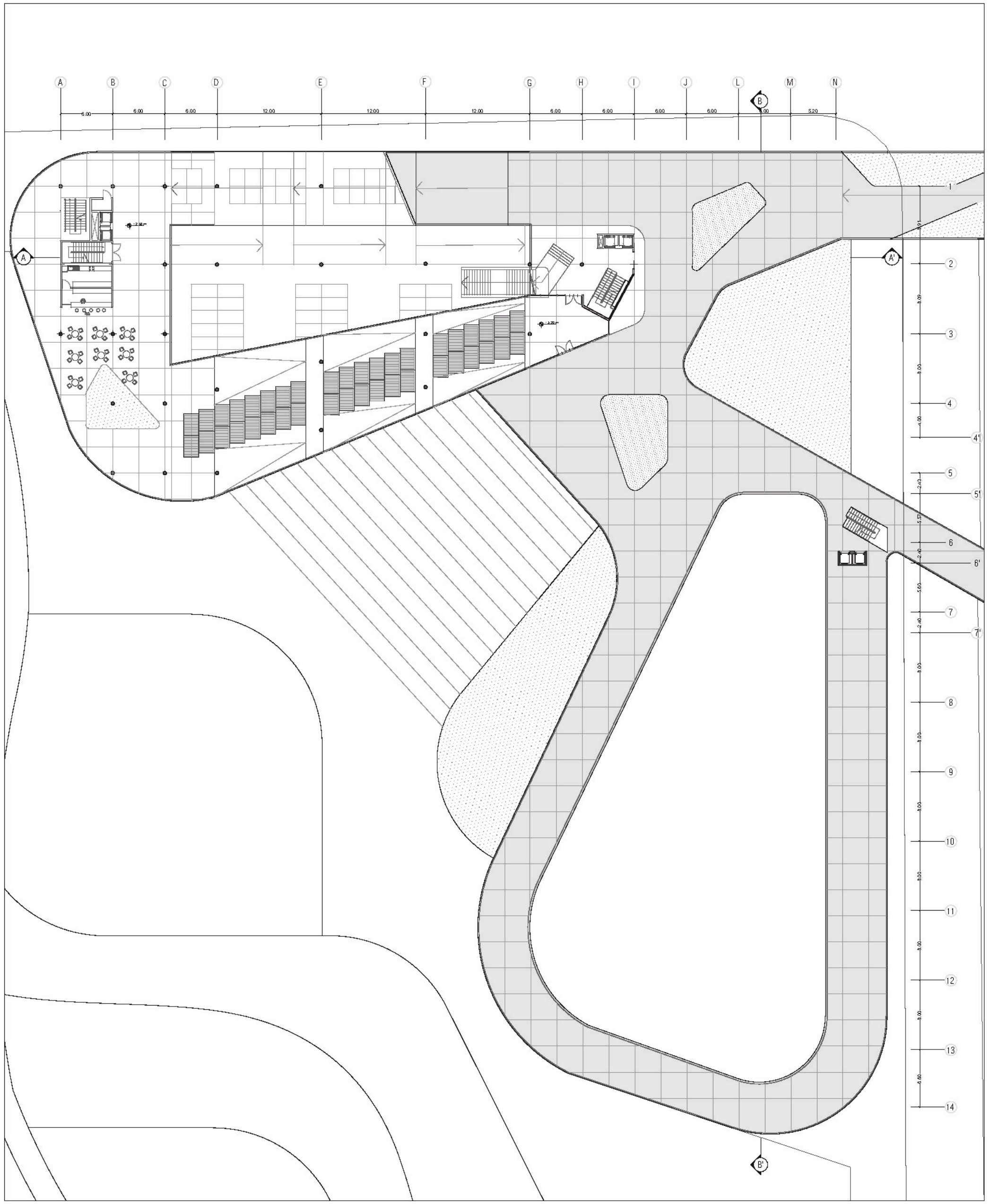
Fig.62. Mercado Anauco.
Axonometric view.



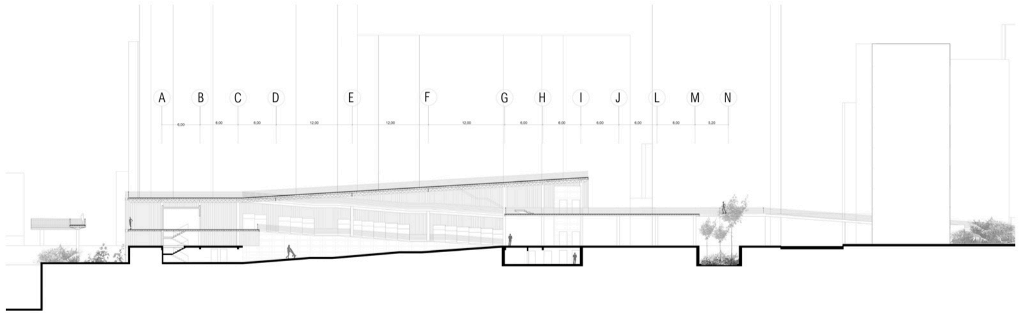
-1 floor plan
SCALE 1 : 200



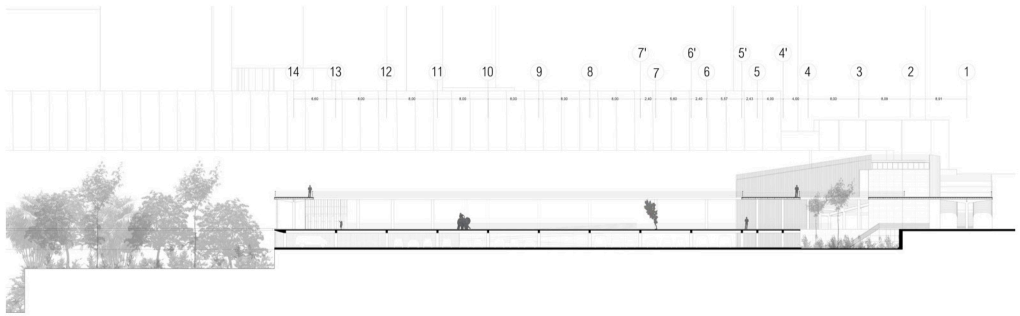
0 floor plan
SCALE 1 : 200



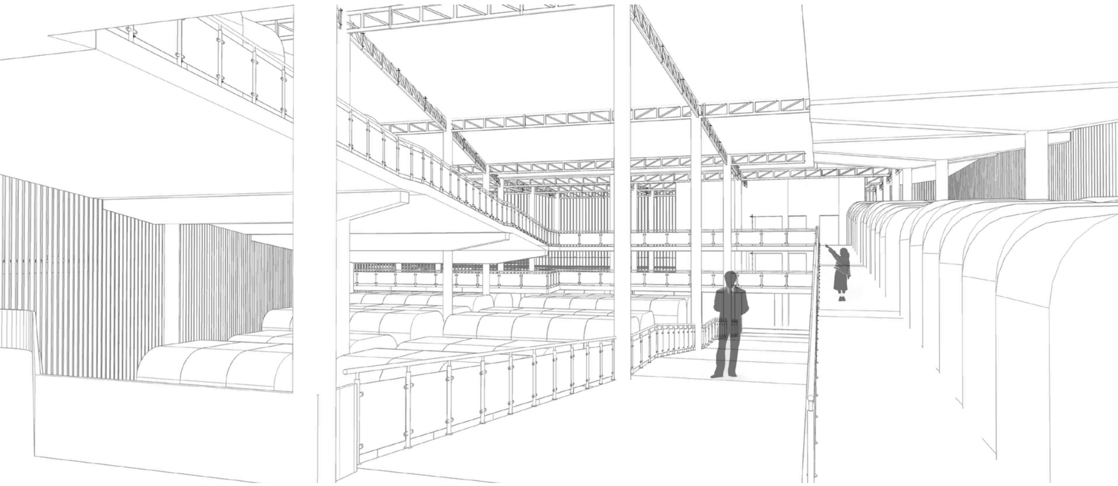
+1 floor plan
SCALE 1 : 200

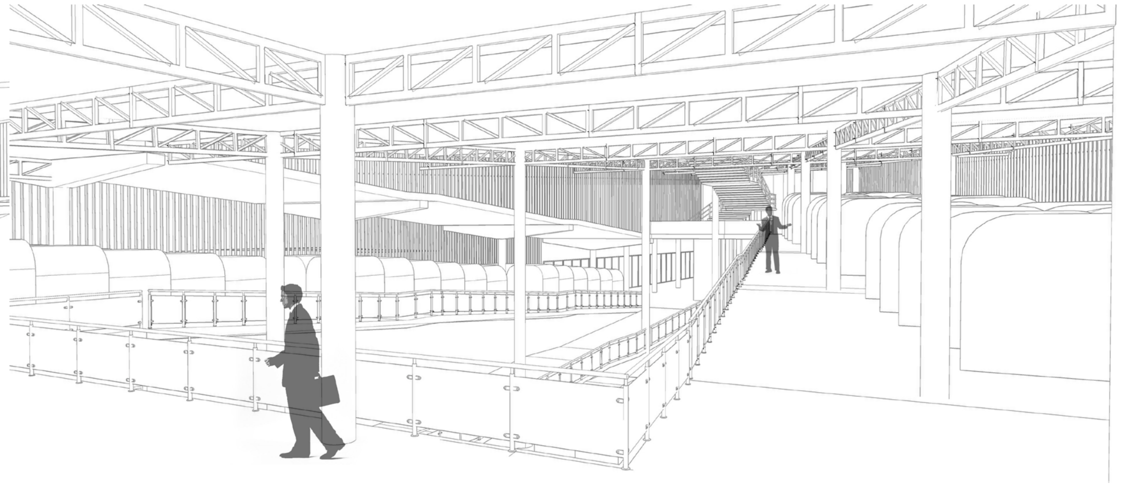


Section A-A`



Section B-B`





CHAPTER VI. CONCLUSIONS

Caracas is a complex city, that rapidly evolved during the 20th century thanks to the oil revenues. Its development happened in distinct bursts, without taking into much account the environmental and urbanistic concerns for a responsible and resilient growth. The construction works involved, among the other interventions, also the canalization and interment of the rivers that characterize the landscape of the city.

These previous interventions, that did not fit together harmoniously as necessary parts of a whole, caused a rapid deterioration of some areas. The new infrastructures and buildings in fact proved to be not resilient enough to phenomena like increasing natural disasters due to climate change, population growth, and evolution of urban dynamics.

The purpose of this thesis work was twofold. First, the urban requalification of the Bellas Artes district, a difficult area from both an urban and environmental point of view, being an area subject to flooding and characterized by a high population density. The second goal was the renaturalization of the Anauco stream which is currently interred. The first goal could not be achieved without working on the second one. In fact, the Anauco stream represents a constant threat to its surroundings during the recurrent heavy rains. Because of the poor design of the grey infrastructure and the lack of its proper maintenance, rainfall cause floods that gradually lowered the quality of life along the riverbanks.

The design phase was preceded by a study of Caracas' evolution and by information gathering about the environmental problems of the city. A thorough analysis has also been carried out about some previous unfinished or abandoned requalification projects. Then, we performed a risk assessment analysis from the hydrogeological point of view, and a requirement analysis for an effective and efficient design of the proposed solution.

Our analysis is subject to some limitations. The available bibliography is not extensive and in some cases it is outdated, in particular the hydrogeological studies. The current political and economical situation of Venezuela does not allow direct access to the area, nor to potentially useful official documentation.

Our urbanistic proposal, aimed at the second goal of the thesis, is composed by two items, the creation of a blue infrastructure and of a green one, following the guidelines for a resilience process. Such process required the daylighting of the Anauco stream, that is the removal of the superstructures, returning it to its natural state.

The architectural proposal instead involved an area limited to the Bellas Artes district, cultural heart of the city. Since the 1970s it has been compromised by the presence of the buried Anauco stream, and is now in a state of abandonment and degradation. Here we designed the Mercado Anauco, as an urban revitalizing element to foster commercial activities and social recuperation.

Future developments

For the sake of this work, the requalification has been limited to one stream and one district of Caracas. However, the contemporary approach to architecture is aimed at a sustainable and resilient development of urban spaces. The same concepts we leveraged could be applied to other areas of the city that suffer from problems due to careless design.

Such interventions could be realized more easily through access to the necessary and updated information, that would also allow a more in-depth engineering analysis. At the same time this thesis work can be considered a starting point for more technical projects that fit harmoniously in the urban context.

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Sustainability has become an ornament.

Rem Koolhaas