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Urban Metropolitan Green Lung, Mexico City.

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Abstract

The object of this work is the creation of an Urban Metropolitan Lung in the east Mexico City, in an area of 750 hectares currently occupied by the Benito Juarez International Airport. The land distribution requirements were stipulated at the 17 Arquine architectural competition. The project proposes the creation a large metropolitan park and a new development that includes housing and buildings for the tertiary sector, as well as the required urban services.

The first step undertaken was the gathering of information concerning social, economic, environmental, and urban aspects and its consequent analysis on different working scales. This allowed to establish the opportunities that had the area, and which were the needs of both the city and the new inhabitants, as well as the way they could influence the generation of the master plan.

The next step was the development of an urban master plan, having as premises to encourage the generation of a less car-dependent urban mobility, a more sustainable management of the water, and the inclusion of the nearby neighborhoods by providing eco-systemic services and the creation of new public spaces for the city.

For the architectural design, it was desired to transfer the philosophy of the urban scale to the particular design of a block of the project. On this section, it was planned to construct a group of low-rise high-density buildings that through a strategic mix of uses will allow the creation of a dynamic neighborhood.

One of the premises for the architectural design was the creation of units of housing, jobs and trade that were completely comfortable from the thermal and visual points of view, and to take advantage of the climatic characteristics of the city, through the use of natural lighting and ventilation. This required a dynamic analysis of the visual and thermal conditions of the building under various construction technologies, so that it was possible to choose the most appropriate ones to achieve this goal. This, together with various cultural and historic considerations made possible to obtain an architectural proposal for a building, with their respective technological and structural specifications.

Sintesi

Lo scopo di questo lavoro è stato la creazione di un Polmone Metropolitano nel oriente della Città del Messico, in un'area di 750 ettari attualmente occupate dalla aeroporto internazionale Benito Juarez. I requisiti di distribuzione della terra sono stati stipulati al 17 concorso di architettura Arquine. Il progetto propone la realizzazione di un grande parco metropolitano e un nuovo sviluppo urbano che comprende abitazioni e edifici per il settore terziario, nonché i servizi urbani richiesti.

Il primo passo intrapreso è stato la raccolta di informazioni riguardanti agli aspetti sociali, economici, ambientali e urbane e la conseguente analisi su diverse scale di lavoro. Questo ha permesso di stabilire le opportunità che aveva l'area, e quale erano le esigenze sia della città che dei nuovi abitanti, così come il modo in cui loro possono influenzare la generazione del master plan.

Il passo successivo è stato lo sviluppo di un piano urbanistico, avendo come premesse incoraggiare la generazione di una mobilità urbana meno auto-dipendente, una gestione più sostenibile dell'acqua, l'inclusione dei quartieri vicini fornendo servizi ecosistemici e la creazione di nuovi spazi pubblici.

Per la progettazione architettonica, si è voluto trasferire la filosofia della scala urbana al particolare disegno di un blocco del progetto. In questa sezione, si voule costruire un gruppo di edifici bassi ad alta densità che attraverso un mix strategico di usi consentiranno la creazione di un quartiere dinamico.

Una delle premesse per la progettazione architettonica è stata la creazione di unità di alloggio, lavoro e commercio che siano completamente confortevole dal punto di vista termico e visivo, e di sfruttare le caratteristiche climatiche della città, attraverso l'uso della luce e la ventilazione naturale. Questo ha richiesto un'analisi dinamica delle condizioni visive e termiche dell'edificio sotto varie tecnologie costruttive, in modo che fosse possibile scegliere i più appropriati. Questo, insieme a varie considerazioni culturali e storiche hanno reso possibile avere una proposta architettonica per un edificio, con le rispettive caratteristiche tecnologiche e strutturali.

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Chapter I: The context

1. Introduction

The development of an urban project in a highly populated city within the criteria of sustainability is a very complex task, and even more so when taking into account the social and cultural conditions of the developing countries where are present processes of accelerated settlement and growth of the cities.

Having in mind our Latin-American origins, we have decided to work on a project located in a place related to our future work context, in order to apply all the knowledge acquired during this Master of Science, but considering the particular conditions of our own countries. For all this reasons, we have chosen Mexico City, and specially, the project of the reconversion of the existing Benito Juarez International Airport into a new hub of urban, economic, social and environmental development.

2. Competition brief

Arquine is a project founded in 1997 in Mexico, dedicated to the construction of architectural culture, a platform for generating content from the magazine, social networks, radio, competitions, conferences, festivals, postgraduate and books.

The International Architecture Competition *Arquine*, has been realized since 1998 and seeks to explore issues of importance and relevance to the Mexican society in general, encouraging the opening of spaces for dialogue and promote the participation of national and international architects to find responses to problems of urban and architectural nature.

After the announcement of the construction of a new international airport for the city in the area of *Texcoco*, The contest aimed to create different proposals for the [future] urban areas with the greatest potential of the country, a total of 746 hectares that could become the catalyst for development and growth of the eastern part of one of the most complex and populated cities of the world.

Finding the vocation of the space now occupied by the Benito Juarez International Airport in Mexico City is one of the most interesting challenges in terms of urban development worldwide. It was presented as an opportunity to inquire through a public and open competition the possibilities of generating a large green area in the east of the continent's most populous metropolis.

2.1. Target of the contest

Define the vocation for the space that is actually used for the airport of Mexico City. The following composition was proposed:

- **75% metropolitan park (5'595,000 m²)**

Create a big green lung in the eastern side of most populated city of the Americas, considering its natural vocation as a floodable space and water regulator.

- **10% housing, services and facilities (746,000 m²)**

Propose a new housing through the recovery, transformation and densification of the space.

- **15% offices, hotels, business center, fair hub. (1'119,000 m²)**

Incorporate uses considering the potentiality of the zone as a hub of international exhibitions.

In addition, the project will propose solutions to optimize the connectivity with the city, the historic center and the new airport that will be located in the adjacent area of *Texcoco*.

3. Actual state

3.1. General information:

Location:
Northeast of Mexico City, in the neighborhood *Peñon de los Baños*, delegation *Venustiano Carranza*.

Elevation:
2237 MAMSL on a lacustrine plain.

Geographical coordinates:
19° 26'07" North Latitude.
99° 04' 20" West longitude.

Built area:
576,802.63 m2 divided in:
Terminal one: 332,136.08 m2.
Terminal two: 242,666.55 m2.

Climatic zone:
Highland subtropical area: temperate weather with dry winters (5°C-25°C).

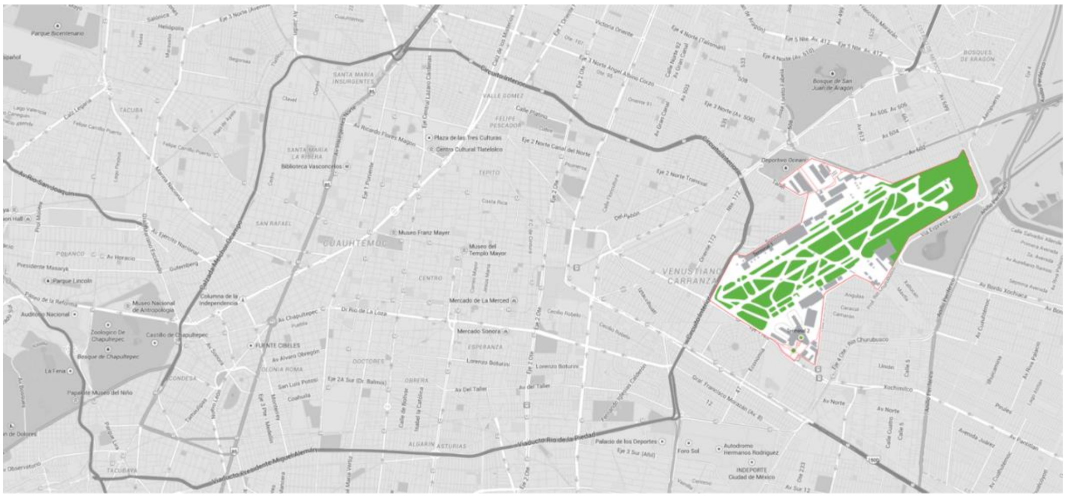
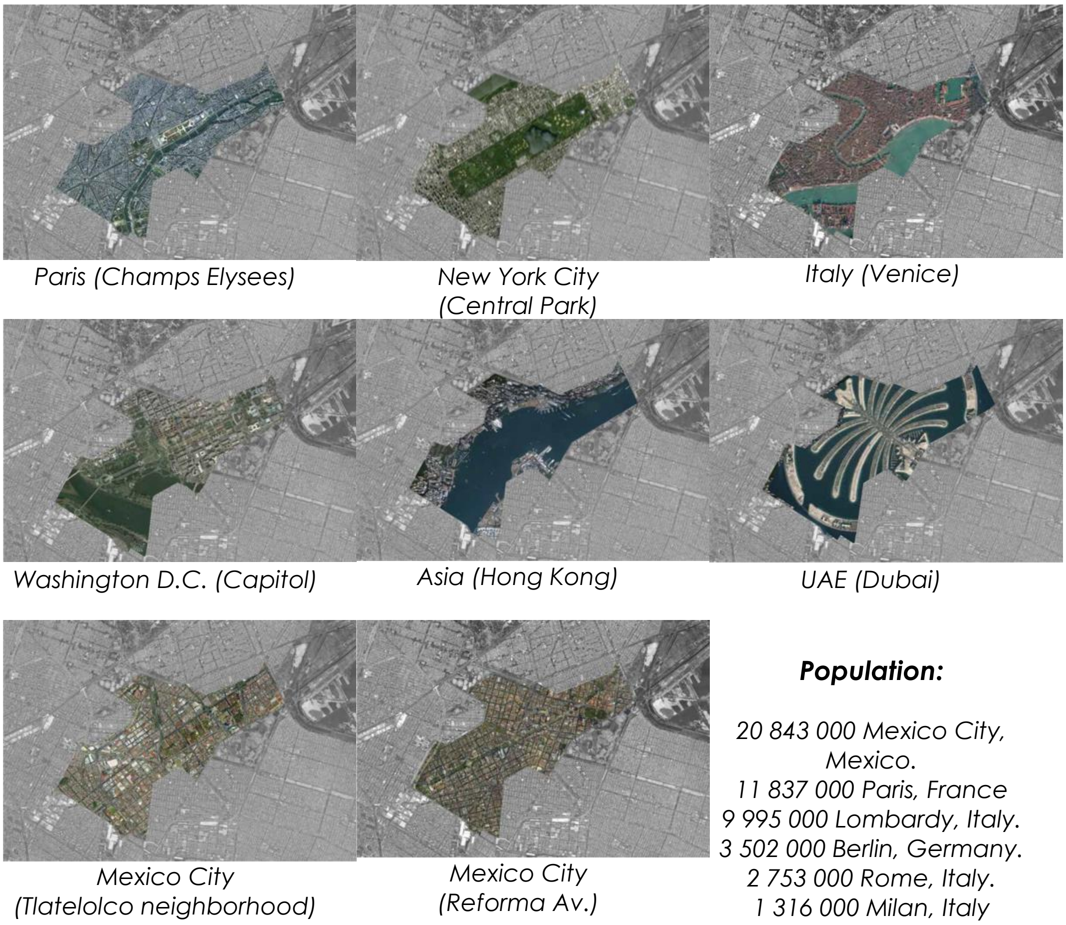


Figure 1: Benito Juarez International Airport in Mexico City

3.2. Scale comparison

Confirmed by the ONU, Mexico City is the 4th most populated city in the world (after Tokyo, Delhi and Shanghai) with 20 million 843 thousands inhabitants. To have a more accurate vision of the scale of the project, a graphic comparison of the area is presented on the next figure, with representative places around the world, and also with other important points within the city itself.



Population:

20 843 000 Mexico City, Mexico.
11 837 000 Paris, France
9 995 000 Lombardy, Italy.
3 502 000 Berlin, Germany.
2 753 000 Rome, Italy.
1 316 000 Milan, Italy

Figure 2: Scale comparison of the project

4. Historical framework

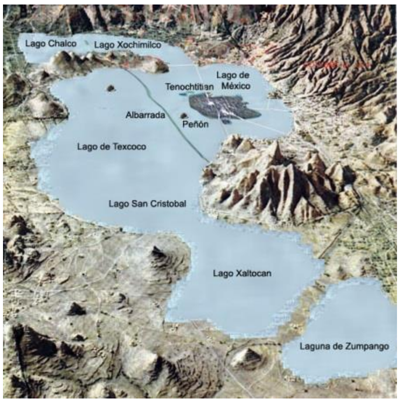


Figure 3: Recreation of the lakes of the Mexico Valley.

The Valley of Mexico has been inhabited for at least 12,000 years, attracting humans with its mild climate due to its location on a highland plateau at 2240 meters above the sea level. Located in the central part of modern Mexican Republic, roughly coterminous with the present-day Distrito Federal and the eastern half of the State of Mexico. Surrounded at the south and the west by the Ajusco Mountains, at the north by the Guadalupe hills, and at the east by the Popocatepetl and Iztaccihuatl volcanoes.

Approximately in the year 1000 BC, around the shores of the Texcoco lake flourished several towns and villages dedicated to activities such as agriculture, commerce and ceramic manufacture. The agricultural prosperity was based in the "*chinampa*" (Figure 4: Agricultural system.), a system of intensive agricultural operation by means of constructing artificial islands in the lakes of the valley which were fertilized by the mud and organic materials deposited in the bottom of the lake. That agricultural system had a constant supply of water that allowed to have several harvest per year.

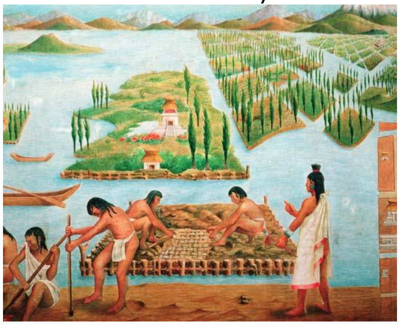


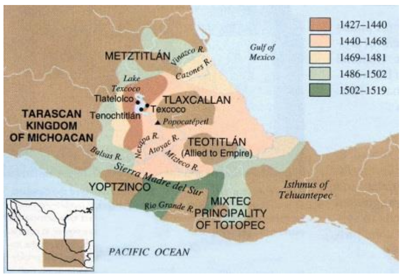
Figure 4: Agricultural system.

Highly developed theocratic societies were conformed: Cuicuilco at the South, Teotihuacan at the North (Figure 5: Sun pyramid, Teotihuacan.). After natural and political problems were abandoned around 600 a. D.

Hundreds of years later, new groups of Nahuatl speaking immigrants from the tribes of the north arrive to the valley. They learned the costumes and agricultural techniques from the former inhabitants of the valley, and also settle little villages that years forward would create a complex and high developed net of production centers and commerce interchange around the shores of Texcoco Lake. Some of that cities were Azcapotzalco, Culhuacan, Texcoco, Mixcoac and Tlacopan. And Mexico-Tenochtitlan that achieve power as once Teotiuhuacan did.

Figure 5: Sun pyramid, Teotihuacan.

Tenochtitlan became the capital of the Aztec Empire and after a strong expansionist campaign extended its domains at regions as far as the Mayan Chiapas and Central America (Figure 6: Aztec Empire).



The city had a very well organized system of fresh water supply, drainage, and ample street and water channels that were used to transport products from all the directions of the empire.

Figure 6: Aztec Empire

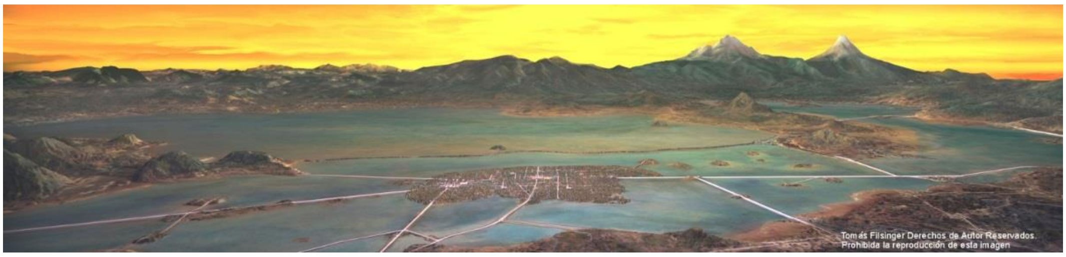


Figure 7: Tenochtitlan in 1521, when the Spanish conquerors arrived.

On august 13 of 1521, Mexico-Tenochtitlan was defeated by the Spanish army. In 1536 was declared the capital of the viceroyalty of New Spain. The Spanish city was built upon the ruins of the indigenous capital, taking the street outline of Tenochtitlan and a big open space in the center that later would become the central square of Mexico City. Around the square were located the sear of the government and the first stone of the future cathedral of Mexico (Figure 8: Zócalo, Mexico City. XIX Century.).

The consolidation of a local administration that from Mexico City controlled justice, taxes and commerce in a huge territory that included the totally of southern part of North America, Central America and the Philippines. It was also the place of construction of a big amount of convents and temples, most of them in baroque style, and size compared with the ones constructed in the capitals of Europe.

At the beginning of the XIX century the city faced the independence movement, in 1847 was occupied by the American army, and later the French invaded the country, facing the second period as empire. This second empire although brief had a big influence on the development of the city. After the fall of the empire, were created the first extensions of the city: *Colonia Guerrero, Santa Maria de la Rivera and Colonia Tabacalera* (for the middle class).

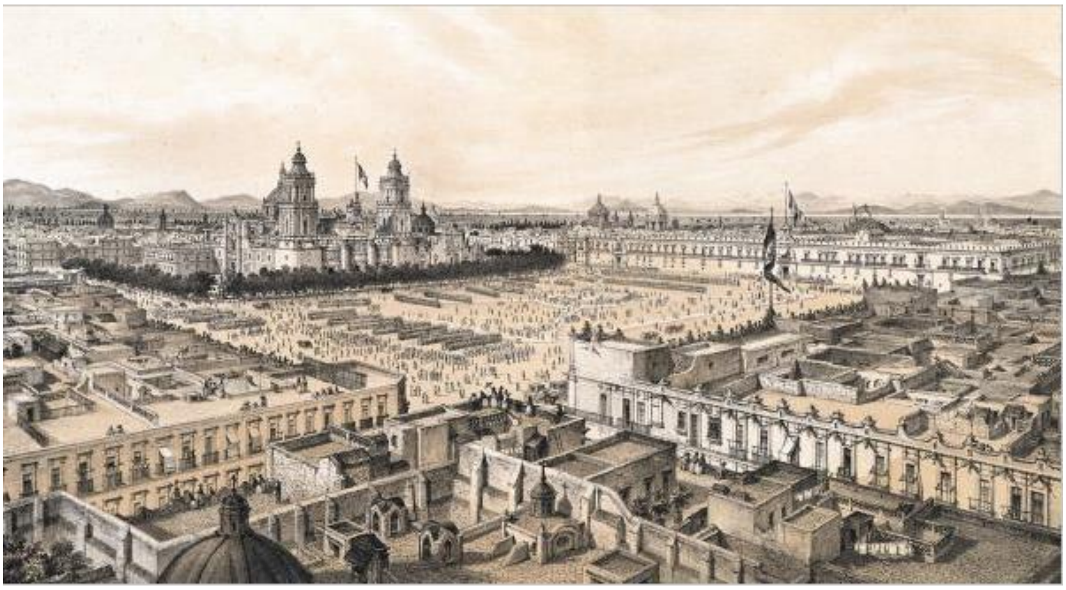


Figure 8: Zócalo, Mexico City. XIX Century.

In the XX century the Mexican Revolution broke out. During the thirties the city was a center of cultural effervescence. New neighborhoods were built: *Colonia Condesa*, *Colonia Roma* and *Colonia del Valle* in the south; *Polanco* and *Lomas de Chapultepec* at the west. It was created also *Insurgentes* avenue. In the 40's the first high density dwelling projects were built. By then the city had 1 million inhabitants. In 1952 was created the *Universidad Nacional Autónoma de México* (UNAM). In the 60's the first American-style suburbs of Mexico City were developed in the northern edge of the metropolitan area. In 1968 it was the headquarters of the Olympic Games. In 1969 was inaugurated the first subway line. In 1985 the city was struck by a magnitude 8.2 earthquake, more than 10 000 people died and several buildings were damaged. In 1987 the historical center and Xochimilco were declared World Heritage by UNESCO. The city received the XXI century with 18 million inhabitants.

5. Information Analysis

This process of the project was developed to have a better understanding of the site, its components and context. The data used during this investigation is mainly from public agencies responsible of this area, but also from the personal experience of one of the authors who lived in the city for several years.

A key element for the understanding of a site is to consider it as part of several systems that are overlapped: urban infrastructure, urban facilities, human activities, environmental services, urban ecosystems and wildlife; all of them interacting in different scales: metropolitan, regional and local.

An ecological planning model (Palazzo & Steiner, 2011) is followed to inventory a list of elements that are considered as fundamental for any site:

- Regional climate: temperature and precipitation.
- Terrain: elevations and slopes.
- Water: precipitation, uses, groundwater, hydrological cycle, flooding areas, water quality, hydrologic system, water supply and sewage treatment systems.
- Soils: Characteristics, capability to support the development of urban agriculture.
- Microclimate: Ventilation, solar radiation, temperatures.
- Vegetation: plant communities, rare, endangered, native and adaptive species.
- Wildlife: species, habitats.
- Existing land use and land users: physical arrangement of space, ownership, settlement patterns, buildings and open spaces types.

As time passes, every place of a city evolves in different ways with the intervention of its inhabitants by means of additions, integrations, redevelopments, restorations, replacements, eliminations or removals (Palazzo & Steiner, 2011). This is why, the study of the history of the site is considered on a project with the following topics:

- Nature of the place: what were the ecological conditions prior to the human settlement and how people have interacted through time.
- Urban texture: How the city has been formed, which actions and forces molded it, when the main transformations occurred.
- Patterns of blocks and their characteristics: Their evolution, their density and they formal composition (height and masses).
- Density: Number of inhabitants per hectare on a given site.
- Single functions of mixed use: what marks or has marked a neighborhood.

- Armatures: those urban elements that act as a polar arrangement in which urban space is arranged on an axis between two key attractors.
- Building typologies: What they are, how they have evolved, which of them have lasted through time.
- Single buildings: Building protected by law for historical, architectural, functional, or other reasons.
- Street network: their sections, functions, their role when they were design and which parts are on use.
- Public space: how they have changed, which functions are carried out now compared to the original planned.
- Landmarks: elements which help the movement of people through the city.

Socio-economic analysis are used to show the changes in composition and character of the people who live in or near the site. Analysis can be done through trends, characterization of the population and projection techniques. Economic analysis are usually carried out to understand the phenomena connected with the work activities, composition of the workforce, and real estate market trends, as well as the possible effects of the transformation.

Another important aspect to consider is the study or the transportation and urban mobility, as the major ways to get in, out and around the study area. Considering the network of streets and roads as well as the land uses is fundamental for understanding the demand of transportation. A good accessibility is achieved considering aspects as travel cost, travel time, destination choice, public transportation, bike and walking paths.

For any urban development it is important to analyze also the existing network of social facilities such as parks, schools, hospitals, social services, religious sites, sport facilities, shops, community centers, and libraries and other cultural facilities, to consider how the demand of new inhabitants will formulate the necessity to create new spaces.

As working in a city with the characteristics of Mexico City is not easy, after the process of gathering information was realized, a set of maps was developed on different scales, starting from the wider zone of influence, that for this project was considered the metropolitan area of the Valley of Mexico, to the local zone near the existing airport of the city. The information was classified according to its relevance into four aspects: Urban structure, Mobility, Ecological value and Facilities.

5.1. Metropolitan scale: The valley of Mexico

In this scale, a set of elements was identified and the analysis done is summarized on the annex U-1.

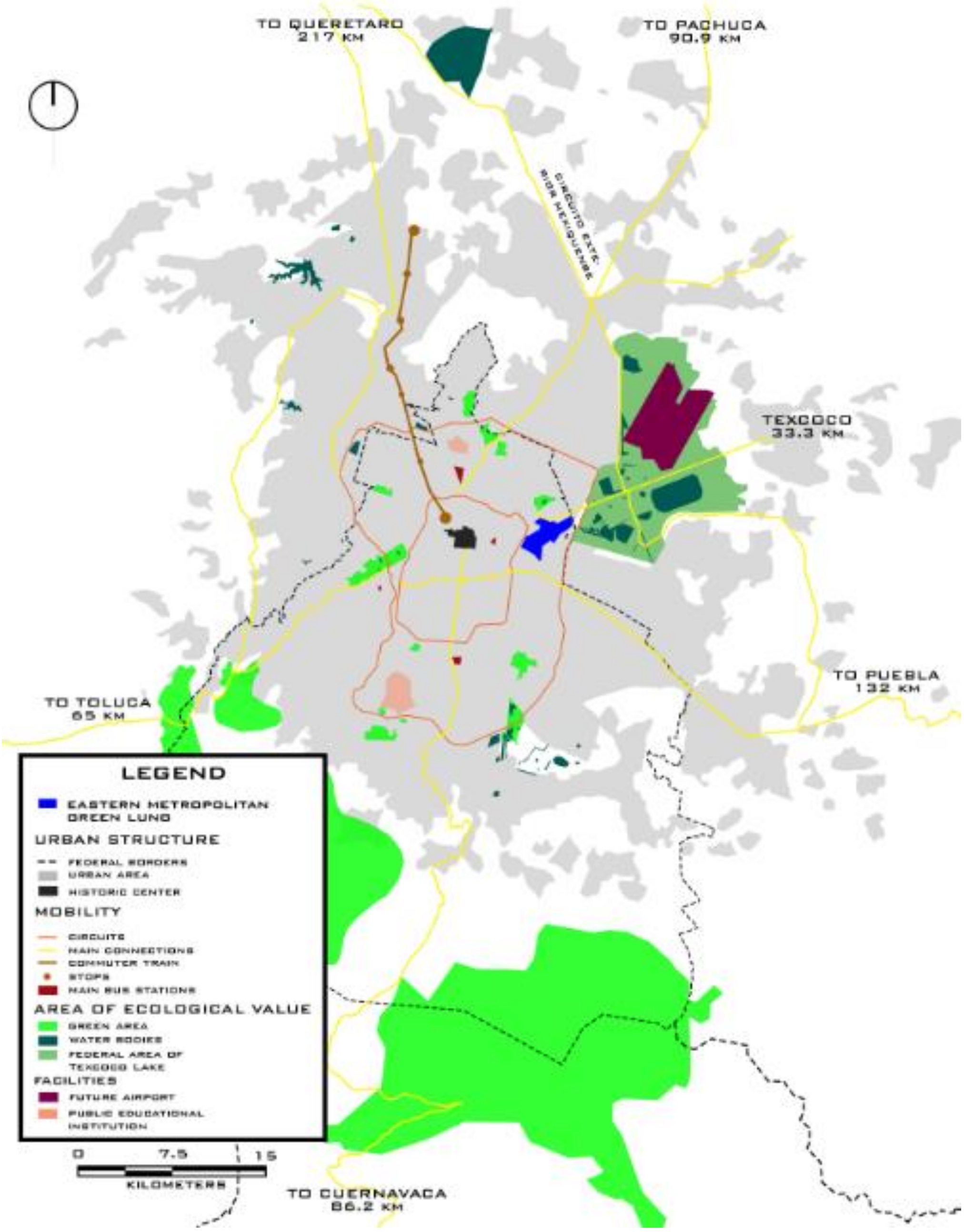


Figure 9: The Eastern Metropolitan Green Lung in the Metropolitan zone of the Valle of Mexico

Related to the urban structure of the Valley of Mexico, it is possible to identify how the Eastern Metropolitan Green Lung is inserted in the limits of the urban area of the valley, at approximately five kilometers from the historic city center that considering the scale of the city can be considered as a relative short distance.

In terms of mobility and accessibility, the most important highways that connect the Mexico City inside and with other cities are identified. It has been seen that the site is right in the middle of the two inner circuits "*Periférico*" and "*Interior*", but also it has an easy connection with: the external circuit "*Mexiquense*", that allows to circulate around the State of Mexico without entering to the City; and with the highway that goes to the city of Texcoco that in the future will be the direct connection with the new airport. The eastern metropolitan bus station (TAPO), which connects with the southeast of the country, is located three kilometers away.

In this map, special attention was given to the identification of the areas of ecological value, considering that they have a big importance for the ecological balance of the valley even when they are few. On this point, the Eastern Metropolitan Green Lung will be located in the vicinity of one of the biggest green areas of the city, Bosque de Aragon. Another special green area for the citizens, Chapultepec forest is located ten kilometers away from the project.

It is important to mention that considering the possible environmental services of the project, the direct connection with the Federal Protected Area of Texcoco Lake is of big importance. This area has been throughout history affected by human activities such as desiccation, urbanization, deposition of waste, and will place in the future the new airport of the city, but is at the same time part of a project of recovery of the historical lakes, which have act as a place of passage for migratory birds.

About the urban facilities of metropolitan importance we identified two that will have an effect on the site. One is the *Instituto Politécnico Nacional* (IPN), a college education center, and the new airport of the city. Both of them located at approximately ten kilometers from the project.

5.1.1. Water in the Valley of Mexico

Water availability and quality is a big problem in the Valley of Mexico. (Ortega Font, 2011) Presents gathered a series of data which illustrate this problem:

The administrative region XIII of Mexico is composed by the municipalities of the State of Mexico, Hidalgo y Tlaxcala and Mexico City. It contains two water basins, the one of the Valley of Mexico and the one of Tula. It has an area of 16,438 km2 and a population of 21,258,911 inhabitants (2008), it contributes with 21.27% of GDP and has the lower disposal of renewable water in all the country, it means the maximum quantity of water that can be used annually and that is renewed by rain and water from other regions.

By the year 2030, the renewable water per capita in Mexico will be 148 m3/hab./year. It is considered that a region is under drought stress when renewable water is less than 1700 m3/hab./year. Mexico counts with 282 aquifers, 101 of them are overexploited. 37% of the water consumed in Mexico has underground source.

In Mexico City already exist 48 rivers, most of them piped. Rivers such as *Chururbusco, de las Avenidas, San Juan Teotihuacán, de la Compañía* and *San Buenaventura* are strongly polluted.

Mexico City has an average annual rainfall of 682,800 m3, 72% evaporates, 4% is recovered from superficial water courses, 14% drains and 11% infiltrates recharging the aquifers. The last two are the only ones available for the inhabitants of the city, which means 1688 hm3/year. The valley of Mexico is covered by sewage system in 97.2% and by potable water in 96.5%.

The Metropolitan Zone of Mexico City needs 2922 hm3/year, which means that the availability is exceeded in 173%. 67% of the water required by Mexico City comes from its own basin, 215 comes from the Lerma and Cutzamala systems and just 12% comes from reused fonts. Between 1997 and 2008, 31 political conflicts related with water were registered between federal and district governments.

On average the water daily consume in Mexico City is of 314 liters/Hab. But 77% of the population consumes less than 150 liters/day. This might be caused by loses of the piping network that round about 30% and 40%.

Between 1449 and 2008 twenty six big flooding have been registered. There is the risk that a big flooding can affect the Metropolitan Area in an area of approximately 650 km2 with a population of nine millions.

On average, Mexico City is sinking 10 cm per year, but in zones such as the International Airport the rate is about 40 cm.

5.2. Urban scale: Mexico City.

For the urban scale the authors have decided that for the scale of the project, it correspond to the Federal District or Mexico City. In this case also the four components were represented in a map that can be found in the annex U-2.

At this scale, for the urban structure it has been realized that the Eastern Metropolitan Green Lung will be located in the federal limits of Mexico City.

In terms of the mobility aspect, it has been identified that the site is well connected to a network of north-south and east-west primary roads that cross the center of the city. The inner circuits (Periférico and Interior) are passing in the boundary of the plot and connect it to different points of the city without passing through the center.

In relation with formal public transportation, Mexico City counts with a metro system composed by 12 lines that correspond to a network of 225.9 km with 195 stations, 115 of them are underground, 55 are superficial, and 25 are elevated. Some metro stations are connected to other train systems such as the light train of Mexico City and the Suburban Railway of the Metropolitan Zone of the Valley of Mexico.

The Eastern Metropolitan Green Lung will be directly connected by three existing metro station, one of them is the headline of three lines, and also with two close stations, giving the opportunity to travel to urban facilities such as public universities.

Beside the metro system, other public transportation systems of great importance for the city are the Bus Rapid Transit systems, the one of Mexico City, named Metrobus, composed by 5 lines and 171 stations; and the system of the state of Mexico named Mexibus which has connection with the metro of Mexico City in Pantitlán Station. The site will be served by one line of Metrobus that goes to the city center and also with the line of Mexibus that departures from Pantitlán.

Considering the areas with ecological value that have big influence for the project on the urban scale are the northeast park of *Bosque* *de Aragón* and *Alameda Central* at the southeast. There is also the small hill of *Peñon de los Baños* in the north side, which has a historic connection with the hill of Bosque de Chapultepec, one of the most important and beloved parks of the Mexicans, and historical source of fresh water of the city of México-Tenochtitlan.

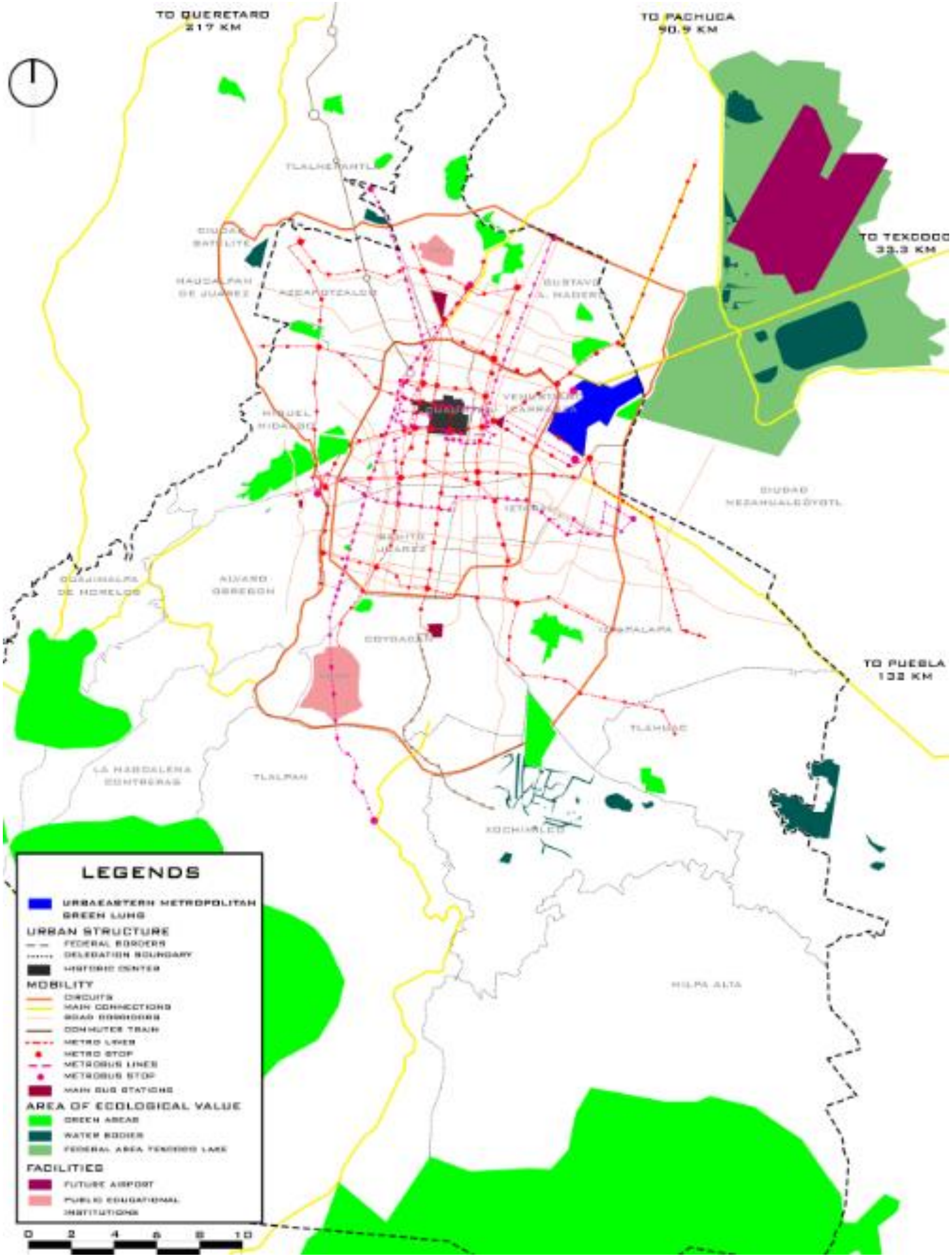


Figure 10: The Eastern Metropolitan Green Lung in Mexico City

Peñon de los Baños is a rocky formation in the northeast of Mexico City, which at the time of the arrival of the Spanish was an islet of Texcoco Lake. The hill is an unusual formation in the middle of the flat landscape in which the Aztec emperors had their hot spring baths recognized by their medicinal properties, which have become in a touristic place of the city. The zone is known also by the discovery of the fossil remains of a prehistoric woman with an antiquity of 12500 years with Asian genetic inheritance.

5.2.1. Climatic conditions of Mexico City

Mexico City is located in the tropical zone of the north hemisphere in a transition zone between the humid south of the country and the arid deserts of the north, the weather is influenced by its high altitude. The temperature is rarely below 3 °C or above 30 °C.

The area receives about 820 millimeters of annual rainfall, which is concentrated from June through September/October with little or no precipitation the remainder of the year. The area has two main seasons. The rainy season runs from June to October when winds bring in tropical moisture from the sea. The dry season runs from November to May, when the air is relatively drier. This dry season subdivides into a cold period and a warm period. The cold period spans from November to February when polar air masses push down from the north and keep the air fairly dry. The warm period extends from March to May when tropical winds again dominate but do not yet carry enough moisture for rain. (Wikipedia, n.d.)

The lower region of the valley receives less rainfall than the upper regions of the south; the lower boroughs of *Iztapalapa, Iztacalco, Venustiano Carranza* and the west portion of *Gustavo A. Madero* are usually drier and warmer than the upper southern boroughs of Tlalpan and Milpa Alta. (Wikipedia, n.d.)

In terms of the relative humidity distribution in the Mexican Republic, (Molina, 1980) presents an study that divides the country in five zones: regions with very low humidity values lower than 50%, low humidity with values between 50% and 60%, medium humidity with values between 60% and 70%, high humidity with values between 70% and 80%, and zones with very high humidity with monthly values higher than 80%.

Mexico City is located in an ample inner area of the country characterized by low relative humidity values between 50% and 60%. Relative humidity increases during the warm seasons and at the first ours of the day, decreasing notably on spring and at noon when the temperatures are higher and convection striking.

The highest monthly values of relative humidity occur at the end of summer and the beginning of autumn (August-September) due to the irruption of moist warm masses of air coming from the Gulf of Mexico and the Sea of the Antilles, during this period, they are in average 72% on August and September.

During spring, relative humidity decreases because the air near the ground overheats causing a strong process of convection, high temperatures and insolation, as well as a reduction of the rainfalls that is stronger at higher latitudes. From north to south in the highlands of Mexico, the relative humidity is very low, at Mexico City, they are in average 44% on March.

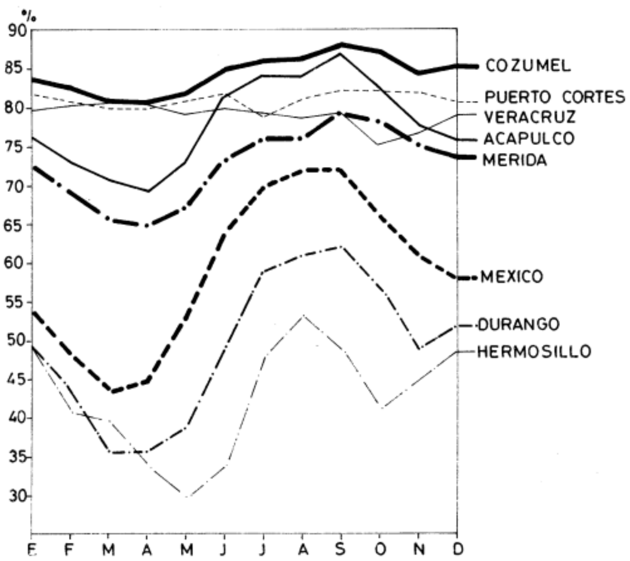


Figure 11: Annual variation of the relative humidity in different cities. (Molina, 1980)

The region of the Valley of Mexico receives anti-cyclonic systems. The weak winds of these systems do not allow for the dispersion, outside the basin, of the air pollutants which are produced by the 50,000 industries and 4 million vehicles operating in and around the metropolitan area. (Wikipedia, n.d.)

(Red Automática de Monitoreo Atmosférico, 2013) Gives a detailed map of the level of pollutants registered by a network of stations and interpolated for all the city. Six pollutants are studied: Ozone (O3), sulfur dioxide (SO2), nitrogen oxides (NOX), carbon monoxide (CO), particulate matter less than 10 micrometers (PM10) and particulate matter less than 2.5 microns (PM2.5). After political decisions, Mexico City has improved the air quality passing from two days with good conditions in 1991 to 230 in 2011. However, there are still problems related to the excessive amount of particles matter less than 2.5 microns.

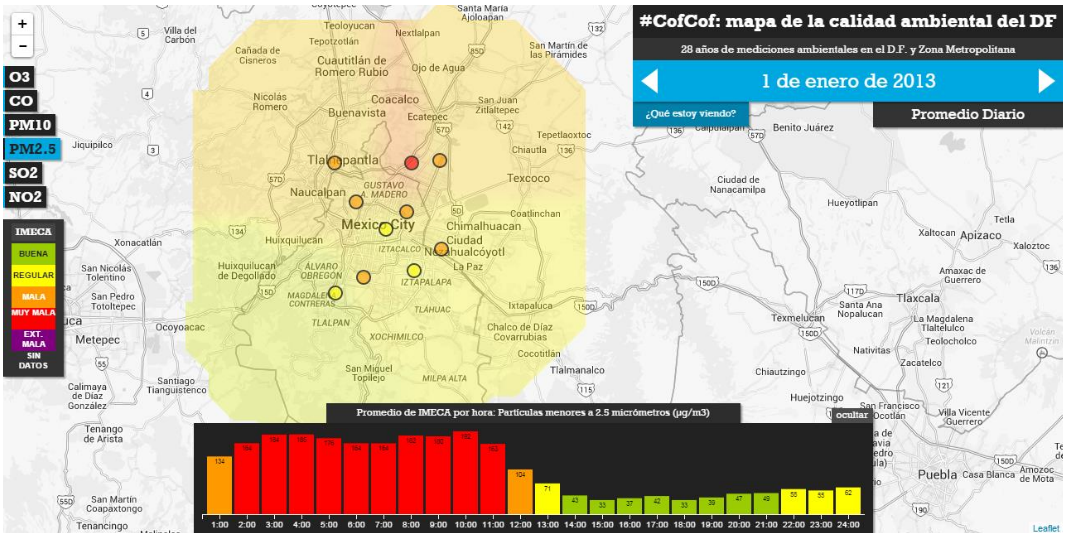


Figure 12: Particulate matter less than 2.5 microns, 01/01/2013.

5.2.2. Public Security in Mexico City

In this section are presented some data obtained from the National Institute of Statistics and Geography (INEGI) referred to some data that are considered important in this project related to the security conditions on Mexico City, by specifying each municipality or borough. Special attention is put in the Borough of *Venustiano Carranza*, where the site of the project is located.

It is possible to realize that the levels of criminality in the borough of interest are of a middle-high level compared to the rest of the city.

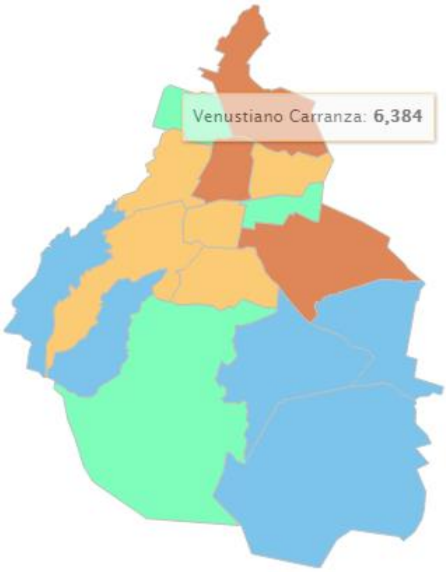


Figure 13: Crimes of theft

Mexico City: Crimes of theft		
	Municipality	Total
	Azcapotzalco	5362
	Coyoacán	7432
	Cuajimalpa de Morelos	1060
	Gustavo A. Madero	12495
	Iztacalco	4068
	Iztapalapa	14513
	La Magdalena Contreras	1266
	Milpa Alta	499
	Álvaro Obregón	6437
	Tláhuac	2206
	Tlalpan	5977
	Xochimilco	2948
	Benito Juárez	7742
	Cuauhtémoc	13522
	Miguel Hidalgo	7402
	Venustiano Carranza	**6384**

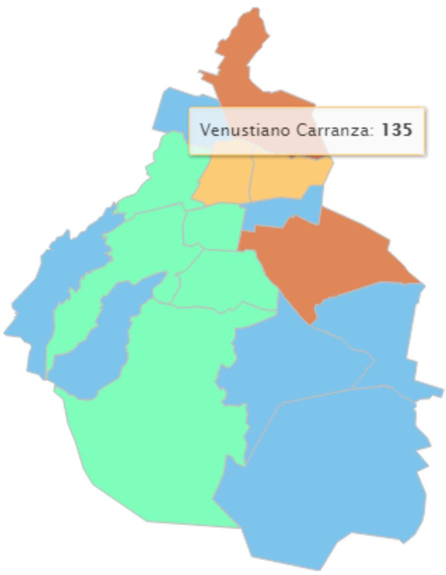


Figure 14: Crimes of murder

Mexico City: Crimes of murder		
	Municipality	Total
	Azcapotzalco	65
	Coyoacán	88
	Cuajimalpa de Morelos	28
	Gustavo A. Madero	238
	Iztacalco	49
	Iztapalapa	285
	La Magdalena Contreras	18
	Milpa Alta	19
	Álvaro Obregón	90
	Tláhuac	53
	Tlalpan	108
	Xochimilco	42
	Benito Juárez	93
	Cuauhtémoc	131
	Miguel Hidalgo	86
	Venustiano Carranza	**135**

5.3. Intermediate Scale

After analyzing the site in the context of Mexico City, it is important to go into an intermediate step before studying the local situation. It has been decided that this analysis were going to be done on a zone that comprises five boroughs. The information is represented on a set of maps that synthetize different aspect in layers that simplify the understanding of the different phenomena.

5.3.1. Land use

Under this tittle can be gathered the analysis that were carried out in relation to the identification of the different land uses, protected sites and neighborhoods, the key attractors of people, landmarks, public spaces and social facilities.

To comprehend better the different characteristics of the neighborhoods analyzed at this scale, it was realized an analysis of the mentioned aspects which can be seen on the annex U-3. As this map is quite complex to understand, the information was divided into different maps.

Figure 15: Land use on the intermediate scale

5.3.1.1. Residential areas

The first map (annex U-4) corresponds to the residential areas. It shows uses such us pure residential, residential with commerce, residential with offices and mixed uses. In the vicinity of the site there is a higher percentage of residential with commerce on the lower floor. It is manly located near the areas that are closer to primary roads such as *Circuito Interior, Avenida Churubusco, Eje 1 Norte, Calzada Ignacio Zaragoza* and *Avenida Oceania*. There is also the presence of pure residential zones near *Bosque de Aragon* Park and of mixed use between *Avenida Churubusco* and *Circuito Exterior*. The presence of this kind of uses denotes that this communities have the possibility to work in the vicinity of their homes, mainly in activities that are related to the existing airport, or that benefit from it.

Special remark can be done on this map when noticing that one of the main zones of economic activities in the city, demarked by a high dense development of mixed uses, goes from *Bosque de Chapultepec* to the limits of the historic city center along the axis of *Avenida Reforma*. This is a pole of attraction of people in terms of work characterized by the presence of some of the most representative landmark buildings of Mexico City.

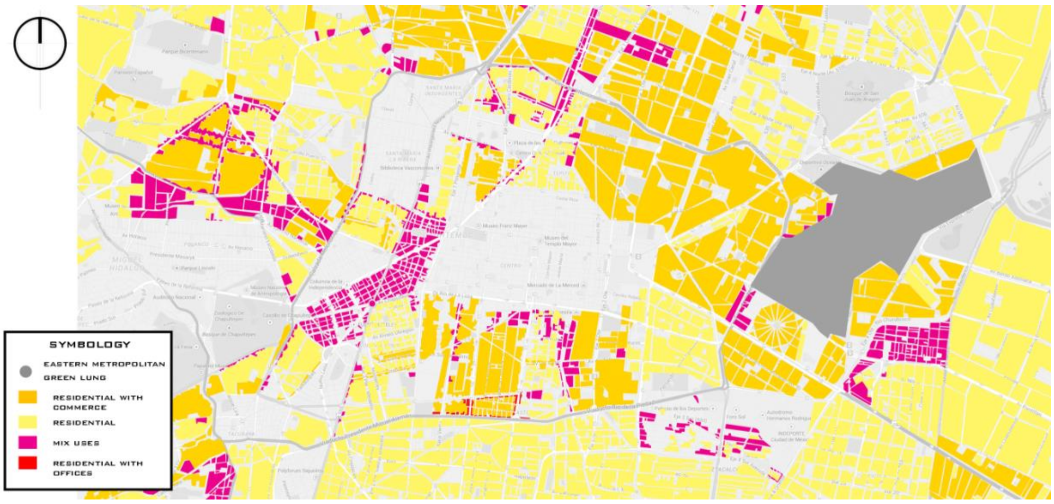


Figure 16: Residential use on the intermediate scale

5.3.1.2. Open- green spaces, protected zones

The second map (annex U-5) represents how the site is inserted in the network of open-green spaces of the area analyzed, as well as the location of the social facilities of different importance and the special planning zones. About the first item, in 1986 it was reported 2.3 m2 of green area per inhabitant. In 2003 the green spaces represented the 20.4% or urban land. Green areas face problems since their creation, regarding their protection and conservation. The two most representative green spaces that can be identified at this scale are the parks of *Bosque de Aragon* in the vicinity of the site, and *Bosque de Chapultepec* at 10 km of distance. In terms of open spaces, the most important of them is of course the central square of Mexico City`s downtown, the Zócalo.

In the map are also included zones under "Special planning" regulation. This areas are subjected to an urban renovation process which has to respect specific considerations due to its architectural value or special regulations for the conservation of zones like the historic center that is protected by UNESCO.

Figure 17: Open- green spaces and protected zones on the intermediate scale

5.3.1.3. Urban facilities of metropolitan influence

As in the previous map it was very difficult to understand how the presence of such a big amount of urban facilities can offer opportunities to the site of this project, it was decided that special attention would be given only to the facilities with a metropolitan importance located in the area of study (annex U-6).

It was possible to identify in the south of the site the presence of a hub of sport and cultural facilities composed by *Palacio de los Deportes, Foro Sol*, the racetrack *Hermanos Rodriguez* and the

Institute of Sports (INDEPORTE). In west there is the presence of the historical markets of *La Merced* and *Jamaica*, and governmental buildings of national order such as the Legislative Palace, the Palace of Justice, the Chambers of Deputies, the General archive of the Nation, among others.

In a wider range of influence it is possible to find educational and health spaces, and a cultural axis of museums that starts in Bosque de Chapultepec and continues through *Reforma* Avenue.

Also in this map is represented the so called Multimode Transfer Center (CETRAM). They are a physical space referred to the mobility that is part of the urban infrastructure, where converge diverse modes of terrestrial transport of passengers, and facilitate people to transfer between them to continue their journey. This kind of transport is regulated in some way but is not completely formal and their influence is remarkable considering the amount of people that use them.

It was noticed that in the south corner of the site of this project is located one CETRAM, the others are relatively close over the *Calzada Ignacio Zaragoza*. This places must be considered because of their potentiality to attract other kind of activities like informal commerce.

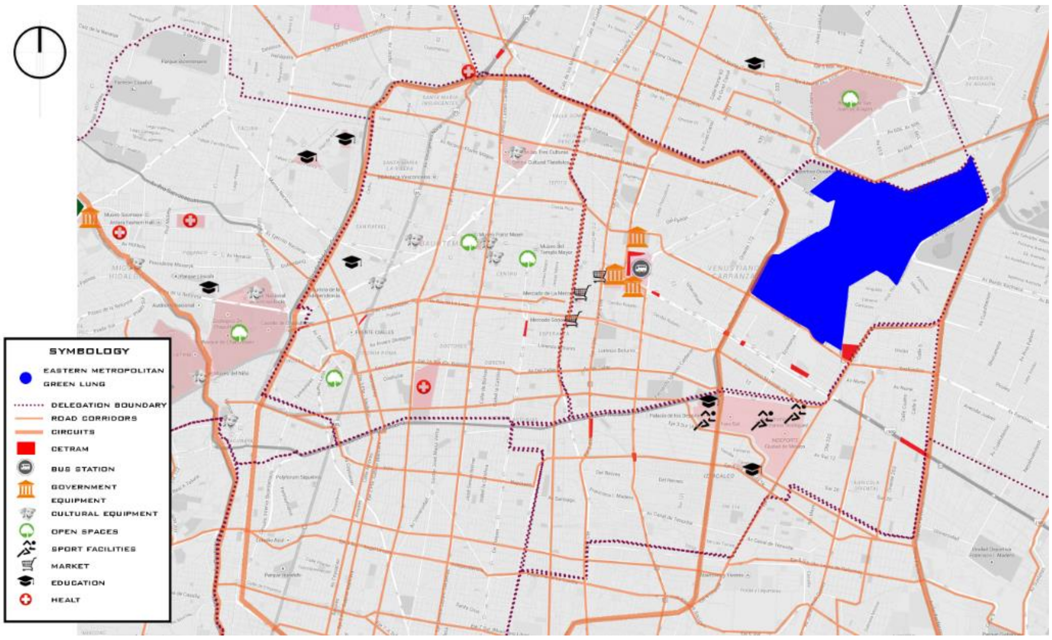


Figure 18: Urban facilities of metropolitan influence

5.3.2. Urban mobility

Considering the importance of accessibility for an urban area of this dimensions, and the possibilities of human activities related with work, leisure and social interaction, different aspects of mobility were analyzed.

5.3.2.1. Public transport

As has been said before, the public transportation system of Mexico City has two components, one informal composed by several buses of different sizes and ownership and a formal organized public system. The first one is partly regulated in the CETRAM stations, but its operation is so complex, that apart from the identification of those stations, is out of the scope of this project.

The formal component of the transportation system has connections with the site of the project trough stations mainly located in the west and north side of the plot, serving the existing terminals of the airport.

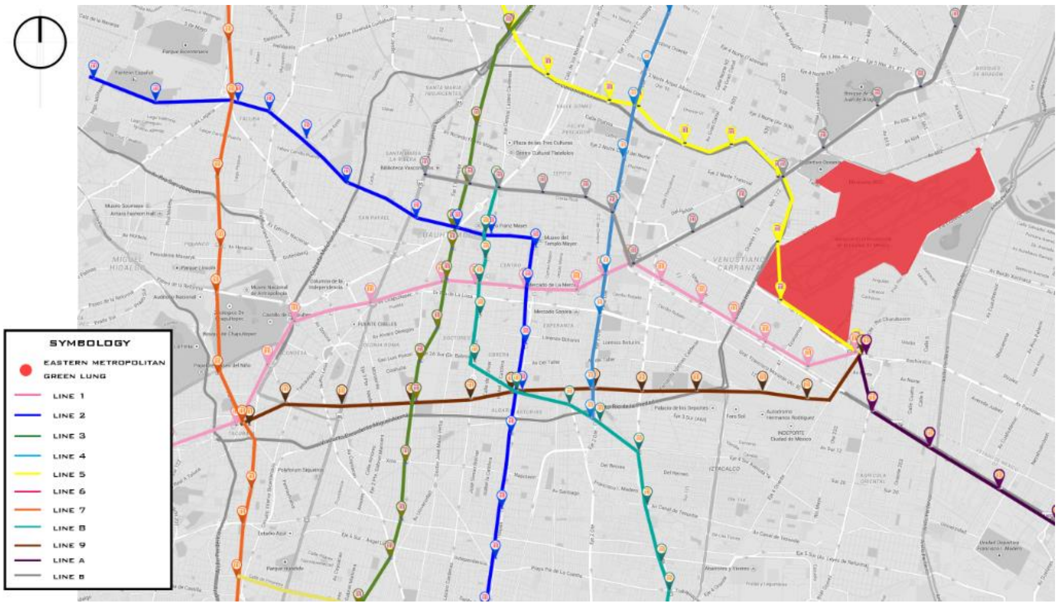


Figure 19: Lines of the subway (metro) system

Considering the Metro system (annex U-7), the site has direct connection with lines 1 (pink), 5 (yellow), line 9 (brown) and A (purple) through Pantitlán station, that is the headline of all of them, and through the stations *Hangares* and *Terminal Aerea* through line 5 (yellow). There is connection with line B (grey) inside the range of walkable distance through the station of *Deportivo Oceania*. Some important places of Mexico City are reachable through metro without changing lines: Bosque de Chapultepec through line 1, Eastern Bus Station (TAPO) by lines 1 and B, Northern Bus Station and *Instituto Politécnico Nacional* (IPN) through line 5.

Metrobus currently connects the existing international airport with the historic city center by 2 stop of line 4, one on each terminal. This line does not count with any special infrastructure regarding exclusive busways or stations. Mexibus has is first station in Pantitlán, and allows the movement of people to the nearer localities of the State of Mexico. (Annex U-8)

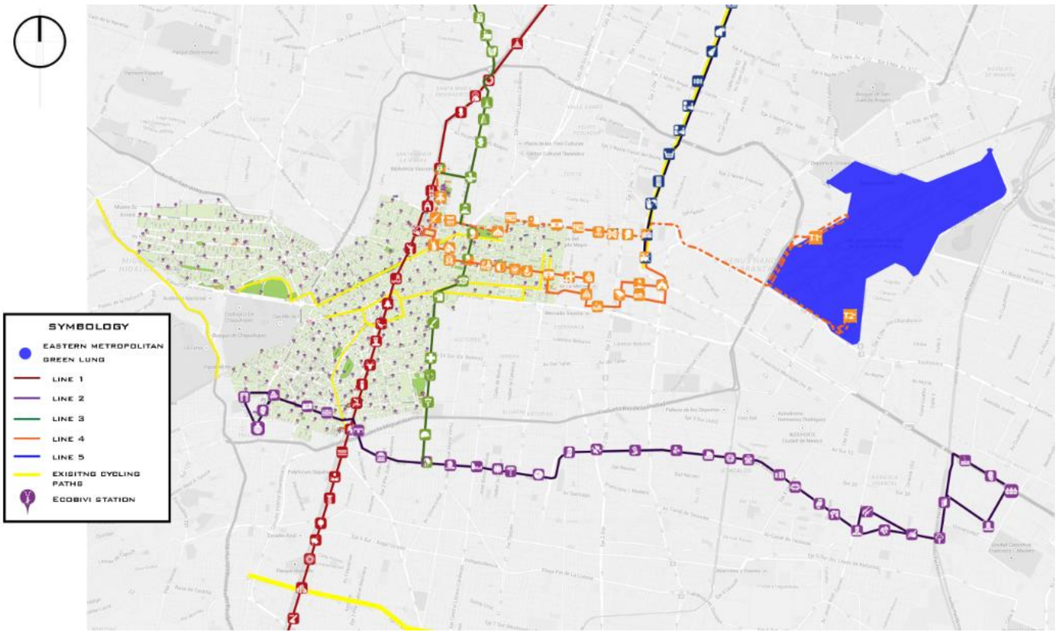


Figure 20: BRT (metrobus) system and bike rental (Ecobici) stations

Regarding the mobility through bicycles, the existing network of cycling paths are all concentrated in the city center and the east part of the city leading to *Bosque de Chapultepec*, where a program of public bicycles named ECOBICI has been implemented. It allows registered users to take a bike from any station and return it on the nearest to their destination in unlimited journeys of 45 minutes. Those who wish to access the system ECOBICI may pay a subscription for one year, a week, three days or a day.

ECOBICI began operations in February 2010 with 84 cycle-stations and 1,200 bicycles. In just five years the demand has driven the expansion of the system by 400%. Currently it has 444 cycle-stations, more than 6,000 bikes and serves from Monday to Sunday over 100,000 users in 42 colonies of three delegations, covering an area of 35Km2.

5.3.2.2. *Street network*

To consider the accessibility to Eastern Metropolitan Green Lung form the different points analyzed in the intermediate scale, a map of traffic conflicts was developed (annex U-9). The network of primary roads of high concentration of vehicles was represented as well as the portions of them which are usually saturated and the nodes of intersection with presence of traffic conflicts.

As expected the most problematic zone in terms of traffic jams is the historic city center, but, regarding the site of this project, the *highways Eje 1 Norte, Calzada Zaragoza, Avenida Oceania*, and the Avenues 602 and 508 with their respective intersections with other primary streets are the zones identified as conflictive.

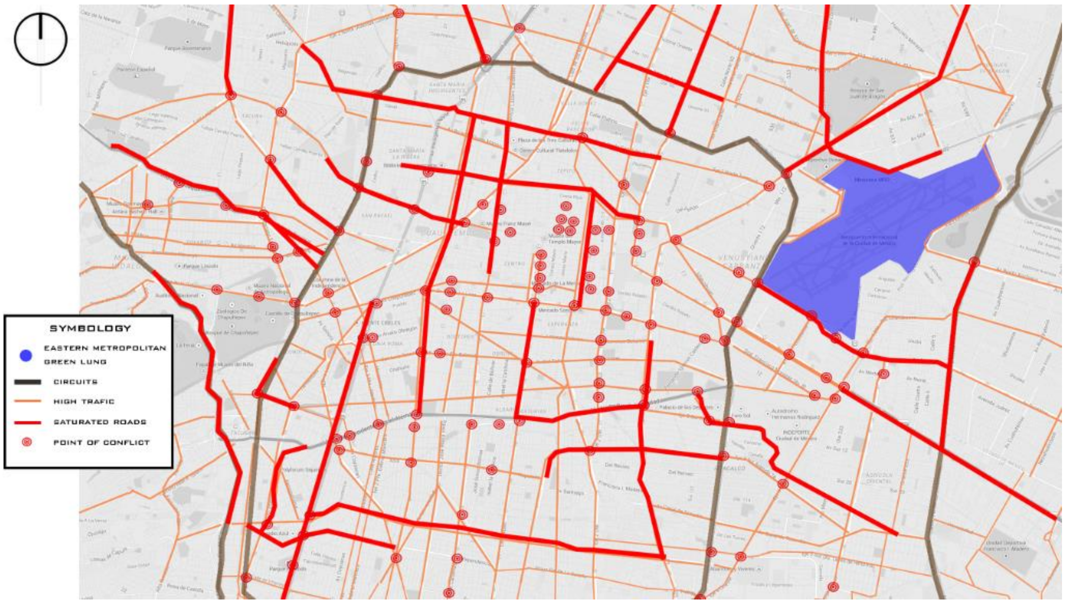


Figure 21: Traffic conflicts on the intermediate scale

5.3.3. Socio-economic conditions

5.3.3.1. *Distribution of the work sources*

In the annexes U-10 and U-11 it is possible to see how is the movement of people on working days from their homes to their jobs and backwards. This help us to identify which zones of the intermediate area have a higher proportion of creation of jobs and which are mainly dedicated for residential uses. Anyway, considering the scale of this project, this arrangement is going to change due to the amount of population that is going to live and work on it.

5.3.3.2. Poverty Index

In the annex U-12 is possible to identify the location of the neighborhoods with the presence of unsatisfied necessities or propensity to poverty. It is presented in a qualitative perspective in three main groups, from a lower medium high poverty, high poverty and finally very high poverty. In the vicinity of the site of this project there is a high proportion of neighborhoods in high poverty conditions, this aspect is of maximum importance as we consider that this project is an excellent opportunity to improve the life conditions of this population.

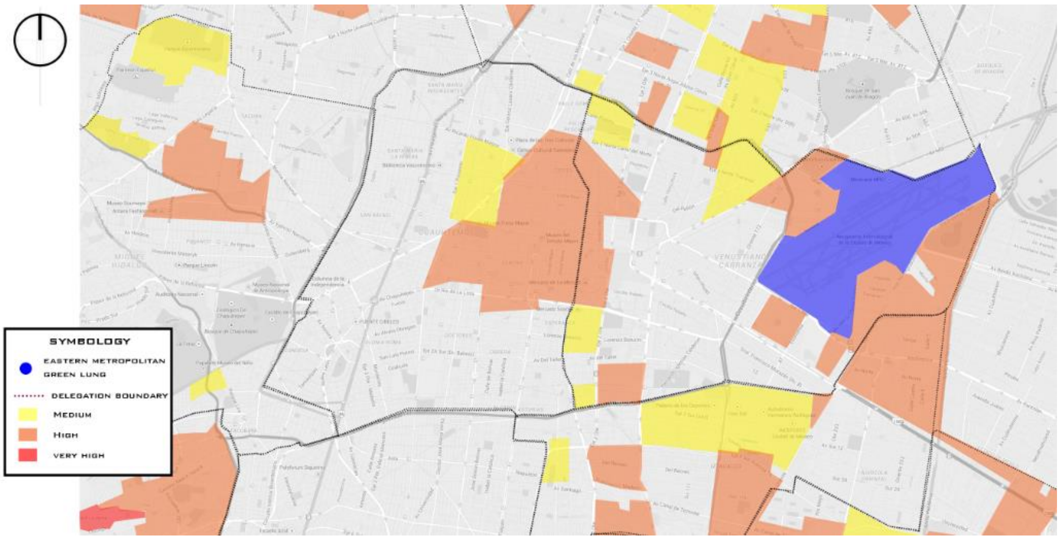


Figure 22: Poverty in the intermediate scale

5.3.4. Ecological conditions

Mexico City is characterized by two main environmental problems: air pollution, which has been explained in the previous scale order and flooding:

5.3.4.1. Flooding propensity

The Mexico City climate has been classified into two seasons: rainy season, from May to October, and dry season, from November to

April. This classification comes from the two main meteorological patterns on the synoptic scale: dry westerly winds with anticyclone conditions from November to April, and moist flows from the east due to weaker trade winds during the other six months [4]. However, Mexico City's meteorology is more complex. Important interactions of the basin with the Mexican plateau and lower coastal areas may occur. Moreover, it is common to have weak large-scale pressure gradients and strong solar radiation throughout the year. These conditions, combined with the surrounding mountains, are ideal for the development of thermally driven winds, such as anabatic and katabatic winds, and also winds driven by the heat island phenomenon. In the annex U-13 it is possible to identify how the eastern part of the city, where is located the site of this project is susceptible to flooding, especially the zones closer to the ancient Lake Texcoco.

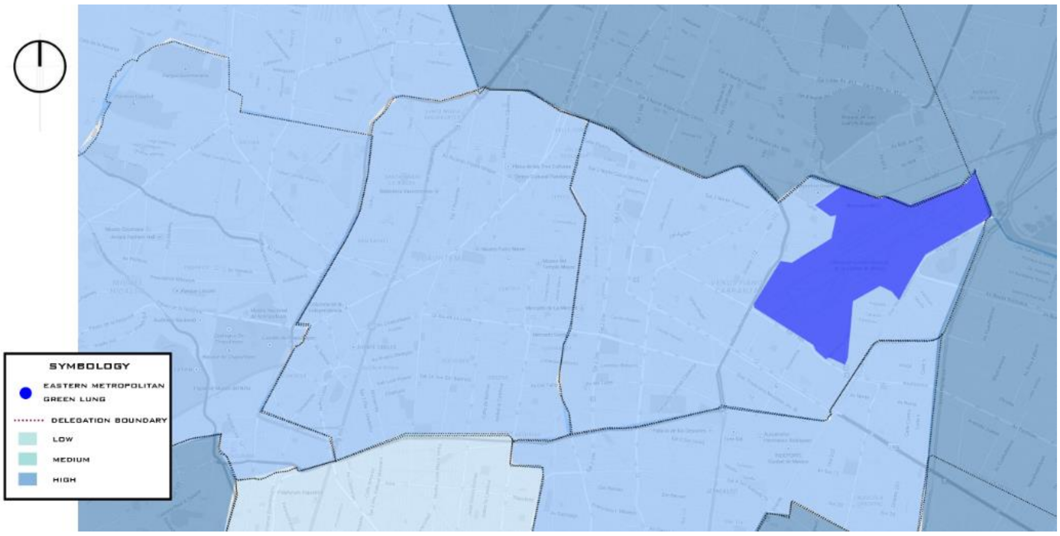


Figure 23: Flooding propensity on the intermediate scale

5.4. Local Scale: The borough of *Venustiano Carranza*

The borough of *Venustiano Carranza* is located in the eastern part of the center of Mexico City, it occupies an area of 3342 hectares and represents the 2.24% of the total extension of it. The zone of the International Airport of Mexico City occupies a 21.89% of the borough, which means 731.73 hectares.

The housing use comprises 34.2% of the total area of the borough, the mixed use comprising 28%, the use of industrial land represents 1.8%, and equipment occupies 8% of its land area, excluding the area of the AICM, to consider this increases to 30%, open spaces occupy only 6% showing the lack of this spaces along the area. (Asamblea Legislativa del Distrito Federal, 2005)

5.4.1. Urban facilities

Regarding the subsystem Education, public institutions available to the borough are: 25 CENDI (Child Development Center) of which 20 are located within the Public Markets, 42 kindergartens, 92 Elementary Schools 23 General Schools, 7 Technical High Schools, 7 Nocturnal High Schools, 3 CONALEP, 1 Preparatory 1 CECYT (Centre for Science and Technology Studies) and 2 CET (Centre for Technology Studies) representing these schools Middle Level Superior. (Asamblea Legislativa del Distrito Federal, 2005)

Within the subsystem of Culture, the equipment located in the borough consists of 12 social centers, 7 seniors clubs, 25 libraries, 3 House of Culture and 7 theaters; also having the General Archive of the Nation and National Archives of Notaries, these two elements provide their services nationwide. The private cultural equipment has 9 dance schools, 3 music schools and a center of cultural studies and art. (Asamblea Legislativa del Distrito Federal, 2005)

With regard to Health Subsystem the borough attends its population with 14 community health centers (SSA), 6 Family Medicine Units (IMSS), 3 clinics (ISSSTE), 1 health unit (*Venustiano Carranza*), 1 children's hospital 1 pediatric hospital (Government of the Federal District), 1 hospital for emergencies (Government of the Federal District) and 1 Mexican Red Cross, 1 Sanitary District.
Service Trade and Public Markets are grouped in the Borough with 42 units, 9 malls, 2 shopping lanes, 2 commercial corridors, 27 mobile market places catering to the population of the Borough and surrounding areas the same. (Asamblea Legislativa del Distrito Federal, 2005)

The borough has 11 spaces suitable for the development and performance of athletes and the general public. The main sports are: Olympic Velodrome, the Park *Plutarco Elias Calles*, *Venustiano Carranza* Park and the sports centers of *20 de Noviembre, Oceania and Jamaica.* (Asamblea Legislativa del Distrito Federal, 2005).

5.4.2. Environmental conditions

5.4.2.1. Soil characterization

The borough where the project is located is settled over a flat terrain with slopes lower than the 2%, the necessary conditions for the drainage management. The 99.5% of the soil has lacustrine origins, as a result of the desiccation of the Lake *Texcoco* during an urbanization process in the 1920`s.

In general, the soils of the borough are characterized by a high permeability. The zone of the International Airport of Mexico City is dominated by a soil type denominated Zm-n/3 (Molic Soil) characterized by a fine-soft texture, dark, fertile and rich in organic matter surface layer saturated in more than 15% with sodium in any portion at less than 125 cm of depth. (Asamblea Legislativa del Distrito Federal, 2005)

Most soils are composed of sandy-loam with gravel materials; the layer thickness is about 3 m. A deeper formation, which consists of soft volcanic clay, 14 m thick, which rests on deep deposits that are composed of loam-sandy materials, loam sands, sandy clay and compacted gravel, of depths of approximately 100 m. The borough is part of the Seismic Zone 3. (Asamblea Legislativa del Distrito Federal, 2005)

5.4.2.2. Pollution

The most important air pollutants in the borough are the ozone and the suspended particles, specifically, those under 10 microns. In relation of the particles under 10 microns, 40% of their emissions come from the ground erosion. Other sources are the diesel-based vehicles, forest fires and other vehicles.

Regarding the water pollution, it can be differentiated according to its source:
Due to domestic use: It is produced by everyday operations the inhabitants, consisting of personal care, household cleaning and food, building maintenance etc. The most common pollutants are: organic matter; detergents and soaps; cleaning auxiliary liquids and solids and coloring.

Due to industrial use: It is used by this sector mainly in the transformation process, which typically has chemical, linked to the raw materials used: soaps, acids, metals, oils, suspended solids, paints, solvents, pigments, greases, etc.
Due to commerce and services uses: the impact on the water resource is mainly related to its operational activities and presents the average following pollutants: organic matter, oil, grease, detergents, soaps, disinfectants and bleaches, tints, dyes, solvents and mineral oils.
It is important to mention that there is no system of treatment plants in the borough and the drainage system is solved in combination. From all the consumed water, almost nothing is reused and nothing is treated.

In relation to soil pollution, In Venustiano Carranza 650,000 tons per day of solid waste is produced, with an estimated average of 1.3 kg per capita, of which 65% is domestic waste, while the remaining 35% is not yet specified (Asamblea Legislativa del Distrito Federal, 2005). Illegal dumping are not precisely quantified, however, they arise from deficiencies within collection system and the lack of education and public awareness; being open channels, ditches, vacant lots, sidewalks and medians, the favorite places for depositing waste.

5.4.3. Risk and Vulnerability

Some of the risk present in the borough where the future Eastern Metropolitan Green Lung have natural and anthropic origin. They can be classified in the following groups: Geological, Hydro-meteorological, Ecological Health.

Geological

Beside the geological faults that can be found around all the city, the most perceptible risk factor is land subsidence, which has origin due to natural and anthropogenic factors, the first refers to the particle size characteristics of the materials that form the lake zone, and the second is attributable to human activity that has favored excessive extraction from deep aquifers and the covering of green areas which prevents adequate infiltration of rainwater, so there is no contribution of liquid into the aquifer. In the Borough, the subsidence in the last thirty years has been between 10 and 15 cm a year in the most critical areas.

Hydro-meteorological

Here are taken into account risk factors related to climate which cause in this borough, floods, hailstorms, extreme temperatures, thunderstorms and thermic inversions. Despite the Borough has a drainage cover of 100%, much of it is deteriorated due to its age. The accumulation of rainfall and hail, is conditioned from the degree of slope of topography of the territory, which in the case of the Borough, 90% of the surface is flat.

The borough *Venustiano Carranza* is part of the basin of the River Montezuma, which drains to the lake *Texcoco*. Several rivers cross the area inside the network of drainage pipes: *Consulado, Guadalupe, La piedad, Churubusco*.

Ecological Health

These agents refer to the risk factors posed by pollution, desertification, epidemics, plagues and acid rain, all of them connected to water, air and soil pollution.

5.4.4. Socio-economic situation

5.4.4.1. Demographic conditions

In the borough of *Venustiano Carranza*, there is a process of decrease on the population due to the substitution of the land uses, the lack of zones for the development of new houses and the high prices of land. While in 1970, the borough represented 10.4% of the population, in the year 2000 it was only 5.4% of the Federal District. In any case, it must be said that this phenomena is characteristic of the central zone of Mexico City (Asamblea Legislativa del Distrito Federal, 2005).

As a consequence of the reduction of population, the density of inhabitants decreased, registering on 2000 a value of 138 inhabitants per hectare, while on Mexico City it is of 141 inhabitants per hectare. Only after 1990 this index went under the registered for the whole city. For the period between the years 1990-2000 the rate of natural growth was 1.2%, while the emigration was 2.8% (Asamblea Legislativa del Distrito Federal, 2005).

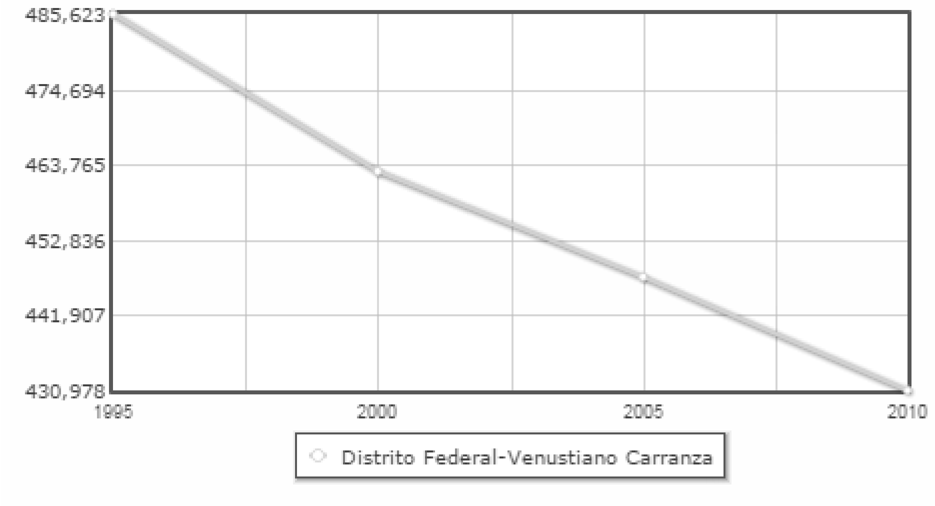


Figure 24: Total population, Borough of Venustiano Carranza. (INEGI)

5.4.4.2. Level of education

Regarding the social and economic conditions, it is important to consider how the population that lives in the surroundings of the site of this project will be benefited from the new opportunities of work, in this sense, it is important for this study to consider the level of education as this new urban development will create several jobs in the tertiary sector.

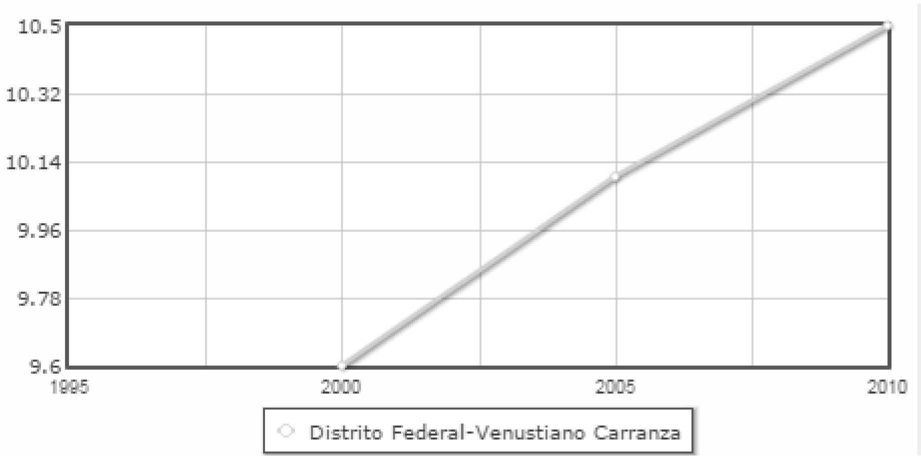


Figure 25: Mean time of education for people of 15 years and above (INEGI)

It is visible that the people that lives in the borough of Venustiano Carranza have on average a level of education that corresponds to the secondary school. Now, in respect to higher levels of education, almost 75,000 inhabitants nowadays have a degree from university. This data is considered very interesting for this project in order that this people will be able to find jobs or have place for their own offices in the new development proposed, as well as they might be the first interested in the possibility to live on it.

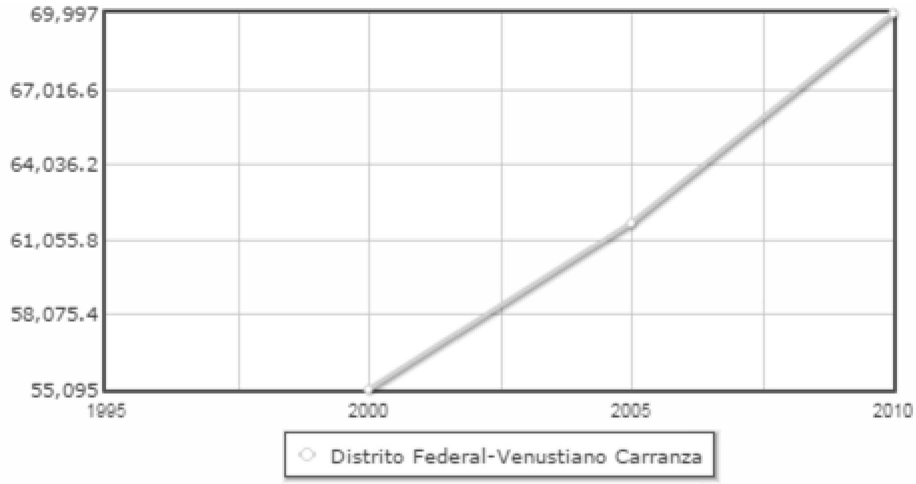


Figure 26: Population of 18 years or above with professional level education (INEGI)

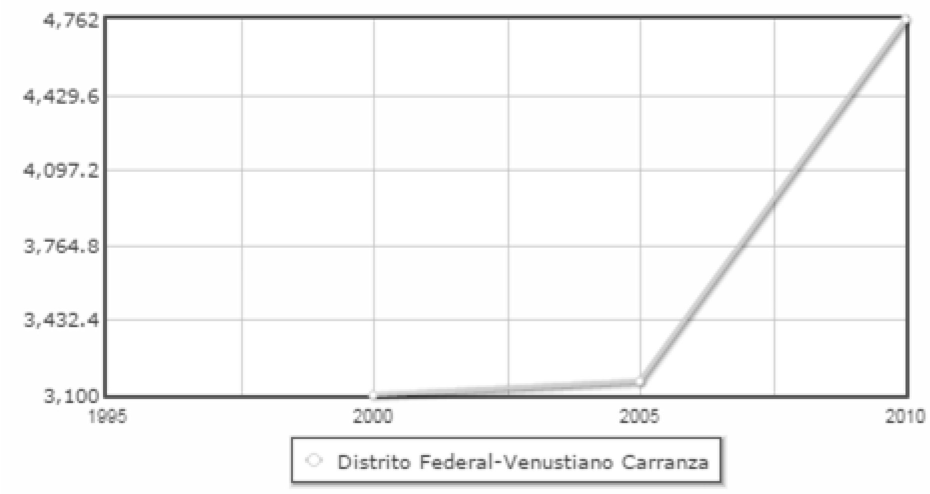


Figure 27: Population of 18 years or above with postgraduate studies

5.4.4.3. Work offer

The borough of *Venustiano Carranza* is able to provide job opportunities in different sectors of the economy. From the part of the population that is economically active, a big proportion works on the tertiary sector, specifically 43.8% in services and 37.59% in commerce, the last 18.61% works in the manufacturing sector (Asamblea Legislativa del Distrito Federal, 2005).

Among the manufacturing sector, the most representative sub-sectors, with 69.9% of the people employed account of textiles, clothing and leather industries; other sectors are food, beverages and snuff; and metal products, machinery and equipment. It must be said, that in any case the presence of the textiles industry is decreasing since the 1990`s (Asamblea Legislativa del Distrito Federal, 2005).

The commerce sector is dominated by the retail, occupying 82% of the population dedicated to this sector and generating 16% of the total incomes of the Borough (Asamblea Legislativa del Distrito Federal, 2005).

Considering the services sector, 79.8% of the units are grouped in restaurants and hotels; professional services; specialized services and maintenance services. It must be said that 9.5 of the restaurants and hotels of Mexico City are located in this Borough (Asamblea Legislativa del Distrito Federal, 2005).

5.5. Analysis Conclusions

Having studied the different phenomena that characterize the site, in the mentioned scales. It was necessary to summarize the most relevant information of the aspects that could benefit or harm the project. To do so, two maps were elaborated showing what in this research were denominated positive (Annex U-14) and negative aspects (Annex U-15).

5.5.1. Positive aspects

Among the aspects that were considered as beneficial for the researchers are the location of the site at just five kilometers from the historic city center, which is under the regulation of a partial plan for its conservation as an UNESCO world heritage site.

The area of the existing International Airport, due to its existing use, is very well connected to the city by a network of highways that lead to all directions, and it will be just on the way to the area where the new airport will be located.

The connectivity for the users of the public transportation systems is also good. There are several metro stations in the vicinity to the zone.

However, all of them are located just on the west and north of it. There is also a Metrobus (BRT) route that can be extended inside and around the project.

The future Eastern Metropolitan Green Lung is surrounded by several recreation and green spaces, such as Parque Aragon, Alameda Oriental, Deportivo Oceania, and Ciudad de los Deportes. This is a clear opportunity for the future metropolitan park to become into an element of connection between this elements of the green network.

It has been found by the researchers, that there is a historical relation between the hills of Peñon de Los Baños just in the north border of the site and Bosque de Chapultepec, 10 kilometers away. This historical connection has enough relevance for the authors to consider the hills as a key element for the urban design of the new development.

It is also important to mention that most of the cultural equipment of the city is located at Reforma Avenue and the historic city center, at less than 10 kilometers from the site, reachable by public transport.

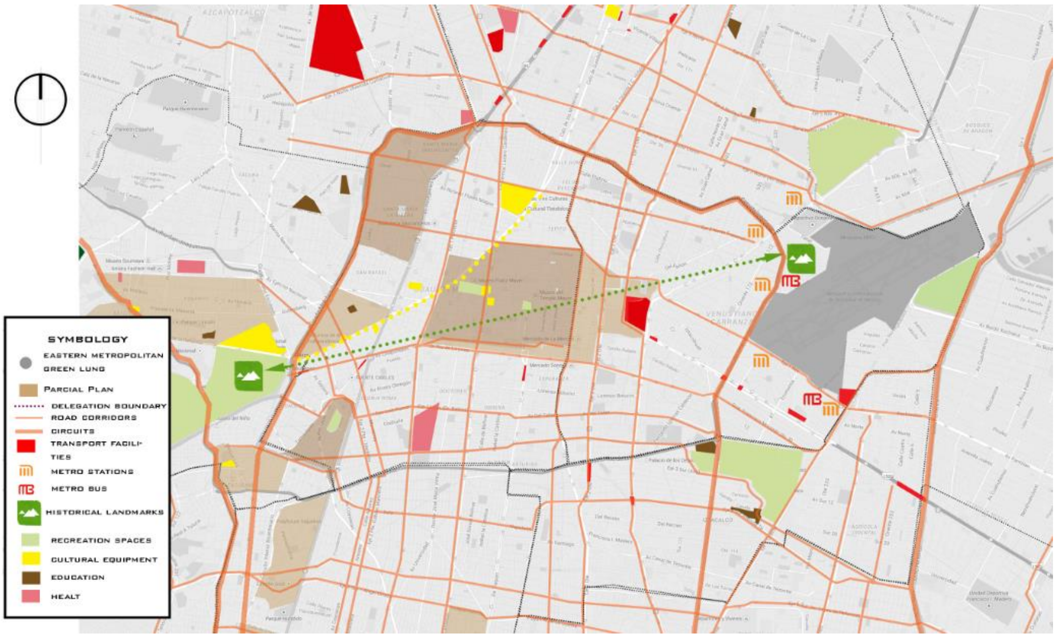


Figure 28: Positive aspects that influence the project

5.5.2. Negative aspects

Among the negative aspects that can represent threats for the well development of this project are the location of the existing airport near to boundaries. The first one is physical and corresponds to the limit between the city and the non-built area of the Federal Protected Zone of Texcoco Lake, which has been polluted for decades by waste disposal. The second boundary is administrative, and can lead to political problems, due to the fact that traditionally this zones are "no man's land" for public investment.

But this barriers are not the only ones. As the airport is a closed infrastructure of the city, historically the neighborhoods which developed around in a random process have grown giving their back to the airport. Also it has increased this problem, by placing enormous fences that do not permit any visual connection to the tourist with the city outside. This kind of barriers have to be demolished and the process to connect the city with this zone will be developed step by step.

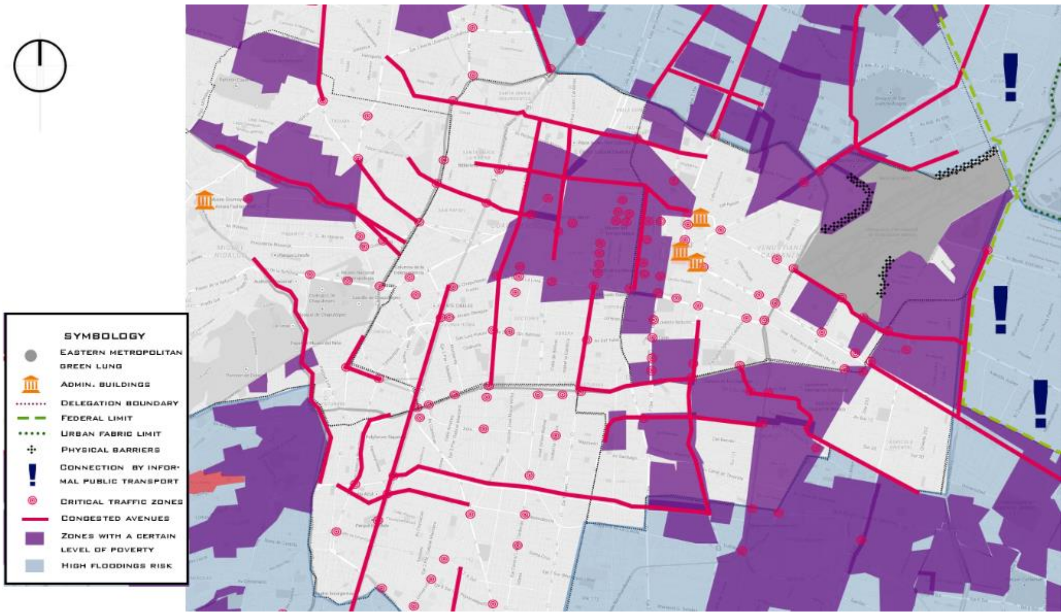


Figure 29: Negative aspects affecting the project

When considering connectivity, it has to be said that even when there is a good network of avenues, most of them have traffic problems, and their intersections, especially close to the existing airport and towards the city center are very problematic. There is also a lack of presence of a formal public transportation system in the eastern side of the plot, and is very difficult to solve it considering that those zones are under regulation of another state.

Flood risk is a problem that must be considered in order to guarantee a resilient neighborhood. It has been detected that all the zones that used to be part of the Texcoco Lake are under this risk, leaving the researchers the conclusion that urbanizing the west of the plot should be avoided.

Special attention has to be put on the levels of poverty of the surrounding areas of this project. This is a challenge for the authors to try to find ways in which the new public spaces will include this population, in order to enhance their life conditions, ensure the security of the zone, and promote the mixture of people from different social backgrounds.

Chapter II: Urban design

1. Objectives

Mexico City is a very particular metropolis; for its location, the history and the way that has grown. The latest development and evolution of the city has not been based in an organized plan, but in the sense of community, and the attachment of people to their cultural heritage.

The approach of the contest is challenging: transform almost 750 hectares in a new green area of metropolitan influence, combined with new developments. The daring is not just in the size, is also to create a project in a way that does not transform the zone into an elitist and exclusionary development causing gentrification, a phenomena that has already happen in the city, but also, is about being respectful with the environment and inclusive with the surrounding inhabitants. This project is all about building a resilient community.

1.1. General Objective

The objective of this project is to deepen the level of knowledge of the sustainable design process applied into the Latin-American context, by means of a conscious urban and architectural design.

1.2. Specific objectives

The challenge of this project is not only on its dimensions, but also in the necessity to integrate an area that has traced borders and barriers in the middle of a city with the surrounding neighborhoods by creating an urban ecosystem, the objectives achieved then are:

- Transform the existing Airport of Mexico City into a new green lung of metropolitan scale that bring environmental services to the city.
- Interconnect the future zone of urban development with the adjacent neighborhoods and the rest of the city, having in mind the existing geographic and social conditions.

- Reestablish the connection between the citizens and their archeological and scenery protected areas.
- Increase the rooting of people with the place they inhabit, in order to reduce the trend of emigration from the city center.
- Integrate into the urban and architectural design several strategies to have a sustainable use of water in a city that lacks of it, by considering the catchment, supply and storage of it.
- Recover the aquifers of the Valley of Mexico and reduce the vulnerability of the city at facing flooding, by developing a sustainable drainage system.

2. Cases of Study

Around the world there have been several examples of airports that have been transformed into new projects for the cities in which they deploy. Some of them with more or less success according to the necessities of people, the political conditions and the challenges that they implied.

After reviewing some of the most renamed projects of transformation of existing airports, the aspects that have been considered interesting for this study, and that could be applicable are shown in the following pages:

2.1. Stapleton, Denver, Colorado.

This airport has been transformed into a “forest city” for 30000 inhabitants which will live in 128000 homes. It requires 20 years to be developed and at the end will account 24% of public spaces. The aim of their plan is to promote a diverse and successful community rather than the typical American isolated single-use developments, as well as retail services and employment opportunities within a walking distance from home.

The project, developed by the architect Peter Calthorpe, is characterized by the combination of different densities and design of houses and buildings, mixing colors and prices to allow social, economic and cultural diversity, but always using the traditional architecture of the zone. Mid-size schools reachable by walking are going to be built, as well as a network of cycling paths and different transport systems. Special importance have been done in the placing of local shops in the corners and in the reduction of the velocities of the streets. Finally, but not less important, the creation of flooding zones near the river and the recycling of the materials of the old airstrips are the main sustainable actions on this project.

2.2. Tempelhof, Berlin, Germany.

Tempelhof was one of the airports of Berlin, and after the project of the Scottish agency GROSS.MAX was transformed into a new park.

The architects considered that this airport has undergone through a process of metamorphosis, first as a field of Templers, then as a Prussian army exercise ground, later as an airport, and finally as a park, so the idea was to continue to this process of transformation, which does not imply strict change. The most relevant aspects to consider on the design of this new park are, the use of the spaces of the terminal and the hangars for expositions, concerts and any other kind of event; the preservation of the airport character, and the creation of a park connected to the strong shape of the terminal, that leave to the users the role to give a meaning to each space.

The distribution of uses in urban scale starting with commerce near the metro stations, through mixed uses and finally near the park, residential use defines the new quarters around the park.

2.3. Carlota, Caracas, Venezuela.

The airport of La Carlota is still working as a military base, even when it is inside the city of Caracas and there have been proposals for its transformation into a new metropolitan park. After a contest developed to find a the design of the new park, the winning team have done a project in which the main proposal is the recovery of the rivers and the landscape of the zone, the modification of the topography to create basins and wetlands, the enhancement of the connection with the green areas of the city and the renovation of the surrounding urban zones by means of some partial plans.

One interesting thing to consider on this project is that the citizens considered that the demolition of the airstrip was inappropriate for a city with high seismic hazard, considering that it could be used in case of an emergency, to evacuate people or bring help from the exterior.

Now, considering that 75% of the project is going to be dedicated to green areas, it has to be analyzed what is the existing situation of the metropolitan parks of Mexico City:

2.4. Bosque de Aragón.

This metropolitan park is the closest to the existing airport. It has 114 hectares of green areas, most of them planted with exotic species such as eucalyptus, and 12 hectares of lakes. It is divided into 7 zones: Recreation and culture, sensitization zone, recreation, sports zone, administration zone, lake and connecting elements.

2.5. Bosque Chapultepec.

This park is one of the most important in Mexico City, not only because of its beauty, but also because of its historical value as the place of the wellsprings of the city of Tenochtitlan. It is located over a hill and accounts for 686 hectares. From it, is possible to see the small hill of Peñon de Los Baños, just in the north of the existing airport.

This park is also divided in zones, according to the number of visitors. In the first section are placed some monuments and landmarks such as the Chapultepec castle, the national museum of anthropology, the museum of modern arts, and the museum of contemporary art, sport facilities, fountains, a zoo, and a botanic garden. In the second section, there is an interactive museum for children, the museum of natural history and environmental culture, some thematic parks, an athletic track, some lakes and fountains. In the third and las zone, characterized by a forest, one can find sport facilities, and equestrian activities.

2.6. Vivero Coyoacán.

The main porpoise of this public space of 39 hectares is to cultivate species for the reforestation of Mexico City and to educate the children in environmental topics while they can experience how some of the ecosystems of the country are. One can find wetlands that manage recycled water from sewage systems. Also an auditorium and an athletic track.

2.7. Ciudad universitaria.

730 hectares dedicated to the biggest public university of Mexico, UNAM. The urban and architectural design has taken into account the patterns used in some pre-Hispanic cities of the country such as the road of the deaths, as well as the use of murals of artists such as Diego Rivera. It is divided in three main areas: one for the Olympic Stadium, areas dedicated to education and sports areas.

2.8. Parque Bicentenario Azcapotzalco.

This park is developed over 55 hectares that used to be an oil refinery. It is divided into 5 thematic areas according to the ecological zones of Mexico. It includes also a botanical garden, green house, cycling paths, picnic zones, skate parks, courts, energy museum, and an artificial lake.

2.9. Parque México.

This park of 9 hectares is located in the area where before used to be a hippodrome. Where there used to be the old racetrack, nowadays there are paths, fountains and open air gymnasiums arranged in an organic way. One of the main features of this park is the open-air theater characterized by the two pergolas that enclose the scenario and the audience.

2.10. Parque Ecológico de Xochimilco.

One of the most interesting and loved parks of the city, with about 215 hectares, is the live testimony of an ancient agricultural technique: the chinampas, a sort of ecosystem developed by the ancient Aztecs to grow crops in the middle of the lake. The park is also a place dedicated to the conservation of an endemic animal named ajolote, and the rehabilitation of endangered species of the zone. The park counts with guided tours, renting of boats and bicycles, a touristic train, a 54 hectares lake, courts, auditorium, archeologic museum, flowers market and renting of places which ensure the its economical sustainability.

2.11. Parque hundido.

Located in the place where there used to be a bricks industry, Parque Hundido, with its 9 hectares is the place for gardens, paths, fountains, cultural tours, and a zone for passive activities enlivened with classic music and poetry. Two important aspects have to be highlighted of this park, one is the conservation of the resulting landscape after decades of mining, and the possibility to appreciate different reproductions of archeologic pieces from different civilizations of the whole country.

Some other examples of metropolitan parks in Latin America that were considered in this project as study cases are:

2.12. Parque Simón Bolívar, Bogotá Colombia.

With its 400 hectares, this is the biggest metropolitan park of the city. According to the amenities, it is divided in different small parks. Important is to highlight that here takes place one of the biggest free rock festivals of Latin America, Rock al Parque, which have led to the creation of other music festivals of salsa, jazz, hip hop, opera and Colombian music, as well as some free events of the Spanish American Theater Festival. The park counts with several lakes, some of them can be used for sailing, sport facilities, palace of sports, museums, a metropolitan library, artisans fair square, and the botanical garden of the city of Bogota.

2.13. Parque el Tunal, Bogotá Colombia.

It is the most important park in the poor south of the city. As near the airport of Mexico City, the social conditions might be very similar, this example is considered essential for understanding how people in Latin America understand their green public spaces, especially considering how successful this park has been for citizens who before didn’t have the opportunity to enjoy this kind of spaces. The park with an area of 62 Ha is located next to a secondary school and has a coliseum, and elderly house, a children park, an open-air gym, a library, 2 lakes, a temple, parking lots, restaurants, sport facilities, greenery for passive activities and a square for events for 30000 people.

During the week days, the park is mostly used in the mornings by professional cyclists, elder people and allowed recreational activities for groups organized by different entities. In the afternoon is a passage zone for students and workers to their houses or to the library. During the weekends it is used by families for recreation, picnics, aerobics class, sport schools and young adults. According to users, 53% of people go there for exercising, 31% to play with their children, 6% go to the library.

The park, as is in a zone of different social problems has the following inadequate uses: drugs, sex, camping, and robbery when the park is almost empty. People let their dogs to poop and also damage the trees. There are conflicts between users: cyclist with ancient people, football players with passive users, and sports schools. Also there are conflict with the infrastructure, as the parkour, the lack of courts for children, and the sub utilization of the courts of volleyball.

People love this park, although, they think that the park needs more toilets and that the security is bad, due to the size of the park, the manager believes that the infrastructure is not appropriate for children, and he has solved some problems of uses by the interaction with the communities, the use of landscaping and trees for defining the uses, and many others.

3. Theoretical framework

As it has been showed, the characteristics of the climate of Mexico City are dependent on its tropical latitude and its high altitude. As main consequences of this location, the region is characterized by its dry and hot spring, a warm and humid summer with lower temperatures than the previous season, high solar radiation and quite cold but comfortable winters. The sky is clear most of the year, promoting solar heating during the days and long-wave radiant loss during the nights, as a consequence, sunlight reflection on light surfaces, may produce intense glare and visual discomfort, as well as significant radiant heat load.

In Mexico City, the most stressful season is the end of spring and the beginning of summer, after this period, the rain season starts and it appease the extreme temperatures. The aim of the urban design will be to mitigate the stress imposed by the climate on people staying outdoors as well as giving the chance to the individual buildings to provide a comfortable indoor environment with minimum usage of energy. To ameliorate the heat on summer days, sidewalks and playgrounds should be shaded as much as possible, either by trees or by buildings along them; adequate ventilation must be ensured, dust minimized and glare reduced.

To modify the urban climate, some design features can be applied, in the following pages they will be introduced:

3.1. Urban density

A high density of the built-up area in a hot-dry climate may have both positive and negative effects on human comfort outdoors and indoors. With a higher urban density, the availability of open spaces between and around the buildings diminishes. The reduction of the distances will have different effects according to the orientation of the walls.

With a reduction of the distance between buildings along the east-west axis, the mutual shading of the east-west walls of the buildings and sidewalks is increased, and the solar impact on the walls is reduced in summer, improving the indoor climate conditions.

At latitudes of 20 degrees, a small distance between buildings in the east-west direction, relative to their height, can be very helpful in providing mutual shading for the walls. For a four stories building with 12 meters height, a distance of 4 meters between buildings would give a 3:1 ratio of height to distance. It means that the sun`s altitude should be more than 70 degrees before the ground between the buildings will be exposed to it, namely between about 11 A.M and 1 P.M. (Giovani).

The distance of the buildings along the north-south axis plays a different role in the climatic considerations of the urban design. A short distance will reduce the possibilities of using solar energy for heating in winter as well as the solar access of the buildings.

With regard to the distance between the buildings in the north-south direction, because of the lower altitude in winter, longer distances between buildings are needed to prevent mutual solar shading. A distance of 1.5-2 times the height of the building would be enough to provide solar access in winter (Giovani).

In neighborhoods with high-rise apartment buildings, higher overall urban densities can be maintained with adequate potential for natural ventilation by ensuring reasonable distances between the buildings. Even a narrow distance of about 2 meters enables the use of wind flowing through the gap between the buildings. This would give an advantage to reduce the distance between them in the east-west direction to about one-fifth of their height (Giovani).

An urban configuration to be avoided is that of high long buildings, of the same height, perpendicular to the wind direction. This configuration blocks the wind and creates poor ventilation conditions both in the streets and for the buildings, as the first row of buildings acts as a wind barrier (Giovani).

The best urban climate conditions exist when density is obtained with high, narrow buildings of different heights placed next to each other, and when the long facades of the buildings are oblique to the wind (Giovani).

3.2. Street layout

The orientation of the streets affects the urban climate in several ways:

- Wind conditions in the urban area as a whole.
- Sun and shade in the streets and the sidewalks.
- Solar exposure of buildings along the streets.
- Ventilation potential of the buildings along the streets.

In Mexico City the provision of shade in the streets in summer is one of the major design means for minimizing the heat stress of people walking in the streets. Streets running north-south have better shading conditions in summer and better light conditions in winter than east-west streets. A street grid in “diagonal” orientation: northeast-southwest and northwest-southeast is preferable from the solar exposure aspect. It provides more shade in summer and more sun exposure in winter (Giovani).

A good street layout from the urban ventilation aspect is when wide main avenues are oriented at an oblique angle to the prevailing winds (at about 30 degrees). The buildings along such avenues are exposed to different air pressures on their front and back facades providing good potential for natural ventilation of the buildings, while at the same time provides good ventilation within the streets in high density residential zones (Giovani).

3.3. Public space

Open green public spaces have a great effect on creating urban environments of high quality, improving the comfort conditions of people by the correct landscaping, modifying wind and sun exposure and the energy needs of the buildings around. In addition to this considerations, urban vegetation can reduce the levels of air pollution and noise, and at the same time improve the appearance of a place and the social activities developed on it.

Large urban parks such as the required Eastern Metropolitan Green Lung, have an important role in stablishing the image of a city and providing areas for large gatherings and social activities. From the climatic aspect, however, the effect of large parks on the climatic conditions of the surrounding built-up areas are quite limited. Thus, the division of the entire space allocated for parks into a large number of small parks, spread over the whole urban area, will have a greater effect on the overall urban climate and the reduction of air pollution, than would be the creation of a small number of large parks. In respect of modifying ambient conditions of buildings far from parks, vegetation in private lots around them can be of more importance (Giovani).

Due to the intense solar radiation, plenty of places to sit in the shade and protect from sun should be provided along roads, in public parks and playgrounds to minimize the danger of overstress and heat strokes. Trees can also help to protect against winds during the cold months enhancing the attractiveness of such spaces.

Areas prone to floods can be grassed and planted with trees which can withstand flooding. Such areas can be utilized as flood controls during and immediately after, rainstorms. In the periods between the storms such areas can again be used as public green spaces (Giovani).

When an open space serves the function of a buffer zone, its potential role as a recreation area is limited due to the noise within the open area itself, therefore as an optimal design solution, the buffer zones should be planned so as to both maximize the noise reduction effect and at the same time to find additional uses, which are not very sensitive to noise, for these buffer areas.

A major source of urban noise is from traffic along highways, its impact can be reduced both by distance and by linear solid barriers. Such barriers can be in the form of raised strips of planted soil on both sides of a sunken highway, creating noise shadows that increase the effectiveness of the buffer zones. Anyway, in order to obtain significant reductions in the noise level (10 dB), at least a 100 meters deep dense vegetation is required. From this it can be concluded that vegetation have a greater psychological effect that a real effective sound reduction by isolating people form the source of noise (Giovani).

In terms of the social function of parks and open spaces, special planning must be considered to maximize the times and intensities of their use. Such planning should determine location of facilities and roads in the urban network, as well as planning details of the surrounding area such as: land use around the park, institutions to attract persons into the area during the various hours of the day, location of public transport facilities, such as bus stations, and so forth (Giovani).

3.4. Sustainable drainage systems

Floods in urban areas can be caused from water, originating in faraway areas, flowing through the city or by excess rainwater generated over the area of the city, which cannot be absorbed in the soil or discharged away fast enough (Giovani). For the central area of Mexico City, where this project is going to be developed, the levels of rainfalls as have been mentioned are quite low, but because of its topographical conditions, it has a big risk of floods coming from faraway places through the piped rivers that cross the city.

As it is now impossible to avoid the development of this area, a resilient approach against floods must be considered for this project. In this case, the objective is to reduce the risk of floods from excess rainwater and to give the place the capacity to withstand certain floods from faraway by details of urban design:

- Increasing rain absorption in the soil in the urban area.
- Preserving land features of natural drainage such as interconnected valley systems.
- Collecting excess runoff in urban reservoirs, such as small lakes.

This features can be integrated to the urban planning of the site to serve both social and climatic functions.

For reducing the runoff volumes, natural vegetation is always the best solution, but as in a city many of the areas are covered, some strategies can be implemented. A significant portion of the paved areas of a city are not subjected to heavy vehicular traffic, such as parking lots, pedestrian areas, and local streets. These areas can be surfaced with permeable pavement and a layer of sand and gravel can be placed below the semi-hard surface to increase the area of effective infiltration and the water absorption rate (Giovani).

Delaying the peak and spreading the duration of the runoff water involves temporary storage of a given amount of water over a land surface, or within a gravel layer over the soil. Natural or excavated grassed depressions can be used as temporary storage for rain water, as well as flat green roofs, that can retain water during the rain and release it slowly afterwards, as well as permit evaporation of part of it during the sunny periods, while reducing the heat load on the building.

In order to achieve water sustainability on this project, an alternative for the traditional drainage system is contemplated. Sustainable Drainage Systems (SuDS) are able to manage the surface water in terms of quantity as in any system, and at the same time improve its quality and serve as amenity for people.

SuDS are systems able to use nature or imitate it in order to manage rainfall close to where it falls. They are designed to retain the water and slow down the flux before it enters into the watercourses. Retaining surface water reduces the need for drainage infrastructure and energy for pumping, with their extensive capital and maintenance costs. Streams, rivers, canals, ponds and lakes can be incorporated into surface water retention systems, whilst simultaneously providing attractive visual landscape features and valuable ecological habitats. They can also be linked to the recycling of grey water (run-off from roofs and other hard surfaces) for the irrigation of plants. (Davies, 2000)

According to (Susdrain, 2015), SuDS are more sustainable than traditional drainage methods because they:

- Manage runoff volumes and flow rates from hard surfaces, reducing the impact of urbanization on flooding.

- Protect or enhance water quality (reducing pollution from runoff).
- Protect natural flow regimes in watercourses.
- Are sympathetic to the environment and the needs of the local community.
- Provide an attractive habitat for wildlife in urban watercourses.
- Provide opportunities for evapotranspiration from vegetation and surface water.
- Encourage natural groundwater/aquifer recharge (where appropriate).
- Create better places to live, work and play.

There are some key principles that influence the planning and design process enabling SuDS to mimic natural drainage by:

- Storing runoff and releasing it slowly (attenuation).
- Allowing water to soak into the ground (infiltration).
- Slowly transporting (conveying) water on the surface.
- Filtering out pollutants.
- Allowing sediments to settle out by controlling the flow of the water.

The cheapest and most efficient way to reduce the water runoffs is to control it on source. Among the systems able to do so are the green roofs, permeable surfaces, rainwater harvesting and water butts. Among the advantages of using them, are the reduction of pollution and that maintenance is done by the owner of the property, reducing cost for the city.
The leading concept of the Sustainable Drainage Systems is the SuDS management train, which as in natural catchment, is a series of drainage techniques that change the flow and quality of the water from runoffs.

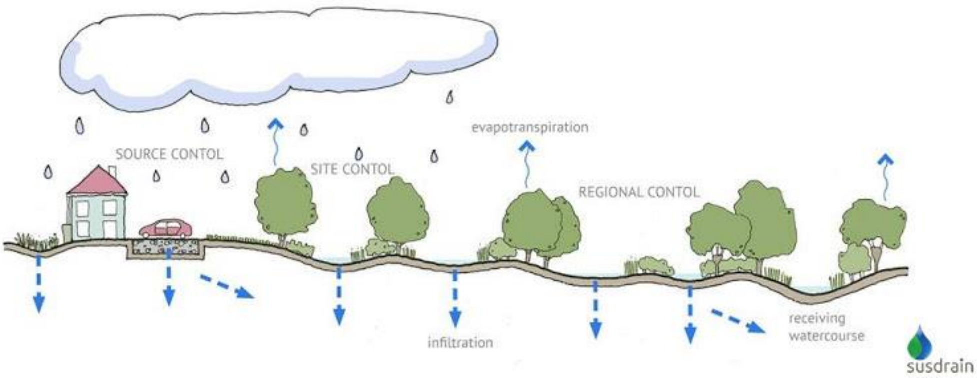


Figure 30: The SuDS management train. (Susdrain, 2015)

The management train starts with prevention of the flooding by avoiding the excessive use of impermeable areas, the reduction of the pollution and continues with the local source controls to larger downstream site and regional controls.

When water cannot be managed onsite, it is possible to conduce it somewhere else at a slow rate, for example, in case the permeability of the soil is not enough, floods, or required treatment before disposal. In any case, solutions with runoff directly discharged to wetlands or ponds should be avoided.

In the following the different components of the Sustainable Drainage System are going to be explained:

3.4.1. Source control:

Their purpose is to manage rainfall close to where it falls, not allowing it to become a problem elsewhere. They are able to handle the more frequent but small rainfalls.

3.4.1.1. Green roofs:

Is a multi-layered systems that covers the roof of a building with vegetation, making it possible to maximize the permeability of the surface, and in this way, increase storage, attenuation, and evapotranspiration meanwhile providing thermal comfort and habitat for different species. Green roofs consist of an impermeable layer, a substrate or growing medium and a drainage layer. They are designed to intercept and retain precipitation, reducing the volume of runoff and attenuating peak flows. (Susdrain, 2015)

Figure 31: Green roof. (Susdrain, 2015)

Green roofs are part of the Mexico City government efforts to purge its air from its pollution. On 2103, he city's environment secretariat spent almost $1m (£595,000) on the Azoteas Verdes Project, bringing the total area of green roofs in hospitals, schools and government buildings to 21,949 sq. m.

3.4.1.2. Pervious paving:

Are special paving in which water is able to soak into the gravel sub-base below, temporarily holding it before it soaks into the ground, or passes to an outfall. The pavement structure is the able to control runoffs and act at the same time as a filter that improves a little the quality of water. (Susdrain, 2015)

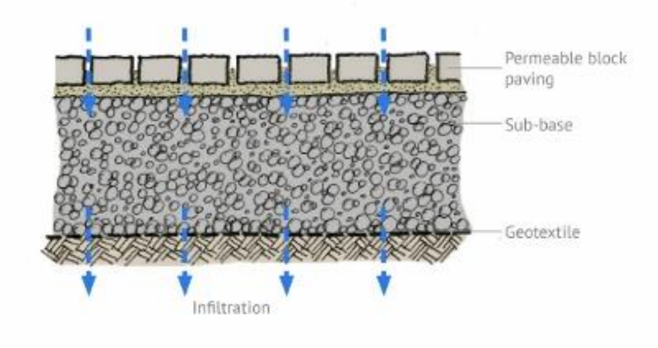


Figure 32: Permeable paving. (Susdrain, 2015)

Pervious surfaces can be either porous or permeable. The important distinction between the two is:

Porous surfacing is a surface that infiltrates water across the entire surface. Some examples of porous surfaces are open-textured soil or granular material, geo-synthetic gravel/grass protection systems, small porous elemental surfacing blocks and continuous-laid porous material.

Permeable surfacing is formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration through the pattern of voids. Permeable surfaces can be built with small or large elemental surfacing blocks.

Figure 34: Porous surfacing.

Figure 33: Permeable surfacing.

Pervious paving can be used in squares, plazas, pedestrian and cycling paths, parking lots, commercial areas and in all the avenues and local streets with velocities under 50 km/h and restriction to heavy trucks traffic.

3.4.2. Swales and conveyance channels:

Transferring of surface water runoff across a site can be achieved in many ways: Through underground pipes (no water quality control), vegetated channels that provide treatment and attenuation, and through canals or rills. The most sustainable strategy is the transport of water through vegetated channels and swales. Discharge of water to a point should be discouraged.

Overland flow routes will also be required to convey and control floodwater safely during extreme events. In general, the greater the number of components used in series, the better the performance is likely to be, and the lower the risk of overall system failure. (Susdrain, 2015)

3.4.2.1. Swales:

Are shallow, broad grassed or vegetated channels used to collect, store and/or move water until the next state of the treatment train. The shallow side slopes and flat bottom means that for most of the time water flows in a thin layer.

Swales are effective at removing polluting suspended solids through filtration and sedimentation. The vegetation traps organic and mineral particles that are then incorporated into the soil, while the vegetation takes up any nutrients. They can provide storage and filtration as well, where the soil and underground water conditions allow.

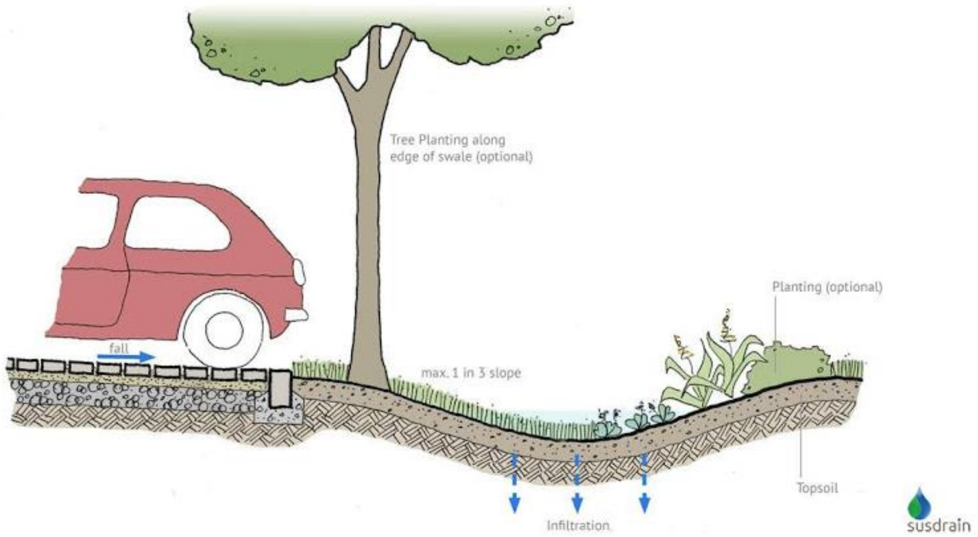


Figure 35: Swales. (Susdrain, 2015)

3.4.2.2. Canals and rills:

They are open surface water features with hard edges able to collect water, slow it down and transport it. They can be built with different cross sections, and planting can be inserted for water treatment. In dense urban developments, they can be an effective way of providing SuDS and if appropriately designed can also act as pre-treatment to remove silt before water is conveyed into other SuDS components. Usually the outlets are designed to act as a mini oil separator and enables the channel to be very effective at treating pollution. (Susdrain, 2015)

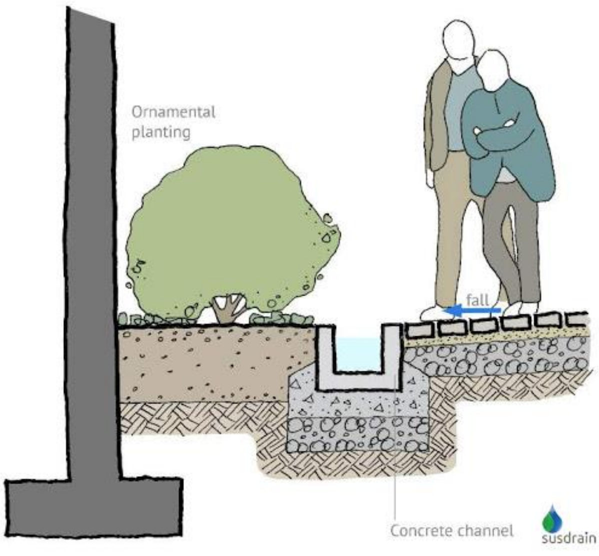


Figure 36: Channel. (Susdrain, 2015)

3.4.3. Filtration:

Filtration and removing sediment or other particles from surface water runoff is one of the main treatment methods for sustainable drainage. The main filtration component used in this project are the bio-retention areas.

3.4.3.1. Bio-retention areas:

Vegetated depressions in the ground with specially designed engineering soils and sand layers, which filter out pollutants from surface water runoff normally associated with highways. The filtration layers are usually under drained using a perforated pipe system and where appropriate can allow infiltration. Trees can also be incorporated into bio-retention systems and they can therefore be integrated with tree pits in streetscapes and other public realm areas. (Susdrain, 2015)

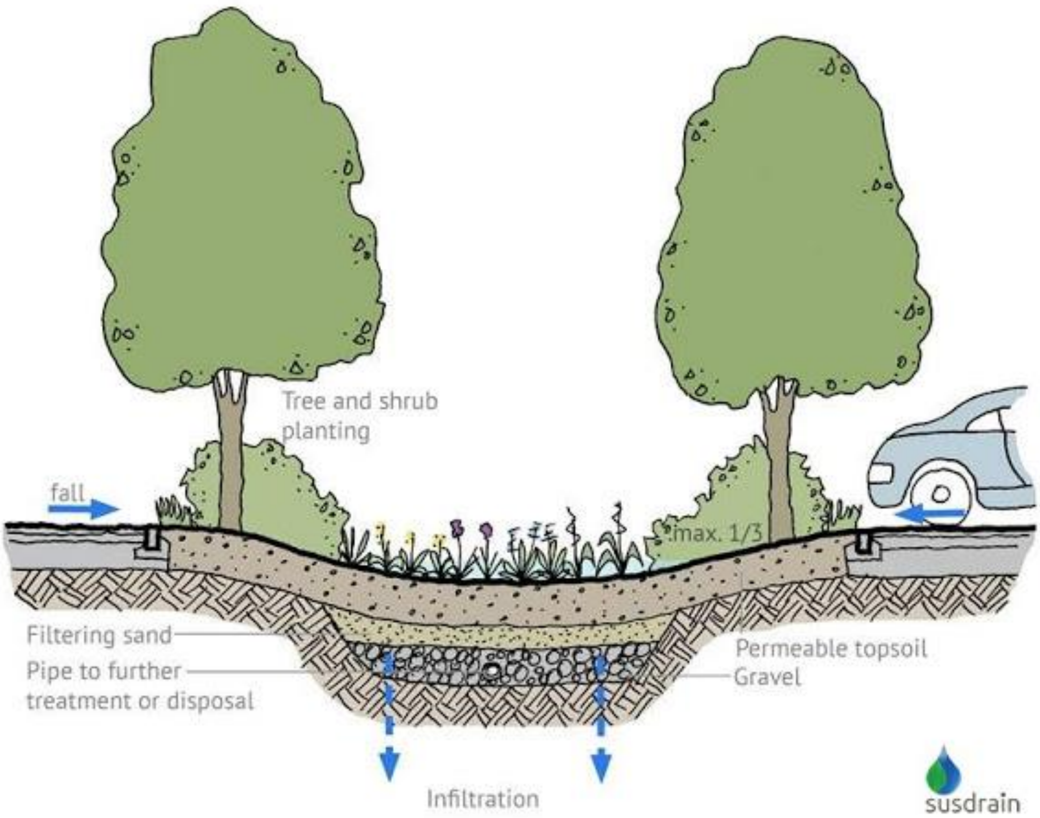


Figure 37: Bio-retention areas. (Susdrain, 2015)

3.4.4. Infiltration:

Infiltration components are used to capture surface water runoff and allow it to infiltrate and filter through to the subsoil layer, before returning it to the water table below. Two main infiltration components are contemplated on this project:

3.4.4.1. Soakaways:

They store and allow its efficient infiltration into the surrounding soil. Drainage from individual properties is often connected to over-sized square or circular, rubble-filled voids lined with brickwork and sited beneath lawns. A soakaway will allow water to soak through the surface into the gravel sub-base below, temporarily holding water before allowing it to either soak into the ground to an outfall. They can be grouped and linked together to drain large areas including highways. (Susdrain, 2015) Infiltration rates of the soil and stability of the structures around must be considered.

3.4.4.2. Infiltration basins:

It is a dry basin or depression designed to promote infiltration of surface water runoff into the ground. Plants in an infiltration basin should be able to withstand periods of ponding and dry periods and, ideally, maintain or enhance the pore space in the underlying soils via deep rooting systems.

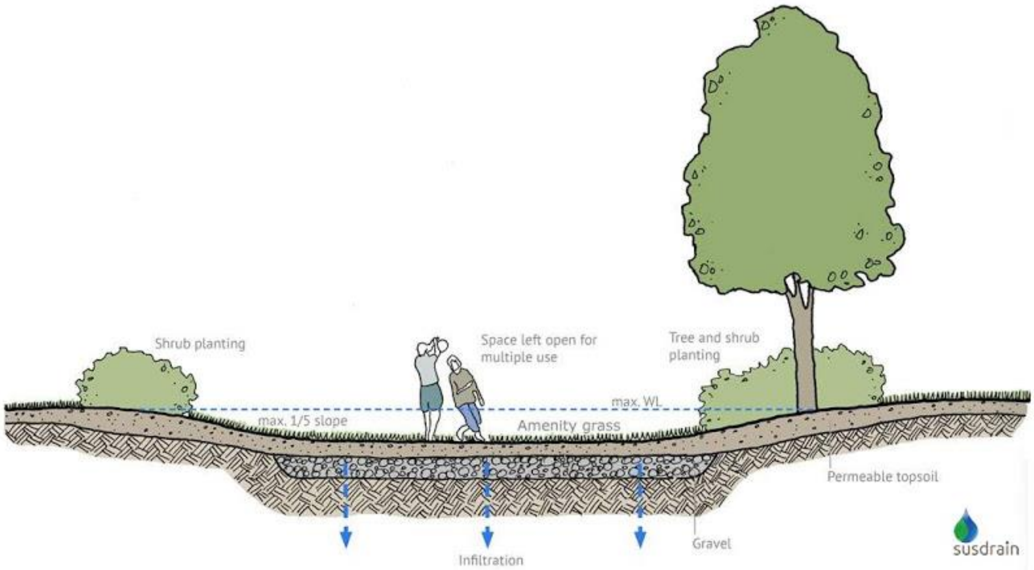


Figure 38: Infiltration basin. (Susdrain, 2015)

3.4.5. Retention and detention:

This components are designed to store through retention or attenuate through detention of surface water runoff. Retention storage on this project will be achieved by the use of ponds and attenuation through the use of basins.

3.4.5.1. Retention ponds

Are open areas of shallow water, designed so they can accommodate rainfall and provide temporary storage for excess water. The level rises temporarily when it rains, and can provide attenuation and treatment to storm-water, helping manage flood risk. There is always a permanent pool of water, so they can to support emergent and submerged aquatic vegetation along their shoreline. The retention time promotes pollutant removal through sedimentation and the opportunity for biological uptake mechanisms to reduce nutrient concentrations. However, there should be upstream components or treatment stages before surface water is conveyed to ponds and wetlands. (Susdrain, 2015)

3.4.5.2. Detention basins

Are open, usually flat areas of grass that are normally dry, except after major storm events. In heavy rainfall they are used to store water for a short time and so they can fill with water. However, basins can also be mixed, including both a permanently wet area for wildlife or treatment of the runoff and an area that is usually dry to cater for flood attenuation.

Basins tend to be found towards the end of the SuDS management train, so are used if extended treatment of the runoff pollutants is required by means of filtering and sedimentation; or if they are required for wildlife or landscape and recreational reasons. In any case, effective operation requires that sediment and debris is removed upstream. (Susdrain, 2015)

3.4.5.3. Wetlands:

Wetlands are densely vegetated water bodies that use sedimentation and filtration to provide treatment of surface water runoff. Artificial wetlands consist of an inlet zone (sediment basin) a macrophyte zone, which is shallow, densely vegetated area; and a high flow bypass channel, which is typically a wide vegetated swale from the inlet pond around the side of the wetland. (Susdrain, 2015)

Where ever possible wetlands should be the last stage of the SuDS management train and should be one of the last treatment stages, after passing through a series of upstream components explained before. Wetlands remove fine sediments, metals and particulates, and dissolved nutrients from polluted runoffs by ensuring a slow flow of water over an extended period of time. In order to provide breakdown of oils by natural organisms, they need a good supply of oxygen which means the permanent water must be shallow enough so that oxygen can reach the bottom of the wetland. (Susdrain, 2015)

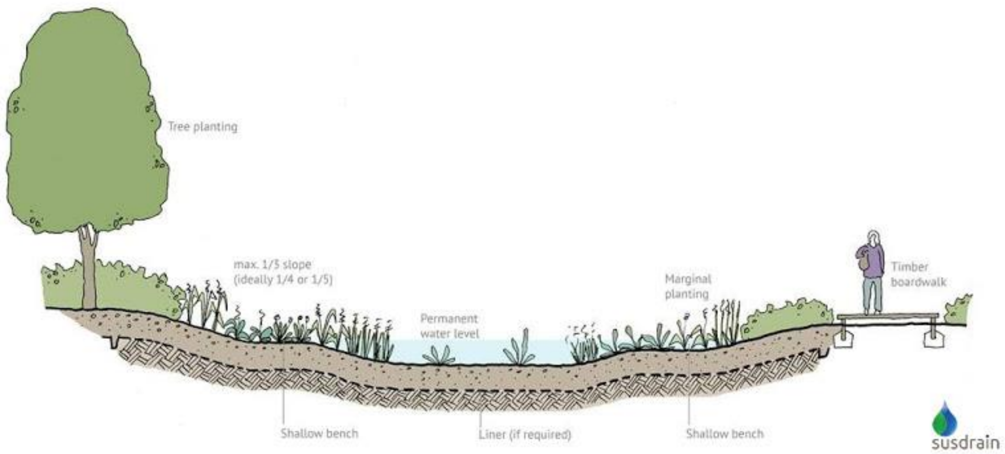


Figure 39: Wetlands. (Susdrain, 2015)

4. Proposal

This project is about building a new landscape inserted in Mexico City, an ecological infrastructure that considers humans as part of an ecosystem, which blurs the city life and the nature of the border of the city. An interesting approach is introduced in (Steiner, 2011) with the seven key axioms of Landscapes Urbanism:

- Cities and landscapes change constantly: cities are in a perpetual state of flux, change should be a consideration in design and planning even in places with different levels of flexibility.
- Technology connects us to each other and our environments in new ways, changing how and where we live: connecting technologies should be embraced in design and planning to help visualize processes that affect livability of cities and regions.
- Sense of place and sense of region produce distinct regional cultural identities: places such as natural environments, pedestrian and shared spaces, art, multi-generational communities and wise energy use are some strategies for strengthening a community through history and heritage.
- Certain regional identities foster creativity: design and planning should reinforce creative regional identities, by connecting urban living to nature in thoughtful and artful ways.
- Landscape-based urban design involves the repetition of patterns across scale: any city is an arrangement of units in several ways that form a unity and adapts to the addition of new parts. Design can enhance existing patterns through the addition of new and complementary elements.
- Design and planning disciplinary boundaries blur in Landscape Urbanism.
- Cities and landscapes are resilient ecosystems.

4.1. Resilience in cities and landscapes

For this project, it is important to deepen in the last axiom, related to resilience in urban ecosystems, such as Mexico City. Located in the Latin-American context, it is possible to realize that for many problems that face the society, implausible solutions are often found, that at first sight could give the impression that they will not work, but in a disconcerting way they work, and in a very good way. This uniqueness of the city, forces the project to respond in original ways to the requirements of the society, far away from any standardized solution.

Resilience has been defined in two different ways in the ecological literature, each reflecting different aspects of stability. One definition focuses on efficiency, constancy and predictability, all attributes of engineer`s desire for fail-safe design. The other focuses on persistence, change and unpredictability, all attributes embraced and celebrated by evolutionary biologists and by those who search for safe-fail designs (Steiner, 2011).

The first definition is tied to standard ideas in ecology, which emphasized equilibrium and stability. The second definition emerges from new ecology, which focuses on non-equilibrium and the adaptability of ecological systems. The last is more appropriate for urban ecosystems, because it suggests that spatial heterogeneity is an important component of the persistence of adaptable metropolitan regions (Steiner, 2011).

Resilience is related to disasters, "Many disasters may follow a predictable pattern of rescue, restoration, rebuilding, and remembrance, yet we can only truly evaluate a recovery based on special circumstances". Urban resilience is linked to the specific qualities of the place where it occurs, based on enhancing social capital, creating knowledge capital and protecting natural capital (Steiner, 2011).

Mexico City is an entity that is growing, changing and adapting continuously, twenty seven million people live in the megalopolis of Mexico City—and a large percentage do so in extremely vulnerable conditions. The city's proliferation of informal employment, the lag in infrastructure, strong social inequality, severe weather, and the sheer size of its population add to the risk of disaster—social disaster, political disaster, and environmental disaster. Mexico City faces significant danger from natural phenomenon. Its geographical conditions make it continually susceptible to seismic hazards, and being located on land that was once a lake makes the city prone to flooding. Runoff from the nearby mountains is improperly managed, which, in addition to flooding, can lead to mudslides and diseases born from standing water. The resilience plan of the city must pass from reactive to proactive in the coming years.

4.2. Sustainable design approach

If everyone in the world live like an average North American, we would need 5 planets to live on, if everyone live like and average European we would need 3 planets to live on. The world is facing climate changes and resources scarcity due to the irresponsible manner in which they have been exploited, being used as if they were unlimited. In an attempt to reduce the deterioration of the planet have been created sustainable frameworks like One Planet Living, LEED, ITACA, that give designers and users a guidance to reduce the impact of their actions.

In order to achieve the goal to build a resilient and more sustainable Mexico City, in this project the approach of One Planet Living for sustainable developments has been adopted.

One Planet Living is an initiative of Bioregional and its partners to make truly sustainable living a reality. One Planet Living uses ecological footprint and carbon footprint as its headline indicators. It is based on ten guiding principles of sustainability as a framework.

4.2.1. Zero carbon print

Making buildings energy efficient and delivering all energy with renewable technologies. To achieve this goal from the very beginning of the urban planning, climate conditions have been considered, such as sun availability, air temperatures and humidity, predominant winds, and pollution sources in order to maximize the advantages of a correct disposition of the urban fabric, the orientation of the buildings and the public spaces. Regarding the use of renewable energy, the city is rich in sources such as the sun and the biomass from waste.

4.2.2. Zero waste

Reducing waste, reusing where possible, and ultimately sending zero waste to landfill. Mexico City has disposed its waste in open landfills for decades, at the edges of the city, creating several problems of pollution and social exclusion, with the aggravating circumstance that most of them are located over the Texcolo Lake, in the vicinity of the site of this project. Important lacustrine ecosystems as well as aquifers are now completely polluted, in a city characterized by the scarcity of drinkable water. One of the main reasons for this is the lack of knowledge of the population in aspects such as recycling and waste disposal, as well as governmental neglect. For this reasons, in this project one of the key aspects on the design is education of people in environmental aspects. The Eastern Metropolitan Green Lung will become a laboratory for sustainability, where people can learn about the best practices of waste disposal and treatment. Recycling is contemplated as well, but most importantly, the resulting organic waste will be transformed into compost in a specific area of the park, for the fertilization of all the green areas.

4.2.3. Sustainable transport

Reducing the need to travel, and encouraging low and zero carbon modes of transport to reduce emissions. The area of the future Eastern Metropolitan Green Lung is, as has been mentioned in the chapters before, well connected from one of its sides by Metro. The strategy adopted to encourage the use of public transport is to orient the design of the new urban development towards the existing transportation system, and extend it where necessary. The whole urban fabric has been designed having in mind walkable distances for the different uses, and from the existing metro and the proposed Metrobus (BRT) stations. Another strategy related to this principle, is the extension of the public bicycle system of Mexico City into our project, by proposing the location of stations in all the important avenues and focal points, connected through a network of bike-paths that will extend towards the city.

4.2.4. Sustainable materials

Using sustainable and healthy products, such as those with low embodied energy, sourced locally, made from renewable or waste resources. For this principle two main actions are contemplated since the urban design, one of them is the reuse of the materials and structures of the old terminals and hangars in the construction of the exposition and fair center. The other one is the recycling of the aggregates obtained from the demolition of the airstrips for the construction of the new roads of the project.

4.2.5. Local and sustainable food

Supporting sustainable and humane farming, promoting access to healthy, low impact, local, seasonal and organic diets and reducing food waste. In order to promote agricultural practices on urban spaces, not only available land is needed, but also involvement of the community and education. The zones dedicated to agriculture need to be located in places where people from the new and the existing neighborhoods can access easily, but at the same time, close enough to the future markets. Urban agriculture is for this project the transitional ecosystem between the urbanized city and the “natural” area of the metropolitan park, and will become the revival of the ancient chinampas, where water, food and people where in equilibrium.

4.2.6. Sustainable water

Using water efficiently in buildings, farming and manufacturing. Designing to avoid local issues such as flooding, drought and water course pollution. Mexico City, and specially this project is located over an ancient lake, however, water scarcity and flooding are one if its biggest problems. Water sustainable use is achieved by capture, storing, conscious use, cleaning, recycling and return to the environment. Regarding the flooding, the main goals are to reduce and delay the storm runoff volumes, and extend the period of draining into the drainage system of the city; this will be obtained by implementing a system of retention ponds, porous paving, and green surfaces, among others.

4.2.7. Land use and wildlife

Protecting and restoring biodiversity and creating new natural habitats through good land use and integration into the built environment. The biggest goal of this project is to recover the ancient ecosystems of the Texcoco Lake, and re-introduce the species that are under danger due to urban expansion. The park needs to integrate to the existing green network of Mexico City and its surroundings and reestablish the cultural meaning that had this landscapes for the ancient Mexicans.

4.2.8. Culture and community

Respecting and reviving local identity, wisdom and culture; encouraging the involvement of people in shaping their community and creating a new culture of sustainability. Recover the lakes of the valley of Mexico, as the center of the culture of the city will create a new attachment of people with their public spaces, and will help the zone to become a catalysis of a new process of community creation with great results in the environmental and social orders.

It has to be said that the urban plan proposed, even when taking in mind several cultural aspects of the citizens, is just an input for the creation and organization of the zone. The construction and transformation of the public and common spaces in Latin America is a process in which the community is involved at a very high level. Part of the Mexican culture and philosophy is that to appreciate something, first must work hard to get it. It´s that why a space built among the community is a successful space. None is better than the community to know their needs, and along the time this attachment is transmitted by heritage, "my parents work to build it…" "My grandparents fought for one day we can have it". It's that why the engagement and participation of the surrounding community, the so called social capital, have to become a key role in the construction of the new public spaces of this project, transforming them over time into livable and successful spaces in accordance to the natural capital that they represent.

4.2.9. Equity and local economy

Creating bioregional economies that support equity and diverse local employment and international fair trade. This principle is one of the most difficult to achieve. The proposal for this item is to mix the most possible the land uses not only in plan around the zone, but also in elevation inside the buildings. There is nothing better to boost a zone and its economy and social relations than work and commerce zones close to the housing. This will open the opportunity to many entrepreneurs and small companies to stablish and growth, increasing the population and avoiding the actual trend of emigration and gentrification of the city center.

4.2.10. Health and happiness

Encouraging active, sociable, meaningful lives to promote good health and wellbeing. This principle for the researchers is the summary of the nine before, only by achieving the others a livable and comfortable city can be generated. It has to be added that in order to increase the health and happiness of the Mexican population, and reduce the levels of stress typical of a big city, it is important to provide enough sport facilities and leisure areas for recreation, as well as encourage people to walk more. In that way their health will be better and the city will be too.

5. Master Plan

The Arquine International Contest for the creation of the Eastern Metropolitan Green Lung, was intended to be a call for ideas for the generation of a new metropolitan park inside the terrain of the existing airport of Mexico City, a big opportunity for the city to provide some space for nature, health and life.

This development needs to be economically sustainable also, and that is why it is needed to create a new neighborhood, with the dimensions of a small city, able to give home to more than 30000 people and place for several complementary uses: tertiary, offices, commerce, and equipment of cultural, educative and recreational orders. It is supposed to become into a strategic piece for the development of the region of the Valley of Mexico.

Mexico City and specially the place where the existing Airport Benito Juarez stands have historically occupied "recovered" lands from a network of fresh and salty lakes, especially in the last century when this growth has been accelerated. The proposal of this project is not focused on occupying more land, but on giving back to the ancient system of lakes and recover their natural environment. The idea is to organize a space of 750 hectares of a new urban ecosystem that is interconnected with the rest of the city in different scales. The result of this reasoning is the master plan of the Eastern Metropolitan Green Lung (Annex U-16).

Figure 40: Eastern Metropolitan Green Lung

The fist aspect that was considered for the design of the master plan of the Eastern Metropolitan Green Lung were the characteristics of the urban transportation, considering the metro stations and the presence of big highways as important elements for the future connectivity. In this sense, the idea was to locate a middle scale park in the western part of the project reachable from two metro stations and close to the terminal 2 of the existing airport and the existing commercial zone in front of it. This new green area will be a preamble of what people of all the metropolitan area could find in the following blocks of the development until the biggest metropolitan park of the east.

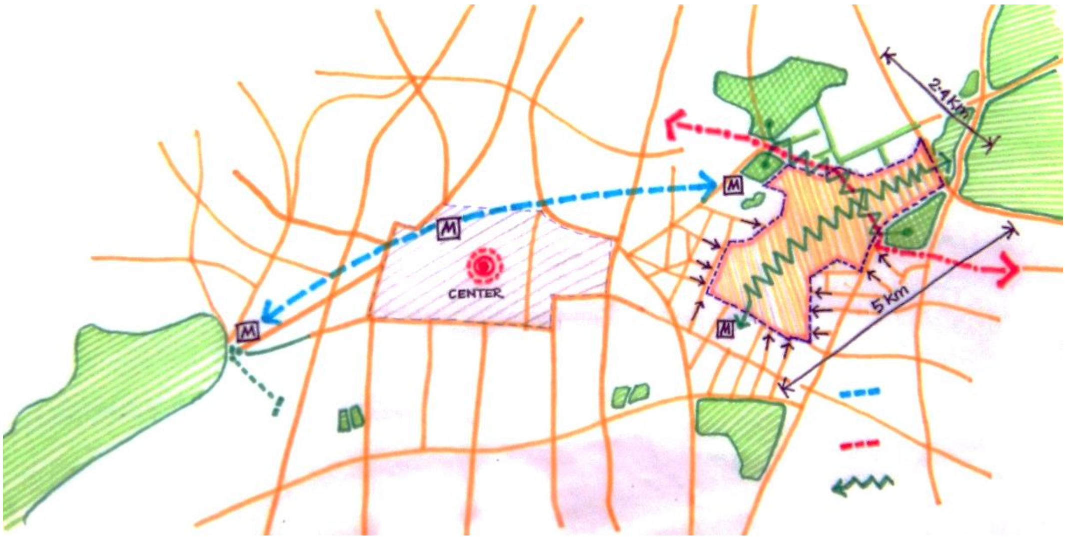


Figure 41: Urban connections of the Eastern Metropolitan Green Lung

It is desired to link all the green areas near the existing airport such as Bosques de Aragón in the north, Deportivo Alameda in the south, Peñon de los Baños in the northwest though a network of new urban smalls parks and squares and a more natural one of metropolitan scale, able to provide different and new ecological services for the city like: water regulation thorough lakes and wetlands, treatment of organic waste to produce fertilizers, education about sustainability for the population, and a new nursery garden to grow the plants that will supply this park and help in the process of reforestation of Mexico City.

Another important point of this proposal is the refurbishment of the existing terminal 2 and part of the terminal 1 for commercial and tertiary uses, as in the case of the Tempelhof. Inside this two buildings are already located services such as hotels and commerce, but also, this buildings can offer space for new offices, spaces for events, small expositions or conferences, lectures, festive banquets, film productions, storage, and so on.

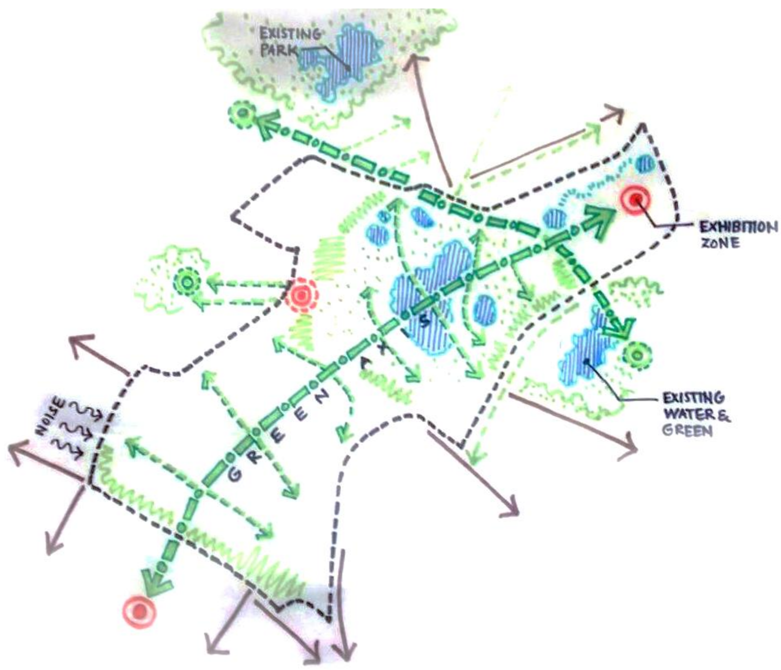


Figure 42: Connection to existing green areas

After preserving the two terminals of the airport, it is important to stablish a connection between them and the existing residential zones through mixed use urbanizations where architecture must play a dominant role in order to give identity and uniqueness. This can be achieved by building homes of different types, areas, and prices to accommodate people from different social origins. On this development, beside the residential use, it is contemplated to dedicate space for offices, schools, commerce and restaurants with small scale parks and urban farming zones that will act as bridges between the urban zone and the bigger parks of the west and east.

It was also reasoned that the localization of the new exhibition and trade center for this zone should be strategically decided, due to the fact that it will create huge problems of traffic congestion. In this sense, it was considered that the best location for this equipment is the eastern part of the plot nearby the existing Texcoco Lake, where there is nowadays less presence of residential zones. It will also have right access from the Periferico external circuit, which connects Mexico City with the State of Mexico and the future new airport of Texcoco.

The project of the Eastern Metropolitan Green Lung is an incredible opportunity for creating a new urban model for Mexico City in which the urban fabric, the infrastructure, the landscape and the citizens work together as a system in which the last ones find themselves living in an environment finally connected with the ecosystems, the history and the culture of the place.

Figure 43: First approach to the project

This sustainable and comfortable lifestyle can be obtained more easily by creating communities where cars are not needed for everything, by making the blocks of the correct size in order to make attractive for people to walk, and most importantly, by locating work, recreation, transport and other services, enough close to their homes.

According to the result of the analyzed information and the sustainability approach adopted, it was concluded that this project would be ruled by three main topics:

- Urban structure and land uses.
- Sustainable mobility.
- Urban ecosystem.

Considering this aspects, in the next following pages, it will be explained in a deeper way how each of them has been tackled.

5.1. Urban structure and land uses:

The authors of the present project have considered that it is not enough to talk about public space and land uses. There is always an interaction between all the spaces, public and privates, and that element in the middle is the human being.

In order to involve the private sector in the creation of public space and the sense of community, in stages beyond the mere construction and speculation of buildings, it is necessary, to go back in time before the modern period and rescue those values that made vibrant communities.

It is a proven fact that in old towns and villages, and even in the irregular neighborhoods of capital cities of Latin America, society can solve their needs through personal and collective initiatives. This is how, inside the same zone one can find: people's houses, a corner shop or minimarket, a nursing home, the church, the square, small enterprises, and so on. This kind of neighborhoods are the most effective in order to maintain security conditions, enhance the ties between people, and make the streets more livable and walkable.

The big question is now, how to apply this idea to the master plan of a development of such a big dimension? Well. It has to be through mixing uses. There can be of course zones more dedicated to the tertiary sector, or others more residential, but a certain level of mixing is needed everywhere. This can be obtained in plan, by organizing the land uses of the blocks, and by elevation, by making "multipurpose" buildings, with for example retail in ground floor and homes in the upper ones.

In the next image, it is possible to see the different land uses contemplated for the design of the urban master plan, and their relations. They are divided into 3 main groups: the green and public space (green) that is taking 75% of the total area; the private equipment, services, offices and tertiary sector which is asked to be 15% of the area (purple), and the residential zones with its basic public equipment, which is asked to be the remaining 10 % (orange).

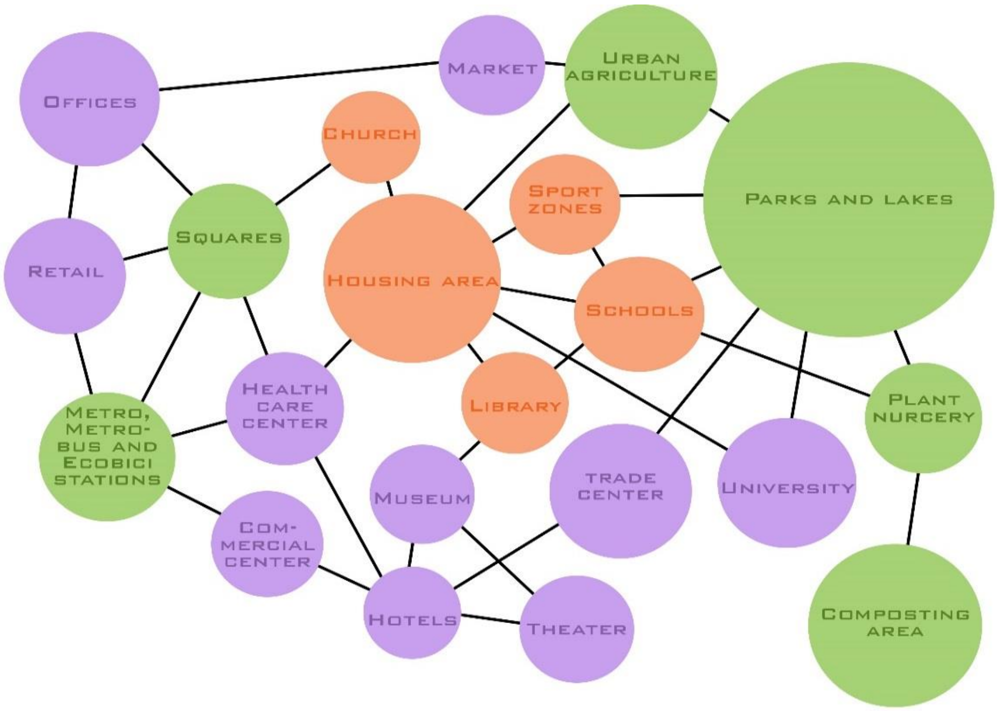


Figure 44: Bubble diagram

However, the designers have decided that this two last percentages do not really need to be strictly related to the occupied available land, but they can be blended in different proportions according to the zone and the necessities.

Another important thing is that to achieve the goal of making people prone to leave their cars and walk in the streets, and to activate local economies, streets have to be attractive, straight and clear. It should be the possible to move in all the directions. There should be local shops, the bus stop, the health center and perhaps a primary school within a walking distance of 10 minutes (800 meters).

The grid is an aspect of major importance also when planning a walkable neighborhood. Block size should be in accordance to the land uses and the expected flux of people in each zone. A grid spacing of 80-100m provides an optimum network for pedestrian and vehicular needs in most circumstances. In most of the predominantly. In central areas with intensive pedestrian activity, grid spacing of 50-70m provides an optimum circulation network (Davies, 2000).

Figure 45: Proposed urban structure of the future Eastern Metropolitan Green Lung

In relation to the urban structure the main goals is the creation of self-sufficient neighborhoods. This would be achieved through the following strategies and actions:

- Maximize the creation of zones where residences are mixed with compatible uses, rather than pure residential zones.
    - Manage different densities and typologies of housing buildings to guarantee a mix of different social sectors in the zone.
    - Localize near the housing zones, schools of mid-size, which allow the students to go by walking.
    - Stablish retail and commercial zones of small scale at street level, available for a walker buyer.
    - Distribute the uses in urban scale starting with commerce near the metro stations, through mixed use and finally near the park, residential use.
- Consider the traditions of architecture in the design of the buildings.

  - Study and application of the environmentally friendly techniques that can be applied in the new buildings.
  - Dedicate some areas near the residences for urban agriculture.
- Recycle the materials of the existing infrastructure.
  - Use the airstrips materials for the base of the new roads.
  - Consider to recycle structures for different public or private users.
  - Refurbish the existing terminal 2 and a part of terminal 1 of the airport for the uses related with expositions, trade center, hotels, commerce, etc.

In the annex U-17 it is possible to see four main land used of the project:

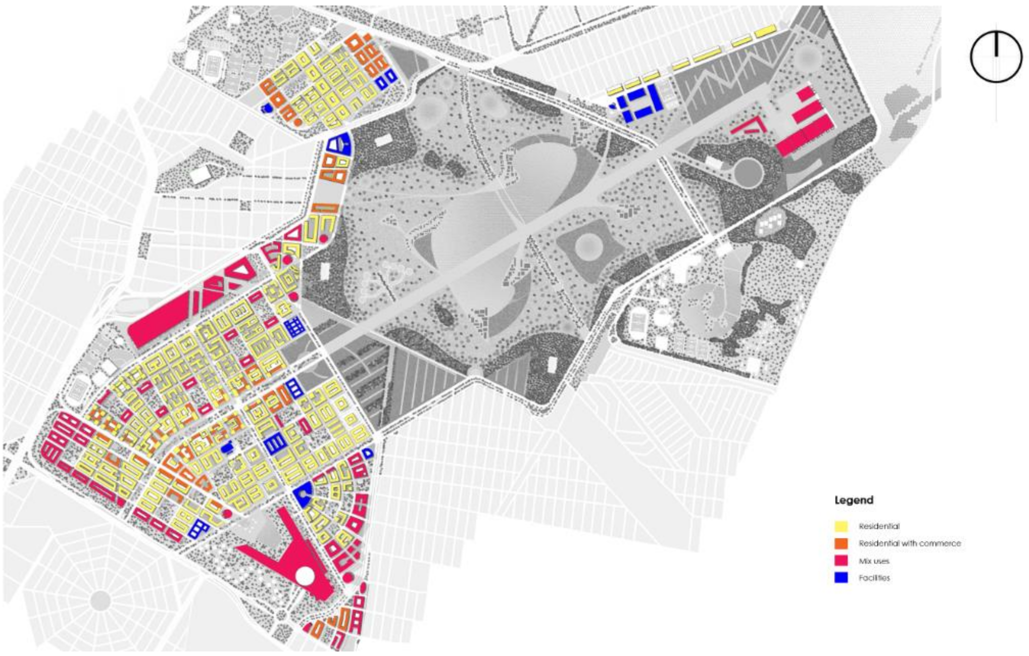


Figure 46: Land use in the future Eastern Metropolitan Green Lung

5.1.1. Mix use:

This zone corresponds to the mixture of different use types related with the tertiary sector, as for example, commerce, business centers, offices, hotels, restaurants, cafes, malls, and so on. They are characterized by a smaller block size of about 70 meters. This zones are located strategically in the following locations:

- Near the existing inner bypass (Circuito Interior) behind a buffer zone of 50 meters. The idea is that this zone would be too noisy for residences, which can start after more than 100 meters, where the noise levels are acceptable.
- In the existing terminals of the airport, which can been seen as part of the history of the place. They belong to the city, and its magnificent location and characteristics should be used for new uses. This is why it was decided that the two of them should be kept, and transformed into new neighborhood social and economic centers.
- In the northwest, west and south limits of the project, where accessibility from metro stations is excellent. This locations also become as a transition between the existing urban zones and the new development, becoming a new hub for jobs not only for the new inhabitants, but also for the people living nearby.
- In the parks and squares of the inner residential zones. The idea here is to create a nice and dynamic atmosphere around the public spaces, where people can find typical things for this areas, such as restaurants, fast foods, retail shops, cafes among others.
- In the east of the project, where is contemplated the location of the trade and exhibitions center, as well as a hotel hub.

5.1.2. Residential with commerce:

The buildings of this zones are characterized by the presence of commerce and offices in the first two floors facing the streets. The upper floors are dedicated exclusively to residential use.
This buildings are located in the following zones:

- In the central rambla that starts in the Hangares Metro Station and finishes at the Metropolitan Part of the East.
- In the Tahel avenue and the Avenue 602 at the north part of the project, close to the Oceania Sport Center.
- In the square that acts as a connection between the Metropolitan Park of the east and the shared space that lead to the hill of Peñon de los Baños.
- In the streets that's come from the Fortino Serrano Park in the northwest and leads to the terminal 2.

As all this zones are connecting important landmarks of inside and outside of the project, it is expected that they will be highly transited. The insertion of commerce on them is an opportunity to make more dynamic the residential zones, and to reduce the distances for inhabitants to find basic goods and services. The bock size of this zones go from 100 to 120 meters.

5.1.3. Equipment:

Some blocks of the project are dedicated to special equipment buildings, as for example:

- Schools: they are located in a way that they are equidistant with other schools of the entire borough of Venustiano Carranza.
- Churches: Placed in front of local parks, one in the north and one in the side of the project.
- Markets: Located close to the urban agriculture zones. In this way, local food can be sell at low economic and environmental costs.
- University: Located in the northwest of the Metropolitan Park of the East. It is intended to serve as a faculty for agricultural, forest and environmental professional careers that can have their practices inside the park.
- Museum and library: Located in an intersection of two main avenues of the project, at the northwest of the existing terminal 2. It will provide education and social inclusion to the surrounding neighborhoods that have been historically forgotten by public investment.
- Theater: Located in the western corner of the same mega block of the museum and library, making this avenue as part of a small cultural corridor that finishes in the urban agriculture area.

5.1.4. Residential:

Al the remaining zones of the urbanized area. Their location and densities will be explained later in the section of sustainable mobility.

5.2. Sustainable Mobility

In order to achieve a sustainable mobility, achieving lower levels of environmental and territorial impact, it was analyzed in the scale of the city, how to connect the new developments with the existing network of public transportation system. This is why, it was decided that the urban plan should be transit oriented.

Transit Oriented Development (TOD) is a growing trend in regional planning and city revitalization that consists on creating sustainable, compact, walkable, mixed-use communities centered around high quality train systems, making possible to reduce the dependency on a car for mobility inside the city up to 85%.

This kind of development is capable to adapt to the fast growing of modern cities but keeping them at restricted dimensions, minimizing the distances and times for transportation, improving the quality of life and helping the governments to invest better on the creation of public spaces, with the support of the private sector.

5.2.1. Components of transit oriented development

The Transit Oriented Development Institute defines the following key factors, to consider in the design of a transit oriented plan:

- Walkable design with pedestrian as the highest priority.
- Train station as prominent feature of town center.
- Public square fronting train station.
- A regional node containing a mixture of uses in close proximity (office, residential, retail, civic).
- High density, walkable mixed use district within 10-minute or 1/2 mile radius walk circle surrounding train station and reduce the density until reaching the existing neighborhoods.
- Collector support transit systems including streetcar, light rail, and buses, etc.
- Designed to include the easy use of bicycles and scooters as daily support transport.
- Large ride-in bicycle parking areas within stations.
- Bike share rental system and bikeway network integrated into stations.
- Reduced and managed parking inside 10-minute walk circle around town center / train station.

- Specialized retail at stations serving commuters and locals including cafes, grocery, dry cleaners.

This kind of development is highly beneficial for Mexico City, due to its capacity to improve the mobility, reduce the traffic congestion, and air pollution, make more affordable for people to buy houses, and more stable the prices of them, increase the foot traffic in areas for business, reduce the sprawl, and the cost of building new roads, and economic competiveness for the city itself.

5.2.2. Mobility in the Eastern Metropolitan Green Lung

The main goal to accomplish during the design phase was to promote the use of sustainable modes of transportation. This goal was achieved with the following strategies and actions:

- Organize the new urban zones according to the location of the transportation systems.
    - Locate near the metro and Metrobus stations major entrances of the new development, as new centralities with public facilities.
    - Create bike parking areas in the zones of the stations to facilitate the connection between different ways of mobility.
- Consider the existing street network in the urban planning.
    - Take into consideration the highways that pass around the plot to manage the traffic entrances.
    - Interconnect the streets that are around the plot, so that a real connection between the separated neighborhoods can be established.
- Promote the use of bikes and walking as a sustainable model for Mexico City.
    - Manage walkable distances.
    - Build bike routes that connect the zone, considering the different uses.
    - Extend the ECOBICI program.

In total there are four stations near the future Eastern Metropolitan Green Lung, corresponding mainly to two lines, and one of them being a headline for several destinations. Two of this four stations are dedicated to the existing two terminals of the airport of Mexico City.

After the identification of this two poles of development, it is was decided that each of the four metro stations would become into the main pedestrian entrances for the people. Other entrances were located strategically to stablish connections with the surrounding neighborhoods, their equipment and historical places.

In any case, the vicinity to the metro stations was the catalyst that defined the density of the future urbanized area. For the researchers, it was necessary to keep the built areas at distances of less than 1 kilometer from them. In the cases when this is not possible, for example, in the zone of the university, the metropolitan park, the exposition center, among others, it was proposed to cover them by the existing rout of the Metrobus (BRT system).

In the zones inside the "1 kilometer area" there was a duality in the selection of the density and the character of the new neighborhoods. First there was for the authors a necessity not to overpass the height of the buildings of the surrounding neighborhoods in no more than 2 floors, this lead to a maximum height in the perimeter of the new zones of 4 floors. This density was intended to increase in a constant trend when getting inside of the neighborhood in order to have a transition from the low-rise buildings to the high dense tall buildings of the new areas. On the other hand, in order to achieve the goals of the Transit Oriented Development, of a compact, mixed-use development, with high densities close to the nodes of transportation, high-rise buildings near the metro stations were required, disrupting completely the existing urban character of the zone.

This problem was solved by keeping the limit of 4 floors in the edges of the urban area, and increasing rapidly the heights of the buildings in the closest areas of the metro stations, with their maximums in the zones near the two terminals. Then the densities would decrease again when approximating to the metropolitan park at the eastern part of the project. An exception to this would be the green passages that connect the different zonal parks, in which pedestrian and bike users would find a more green, friendly and human scale development.

In the following image it is possible to see the result obtained by the approach adopted regarding the urban density. 3 of the 4 metro stations are marked. The idea is to make them and their surrounding development well integrated and pedestrian and bicycle friendly.

This task was achieved by extending a network of pedestrian and bike friendly paths that move around the different mega blocks connecting all the public and green spaces. Walking and biking to the station will become a choice for many.


Figure 47: Metro stations, urban catalyst.

In Mexico City exist nowadays a system of shared public bicycles that has become as an essential part of the mobility of the inhabitants of the city, its surroundings and the tourist. It serves the historic city center and some middle class neighborhoods at the west of it. This system can be implemented also inside the Eastern metropolitan Green Lung, integrating it with the network of existing metro and proposed Metrobus stations, in order to serve the last part of the journeys by making fast door-to-door connections easy with the ability to ride and drop off the bike almost anywhere.

In the annex U-18, it is possible to see the proposed network for a sustainable mobility of people inside the project, by integrating the three mentioned systems. In orange are marked the metro stations, in red the proposed Metrobus stations, located strategically each 400 meters. This buses will serve not only the few habitational zones outside of the 1 kilometer radio of the metro station, but also all the surrounding neighborhoods of the existing terminal, that before did not have any formal and stable option of public transportation, and will be able to carry users of all the city to the new metropolitan park, the university campus and the new fair and conventions center, located at the east of the project.

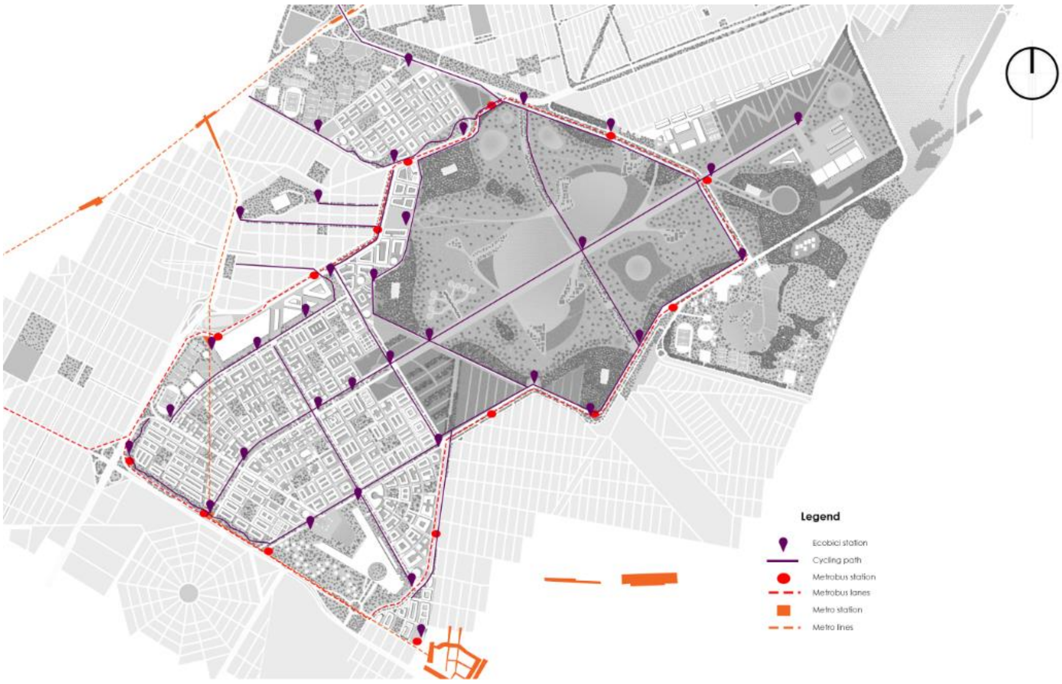


Figure 48: Sustainable mobility in the Eastern Metropolitan Green Lung

Regarding the mobility with bicycles, it has to be said that ECOBICI stations are located at a maximum distance of 400 meters, in all the metro and Metrobus stations, in the main pedestrian entrances of the project characterized by the presence of a welcoming squares, in front of the renovated terminals of the airport, inside the park and near the hill of Peñon de los Baños.

The final transport element to be considered on this project is certainly the car. The first aspect studied was the surrounding network of streets and avenues, their flow directions and hierarchy. This defined the location of the different entrances and exists for the vehicles and the location of the most important streets inside the project.

The entire plot was divided in 10 mega blocks, being the ones with more mixture of uses, the smallest. The traffic inside them is regulated through the localization of local parks that block some local streets in order to avoid the use of them as shortcuts. In the following image, it is possible to visualize the proposed arrangement of the traffic flow for the principle avenues of the project.

Figure 49: Traffic flow on the main avenues.

5.3. Urban Ecosystem

“An urban ecosystem is an ecological system located within a city or other densely settled area or, in a broader sense, the greater ecological system that makes up an entire metropolitan area. Urban ecosystems, like all ecosystems, are composed of biological components (plants, animals, and other forms of life) and physical components (soil, water, air, climate, and topography). In all ecosystems these components interact with one another within a specified area. In the case of urban ecosystems, however, the biological complex also includes human populations, their demographic characteristics, their institutional structures, and the social and economic tools they employ. The physical complex includes buildings, transportation networks, modified surfaces (e.g., parking lots, roofs, and landscaping), and the environmental alterations resulting from human decision making. The physical components of urban ecosystems also include energy use and the import, transformation, and export of materials”. (Encyclopædia Britannica, 2015)

In order to build a healthier community in contact with their ecological resources, the main goal to be achieved is to encourage a healthier lifestyle with the creation of new public spaces that can work both in the metropolitan and local scales. This would be realized by the following actions:

- Connect the plot with the urban fabric into a net of public spaces.
- Create a connection between the new metropolitan park, with the parks of Bosque de Aragon, Deportivo Oceania and Alameda Oriente.
- Create an urban system of public spaces of different dimensions along the residential and mixed use zones.
- Create paths around the plot for walking, jogging and running.
- Organize the public spaces in "zones" according to activities such as sports, recreation, leisure, culture.

Some aspects need to be considered when building this new urban ecosystem: energy, biodiversity, and water.

5.3.1. Energy:

In order to optimize the solar potential and the advantages of wind flow inside the built up areas, the orientation of the streets and buildings is a key factor. It is known that in the northern hemisphere the best building orientation for energy porpoises is when the main facades are facing the south. This tends to result in an East -West street pattern. However, another important aspect to consider is the predominant winds direction, which may have an important role in ameliorating the microclimatic conditions in summer. As winds come throughout the year mainly from the northeast, it is desirable to orient the streets in an oblique direction. It is possible to move from south up to 30° away and yet have 90-95% of the maximum output of a photovoltaic module or a solar collector. This let the possibility to build a perpendicular grid that adapts to the urban fabric of the surrounding neighborhoods, and to the position of the two remaining terminals. At the end, the final result is that most of the blocks are in an oblique positions of +/- 30° from the south with the only exception located at the north of the project, near the Oceania Sport Center, were an existing street pattern was reutilized and the rotation is of 37°.

This configuration is also useful during the hot months, taking into account that there will not be facades facing directly the west, and it will be easier to achieve solar shading and natural light when designing the buildings.

Energy was not only considered in the urbanized area of the project. Indeed, one of the most important features of the Metropolitan Park of the East, is the production of energy through photovoltaic panels. This panels are located over the remaining part of the intersection of some airstrips, in a sort of leaves that produce energy as in a real tree. This energy will be able to provide lighting for the public spaces of the neighborhood, and in case of emergencies for the airstrip that was kept in the park.

Other important feature of the park are:

- The composting area that will not only produce fertilized ground for the green areas, but also energy obtained from methane captured and processed.
- A network of solar farms that will be interconnected with the refurbished central air-strip.

5.3.2. Biodiversity:

Mexico is part of the group of 12 megadiverse countries that count with more than the 70% of the total biodiversity of the planet being first place in reptile diversity, second in mammals, fourth in amphibians and vascular plants and tenth in birds. In general terms, it is estimated that more than 10% of all world's species live in the country.

Mexico City is indeed an interesting example of this richness. Located over 2240 m.a.s.l. it is home for different ecosystems such as the xeric grassland, the forest lands, the ones associated to fresh and salty lakes, among others.

However, this diversity is in high risk due to the process of dryness and contamination of water bodies and air. Nowadays, the nearby lake of Texcoco is the most important water body of the entire Valley of Mexico, and despite of it, it has been place for waste and pollution.

As it has been said, the zone where nowadays is located the Benito Juarez International Airport was part of this ancient lake, that after an excessive process of dryness have left an arid landscape prone to dust devils, that with the cumulative effect of other pollutants, have reduce the air visibility of the city and increased the presence of health problems.

As a result of drastic anthropogenic environmental change caused by the replacement of forests, even in the mountainsides in the last decades, the reduction of green areas has led to the extinction of many plant species. It is estimated that during the past 35 years, The Valley of Mexico has lost 17% of forests, 40% of undergrowth of scrub, 42% of the chinampas of the agricultural land and a reduction of 7.4% of the milpa agro-ecosystem every year. (DE LA ISLA DE BAUER, 2015)

In order to recover part of the lost biodiversity, it is important for the authors to reestablish the links between the Inhabitants with their lakes, and the ecosystems related with them. This will be achieved through the following actions:

- Consider Peñon de los Baños and the Texcoco Lake as environmental protected zones, and make them the principal feature of the project.
- Treat the sewage and rain waters of the zone.
- Stablish zones of wetlands and water reservoirs to minimize the loads on the sewage system of the city and reestablish the lost habitats.
- Treatment of organic waste to produce fertilizers.

The project of the Eastern Metropolitan Green Lung contemplates the creation of a sustainable urban ecosystem in which people and wildlife can coexist together. This ecosystem will be achieved with by stablishing a network of public and green spaces such as greenways, parks, gardens, plazas and playgrounds that will "disembogue" into a metropolitan park located at the east.

In the annex U-19, it is possible to see how the green infrastructure of the project is contemplated:

- Going from west to east, it is possible to find first an environmental strip or buffer zone of 50 meters width, that with a combination of landscaping and trees will be able to diminish the noise levels coming from the Circuito Interior Avenue.
- This buffer zone becomes into a middle scale park in front of the terminal 2. It is contemplated that this park will be hosting a gastronomic and cultural alley in which it restaurants and cafes can work at daytime and bars and pubs will give life and dynamism to the zone without perturbing the residents. Also, this park will have, in the middle of the two wings of the terminal 2, a

large artisan's plaza dedicated for outdoor exhibitions, civic and cultural events.

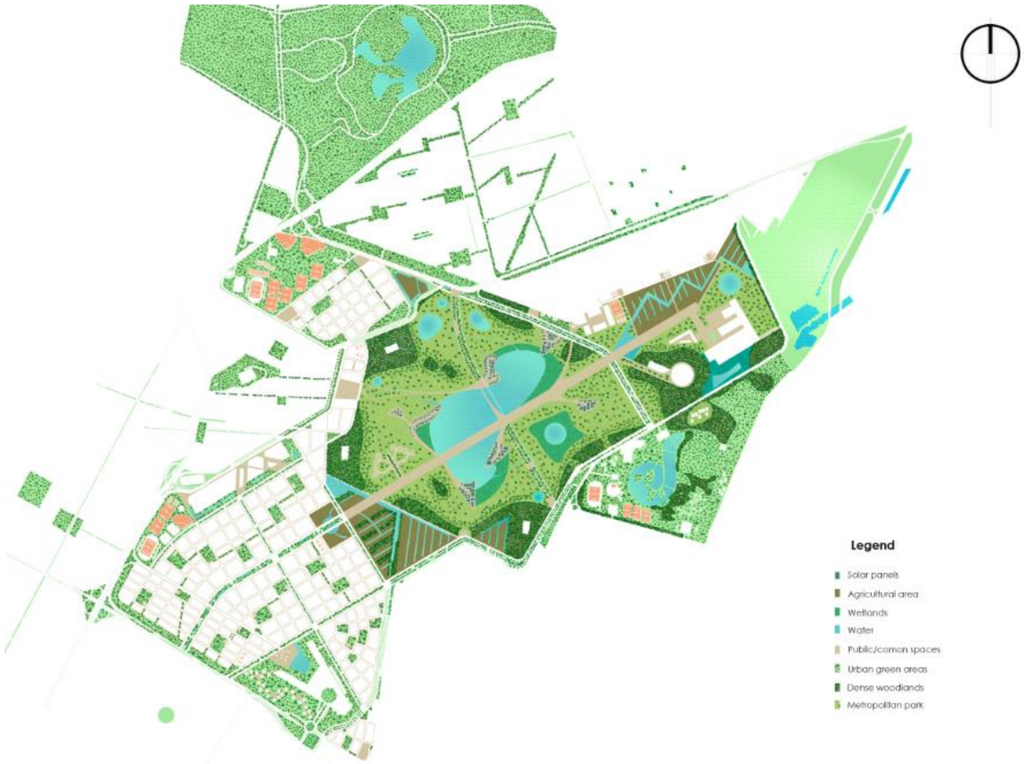


Figure 50: Green network of the Eastern Metropolitan Green Lung

- A network of local scale parks of areas that range from 1 to 1.5 hectares, interconnected with green forested walkways that cover all the neighborhoods, and lead locals and foreigners to the Metropolitan Park at the eastern part.
- A system of agricultural lands that act as a transition zone between the built up area and the more natural metropolitan park. This areas are designed in a way that they can benefit from recycled water coming from the new and existing neighborhoods, and finish the process of filtering. The water will become part of the landscape as it configures a network of channels that work as extensions of the surrounding streets. This crops will be organized as in the ancient chinampas, where traditions, nature and social development merge in a sustainable cultural landscape.
- A combination of native grasslands and forests inside the metropolitan park. This forest will be located at least in the perimeter of the water treatment plants and composting area, with a minimum width of 100 meters. The forest will not only prevent escape of possible odor, but also filter the air of possible

sand storms or suspended pollutants coming from the Texcoco Lake.

- A system of wetlands, pounds, aquifers and lakes that will be in charge of filtering the water after its departure from the treatment plants. This system will also increase the capability of the city to deal with storms and floods.
- A series of greenways, and shared spaces that connect the new green spaces with the surrounding parks, sport centers and historical places. It has to be highlighted in this part that one of the main objectives of this project is to rescue the historical importance of the hill of Peñon de los Baños. This is why it was decided that a formal connection between it and the Metropolitan Park should be stablished. For this purpose, two streets of the nearby neighborhood are transformed into shared spaces, that pass at a side of the historical square of the ancient town of Peñon de los Baños and lead to a new monumental plaza that act as a threshold between the park and the hill.

Figure 51: Green network: ecological corridors.

In the previous image, it is possible to see the proposed ecological corridors that will allow the transit of people in sustainable ways such as cycling and walking. This ecological corridors, are connecting the different public and green spaces of inside and outside of the project.

In order to increase the biodiversity of the area, it is required that the species planted correspond to the indigenous ecosystem. For this reason the authors have done a selection of trees with low requirements of water, and high tolerance to flooding conditions, as well as cultural significance:

5.3.2.1. Streets, squares and gardens:

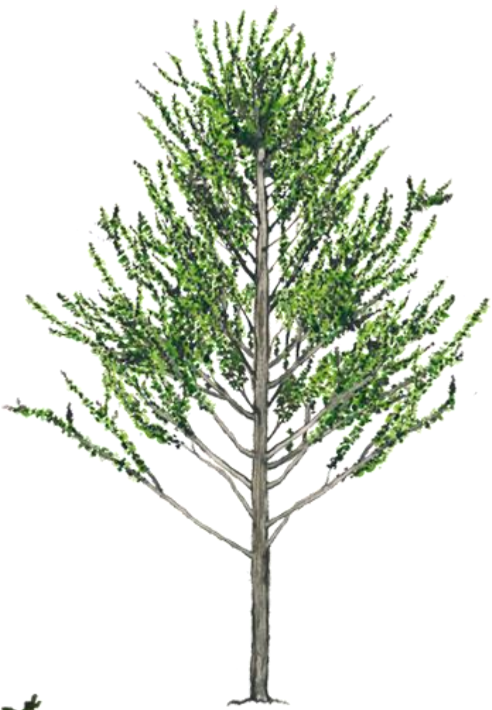
White Cedar: Tree up to 30 m tall, straight trunk with very light gray fissured bark. Pyramidal treetop and permanent foliage. It is fast growing approximately 0.70 to 1.40 m per year. It grows well in acidic, rocky, deep soil with humus and in shallow and sandy clay with good drainage and watering should be moderate. A distance of between 6 and 10 m between each tree must exist. It is advisable to fertilize when the soil is poor and in times of drought, if not they can be severely attacked by bark beetles and fungi.

Mexican Palm: Palm up to 25 m high, with columnar trunk alone up to 40 cm in diameter, marked by the remains of the foundations of the old leaves that are rough and thorny bark. Cup tuft of leaves, old leaves dangling from the base of the crown and permanent foliage. Enormous leaves 90 to 150 cm, frayed fan shaped, compressed base and orange spines. White Flowers bisexual 8 mm long, grow in special branches in the leaves up to 2-4 m long with 1-3 branches. Pollinated by insects. Blackish fruit of 7-10 mm with single seed ovoid. Very resistant to cold and drought.

Capulín: Shrub or small tree up to 8 m tall and wide stratified treetop. It has white flowers and the fruit is a fleshy berry, ellipsoid, juicy and sweet, dark red. The tree grows in clay, silty, sandy, acidic, occasionally wet, alkaline or slightly acidic, well-drained soils, has low water requirements and high tolerance to drought. It should be kept a distance of 7 m between each tree. It does not need to be fertilized.

5.3.2.2. Parks and forests:

Aile: Tree up to 25 m tall, with thick trunk, branched from one meter high. Horizontal light gray smooth bark warts. Globular treetop and foliage for several months. It grows fast and is colonizer of deforested areas. It is recommended for reforestation because with the fixing of nitrogen in their roots, enriches the soil.



Oak: Monoecious deciduous tree, up to 30 m high, wide and rounded crown, is slow growing and lives 100 to 150 years. Supports clayey soils, shallow, acidic, stony, dry or wet so the need for irrigation is low. It should be at a distance of 8-10 m between trees and at spaced locations. Fertilization required.

Ahuehuete: Tree up to 40 m tall, with very thick trunk, bark grayish brown cracked into long strips. Globular treetop, diameter 9-30 m, pyramidal shape and foliage for several months. Pollinated by the wind. It can develop in acid to alkaline soils, humid and poorly drained. It requires abundant watering, when not enough foliage color turns brown and the tree stops growing until the moisture condition normalizes. It must be planted at a distance of 10-15 m between individuals. It should be fertilized at least once a year.

Ash tree: Tree over 30 m high, with straight and deeply fissured bark light gray trunk. Globular treetop and dense foliage for a few months. Male and female flowers are produced on different trees. Pollinated by wind. Round and surrounded by a long wing with a single seed fruit. It grows in different soil types, can be clayey, sandy, acidic or calcareous. It should be watered moderately and is drought tolerant. In plantations should be kept at a distance of 10 m between individuals and sidewalks of not less than 8 m wide, to avoid root lift sidewalks and walls or broken pipes and drains. It does not require fertilization and grows well in poor soils.

Source and images from (SEMARNAT, 2015) and (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2015).

5.3.3. Water:

Water sustainability is a major issue for Mexico City, not only because of the scarcity of sources, but also for the inefficiency of the aqueduct network, characterized by its high losses. This problem is exacerbated by the irregular growing of the city and the soil settlement that affect the pipes.

In order to reduce the pressure to search for new sources of fresh water, an intensive strategy of water recycling need to be implemented. Nowadays, the Borough of Venustiano Carranza, where the International Airport Benito Juarez is located, uses treated wastewater to irrigate the green areas that fall within the demarcation being represented by 2.49 Km^2 sports, gardens, parks, and ridges. This activity requires a system for which the Borough has a 36,330 meters network. Water comes from treatment plants of San Juan de Aragón with an input of 230 liters/se; the main uptake is the residual water from the Grand Drainage Canal and the Sports City with a contribution of 130 l/s, located in boroughs Gustavo A. Madero and Iztacalco. (Asamblea Legislativa del Distrito Federal, 2005)

It is noteworthy that in this water is delivered to Cuauhtémoc, Benito Juárez and Coyoacán boroughs. The San Juan de Aragón treated water supplies primarily for the maintenance and upkeep of Deportivo Oceania and the northern part of the Av. Oceania. The rest of the green areas is supplied through treated water networks that come from the treatment plant Sports City. Currently the network of treated water has a coverage of 45% of the Borough, 82% of green areas use the distribution network and 18% occupies the tank trucks using a watering program. (Asamblea Legislativa del Distrito Federal, 2005)

5.3.3.1. SuDS in the Eastern Metropolitan Green Lung

In the annex U-20, it is possible to see two sections that correspond to the strategies developed for the sustainable drainage system of urban areas in the Eastern Metropolitan Green Lung, and that can be applied along the project according to the conditions of the zone, the land use, availability of space and traffic conditions.

The upper image is showing the main concept applicable for maximizing the infiltration of water on site in order to recharge the aquifers of the zone. It will be achieved by the use of continuous-laid porous material such as concrete or asphalt pavements with a low content of fine aggregates in local and low-traffic streets and parking lots. In squares, sidewalks or shared spaces, the use of small elemental surface blocks will achieve the same results, with a nicer appearance for the users. Underneath this materials, the base partly filter the water until an underground perforated pipe, which also will take the water coming from open-air channels located above.

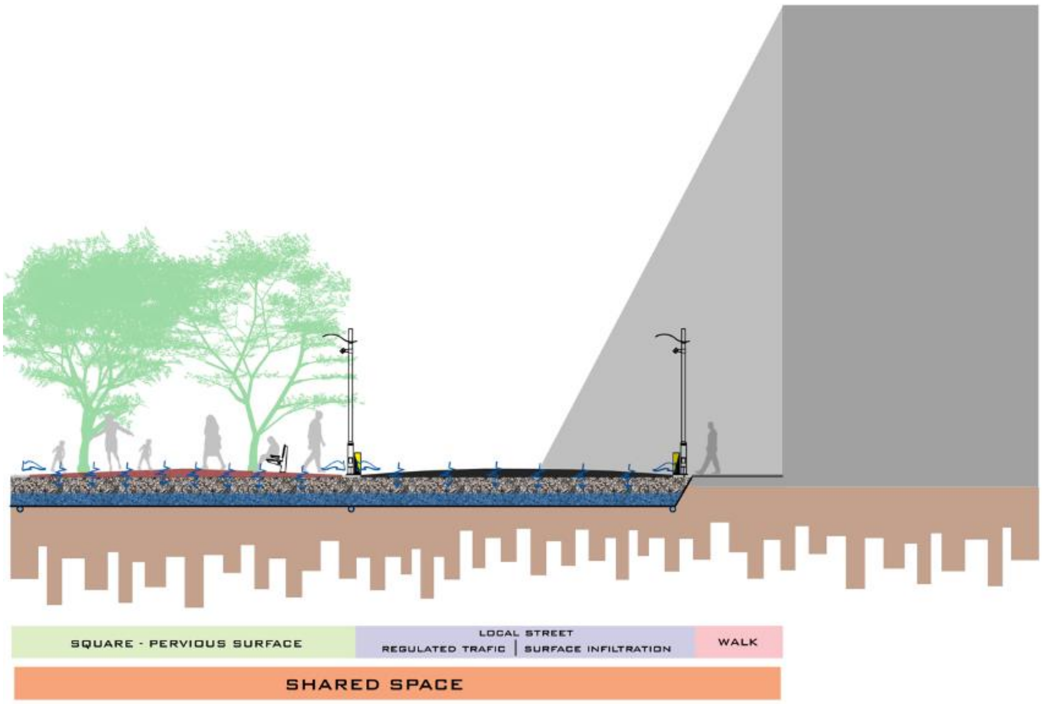


Figure 52: SuDS proposal for a shared space

The lower image is showing the strategy applicable in the northern part of the project, where an existing avenue is separated from a new local street by a linear park. In the existing avenue, where the pavement cannot be changed to a pervious one, the adaptation to a more sustainable system can be achieved by leading the slope of the surfaces to the road divider, so that the runoffs can be conducted and filtrated by this green fringe. For better results, the ground can be changed for a more permeable and layered structure in order to build a bio-retention area.

About the linear park, the surrounding neighborhood can drain some of its water to a combination of bio-retention areas and infiltration ponds, depending on the space availability.

The annex U-21 is showing two sections of the retrofitting of the highway that is passing in front of the Terminal 1 of the International Airport. Nowadays this avenue has a big parking lot in the middle of the two rails of the avenue. The proposal is to insert an exclusive line for the Metrobus (BRT) system, and leave the rest of the space for green areas that can have a drainage function for the existing and future neighborhoods. In this case, the use of pervious materials is not possible due to the expected weight of the vehicles that are going to transit. In this case, a combination of bio-retention areas with a system of soackaways will transport the water slowly until the other stages of the management train.

A network of perforated tubes and soakaways will carry the rainwater not captured on the green roofs of the single buildings of the project, as well as the one of the streets, until the soakaways that start at the end of the streets and cross the agricultural lands unto the metropolitan park.

From here, the remaining water that was not infiltrated, for example in the case of heavy storms or flooding, is going to be redirected to a series of detention basins of different sizes in which the pollutants will have enough time to settle before the water continues until the wetlands where the treatment process will finish. The clean water that comes after the wetlands will be redirected to the central lake, were people will be able to practice watersports, and fishing among other activities.

Regarding the wastewater from human activities, it is planned to provide 8 wastewater treatment plants ASA / JET 3000 in the perimeter of the metropolitan park. Located in 4 zones. This plants are produced since 1986 by Agua y Saneamiento Ambiental S.A., a Mexican company with offices and manufacturing plant in the city of Guadalajara. They use the JET INC technology for modular prefabricated wastewater treatment plants, certified by NSF (NATIONAL, SANITATION, FOUNDATION).

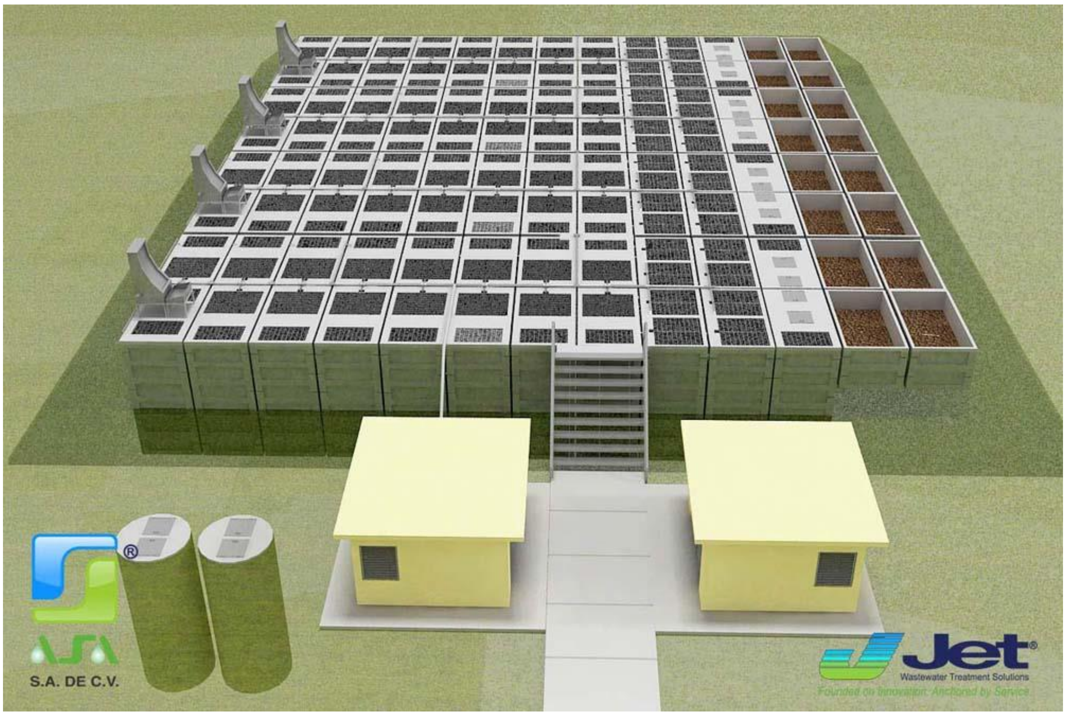


Figure 53: Render of 1 wastewater treatment plants ASA / JET 3000 with capacity for 3,800 m³ / day.

The reason for choosing this technology is due to the easiness of installation, maintenance and capacity to increase its capacity due to its flexible, modular and prefabricated reinforced concrete design.

The maximum size provided has a capacity up to 3,800 m³ / day, and uses the biological treatment process of activated sludge in the form of extended aeration.

Considering that Mexico City has a per capita water consumption of 314 liters / person / day, but about 77% of the population uses less than 150, yet it is one of the Latin American cities with more consumption. For instance Bogota, Colombia has an averaged 76.32 liters / person / day.

Having in mind that the project contemplates the construction of a new network of pipes for fresh water and the retrofitting of the existing networks of the surrounding neighborhoods which will be served as well; it is not acceptable to have leaks in the system as in the rest of the of Mexico City, where they account for 60% of the liquid. It can be said that a maximum and conscious water consumption of 100 liters / person / day is acceptable.

If the project will host 60 000 residents and 5000 workers or floating population, it will give a total of 6.5 million liters / day that can be treated by two compact plans ASA / JET 3000 with maximum capacity of 3,800,000 m^3 / day.

The idea of this project, is that the Eastern Metropolitan Green Lung, as will be the place for exalting the importance of the Texcoco Lake for the City of Mexico and its inhabitants, can function also as a big system of treatment plants able to clean the wastewater from the surrounding neighborhoods. For this, it is needed a plan for the separation of this types of waters from the rainwater drainage system that is needed for feeding the agricultural lands of the park.

Having a separated drainage system will allow to treat in this 4 pair of plants the wastewater of 260000 people, almost 60% of the total population of the Venustiano Carranza Borough, and give a second use to this water to feed the existing network of water that supplies the watering program for all the green areas of the area, which with the parks of the project, will be increased substantially.

Chapter III: Architectural design

1. Transition scale

Every city is a complex system characterized by intricate relations between multiple entities. In this sense, a city of the dimensions of Mexico City, and consequently a project of almost 750 hectares cannot be explained in few words. During the realization of this project, it has been possible to see that understanding the master plan with its wide number of functions, is not easy even for the people that have been in contact with it. This is why, it is not possible to introduce directly the architectural project without passing through a transition between the urban scale and the architectural one.

For this purpose, the designers have delimited the area of analysis to the neighborhoods located at the east of Circuito Interior Avenue and at the south of Oceania Avenue. This highways are acting as a sort of barrier that will discourage people from outside of this boundaries to come inside the zone selected to develop the architectural project. Thus, only the people living inside those boundaries will be the one that will be more in contact with the project.

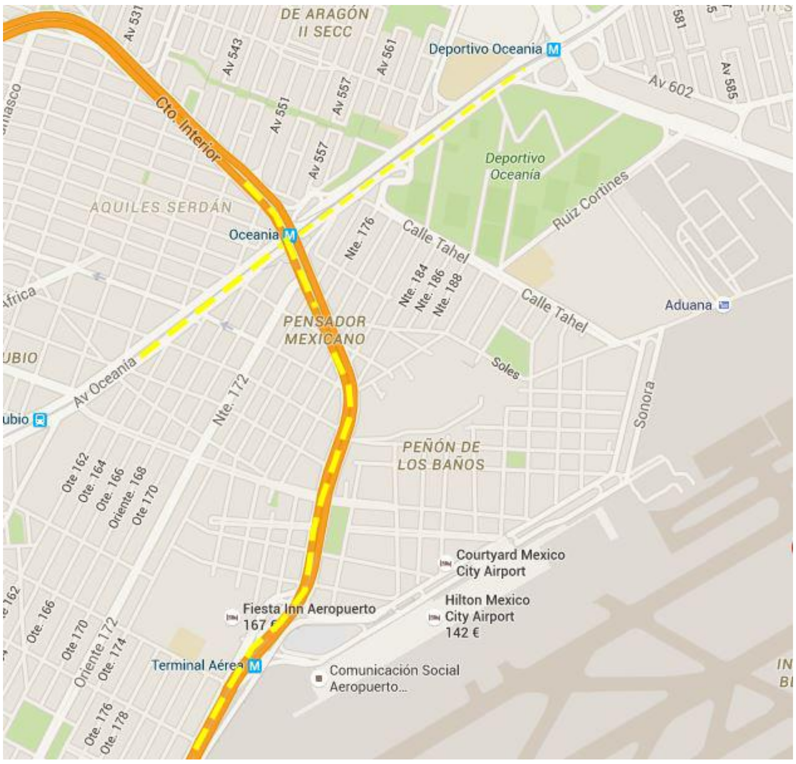


Figure 54: Delimitation of the transition scale

The aim to analyze more in detail this area, was to determine if there is the lack of any service in order to help in the process to propose a list of uses for the designed buildings and open spaces.

As have been already mentioned, Peñon de los Baños was a Pre-Hispanic town that with the time was incorporated into the metropolitan zone. However, the surrounding area started to have an accelerated development after the 70's decade. Under those condition it was assumed that this neighborhood is are already settled and that it counts with all the services needed for the existing population.

As it possible to appreciate in the annex A-1, there is a concentration of restaurants in the streets that are close to the airport, as well as other services such as supermarkets, car rentals, hotels, schools and retail shops. Other services that could not be represented, but that are still important, are the local grocery shops and small family business.

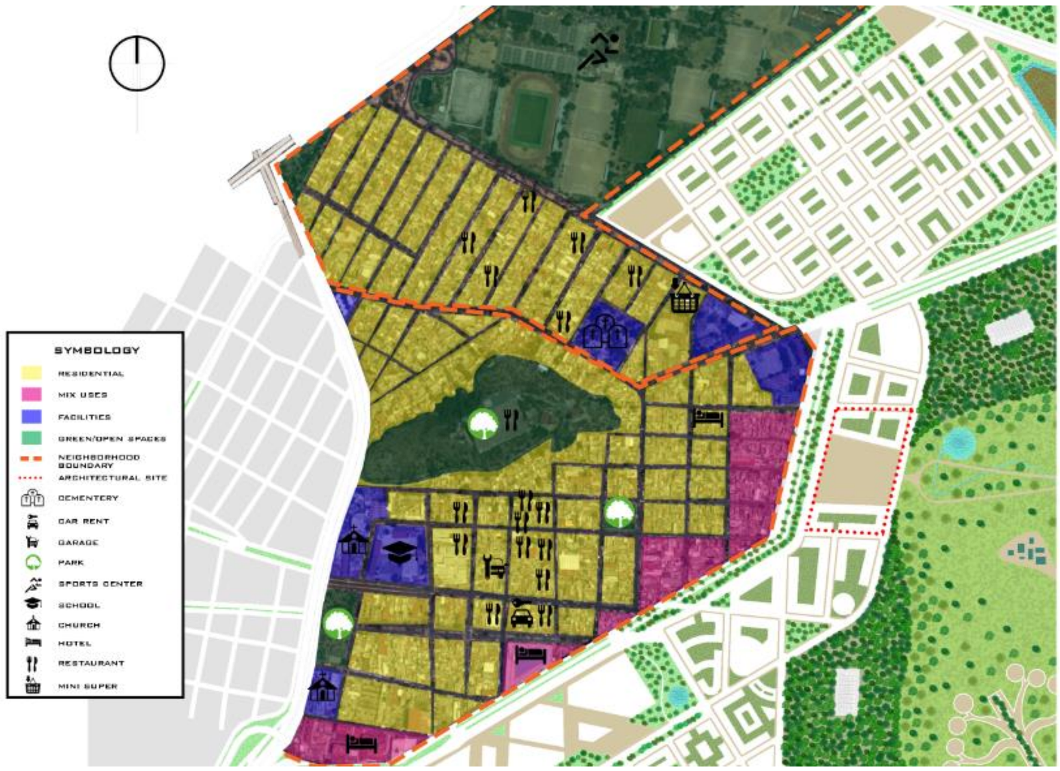


Figure 55: Transition scale between the urban and the architectural project

Based on that information, it was decided to introduce new services that fulfill the needs of the people that will live and work in the zone of the project, and serve partly the requirements of the immediate neighbors.

2. Potential options

Considering the proportions of the urban design developed on this project, it is possible to infer that there is an ample range of options to develop in an architectural scale. However, from the beginning of the project, it was decided that only the projects in which will exist a direct relation with the surrounding existing communities will be considered. This conditions, left the authors with three final options:

Figure 56: Possible options to develop for the architectural design.

- Option 1, a church: Located over Calle de Tahel, one block before the intersection with Ruiz Cortines, and in the vicinity of Oceania Sport Center. This project was considered interesting due to the presence of a plaza in front of it, which the authors found as an opportunity to develop a shared space that connects this two elements. There is also the possibility to develop in a detailed scale most of the proposals of the urban scale.

- Option 2, a school: Located in the intersection of Calle de Sonora and an existing street that nowadays is for restricted use of the airport. This project has the possibility to show how it will be possible to develop a public building for education that is connected to the rest of the city BRT systems by means of public open spaces.
- Option 3, the plaza located halfway over Avenida de Sonora: This plaza was created in the urban master plan in order to stablish a connection between the Peñon de los Baños and the new Metropolitan Park. This public spaces is surrounded by to mixed use residential blocks.

After making a balance of the advantages and disadvantages of the possible projects, it was decided that the best option was the last one. By designing this Plaza, it was possible to highlight the historic and environmental importance of the hill of Peñon de los Baños; as well as apply most of the sustainable development strategies presented on the urban master plan such as the mixture of land uses, the use of green areas and vegetation to create naturally shaded public and private open spaces, and the construction of buildings able to maximize the use of zero carbon natural resources such as natural lighting and ventilation.

3. Objectives

The main objective of the authors was to display in the architectural project most of the strategies developed in the urban master plan in order to achieve a more sustainable Mexico City. In this way, it would be possible to understand the kind of development that people would find in the future Eastern Metropolitan Green Lung.

Another important aspect that the authors have considered essential is that the project developed would respect the architecture features of the surrounding neighborhoods, such as morphology, colors, mixture of uses and so on.

4. Theoretical framework

4.1. Climatic characteristics of housing types

Each type of housing has some specific impact on the thermal comfort and the energy expenditure needed to achieve it. Different building types have different potentials for providing effective cross-ventilation, passive solar heating, and application of various passive cooling systems (Giovani). As for this project the aim is to maximize the time in which natural cross-ventilation is used, the advantages of each building type regarding this item will be highlighted.

4.1.1. Row houses

They are a string of dwelling units, from one to three stories height, attached to one another at their sidewalls. Each unit occupies the whole vertical section of the building. From the ventilation point of view the highly effective height facilitates the "chimney effect" in natural thermosyphonic ventilation, especially during the windless hours (Giovani).

From the energy viewpoint, row houses are in between the detached houses and the apartment block, due to the fact that every dwelling has its own roof and underground area, but also share a common wall with other units, reducing then the total exposed surface.

4.1.2. Multistoried apartment buildings

From the thermal point of view, this type of buildings have less envelope surface area that other types of residential buildings. In particular this applies to units which have adjoining neighbors on each side, above and below. However this applies only for heated or air conditioned buildings. With some types of multistoried apartment buildings the opportunities of natural ventilation which can eliminate the need for air conditioning, or reduce its use, are not available, so a proper architectural design is required (Giovani).

Multistory apartment blocks can be divided, from the climatic performance aspect, into two basic types, and each of them can be further subdivided into two subtypes:

- Buildings with long corridors providing access to the units along them. Vertical access to the corridors is provided by staircases or elevators.
    - Buildings with an internal corridor, providing access to units on both sides. (Double-loaded corridors.)
    - Buildings with an external corridor located along one wall of the building. (Single-loaded corridors.)
- Buildings with staircases or elevators providing access to two, three or four units.
    - Multiple staircases or elevators serving two apartments on each floor.
    - Staircases or elevators serving more than two units at each floor.

Considering the limitations for ensuring natural cross ventilation of double-loaded corridors buildings, this option has not been adopted on this project. While the building with more than two units served by a staircase or elevator have been only considered in some corners of the blocks with a maximum of three units per floor.

4.1.3. High-rise buildings

As high-rise buildings depend completely on elevators and other sophisticated mechanical systems for their functioning, are only suitable for high income people. From the climatic point of view, they have a special impact on the ground-level urban climate in the area around them, by changing the urban wind field.

High-rise buildings, placed among lower buildings surrounding them, increase the mixing of the air flowing above the urban canopy with air at ground level, and thus, reduces the pollution concentration at the ground level. This types of buildings also increase the speed and turbulence of the wind, being an advantage for places with low wind velocities (Giovani).

4.2. Architectural features affecting ventilation

The main design features which affect the indoor ventilation conditions are:

- Type of building.
- Orientation of the building, especially the openings, with respect to wind direction.
- Total area of openings in the pressure and suction regions of the building's envelope.
- Type of windows and details if their opening.
- Vertical location of openings.
- Interior obstructions to airflow from the inlet to the outlet openings.
- Presence or absence of fly screens in the openings.
- Specialized details which direct the air into the building.

Ventilation has three functions, which require different levels of airflow through the building (Giovani):

- Maintaining acceptable indoor air quality by replacing indoor air, vitiated in the processes of living and occupancy, which fresh outdoor air.
- Providing thermal comfort in a warm environment by increasing convective heat loss from the body and preventing discomfort from excessively moist skin through a higher airspeed over the body.
- Cooling the structural mass of the building during night and utilizing the cooled mass as a "heat sink" during the following daytime hours in order to maintain the indoor temperature well below the outdoor level.

There are two ways in which ventilation can improve comfort (Giovani):

4.2.1. Comfort ventilation:

It is a ventilation strategy that consist in providing a higher indoor airspeed by opening the windows of a building or space to let the wind enter, and reduce the heat sensation of the inhabitants by extending the limits of acceptable temperature and humidity.

The only disadvantage of this technique is that it can only be applied when comfort can be experienced at outdoor temperatures, due to the fact that the indoor air and surfaces will follow closely that parameter. Usually, the temperatures that can be considered as acceptable for summer natural ventilation, with an indoor airspeed of 2 m/s range from 20°C to 30 °C for relative humidity below 50%. For a higher humidity, the maximum admissible temperature will be 28 °C.

4.2.2. Nocturnal ventilation cooling:

It is the strategy to ventilate the building only at night and thus cool the interior mass of the building. During the following day the cooled mass reduces the rate of indoor temperature rise.

The potential for lowering the indoor daytime temperature below the outdoor level is proportional to the outdoors diurnal temperature range, which increases as the humidity is lower. A significant reduction of the indoor daytime temperature below the outdoors maximum can be obtained only in high mass building with effective solar control.

5. Proposal

After having chosen the design of the Plaza and the surrounding two blocks of the architectural design, it was the time for reviewing the requirements set by the urban master plan. From that design phase, it was stipulated that the buildings facing the plaza must contemplate the mixing of land uses.

Figure 57: Localization of the site of the architectural project

5.1. Space characterization

On a first approximation, the designers have proposed to have commercial units on the ground level, behind a covered colonnade that will provide sheltering from sun and rainfall. On the upper levels, residential units will be grouped on multistoried apartment blocks with a separation between them of 8 meters, in order to permit sunlight and air to access all the indoor spaces of the buildings. Behind this row of buildings were placed several apartment blocks of three units per floor and heights from 4 to 7 levels. Between this blocks it was possible to create a series of interconnected open semiprivate spaces that could host different activities and uses.

Natural daylight and air flow was guaranteed on this approach, due to the fact that it was possible to orient the building to their most optimal positions considering sun location and prevalent winds. However it was possible to realize by the authors that there was a big problem on this proposal: there was not a dialog between the different components of the project, with the worst conditions when looking at the lack of connection between the main volumes surrounding the plaza and the blocks behind them.

Considering that the architecture in Mexico City is characterized by the presence of high-dense, compact and low rise buildings, especially in the areas around the existing International Airport due to the restrictions imposed by the air traffic. It was decided that the previous proposal should be avoided, and instead, it was necessary to go back to the urban master plan proposal of compact volumes with closed facades facing the streets.

The second proposal for the architectural solution started by identifying the possibilities that represented the location of the different streets around the project, in order to improve the accessibility of the different private and public spaces proposed. Beside the highways and streets that pass nearby the project, and the strong connection that is created between the Metropolitan Park and the hill of Peñon de los Baños on the east-west direction, there will be a street ending almost at the midpoint of the south side of the plot. In the north side, the next block is divided by a pedestrian path that reaches at around 2/3 of the length of the block object of design.

It was decided to insert this points of accessibility in the definition of the architectural design by transforming them into axis of trace for the project, by dividing it in 4 blocks of different dimensions. Thus, allowing the continuation of the pedestrian paths and the increase on the accessibility of the core of the project: the plaza.

5.2. Building assessment and architectural design

Regarding the buildings inside each of this four blocks, it was decided that they should not have a depth of more than 12 meters, in order to guarantee that each of the dwellings will count with natural daylight and cross-ventilation. After building up the first 12 meters, four courtyards, one for each block, were created. This semi-private spaces will allow the entrance of air and light, but most important, the keeping of a considerable area as permeable surfaces, able to integrate nature in the creation of sustainable, naturally shaded spaces for the use of the residents.

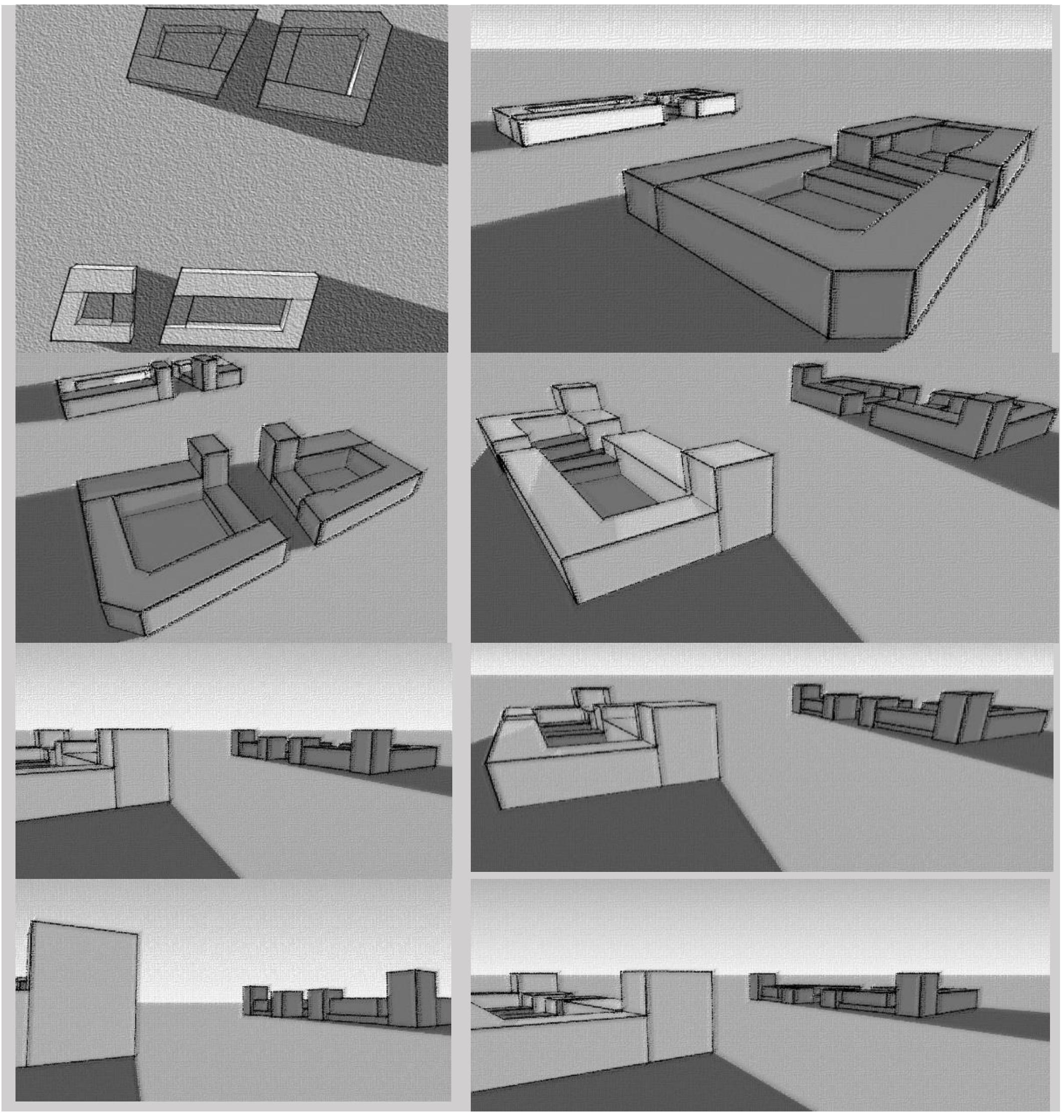
In order to increase the typologies of buildings inside the project it was decided to replace the multistory buildings in the created pedestrian central strip that goes from north to south by row houses of just two levels. This low-rise buildings will highlight the human scale of the project, making the public spaces more user-friendly.

For the volumes facing the plaza, the authors have proposed to join them into two single volumes, one at the north and one at the south of the plaza, leaving open the ground floor where pedestrian north-south connection requires. It was also decided to preserve the idea of the commercial passages around the plaza, but not only on the ground level, but also on the first one, by the creation of single and two floor shops and offices.

On the upper levels, the idea was to mix residential use with job spaces in one single space. So, instead of building apartments, the lofts will able independent professionals to live and work at home with an optimum location. However, it was realized that the repetition of the loft module for such a long distance (almost 150 meters) gave the building and the whole area a plane and boring appearance. For this reason, this specific idea for the buildings near the plaza was again rejected.

Taking into account the importance of the buildings facing the plaza in the definition of the overall character of the site, the designers have played with different volumes, alignments and colors, in order to have the more harmonious design, always having in mind different examples coming from the Mexican architecture.

After experimenting with the four basic volumes of the project, the final result consist on: 4 well defined bodies with towers located at the corners that face the plaza. The 2 towers in front of the Metropolitan Park were limited to 7 levels; instead, the 2 towers of the opposite corner, leading to the hill were raised until 13 levels. This last 2, will act as landmarks able to tell people even coming from long distances that in this place "something interesting is happening".



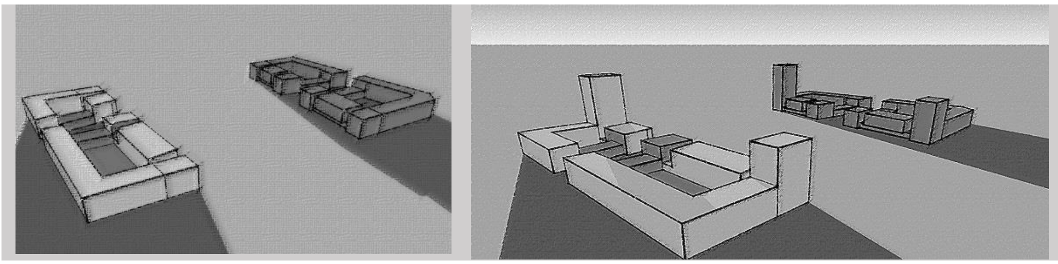


Figure 58: Volumetric assessment

Having placed the towers, it was decided to separate them partly from the rest of the central volumes above the ground level by means of terraces. In some cases, when the lower volumes of the plaza where too long, it was decided to split them again above the ground level with other terraces.

Figure 59: View of the buildings form the central square

The ground level was kept again as a unique body of commercial use in each of the 4 volumes of the project. However, this time only few units will have an extra level, the use dedicated to them will be restaurant or cafeteria. To this units will correspond the usufruct of the terraces in-between the buildings.

Above the commercial ground floor, a mixture of uses in height is achieved by placing different combinations of offices, lofts and apartments on the first, second and third levels. This mixture will guarantee the users the feeling that they are living and working in unique spaces, and will also show through the facades the social diversity of this project.

In order to guarantee the protection against sun and rainfall, it was decided to set back the facing of the ground floor and cover it by a cantilevered structure on the central volumes, on which it is possible to have part of the upper lofts, offices and apartments. In the buildings of the corners, the solution adopted was again a colonnade that act as an alley for the shops of the ground floor and support the upper levels of the buildings on which other uses are places.

Figure 60: Commercial ground floor

5.3. Design of public spaces

The plaza, as has been mentioned is a key part of the project, as it acts as one of the "entrances" of the Eastern Metropolitan Green Lung and highlights the presence of the hill of Peñon de los Baños. In order to enhance this relationship it was decided to create a pedestrian walkway lined with trees that crosses the plaza and links this two landmarks. Thus, visitor coming from the park across the plaza have a front view of the hill, and vice versa, someone coming from the hill has the view of the access to the park.

Besides giving the plaza a purely contemplative or recreational use, the authors have decided that it might hold the weekly market of the new urbanized areas, as well as those in its vicinity. Usually the weekly markets in Mexico City are located on the carriageway of the streets, blocking traffic. The proposed solution will then be an opportunity to improve the traffic conditions of the zone.

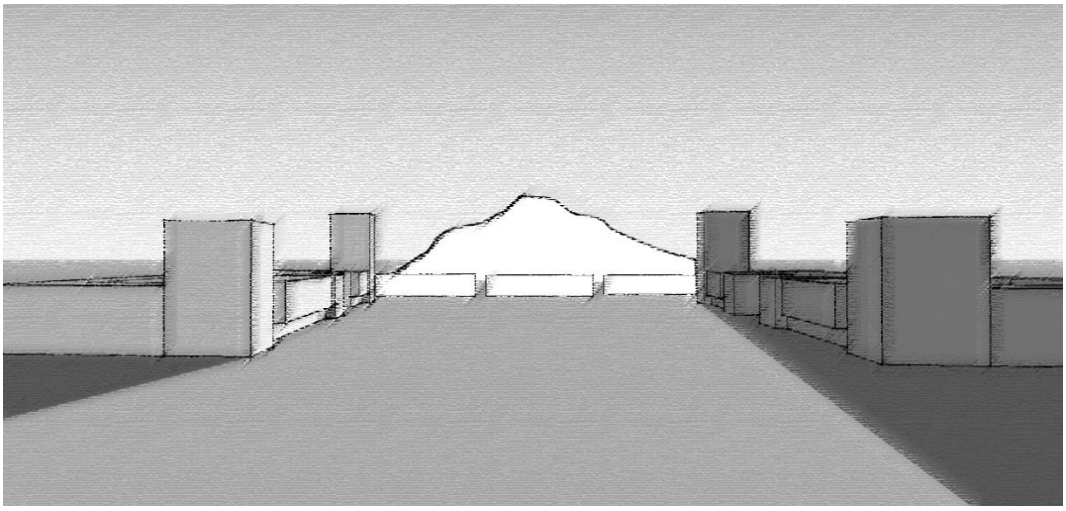


Figure 61: View of Peñón de los Baños from the Plaza

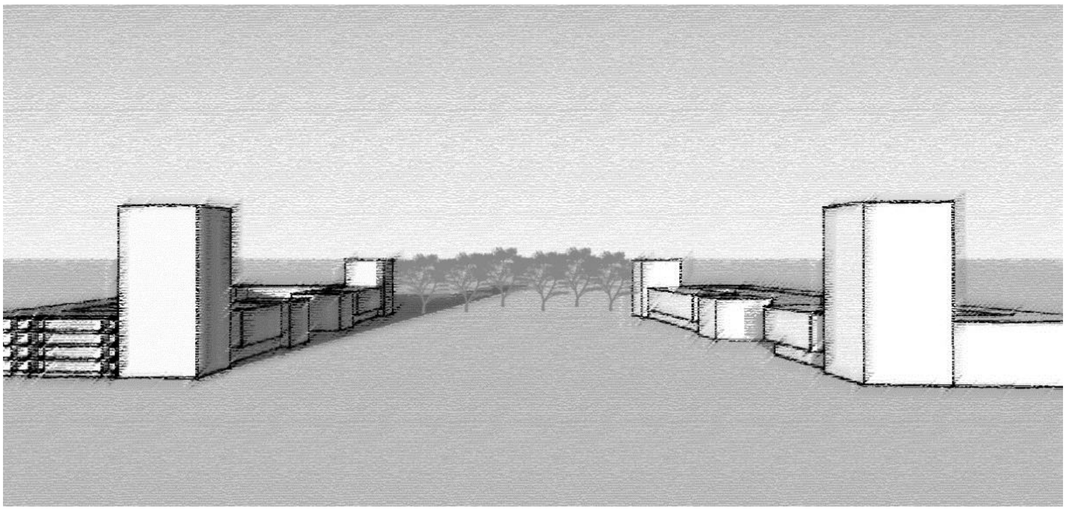


Figure 62: View of the Metropolitan Park from the plaza.

With regard to the design of the space where the market will develop, in the architectural design it has been planned that the axes of the passageways running north to south should be extended and expanded as they approach the plaza, in order to create two areas that will act as small squares within the overall assembly of public space. To differentiate them, the designers have decided to play with the overall landscape and lower down the floor levels of the markets in 0.45 m below the surroundings. The steps around this squares will serve to give people seat, allowing the transformation of this spaces into small theaters and auditoriums, when they are not harboring the market.

Figure 63: Prolongation of the walkways and creation of the marketplaces.

On the sides of the marketplaces it has been planned to construct a corridor covered by a pergola that can enclose the space, act as a threshold and also serve as support for an array of wires on which can be hung tarpaulins or tents to cover from rain and sun traders and customers that will use these spaces.

Figure 64: View of one of the marketplaces

To supply the market, 2 lanes, one on the south border and the other in the north one were allocated. They are flanked on one side by trees and bollards and other side by high planters, which will prevent the vehicles to invade areas for exclusive pedestrian use. Each lane has a small area for loading and unloading products. Regarding the parking are for the trucks, it has been placed in the eastern side of the plaza, close to the entrance of the Metropolitan Park, and will be bounded by removable bollards, as this space will only be used as parking by market traders and not as an everyday activity.

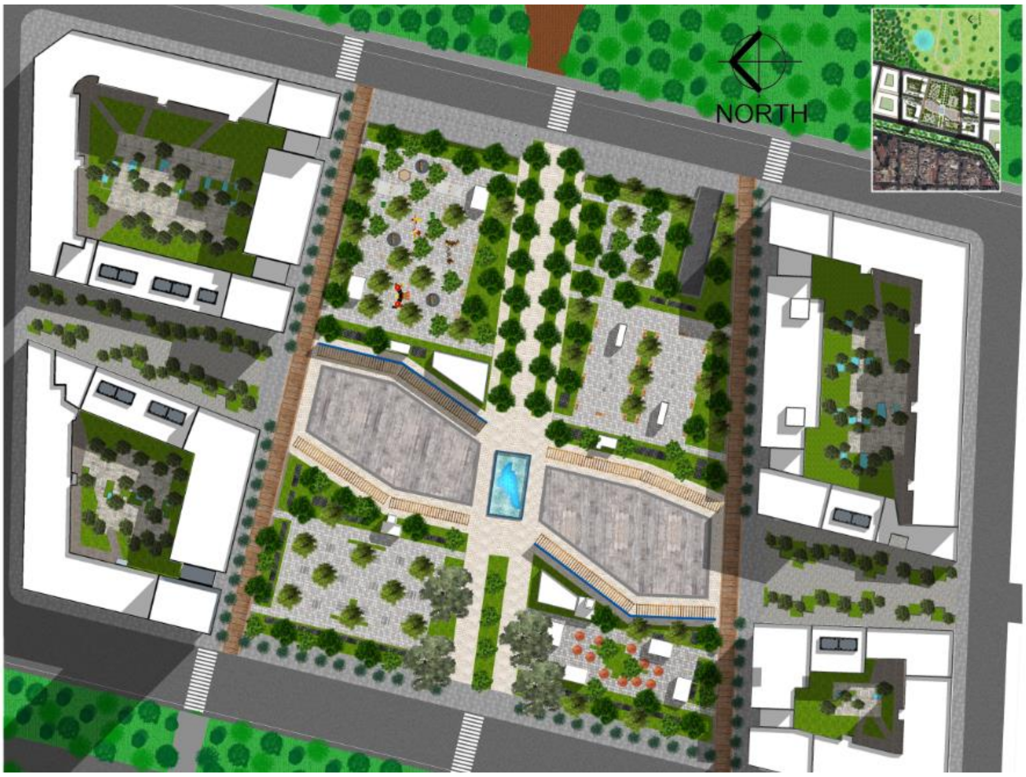


Figure 65: Top view of the architectural project

The two marketplaces located in the north-south axis and the pedestrian walkway that crosses the plaza from east to west divide this big public space into 4 smaller squares, each of them dedicated to a different function:

- A square for social and gathering activities, located in the south-western part of the plaza, where a certain level of noise coming from the adjacent avenue can be acceptable. On this square people will be able to find small cafes, restaurants or magazine shops, with their corresponding temporary furniture and urban facilities.

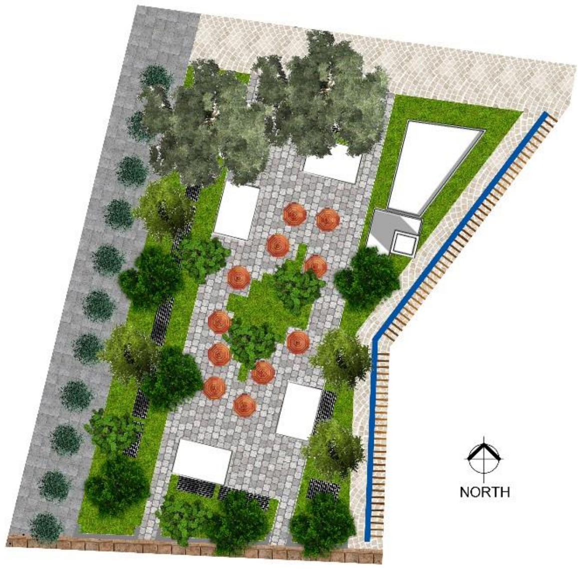


Figure 66: Cafes and restaurants square

- A square for games and leisure located in the north-western side of the plaza, where users will be able to find fixed concrete furniture. On them people will be able to play their preferred table games, and the workers of the nearby offices can have their lunch break.

Figure 67: Games and leisure square

- A square for children. As they are a key aspect to consider in every public space, considering that every family should be able to find activities for each of their members, this square will give the youngest the opportunity to have fun in a safe and comfortable environment far from crowded streets. For this reason, this square was located in the north-eastern side of the plaza, where kids will not disturb or interfere with the other activities of the plaza.

Figure 68: Children square

- The last quarter of the square, located in the south-eastern side of the plaza in a zone characterized by its peacefulness will be dedicated for activities such as reading and relaxation.

Figure 69: Reading and relaxation square

Water and vegetation are due elements that have been present on this project since the urban master plan. For this reason, they are present also on the plaza and each of its subdivisions in the form of gardens and fountains that gradually make the transition from the urban environment to the more natural conditions of the Metropolitan Park.

Among all the plant species used on the park, one deserves special attention: The ahuehuete. This huge tree can reach almost 40 meters of height, is able to grow in almost all the altitudes of the country and has also linked a historical meaning for all the Mexicans. This trees will be used as natural landmarks that will act as a framework for the pedestrian walkway that links the hill of Peñón de los Baños with the Metropolitan Park.

Regarding the public walkways that arrive to the plaza coming from north and south, it was considered that they should be welcoming, safe and comfortable for visitors but at the same time give the residents of the houses located at the sides a sense of privacy and peace. Once again, with the use of greenery by means of irregular gardened strips that divide the walkways between a wider and more public pedestrian way that variates its width in its overall length and two smaller and more "private" paths, mostly used by the residents of the nearby houses.

5.4. Design of the semi-private open spaces

The design of the courtyards of each of the four architectural volumes is also a key aspect. The designers wanted to create livable spaces that enrich the relationships between the neighbors through the creation of areas where people will be able to do different open-air activities with excellent micro-climatic conditions. This features will lead to the formation of pride and sense of place on the residents.

Usually, the open spaces in Mexico City are mostly used at afternoons, when kids return from the schools and go out to play after doing their homework. It has been thus considered that at from 4 p.m. to 6 p.m. is when this spaces will be used at its maximum potential.

It was then realized a study of the daylight and the shadows for the open semi-private spaces, with special attention given to the most critical months in terms of solar radiation and heat: March, April, May. In the next graph it is possible to see some of the obtained results, with the most critical situations marked in red.

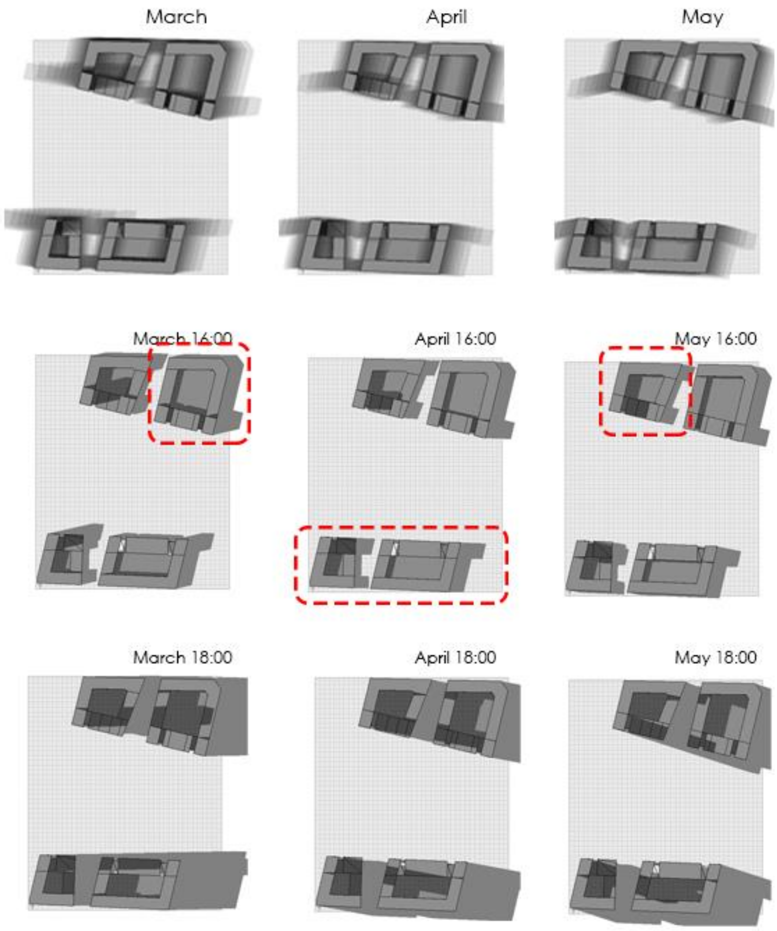


Figure 70: Sunlight and shadows study for the semi-private spaces

After having analyzed how sunlight is striking the courtyards at different seasons, it has been found that for the hottest months of the year, the surrounding buildings, with a height of about 13-14 meters, are able to shade an open area of about 15 to 20 meters width measured in the east-west direction. This led the designers to divide the courtyards by natural barriers located at almost the mentioned distance. This natural barriers will consist on planters with tall trees, sitting areas and fountains that will create a comfortable environment from the aesthetic and climatic point of view.

For the sake of an easy understanding, the blocks will be named as: 1 for the top left one; 2 is the one of the top right; the bottom left is number 3; and finally, the bottom right is number 4.

Figure 71: North-western block, semi-private courtyard number 1

For the courtyard of the block number 1, was just necessary one line of trees in the middle to cover the social space. It was combined with some fountains that also help to increase the thermal comfort of the users by providing evaporative cooling. To give some movement to the design, in the edges of the square were created some insets, where were placed also some trees that help to delimit the space.

The case of the block number 2, as it is possible to see from the solar analysis, was a little bit different. The shadow projected by the buildings is just covering a small portion of the green space. Thus, in this area were created one central line of trees and one on the left edge of the square so that the users will be shaded in all spaces.

Figure 72: North-eastern block, semi-private courtyard number 2.

Figure 73: South-western block, semi-private courtyard number 3

It was discover that in the case of block number 3, there is no need of shading because the buildings around are providing enough solar protection. However, in this case some trees and a fountain was placed to create a nicer environment. It is important to mention that from this courtyard was taken the "required span" to create a module for the spacing between the trees when placing them in lines running in the north-south direction with separations of 15-20 meters.

The block number 4 is the most critical one due to its geometry: It is the widest one. As the case of block number 2, the shadow projected by the building is just covering a small portion of the open space. A set of trees and fountains were placed with a separation of 15 meters starting from the very left side. The trees in the right side of the square were added in order to keep the symmetry and to delimit the space.

Figure 74: South-eastern block, semi-private courtyard number 4.

5.5. Design of the building facades

Functionalist says: the form follows the function. For the design of the buildings it was decided to focus in solving the function first and then to focus on the form. After having solved the buildings it was required to design the facades in order to let pass enough daylight and fresh air, but also give identity to the buildings and the neighborhood.

For the natural light, the most logic and easier solution was to increase the dimensions of the windows: big openings that lead to have light and also natural ventilation. However, this approach would result in having excessive glare and overheating.

Then it was decided that the best solution would be the inclusion of roller blinders as the main architectural element that will define the façade, giving the possibility to the users to adapt to the climatologic conditions of each day. The technical aspects of this solution will be more explained in the technological design chapter.

Being a functionalist design, it is able to answers to all the needs of the users, this means that the building can be in many places and work well. Thus a new concern appeared, to give identity to the building, and blend it into the Mexican contest.

The architecture of Mexico City has been, since the conquest influenced by the European architecture. Spanish destroyed examples of the traditional indigenous architecture such as the pyramids and temples, and replaced them with colonial buildings of Romanic and gothic architecture, such as church, abbeys, etc.

After the independence of the country, the European architecture became a symbol of progress, opulence and power. As a result of this trend, the historical city center is full of buildings in with French and Italian influences. Examples of this period are the main Post office made by the Italian architect Adamo Boari and the military Mexican engineer Gonzalo Garita, with a clear frenchfied design and the blacksmith made in Florence. In the next images, it is possible to see some of the features of this building.

Figure 75: The post office of Mexico City.

Luis Barragan, an international icon of Mexican architecture, winner of the Pritzker price started his career in the city of Guadalajara. However, is after traveling to Europe to learn the techniques used in that continent, that he developed some of his most recognizable work. The key of his architecture was his masterful use of the light and colors. Barragan did a detailed study of them to determine the perfect amount of light required for each space and the right use of the colors to provide the user a specific sensation when using that space. The two best examples of this are the Chapel of the Capuchinas and his studio house in Tacubaya.

In the first one, he has used a window made with onyx that combined with the oblique position of the walls make possible to bath the space with an amber light that give the worshipers a sensation of divinity. The roof terrace of his Studio house, despite being located close to two of the busiest avenues of the city such as Anillo Periferico and Constituyentes, is a quiet and pacific place thanks to the use of high-massive walls that block the view of except the sky, then the user can have the sensation to be in a heavenly place, instead of being in the middle of the crowded, polluted and chaotic Mexico city.

Figure 76: Chapel of Capuchinas, by Luis Barragan

Figure 77: Roof terrace of the studio house of Luis Barragan

Barragan is not the only one, neither the pioneer in the use of colors. An excellent example of this aspect is the Frida Kahlo house: the world famous blue house. Even in the architecture of the small towns is possible to find buildings full of color.

Figure 78: Blue house of Frida Kahlo

Figure 79: Traditional Mexican town

There are many others that after Barragan, following the "stigma" that he gave to Mexican architecture in the world eyes, started to incorporate the use of colors in their designs, mixing it with the use of some other distinctive components such as vegetation. That is the case of O'Gorman whose architectural phase was short, but is well represented by the house of Frida and Diego in "El Pedregal". On it, it is possible to find a very modern building in which cactuses were used as a fence.

Figure 80: Frida and Diego house by O'Gorman

The use of colors in not simply part of a trend that started with architecture, it is present also in the Mexican typical dresses, and some of their traditions. Thus, it means that color has to be part of the architectural design of the buildings, the problem was then where and how to use it.

Another incredible example of Mexican architecture in which the culture and the identity of the country was used as a major characteristic on the building facades is Ciudad Universitaria in Mexico City. In most of its buildings, such as the rectory and the library, were used typical prints from pre-Hispanic cultures.

Figure 81: Library of Ciudad Universitaria, Mexico City.

When approaching to the use of colors in the specific design of the buildings, a couple of test were performed on the balconies and on the external walls, but the results were not satisfactory at all. Then, it was realized that the blinders, which are the movable elements of the façade, could help to give color and dynamism to the façade. As this devices are controlled manually, they won't be always in the same position.

The selected colors have been "applied" on the blinders based on the use of the spaces inside the buildings, in a way to show to the people outside that they are not merely residential buildings, and that diversity is a key aspect of them.

According to the provider of the textiles, it is possible to have different images painted over them. This feature was used as an opportunity to incorporate some traditional and iconic patterns of the Latin-American and Mexican cultures.
The designers have asked for advisory to the Architect Ismael Rodriguez from Universidad de Guadalajara, who now is dedicated to handcrafts and plastic arts, and has a deeper knowledge about Latin-American iconography. He has suggested the use of the "canamayte".

The “canamayte” is the central square in the row of squares of the dorsum of the snake *Crotalus dirissus dirisus*. The design is a geometrical model which corresponds to a square inscribed in another one. This pattern was used by the Mayas to solve problems related to the construction of buildings, and it is sometimes related as the golden ration for that culture.

Figure 82: Crotalus dirissus dirisus snake.

The Mayas based their mathematical and astronomical knowledge in the mentioned diamond-shaped pattern, which is crossed by a cross type "St Andrew" or inclined, as shown in the next image. It is composed by 13 scales per side, separated by the cross mentioned in two sections of 6 with 1 scale in the center. On all four sides it is possible to see the 13 scales, while the center 25 are framed with light-colored scales.

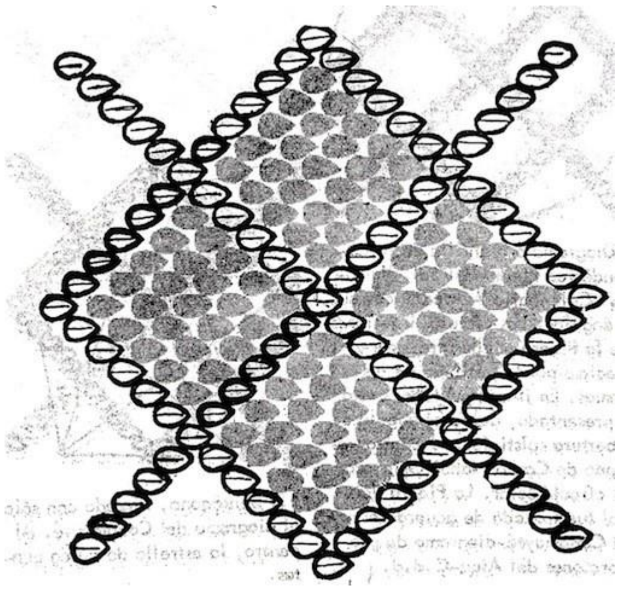


Figure 83: The mayan “canamayte”

As the squares in the skin of snake can become into diamonds when it crawls and then they recover their previous shapes, the designers have considered that this ability to adapt their shape could be translated in the building, and especially on its façade, as an iconic element that gives shelter to the people inside. The “canamayte” will be then the structure, envelope and symbol of the building.

The final result of this approach, can be seen in the next image:

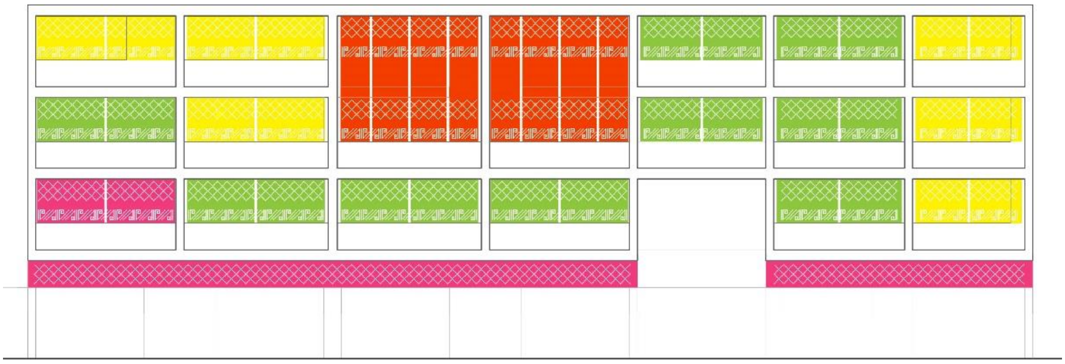


Figure 84: Main facade of a building with the blinds down.

Chapter IV: Structural design

The present chapter includes the study, analysis and design of the structural elements of one of the buildings proposed in the architectural design.

The structure to be designed corresponds to a mixed use low rise building located in the eastern part of Mexico City, where used to be a lake before the expansion of the city during the XX century.

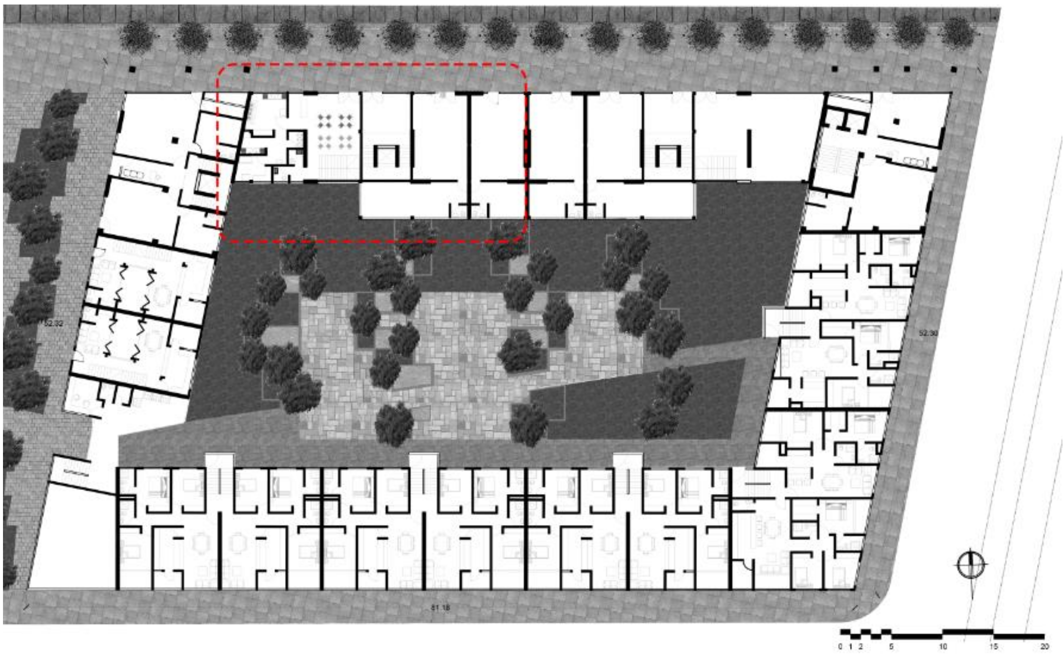


Figure 85: Location of the designed building in the architectural project.

The dimensioning and detailing will be in accordance with the criteria for the limit states of ultimate failure and serviceability limit states.

According to the limit states criteria, the structures must be dimensioned so that the design strength of the entire section for each internal force or moment acting on it is equal to or greater than the design value of the force or moment inmates. The design strengths should include the appropriate resistance factor (FR). Internal forces and design moments are obtained by multiplying by the corresponding load factor values of these internal forces and moments calculated under the actions specified in the Mexican code.

In addition, it will be checked that the responses of the structure (deformation, cracking, etc.) remain limited to values such that the operation in satisfactory conditions of service.

1. Proposed structural system

The building will be supported by a reinforced concrete combined structural system, in which the vertical loads are resisted by a frame not resistant to moments and the horizontal forces are resisted by walls or frames with diagonals.

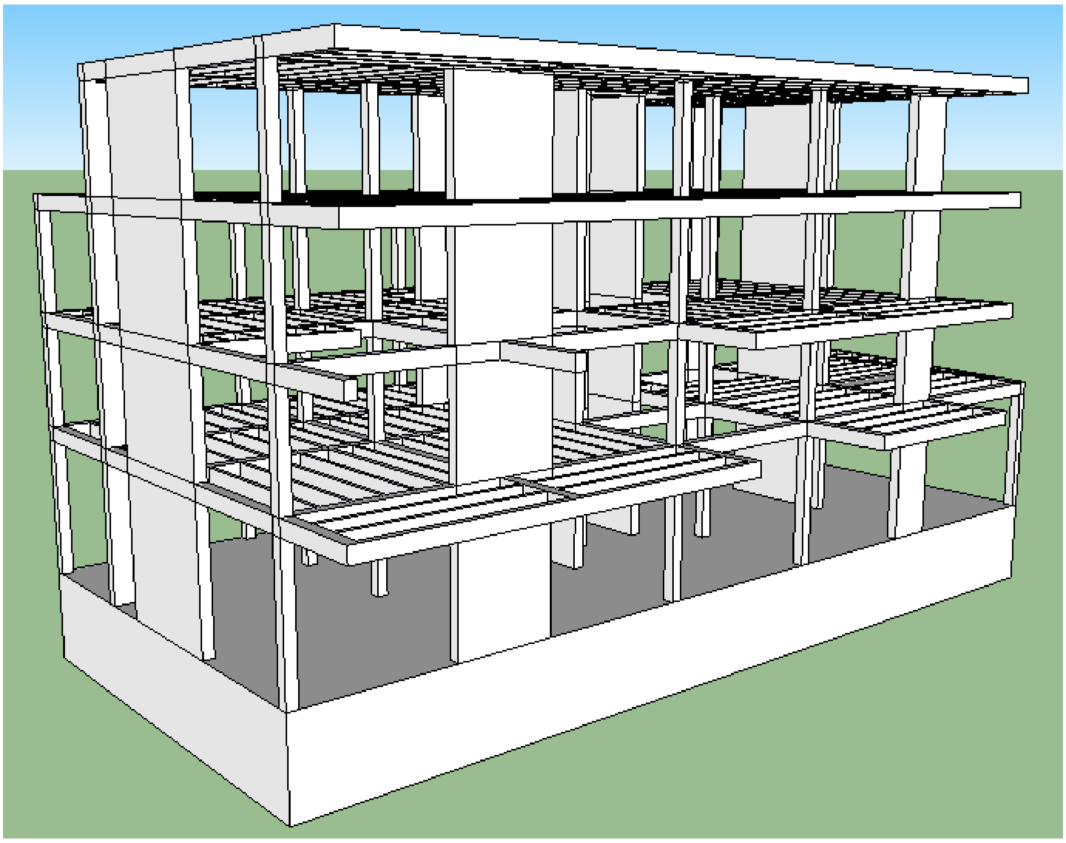


Figure 86: 3D view of the proposed structural system

2. Material Properties

On the following table is presented a summary of the mechanical properties of the materials used in the structure:

Concrete	
Concrete type	1
Specified compression strength f'c [Mpa]:	25
Nominal compression strength fc* [Mpa]:	20
Medium tensile strength ft [Mpa]:	2.35
Nominal tensile strength ft* [Mpa]:	1.76
Flexural strength ff* [Mpa]:	2.65
Modulus of elasticity Ec [Mpa]:	22000
Steel	
Yield strength fy [Mpa]:	412
Modulus of elasticity Es [Mpa]:	200000

Table 1: Mechanical properties for the used materials

3. Load assessment

Three categories of actions, according to the duration on which they act on the structures with its maximum intensity are considered.

Permanent actions are acting continuously over the structure with an intensity that varies little with time. The main actions in this category are: dead load; static earth and fluid pressures and displacements and deformations imposed over the structure that vary little over time, such as those due to pre-stressing or permanent differential movements of the support.

Variable actions are those that act on the structure with an intensity that varies significantly over time. The main actions that fall into this category are: the live load; temperature effects; deformations imposed and differential subsidence having a variable intensity over time, and actions due to the operation of machinery and equipment.

Accidental actions are not due to normal operation of the building and can achieve significant intensities for brief periods only. This category includes: seismic actions; wind effects; loads of hail; the effects of explosions, fires and other phenomena that can occur in rare cases.

The safety of the structure has been verified to the combined effect of all actions that have a non-negligible probability of occurring simultaneously under the following load combinations:

- 1.4 D
- 1.4 D + 1.4 L

Where D corresponds to dead load and L to live load.

3.1. Permanent loads

3.1.1. Self-weight of structural and non-structural elements

This loads correspond to the self-weight of the structural elements and the non-structural ones such as the vertical closures, inside partitions, and all loads applied over the slabs permanently.

Vertical closures			
Material	Thickness (m)	Specific weight (kN/m³)	Weight (kN/m²)
Plaster	0.015	18	0.27
Problock masonry	0.12	19.5	2.34
XPS	0.051	0.3	0.02
Plaster	0.015	18	0.27
Total (kN/m²)			2.90
Floor height (m)			2.76
Load (kN/m)			7.99
Load (walls with openings) (kN/m)			4.00

Table 2: Permanent loads. Vertical closures

For the calculation of the total load of the inside partitions, it was considered to be uniformly distributed in order to avoid further calculations in case of a possible change of disposition of partitions during the design working life of the building. Assuming a 3.0 m span between inside walls, the correspondent equivalent uniformly distributed load is 2.65 KN/m2.

Inside partitions			
Material	Thickness	Specific weight	Weight
	(m)	(kN/m³)	(kN/m²)
Plaster	0.015	18	0.27
Problock masonry	0.12	19.5	2.34
Plaster	0.015	18	0.27
Total (kN/m²)			2.88
Floor height (m)			2.76
Load (kN/m)			7.95
Total (kN/m²)			2.65

Table 3: Permanent loads: inside partitions.

Typical floor						
Dimensions [m]			Material	Thickness	Specific weight	Weight
Joist width	0.12			(m)	(kN/m³)	(kN/m²)
Joist height	0.2		Deko sky	0.016	1.05	0.02
Joist free spacing	0.7		EPS + RC	0.2	3.30	0.66
Materials density [kg/m³]			RC	0.05	25	1.25
RC	2500		Mortar	0.03	20	0.60
EPS	35		Ceramic tiles	0.02	18.5	0.37
RC + EPS	329.88					
			Total (kN/m²)			**2.90**

Table 4: Permanent loads on the typical floor.

Green Roof			Material	Thickness	Specific weight	Weight
				(m)	(kN/m³)	(kN/m²)
Dimensions [m]			Deko sky	0.016	1.05	0.02
			EPS + RC	0.3	3.30	0.99
Joist width	0.12		RC	0.05	25	1.25
Joist height	0.3		Mortar	0.03	20	0.60
Joist free spacing	0.7		Water-proofing	0.01	17	0.17
Materials density [kg/m³]			Anti-root membrane	0.005	1	0.01
			Rockwool	0.032	1.4	0.04
			Natural aggregate	0.02	1.5	0.03
RC	2500		Plants	0.18	4	0.72
EPS	35					
RC + EPS	329.88		**Total (kN/m²)**			**3.66**

Table 5: Permanent loads of the green roof.

3.2. Variable actions

3.2.1. Live loads

The live loads for the different uses of the spaces in the building are shown in the next table.

Use the space	Unitary live loads (kN/m²)		
	W	Wa	Wm
Residential	0.7	0.9	1.7
Offices	1	1.8	2.5
Restaurants	0.4	2.5	3.5
Commerce	2.8	3.15	3.5
Balconies	0.15	0.7	3
Roofs with less than 5% of slope	0.15	0.7	1

Table 6: Live loads on the building

Where Wm is used in the design for gravitational loads, and to design foundations; Wa is used when considering also seismic and wind design, and where there are more unfavorable distributions of load compared to the distributed one; W is used for calculating differed settlements.

3.3. Accidental actions

3.3.1. Hail loads

In order to take into account the effect of hail Wm will be taken as 1.0 kN/m2 and will be considered as an accidental load when calculating load factors.

4. Analysis and design

4.1. Resistance factors

According to the Mexican code, the resistance of the different elements should be affected by a reduction factor, FR. The resistance factors have the following values:

- FR=0.9 for flexion.
- FR=0.8 for shear and torsion.
- FR=0.7 for the transmission of shear and flexion on slabs and spread footings.
- Combination of flexion and compression:
    - FR=0.8 when the core is confined.
    - FR=0.8 when the element fails due to tension.
    - FR=0.7 when the element is not confined and it fails due to compression.
- FR=0.7 for flattening.

These reduced resistance (design strengths) are those that, when dimensioning, are compared with the design internal forces that are obtained when multiplying the loads by load factors.

4.2. Hypothesis for the analysis and designs of elements under bending and axial forces:

The determination of the resistances of the cross sections of the elements under bending and axial loads was developed under the following conditions:

- The distribution of the strain over the cross-section of an element is plane.
- There is a perfect bonding between concrete and steel is such that the strain for steel is equal to the adjacent concrete.
- The strain of the concrete under compression when the resistance of the cross-section is achieved is 0.003.
- Concrete do not resist tension stresses.
- The distribution of stresses of compression for the concrete, when achieving the resistance of the cross-section is considered uniform with a value fc''=0.85fc* until a depth of the compression zone equal to β1c, where β1=0.85 if fc* is lower or equal to 28 MPa.

4.3. Analysis and design of the slabs

On this subchapter are summarized the calculations developed to analyze and design the joist J-1. On the next image is possible to see the exact location of it in the building.

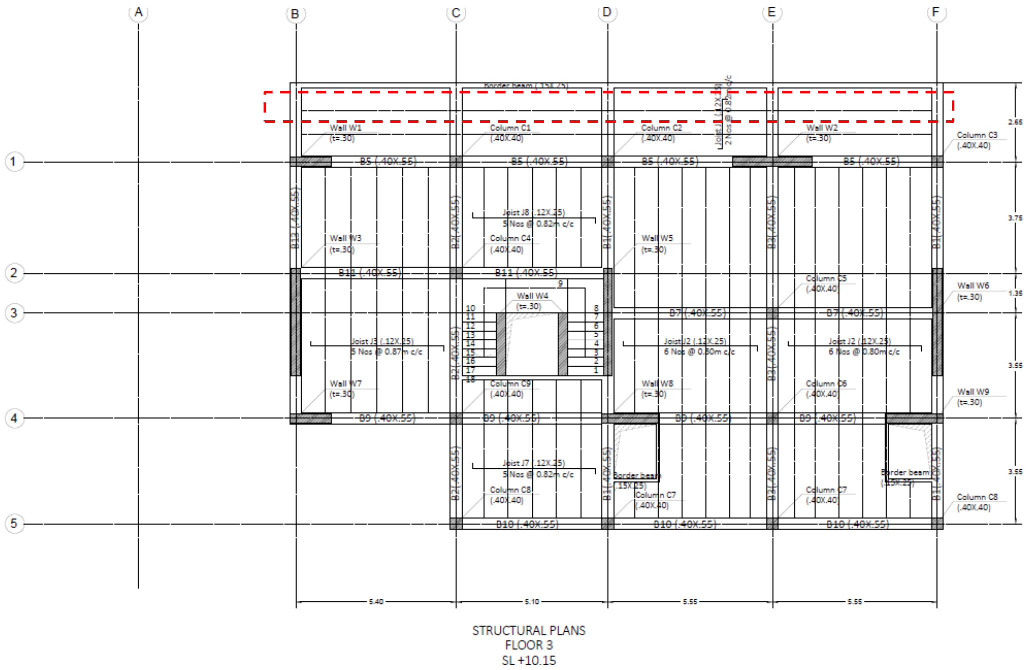


Figure 87: Localization of the joist J-1 in the structural plan of the third floor.

The typical slab is a tile-lintel floor made of concrete joist and extruded polystyrene as lightening, with a concrete topping. The design of the slab is done by considering the area that is contributing load to the joist, thus a strip of 0.82 m wide.

The permanent load is 2.90 kN/m2 and the variable ones are assigned according to the different uses of the spaces. On this case, it was analyzed a joist that has the following conditions:

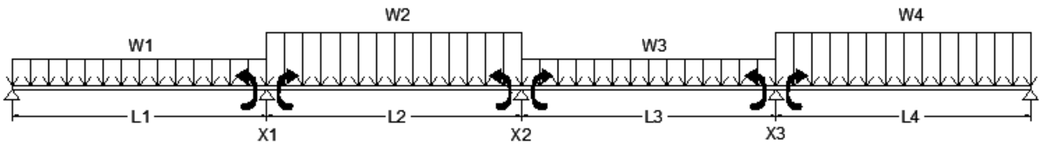
- Office: 2.5 kN/m2.
- Residential: 1.7 kN/m2.
- In addition, the inside partitions self-weight will be considered among this last group, with a magnitude of 2.65 kN/m2.

The structural analysis will be carried out considering the load cases contemplated on the Mexican code:

1.4*D+1.4*L

4.3.1. Combination 1: Minimum moment at the continuity support:

The structure is solved using the flexibility method:



The system of equation is then:

$$\begin{vmatrix} \frac{L1}{3EI}+\frac{L2}{3EI} & \frac{L2}{6EI} & 0 \\ \frac{L2}{6EI} & \frac{L2}{3EI}+\frac{L3}{3EI} & \frac{L3}{6EI} \\ 0 & \frac{L3}{6EI} & \frac{L3}{3EI}+\frac{L4}{3EI} \end{vmatrix} \mathrm{X} \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -\frac{W1L1^3}{24EI}+\frac{W2L2^3}{24EI} \\ -\frac{W2L2^3}{24EI}+\frac{W3L3^3}{24EI} \\ -\frac{W3L3^3}{24EI}+\frac{W4L4^3}{24EI} \end{vmatrix}$$

Where W1, W2, W3 and W4 are the sum of the corresponding load combinations for each span. This led to only variate the W for each of the load combinations on the spans.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	2.65	2.5	6.60	9.24
2	5.1	2.90	2.65	2.5	6.60	9.24
3	5.55	2.90	2.65	1.7	5.94	8.32
4	5.55	2.90	2.65	1.7	5.94	8.32

In this load combination, the system of equations take the following values:

$$\begin{vmatrix} 3.5 & 0.85 & 0 \\ 0.85 & 3.55 & 0.925 \\ 0 & 0.925 & 3.7 \end{vmatrix} \mathrm{X} \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -111.66 \\ -110.31 \\ -118.51 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -27.72 \\ -17.21 \\ -27.73 \end{vmatrix}$$

4.3.2. Combination 2: Maximum moment in the span 1

The structure is solved in the same way as in the previous combination case. The difference now is that the variable loads are only applied on the span 1. Which corresponds to an office use. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	2.65	2.5	6.60	9.24
2	5.1	2.90	0.00	0	2.38	3.33
3	5.55	2.90	0.00	0	2.38	3.33
4	5.55	2.90	0.00	0	2.38	3.33

In this load combination, the system of equations take the following values:

$$\begin{vmatrix} 3.5 & 0.85 & 0 \\ 0.85 & 3.55 & 0.925 \\ 0 & 0.925 & 3.7 \end{vmatrix} \text{X} \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -78.98 \\ -42.07 \\ -47.37 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -21.71 \\ -3.55 \\ -11.92 \end{vmatrix}$$

4.3.3. Combination 3: Maximum moment in the span 2

The structure is solved in the same way as in the previous combination case. The difference now is that the variable loads are only applied on the span 2, which corresponds to an office use. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	0.00	0	2.38	3.33
2	5.1	2.90	2.65	2.5	6.60	9.24
3	5.55	2.90	0.00	0	2.38	3.33
4	5.55	2.90	0.00	0	2.38	3.33

In this load combination, the system of equations take the following values:

$$\begin{vmatrix} 3.5 & 0.85 & 0 \\ 0.85 & 3.55 & 0.925 \\ 0 & 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -72.87 \\ -74.74 \\ -47.37 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -17.29 \\ -14.52 \\ -9.17 \end{vmatrix}$$

4.3.4. Combination 4: Maximum moment in the span 3

The structure is solved in the same way as in the previous combination case. The difference now is that the variable loads are only applied on the span 3, which corresponds to a residential use. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	0.00	0	2.38	3.33
2	5.1	2.90	0.00	0	2.38	3.33
3	5.55	2.90	2.65	1.7	5.94	8.32
4	5.55	2.90	0.00	0	2.38	3.33

In this load combination, the system of equations take the following values:

$$\begin{vmatrix} 3.5 & 0.85 & 0 \\ 0.85 & 3.55 & 0.925 \\ 0 & 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -40.20 \\ -77.63 \\ -82.94 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -7.81 \\ -15.15 \\ -18.63 \end{vmatrix}$$

4.3.5. Combination 5: Maximum moment in the span 4

The structure is solved in the same way as in the previous combination case. The difference now is that the variable loads are only applied on the span 4, which corresponds to a residential use. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	0.00	0	2.38	3.33
2	5.1	2.90	0.00	0	2.38	3.33
3	5.55	2.90	0.00	0	2.38	3.33
4	5.55	2.90	2.65	1.7	5.94	8.32

In this load combination, the system of equations take the following values:

$$\begin{vmatrix} 3.5 & 0.85 & 0 \\ 0.85 & 3.55 & 0.925 \\ 0 & 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -40.20 \\ -42.07 \\ -82.94 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \\ X3 \end{vmatrix} = \begin{vmatrix} -10.58 \\ -3.72 \\ -21.49 \end{vmatrix}$$

In the next table are summarized the reactions on the supports of the joist for each load combination, this results were used in order to calculate the shear and moment diagrams that will be displayed in the following pages.

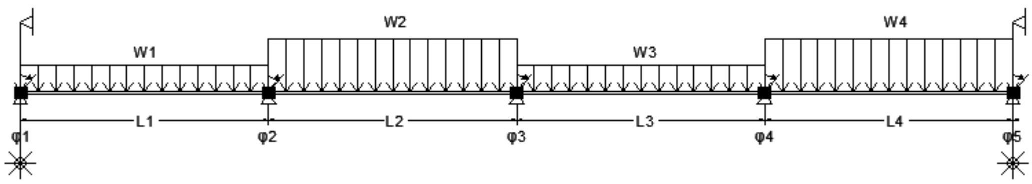
Reactions	Comb 1	Comb 2	Comb 3	Comb 4	Comb 5
Ra (kN)	19.81	20.92	5.78	7.53	7.02
Rb (kN)	55.69	41.00	36.28	17.46	20.76
Rc (kN)	42.68	12.64	33.20	32.37	13.16
Rd (kN)	53.06	22.11	19.14	36.30	39.38
Re (kN)	18.09	7.08	7.57	5.87	19.21

Table 7: Summary of the reactions on the supports of the Joist J-1

However, it is important also to estimate the value of the negative moments at the ends of the joist, due to the partial constrain given by the longitudinal beams.

4.3.6. Combination 6: Minimum moment in the span 1

For the calculation of the negative moments on the left span, the partial scheme shown in the next figure was used to represent the real conditions of a multistory building. The frame structure was solved using the stiffness method, assuming as unknowns the clockwise rotations of the five nodes.



The equilibrium system of equations is the following:

$$\begin{vmatrix} m11 & m12 & 0 & 0 & 0 \\ m21 & m22 & m23 & 0 & 0 \\ 0 & m32 & m33 & m34 & 0 \\ 0 & 0 & m43 & m44 & m45 \\ 0 & 0 & 0 & m54 & m55 \end{vmatrix} \times \begin{vmatrix} \varphi 1 \\ \varphi 2 \\ \varphi 3 \\ \varphi 4 \\ \varphi 5 \end{vmatrix} + \begin{vmatrix} m10 \\ m20 \\ m30 \\ m40 \\ m50 \end{vmatrix} = 0$$

$$m_{1,1} = 2 * \frac{3EIc}{h/_2} + \frac{4EIs}{L1} \quad m_{1,2} = m_{2,1} = \frac{2EIs}{L1} \quad m_{1,0} = -\frac{W1\,L1^2}{12}$$

$$m_{2,2} = \frac{4EIs}{L1} + \frac{4EIs}{L2} \quad m_{2,3} = m_{3,2} = \frac{2EIs}{L2} \quad m_{2,0} = \frac{W1\,L1^2}{12} - \frac{W2\,L2^2}{12}$$

$$m_{3,3} = \frac{4EIs}{L2} + \frac{4EIs}{L3} \quad m_{3,4} = m_{4,3} = \frac{2EIs}{L3} \quad m_{3,0} = \frac{W2\,L2^2}{12} - \frac{W3\,L3^2}{12}$$

$$m_{4,4} = \frac{4EIs}{L3} + \frac{4EIs}{L4} \quad m_{4,5} = m_{5,4} = \frac{2EIs}{L4} \quad m_{4,0} = \frac{W3\,L3^2}{12} - \frac{W4\,L4^2}{12}$$

$$m_{5,5} = 2 * \frac{3EIc}{h/_2} + \frac{4EIs}{L5} \quad m_{5,0} = \frac{W4\,L4^2}{12}$$

The pillar stiffness was calculated by distributing the column stiffness along the column average spacing and then calculating the equivalent stiffness of the column in relation to the barycentric moment of inertia of the cross section of the joist.

Column properties			**Slab properties**		
Height (m)	3.16		B plate (m)		0.82
B (m)	0.40		H plate (m)		0.05
L (m)	0.40		B joist (m)		0.12
AREA (m2)	0.16		H joist (m)		0.20
INERTIA (m4)	0.00213		Yg (m)		0.07
I* column (m4/ml)	3.95E-04		Inertia slab (m4)		3.25E-04
I* column (m4/0.82ml)	3.24E-04		I*column=	9.97E-01	I slab

Table 8: Column and slab geometrical properties.

For the load combination, it was considered that the live loads were only present on the first span. This assumption will eliminate the effects of compensation of moments created when other loads are placed on the resting spans.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	2.65	2.5	6.60	9.24
2	5.1	2.90	0.00	0	2.38	3.33
3	5.55	2.90	0.00	0	2.38	3.33
4	5.55	2.90	0.00	0	2.38	3.33

The solution of the linear system is:

φ1		5.987766	
φ2		-12.5519	kNm²
φ3	=	4.299859	――――
φ4		-0.61357	Eislab
φ5		-1.84559	

Ra (kN)	26.29
Rb (kN)	33.97
Rc (kN)	15.09
Rd (kN)	19.65
Re (kN)	8.75

4.3.7. Combination 7: Minimum moment in the span 4

In this case, again the live load is not considered on the three first spans, and the calculations are developed as in the previous combination case.

Span	Length (m)	Permanent actions (kN/m²)	Live loads (kN/m²)		Q (kN/m)	Qu (kN/m)
			Partitions	Others		
1	5.4	2.90	0.00	0	2.38	3.33
2	5.1	2.90	0.00	0	2.38	3.33
3	5.55	2.90	0.00	0	2.38	3.33
4	5.55	2.90	2.65	1.7	5.94	8.32

The solution of the linear system is:

φ1		1.837352	
φ2		-0.63098	kNm²
φ3	=	-1.50729	――――
φ4		10.66708	Eislab
φ5		-5.59307	

Ra (kN)	8.73
Rb (kN)	18.20
Rc (kN)	15.43
Rd (kN)	33.11
Re (kN)	24.07

4.3.8. Pre-dimensioning of the reinforcement

The pre-dimensioning of the reinforcement was calculated in the most critical sections according to the envelope diagram of bending moments calculated from the load combination cases.

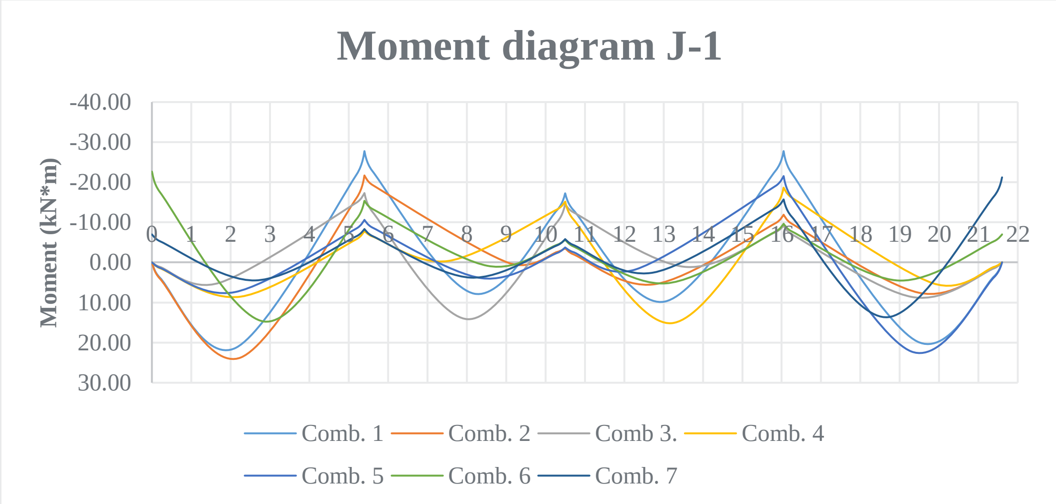


Figure 88: Envelope of the bending moments for the joist J-1

For the pre-dimensioning of the reinforcement, the effective depth of the cross-section was calculated:

Cmin,b (mm)	14
Cmin,dur (mm)	15
ΔCdev. (mm)	10
Cnom (mm)	**25**
dSlab (mm)	**218**

The conditions of equilibrium and the hypothesis of analysis and design previously described lead to the following expressions for the resistance to bending MR. On these expressions FR was taken equal to 0.9.

$$M_R = F_R A_s f_y d \left(1 - 0.5 \frac{A_s f_y}{b d f_c''}\right)$$

Where b is the width of the cross-section, d is the effective depth, fc'' is the uniform compression strength and As is the area of the reinforcement.

The minimum acceptable reinforcement is:

$$A_{s,min} = \frac{0.22\sqrt{f_c'}}{f_y}bd$$

However, it is not necessary that the minimum reinforcement is less than 1.33 times the required by the analysis.

On the following table, it is possible to see an example of the calculations for the required reinforcement area, as well as the proposed selection of steel bars.

Position	As mm²	As **n° Φ**	mm²	x	x/d < 0.641	Mrd
0.00	380.19	2 Φ 14, 1 Φ 10	386.42	11.42	0.05	30.42
0.20	245.47	2 Φ 14, 1 Φ 10	386.42	78.04	0.36	25.64
2.28	377.86	2 Φ 14, 1 Φ 10	386.42	11.42	0.05	30.42
5.20	317.54	3Φ 14	461.81	93.27	0.43	29.34
5.40	457.26	3Φ 14	461.81	13.65	0.06	36.16
5.60	333.33	3Φ 14	461.81	93.27	0.43	29.34
8.26	235.46	2 Φ 14	307.88	9.10	0.04	24.37
10.30	178.38	1 Φ 14 +2 Φ 10	311.02	62.81	0.29	21.52
10.50	287.38	1 Φ 14 +2 Φ 10	311.02	9.19	0.04	24.61
10.70	177.06	1 Φ 14 +2 Φ 10	311.02	62.81	0.29	21.52
12.95	252.78	2 Φ 14	307.88	9.10	0.04	24.37
15.85	335.35	3Φ 14	461.81	93.27	0.43	29.34
16.05	457.33	3Φ 14	461.81	13.65	0.06	36.16
16.25	324.31	3Φ 14	461.81	93.27	0.43	29.34
19.29	372.10	2 Φ 14, 1 Φ 10	386.42	11.42	0.05	30.42
21.40	228.53	2 Φ 14, 1 Φ 10	386.42	78.04	0.36	25.64
21.60	354.66	2 Φ 14, 1 Φ 10	386.42	11.42	0.05	30.42

Table 9: Dimensioning of the longitudinal reinforcement of the joist J-1

4.3.9. Shear ultimate state verification

Solid sections at the end of the joist are not considered due to the presence of beams, since the width of the joist provides the required resistance for shear. The critical sections for this actions were then, the ones located just in the vicinity to the beam.

The resistance of a member without shear reinforcement and with an L/h ratio not lower than 5 (as on this case), was calculated with the next equation:

- If ρ<0.015 $V_{cR} = 0.3F_R bd(0.2 + 20\rho)\sqrt{f_c^*}$
- If ρ≥0.015 $V_{cR} = 0.16F_R bd\sqrt{f_c^*}$

In the members it has to be installed a minimum reinforcement for shear when the shear force of design is less than the resisted by the concrete VcR:

$$A_{v,min} = 0.10\sqrt{f_c^*}\frac{bs}{f_y}$$

Where the separation between the stirrups will not be less than d/2. For the studied joist, this means an area of 14.20 mm2 each 100 mm.

When Vu is more than VcR, the separation of the stirrups was determined according to:

$$s = \frac{F_R A_V f_y d(sin\theta + cos\theta)}{V_{sR}}$$

Where

- Av is the transversal area of the shear reinforcement at a distance s.
- Θ is the angle between that reinforcement and the longitudinal axis of the element.
- VsR is the shear force that is resisted by the transversal reinforcement.

When Vu is greater than VcR but lower than $0.47F_R bd\sqrt{f_c^*}$ the separation between stirrups perpendicular to the axis of the element will not be more than 0.5d; in the case it is greater than that previous expression, the separation of the stirrups cannot be more than 0.25d.

On the next table is shown the summary of the shear limit state verification for the joist J-1:

Position	**Vu**	***b (mm)***	**ρ**	***VcR***	**VsR**	**Asw**	**s (mm)**
0.00	26.29	820.0	0.0022	46.67			
0.20	24.44	120.0	0.0148	13.91	10.53	56.55	385.77
2.28	0.03	820.0	0.0022	46.67			
5.20	28.23	120.0	0.0177	14.97	13.25	56.55	306.62
5.40	30.07	820.0	0.0026	48.29			
5.40	25.62	820.0	0.0026	48.29			
5.60	23.77	120.0	0.0177	14.97	8.79	56.55	462.08
8.26	0.13	820.0	0.0017	44.98			
10.30	21.16	120.0	0.0119	12.29	8.87	56.55	457.99
10.50	23.01	820.0	0.0017	45.05			
10.50	22.46	820.0	0.0017	45.05			
10.70	20.79	120.0	0.0119	12.29	8.50	56.55	477.99

12.95	0.18	820.0	0.0017	44.98			
15.85	23.32	120.0	0.0177	14.97	8.34	56.55	487.17
16.05	24.98	820.0	0.0026	48.29			
16.05	28.08	820.0	0.0026	48.29			
16.25	26.42	120.0	0.0177	14.97	11.44	56.55	355.13
19.29	0.08	820.0	0.0022	46.67			
21.40	22.41	120.0	0.0148	13.91	8.50	56.55	478.12
21.60	24.07	820.0	0.0022	46.67			

Table 10: Dimensioning of the transversal reinforcement of the joist J-1

It has been decided provide a shear reinforcement consisting in closed stirrups of a diameter of 6 mm, taking into consideration that the minimum required area of shear reinforcement for the joist is less than the proposed one. For this area of reinforcement, the required separation is always greater than the d/2, it has been decided to place them each 10 cm in the regions where the concrete section cannot resist the ultimate shear force and in the others, a spacing of 25 cm was adopted in order to guarantee the correct placement of the longitudinal reinforcement.

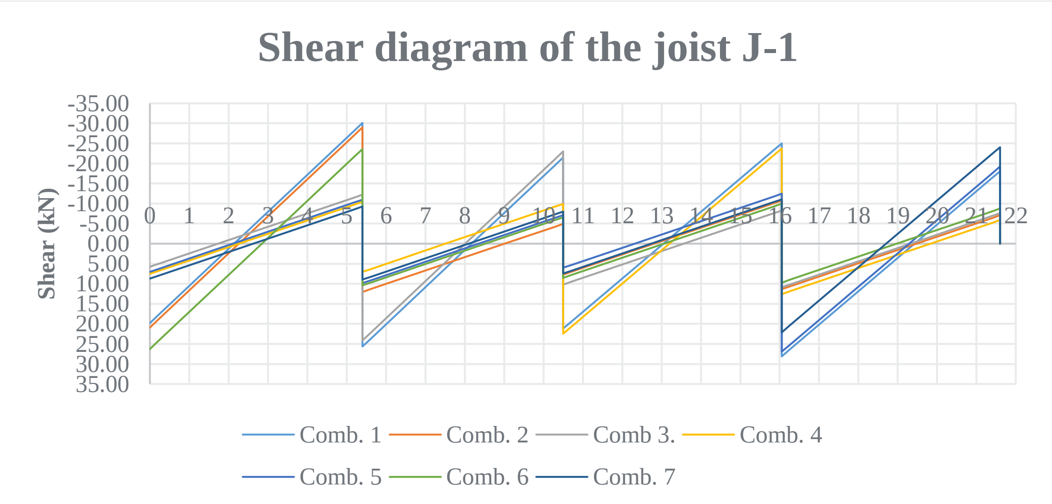


Figure 89: Envelope of shear for the joist J-1

For the reinforcement arrangement were considered the corresponding anchorage lengths of the steel bars according to the equations and reduction factors given by the Mexican code.

Diameter	Ldb	Ld	Ldb 90	Ld 90	Anchorage	Overlap
6	178	**300**	119	**150**	**72**	**400**
10	298	**300**	198	**150**	**120**	**400**
14	583	**467**	277	**155**	**168**	**621**

Table 11: Anchorage lengths for the reinforcement bars used in the joists

For the bar of 14 millimeters diameter, were chosen the following anchorage lengths: Ld equal to 470 millimeters, Ld 90 equal to 155 millimeters and the anchorage after the 90° bending on the support, of 170 millimeters.

The following reinforcement arrangement was obtained:

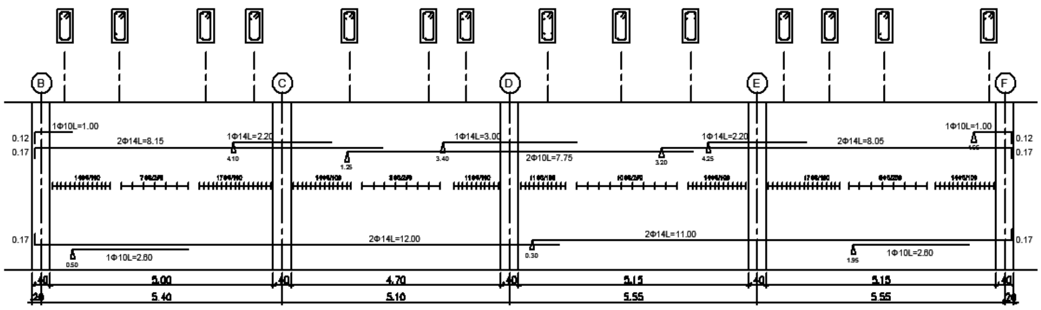


Figure 90: Reinforcement arrangement of the joist J-1

4.3.10. Serviceability limit state verification

The bending moments due to the actions of the service loads were evaluated, having in mind that in this case, the loads are not multiplied with any load factor. The process developed for calculating the bending moments on the most critical cross-sections, was carried out in the same way as in the ultimate limit state analysis, but changing the values of Qu with the ones with Q. This means that at the end, the number of load combinations is exactly the same.

The following diagram of bending moments was obtained for the service loads combinations.

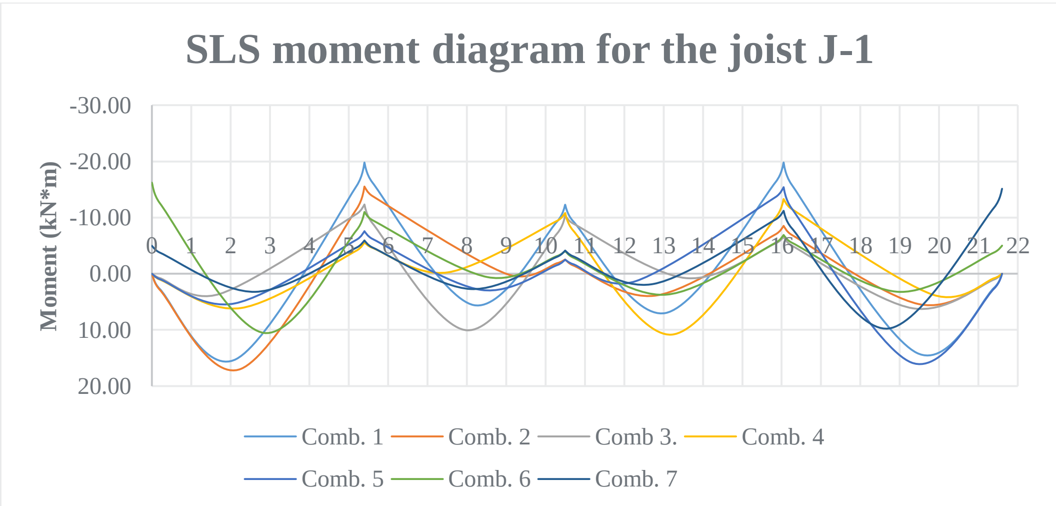


Figure 91: SLS bending moments diagram for the joist J-1

4.3.10.1. Stress limitation and crack control

Having in mind the working hypothesis mentioned at the beginning of this chapter, a stress verification has been carried out in the cross-sections that were considered as critical.

In all the cases the stresses had to follow the following conditions:

- σc≤fc*= 20 Mpa.
- σs≤fy = 420 Mpa.

In the next table is summarized the stress verification of the most critical sections of the joist J-1.

Position (m)	*b (mm)*	M (kN*m)	x (mm)	σc (Mpa)		σs (Mpa)	
0.00	820.0	-16.19	39.15	4.92	Ok	204.37	Ok
0.20	120.0	-12.56	87.43	12.68	Ok	172.13	Ok
2.28	820.0	16.92	39.15	5.14	Ok	213.67	Ok
5.20	120.0	-15.64	93.38	14.94	Ok	181.20	Ok
5.40	820.0	-19.80	42.40	5.59	Ok	210.33	Ok
5.60	120.0	-16.27	93.38	15.54	Ok	188.58	Ok
8.24	820.0	10.10	35.31	3.38	Ok	159.07	Ok
10.30	120.0	-9.45	80.50	10.23	Ok	158.91	Ok
10.50	820.0	-12.29	35.48	4.10	Ok	191.71	Ok
10.70	120.0	-9.38	80.50	10.16	Ok	157.84	Ok
12.96	820.0	10.83	35.31	3.63	Ok	170.61	Ok
15.85	120.0	-16.36	93.38	15.62	Ok	189.51	Ok
16.05	820.0	-19.80	42.40	5.59	Ok	210.36	Ok
16.25	120.0	-15.91	93.38	15.20	Ok	184.38	Ok
19.29	820.0	15.81	39.15	4.81	Ok	199.66	Ok
21.40	120.0	-11.80	87.43	11.91	Ok	161.67	Ok
21.60	820.0	-15.12	39.15	4.60	Ok	190.90	Ok

Table 12: Stress verification of the joist J-1

The control of cracking without direct calculation was performed comparing the stress in tension of the reinforcement with limits given in function of the bar size and the crack width.

σs (Mpa)	Φmax (mm) Wk=0.4 mm	Φmax (mm) Wk=0.3 mm	Φmax (mm) Wk=0.2 mm
160	40	32	25
200	32	25	16
240	20	16	12
280	16	12	8
320	12	10	6
360	10	8	5
400	8	6	4

Table 13: Maximum bar diameter for crack control

It can be verified that the stress in the steel is always less than the admissible values for a crack of width of Wk=0.4 mm.

4.3.10.2. Deflection control

If the span/effective depth ratio, l/d, is less than the following limit, the deflection of the members do not have to be calculated:

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f'c}\frac{\rho_0}{\rho} + 3.2\sqrt{f'c}\left(\frac{\rho_0}{\rho} - 1\right)^{3/2}\right] \; with \;\; \rho \leq \rho_0$$

Where

- 1.3 for one-way slabs
- $\rho_0 = \sqrt{f'c}\,10^{-3}$
- ρ = mid span reinforcement ratio

Position	As mm²	ρo / ρ	L/d	<	?
2.28	386.42	2.31	24.77	68.15	Ok
8.24	307.88	2.90	23.39	97.21	Ok
12.96	307.88	2.90	25.46	97.21	Ok
19.29	386.42	2.31	25.46	68.15	Ok

Table 14: Deflection verification of the joist J-1.

The obtained results mean that there is no need to realize direct calculations of the deflections of the analyzed joist.

4.4. Analysis and design of the beams

For the design of the beam, it has been decided to use the beam B-10 as an example of the calculation process. This beam is sustained by the columns of the axis 5. On the next image is represented the exact location of this structural element.

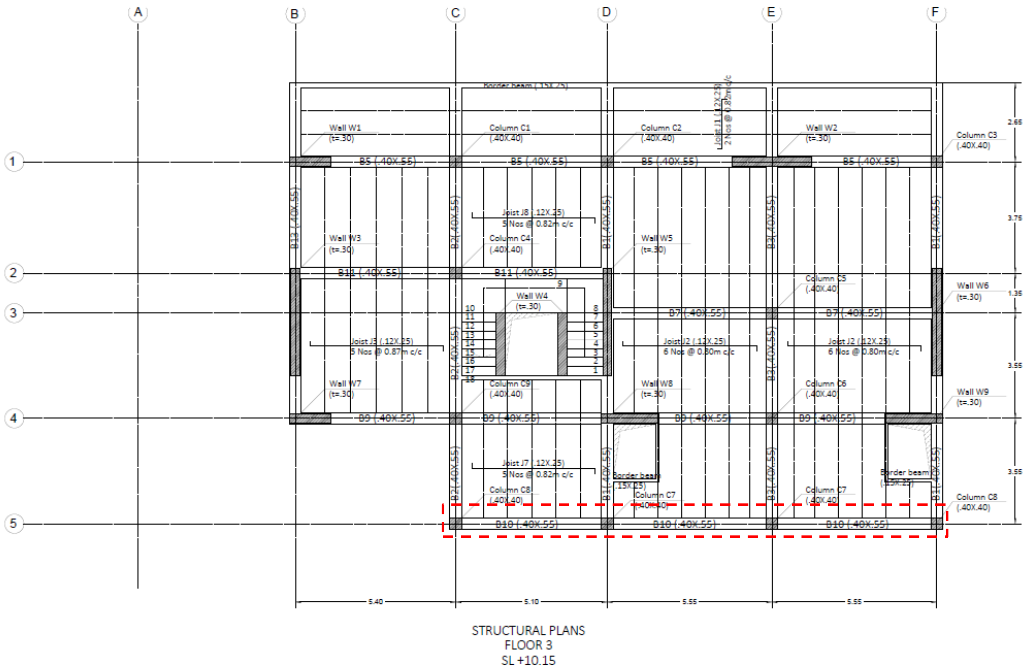


Figure 92: Localization of the beam B-10 in the structural plan of third floor.

The value of the permanent and variable loads considered on the design comes from the reactions obtained by the analysis of the joist that are supported by this beam, in particular, J-2 and J-5, depending on the analyzed floor.

After gathering the values for the different load combinations for each joist, the maximum and minimum values were taken in order to use them on this design:

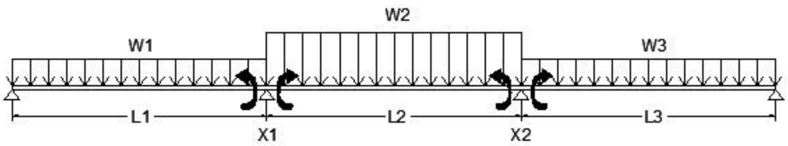
Span	Length (m)	Min [kN/m]	Max [kN/m]
1	5.1	8.94	19.72
2	5.55	7.59	19.87
3	5.55	7.59	19.87

B (m)	0.40
H (m)	0.55
A (m2)	0.22
I (m4)	0.005546
W [kN/m]	5.50

Table 15: Maximum and minimum service-ability loads supported by the analyzed beam.

4.4.1. Combination 1: Minimum moment at the continuity support:

The structure is solved using the flexibility method, similar to the process developed for solving the slabs.



The system of equations of this beam is the following:

$$\begin{vmatrix} \frac{L1}{3EI}+\frac{L2}{3EI} & \frac{L2}{6EI} \\ \frac{L2}{6EI} & \frac{L2}{3EI}+\frac{L3}{3EI} \end{vmatrix} \text{X} \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -\frac{W1L1^3}{24EI}+\frac{W2L2^3}{24EI} \\ -\frac{W2L2^3}{24EI}+\frac{W3L3^3}{24EI} \end{vmatrix}$$

Where W1, W2 and W3 are the sum of the corresponding load combinations for each span. In this case:

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	19.72	25.22	35.31
2	5.55	5.50	19.87	25.37	35.52
3	5.55	5.50	19.87	25.37	35.52

For this load combination, the systems of equations take the following values:

$$\begin{vmatrix} 3.55 & 0.925 \\ 0.925 & 3.7 \end{vmatrix} \text{X} \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -448.18 \\ -506.09 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -96.92 \\ -112.55 \end{vmatrix}$$

4.4.2. Combination 2: Maximum moment in the span 1

The structure is solved in the same way as in the previous combination case. The difference now is that the maximum loads are only applied on the span 1, and in the others the minimum obtained from the joist reactions. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	19.72	25.22	35.31
2	5.55	5.50	7.59	13.09	18.32
3	5.55	5.50	7.59	13.09	18.32

For this load combination, the systems of equations take the following values:

$$\begin{vmatrix} 3.55 & 0.925 \\ 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -325.64 \\ -261.00 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -78.46 \\ -50.92 \end{vmatrix}$$

4.4.3. Combination 3: Maximum moment in the span 2

The structure is solved in the same way as in the previous combination case. The difference now is that the maximum loads are only applied on the span 2. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	8.94	14.44	20.21
2	5.55	5.50	19.87	25.37	35.52
3	5.55	5.50	7.59	13.09	18.32

For this load combination, the systems of equations take the following values:

$$\begin{vmatrix} 3.55 & 0.925 \\ 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -364.77 \\ -383.54 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -81.02 \\ -83.41 \end{vmatrix}$$

4.4.4. Combination 4: Maximum moment in the span 3

The structure is solved in the same way as in the previous combination case. The difference now is that the maximum loads are only applied on the span 3. In the next table is possible to see the summary of the mentioned loads.

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	8.94	14.44	20.21
2	5.55	5.50	7.59	13.09	18.32
3	5.55	5.50	19.87	25.37	35.52

For this load combination, the systems of equations take the following values:

$$\begin{vmatrix} 3.55 & 0.925 \\ 0.925 & 3.7 \end{vmatrix} X \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -242.22 \\ -383.54 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -44.09 \\ -92.64 \end{vmatrix}$$

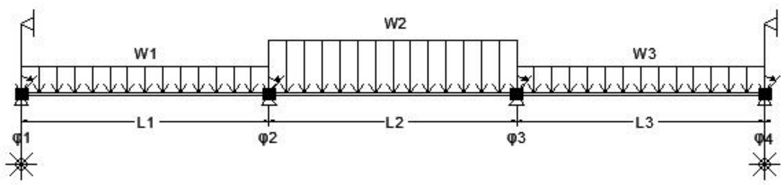
In the next table are summarized the reactions on the supports of the beams for each load combination, this results were used in order to calculate the shear and moment diagrams that will be displayed in the following pages.

Reactions	Comb 1	Comb 2	Comb 3	Comb 4
Ra (kN)	71.03	74.65	35.66	42.90
Rb (kN)	204.80	161.21	165.58	102.28
Rc (kN)	220.26	105.89	164.88	174.86
Rd (kN)	78.30	41.66	35.81	81.89

However, it is important also to estimate the value of the negative moments at the ends of the beams, due to the partial constrain given by the columns.

4.4.5. Combination 5: Minimum moment in the span 1

For the calculation of the negative moments on the left span, the partial scheme shown in the next figure was used to represent the real conditions of a multistory building. The frame structure was solved using the stiffness method, assuming as unknowns the clockwise rotations of the five nodes.



The equilibrium system of equations is the following:

$$\begin{vmatrix} m11 & m12 & 0 & 0 \\ m21 & m22 & m23 & 0 \\ 0 & m32 & m33 & m34 \\ 0 & 0 & m43 & m44 \end{vmatrix} \text{X} \begin{vmatrix} \varphi1 \\ \varphi2 \\ \varphi3 \\ \varphi4 \end{vmatrix} + \begin{vmatrix} m10 \\ m20 \\ m30 \\ m40 \end{vmatrix} = 0$$

$$m_{1,1} = 2 * \frac{3EIc}{h/_2} + \frac{4EIb}{L1} \qquad m_{1,2} = m_{2,1} = \frac{2EIb}{L1} \qquad m_{1,0} = -\frac{W1\,L1^2}{12}$$

$$m_{2,2} = \frac{4EIb}{L1} + \frac{4EIb}{L2} \qquad m_{2,3} = m_{3,2} = \frac{2EIb}{L2} \qquad m_{2,0} = \frac{W1\,L1^2}{12} - \frac{W2\,L2^2}{12}$$

$$m_{3,3} = \frac{4EIb}{L2} + \frac{4EIb}{L3} \qquad m_{3,4} = m_{4,3} = \frac{2EIb}{L3} \qquad m_{3,0} = \frac{W2\,L2^2}{12} - \frac{W3\,L3^2}{12}$$

$$m_{4,4} = \frac{4EIb}{L3} + 2 * \frac{3EIc}{h/_2} \qquad m_{4,0} = \frac{W3\,L3^2}{12}$$

The equivalent stiffness of the column in relation to the barycentric moment of inertia of the cross section of the beam was calculated. In the next table are summarized the geometrical properties of the beam and columns, required for the analysis.

Column properties			**Beam properties**		
Height (m)	3.16		B (m)		0.40
B (m)	0.40		H (m)		0.55
L (m)	0.40		Yg (m)		0.275
AREA (m2)	0.16		INERTIA (m4)		0.00555
INERTIA (m4)	0.00213		I*column=	0.38467	I beam

Table 16: Beam and column geometrical properties

For the load combination, it was considered that the maximum loads were only present on the first span. This assumption will eliminate the effects of compensation of moments created when other loads are placed on the other spans.

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	19.72	25.22	35.31
2	5.55	5.50	7.59	13.09	18.32
3	5.55	5.50	7.59	13.09	18.32

The solution of the linear system is:

φ1	=	39.9259	kNm² / Eislab
φ2		-33.4370	
φ3		14.3407	
φ4		-23.9258	

Ra (kN)	88.53
Rb (kN)	146.09
Rc (kN)	99.83
Rd (kN)	48.97

4.4.6. Combination 6: Minimum moment in the span 4

In this case, again the maximum load is not considered on the two first spans, and the calculations are developed as in the previous combination case.

Span	Length (m)	Self-weight (kN/m)	Slab loads (kN/m)	Q (kN/m)	Qu (kN/m)
1	5.1	5.50	8.94	14.44	20.21
2	5.55	5.50	7.59	13.09	18.32
3	5.55	5.50	19.87	25.37	35.52

The solution of the linear system is:

φ1	=	22.1012	kNm² / Eislab
φ2		-14.8090	
φ3		46.7183	
φ4		-49.5175	

Ra (kN)	49.86
Rb (kN)	97.85
Rc (kN)	156.18
Rd (kN)	98.04

4.4.7. Pre-dimensioning of the reinforcement

The pre-dimensioning of the reinforcement was calculated in the most critical sections according to the envelope diagram of bending moments calculated from the load combination cases.

For the pre-dimensioning of the reinforcement, the effective depth of the cross-section was calculated, as it is visible in the annexed table.

Cmin,b (mm)	20
Cmin,dur (mm)	15
ΔCdev. (mm)	10
Cnom (mm)	**30**
dSlab (mm)	**510**

In the next image, is possible to see the diagram of bending moments of the beam B-10.

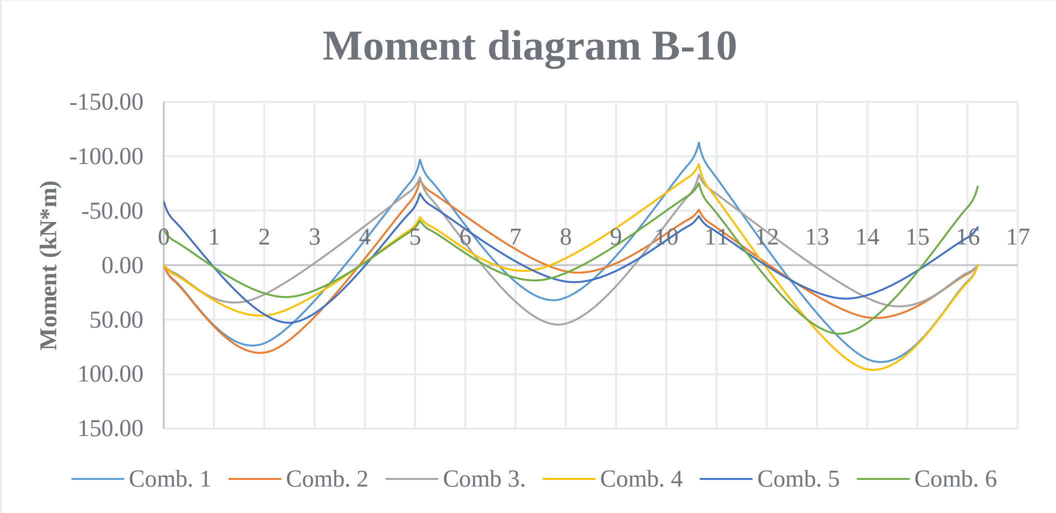


Figure 93: Envelope of the bending moments for the beam B-10

Following the same equations already presented in the slab section, was realized the pre-dimensioning of the required area of longitudinal reinforcement for the analyzed bending moments in the most critical sections. On the following table, it is possible to see an example of obtained reinforcement area for the analyzed beam, as well as the proposed selection of steel bars.

Position	As mm²	As n° Φ	mm²	x		x/d < 0.641	Mrd
0.00	417.99	4 Φ 14	615.75	37.31		0.07	112.18
0.20	294.50	4 Φ 14	615.75	37.31		0.07	112.18
2.17	544.66	4 Φ 14	615.75	37.31		0.07	112.18
4.90	544.66	4 Φ 14	615.75	37.31		0.07	112.18
5.10	544.66	4 Φ 14	615.75	37.31		0.07	112.18
5.30	544.66	4 Φ 14	615.75	37.31		0.07	112.18
7.79	390.60	4 Φ 14	615.75	37.31		0.07	112.18
10.45	544.66	4 Φ 14	615.75	37.31		0.07	112.18
10.65	617.84	5 Φ 14	769.69	46.63		0.09	138.90
10.85	544.66	4 Φ 14	615.75	37.31		0.07	112.18
13.85	544.66	4 Φ 14	615.75	37.31		0.07	112.18
16.00	382.36	4 Φ 14	615.75	37.31		0.07	112.18
16.20	520.85	4 Φ 14	615.75	37.31		0.07	112.18

Table 17: Dimensioning of the longitudinal reinforcement of the beam B-10

4.4.8. Shear ultimate state verification

The critical sections for this actions are the ones located just in the vicinity to the columns.

The resistance of the beam without shear reinforcement, as well as the required transversal reinforcement were calculated with the equations given by the Mexican code, and already presented on the section of the slabs design. In the next table is summarized the shear ultimate state verification of the analyzed beam.

Position	Vu	*b (mm)*	ρ	*VcR*	VsR	Asw	s (mm)
0.00	88.53	400.0	0.0030	57.01			
0.20	81.47	400.0	0.0030	57.01	24.46	100.53	690.81
2.17	0.11	400.0	0.0030	57.01			
4.90	101.97	400.0	0.0030	57.01	44.96	100.53	375.83
5.10	109.03	400.0	0.0030	57.01			
5.10	98.15	400.0	0.0030	57.01			
5.30	91.05	400.0	0.0030	57.01	34.04	100.53	496.49
7.79	0.47	400.0	0.0030	57.01			
10.45	94.29	400.0	0.0030	57.01	37.28	100.53	453.26
10.65	101.40	400.0	0.0038	60.31			
10.65	118.86	400.0	0.0038	60.31			
10.85	111.76	400.0	0.0030	57.01	54.75	100.53	308.68
13.85	0.38	400.0	0.0030	57.01			
16.00	90.93	400.0	0.0030	57.01	33.92	100.53	498.17
16.20	98.04	400.0	0.0030	57.01			

Table 18: Dimensioning of the transversal reinforcement of the beam B-10

It has been decided to provide a shear reinforcement consisting in closed stirrups of a diameter of 8 mm. This reinforcement was placed according to the conditions defined for members subjected to bending moments and that are part of a ductile frame. This means that for the confinement zones of the beam the maximum spacing was set as d/4 (10 cm) and for the rest of the beam, the maximum spacing of the stirrups is d/2 (25 cm). In all the cases, it was checked that a spacing of d/2 was enough to guarantee the resistance of the beam against the shear.

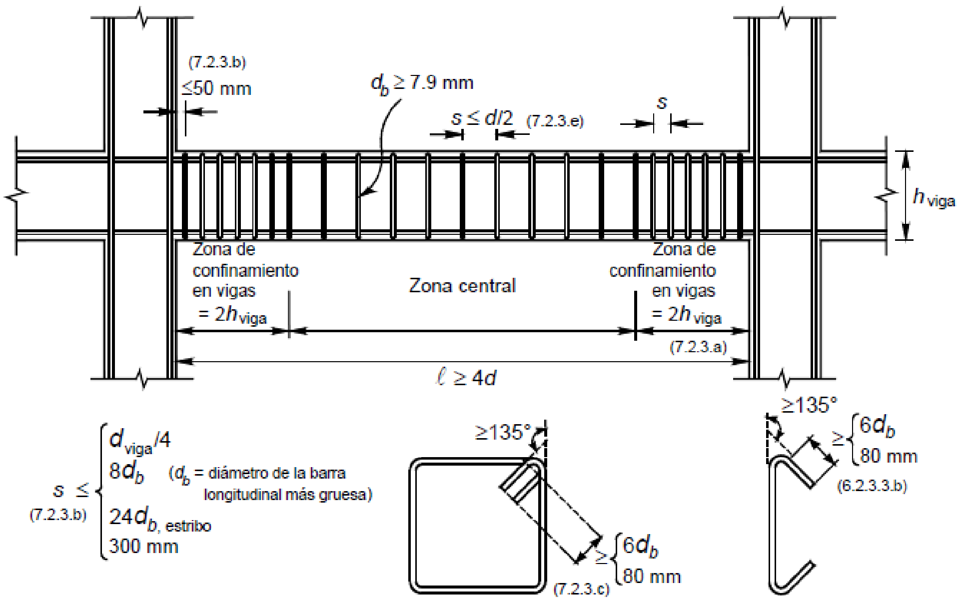


Figure 94: Detailing of a beam part of a ductile frame.

The next figure represents the shear envelope diagram of the beam B-10:

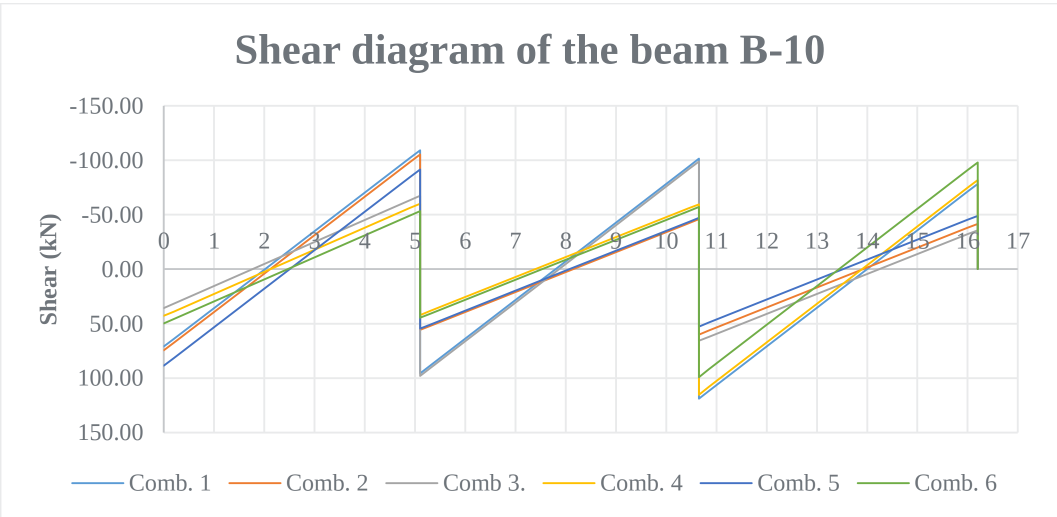


Figure 95: Envelope of shear for the beam B-10

For the reinforcement arrangement were considered the corresponding anchorage lengths of the steel bars according to the equations and reduction factors given by the Mexican code.

Diameter	Ldb	Ld	Ldb 90	Ld 90	Anchorage	Overlap
14	583	**467**	277	**155**	**168**	**280**
20	1191	**1191**	396	**221**	**240**	**714**
25	1861	**1861**	494	**277**	**300**	**1116**

Table 19: Anchorage lengths for the reinforcement bars used in the beams

For the bar of 14 millimeters diameter, were chosen the following anchorage lengths: Ld equal to 470 millimeters, Ld 90 equal to 155 millimeters and the anchorage after the 90° bending on the support, of 170 millimeters. For the bar of 20 millimeters diameter, were chosen the following anchorage lengths: Ld equal to 1200 millimeters, Ld 90 equal to 225 millimeters and the anchorage after the 90° bending on the support, of 240 millimeters. For the bar of 25 millimeters diameter, were chosen the following anchorage lengths: Ld equal to 1900 millimeters, Ld 90 equal to 280 millimeters and the anchorage after the 90° bending on the support, of 300 millimeters.

The following reinforcement arrangement was obtained:

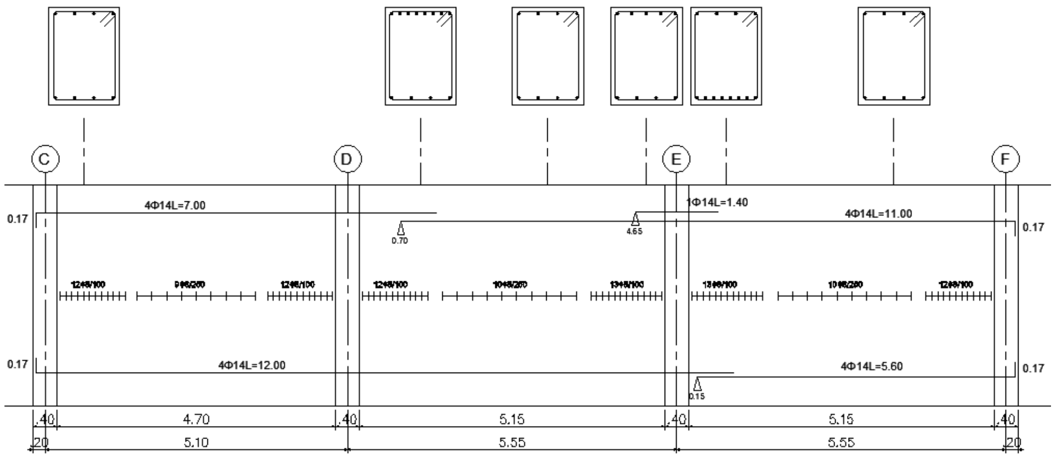


Figure 96: Reinforcement arrangement of the beam B-10

4.4.9. Serviceability limit state verification

The bending moments due to the actions of the service loads were evaluated, having in mind that in this case, the loads are not multiplied with any load factor. The process developed for calculating the bending moments on the most critical cross-sections, was carried out in the same way as in the ultimate limit state analysis, but changing the values of Qu with the ones with Q. This means that at the end, the number of load combinations is exactly the same.

The following diagram of bending moments was obtained for the service loads combinations.

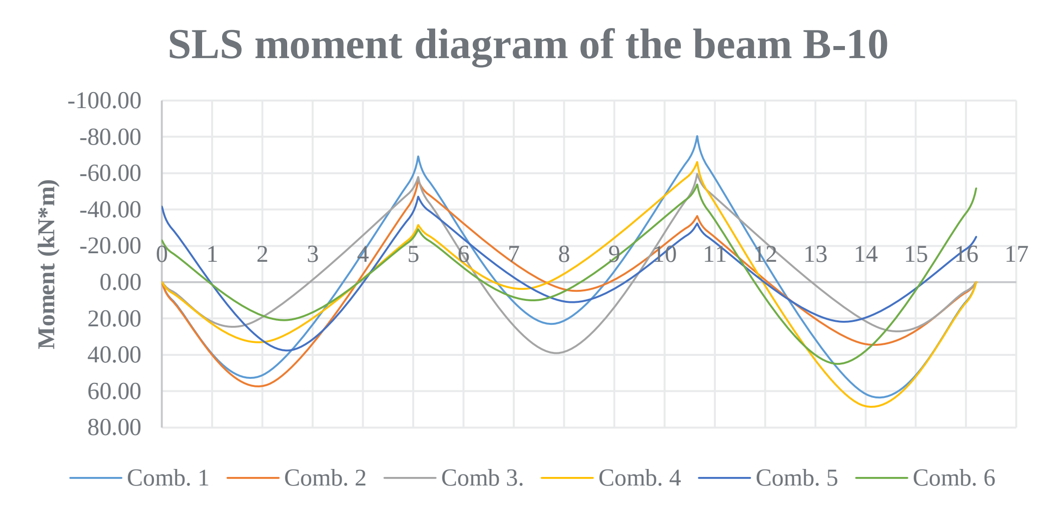


Figure 97: SLS bending moments diagram for the beam B-10

4.4.9.1. Stress limitation and crack control

Having in mind the working hypothesis mentioned at the beginning of this chapter, a stress verification has been carried out in the cross-sections that were considered as critical.

In all the cases the stresses had to follow the following conditions:

- σc≤fc*= 20 Mpa.
- σs≤fy = 420 Mpa.

In the next table is summarized the stress verifications for the critical sections analyzed:

Position	*b (mm)*	**M (kN*m)**	**x (mm)**	**σc (Mpa)**		**σs (Mpa)**	
0.00	400.0	-41.66	106.30	4.13	Ok	142.56	Ok
0.20	400.0	-29.52	106.30	2.93	Ok	101.01	Ok
2.17	400.0	56.36	106.30	5.59	Ok	192.88	Ok
4.90	400.0	-54.16	106.30	5.37	Ok	185.34	Ok
5.10	400.0	-69.23	106.30	6.86	Ok	236.91	Ok
5.30	400.0	-56.06	106.30	5.56	Ok	191.83	Ok
7.79	400.0	38.98	106.30	3.86	Ok	133.39	Ok
10.45	400.0	-66.42	106.30	6.58	Ok	227.28	Ok
10.65	400.0	-80.39	117.22	7.28	Ok	221.79	Ok
10.85	400.0	-63.92	106.30	6.34	Ok	218.74	Ok
13.85	400.0	67.42	106.30	6.68	Ok	230.71	Ok
16.00	400.0	-38.17	106.30	3.78	Ok	130.62	Ok
16.20	400.0	-51.67	106.30	5.12	Ok	176.81	Ok

Table 20: Stress verification of the beam B-10

The control of cracking without direct calculation was performed comparing the stress in tension of the reinforcement with limits given in function of the bar size and the crack width.

σs (Mpa)	Φmax (mm) Wk=0.4 mm	Φmax (mm) Wk=0.3 mm	Φmax (mm) Wk=0.2 mm
160	40	32	25
200	32	25	16
240	20	16	12
280	16	12	8
320	12	10	6
360	10	8	5
400	8	6	4

Table 21: Maximum bar diameter for crack control

It can be verified that the stress in the steel is always less than the admissible values for a crack of width of Wk=0.4 mm.

4.4.9.2. Deflection control

If the span/effective depth ratio, l/d, is less than the following limit, the deflection of the members do not have to be calculated:

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f'c}\,\frac{\rho_0}{\rho} + 3.2\sqrt{f'c}\left(\frac{\rho_0}{\rho} - 1\right)^{3/2}\right] \; with \;\; \rho \leq \rho_0$$

Where

- 1.3 for one-way slabs
- $\rho_0 = \sqrt{f'c}\;10^{-3}$
- ρ = mid span reinforcement ratio

Position	As mm²	ρo / ρ	L/d	<	?
2.17	615.75	1.66	10.00	41.52	Ok
7.79	615.75	1.66	10.88	41.52	Ok
13.85	615.75	1.66	10.88	41.52	Ok

Table 22: Deflection verifications for the beam B-10.

The obtained results mean that there is no need to realize direct calculations of the deflections of the analyzed beam.

4.5. Analysis and design of the columns

The inside column C5 was analyzed in this project. This element is mainly subjected to axial loads, which have been taken from the reactions coming from the analyzed beams that are supported on it. The next figure shows the exact location of the analyzed column on the structural plan:

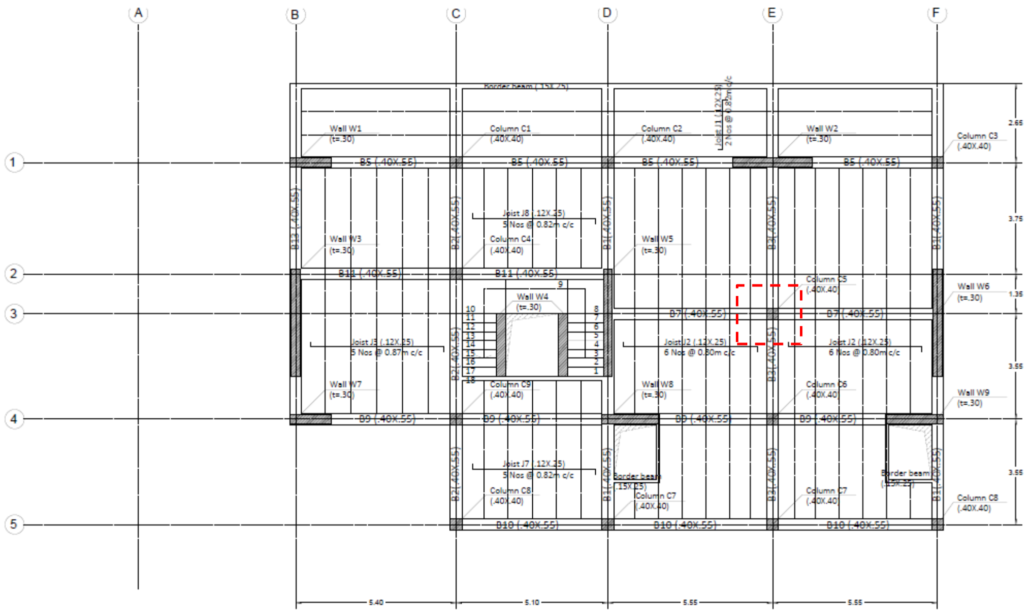


Figure 98: Localization of the column C-5 in the structural plan of third floor.

In order to have the vertical loads of each of the slab, the adopted approach consisted on taking the service-ability loads obtained on each combo analyzed of the beams supported by the column. As the load factors of the death and live loads are equal to 1.4, this approach can be adopted.

Floor	Combo					
	1	2	3	4	5	Max
Roof	428.25	339.61	339.61	313.91	313.91	428.25
3	373.45	301.02	301.02	277.95	277.95	373.45
2	373.45	301.02	301.02	277.95	277.95	373.45
1	373.45	301.02	301.02	277.95	277.95	373.45
0	373.45	301.02	301.02	277.95	277.95	373.45

Table 23: Service loads taken by the column from beams B-3 and B-7

For the ultimate limit state combination of actions, it has to be reminded that the load factor contemplated by the Mexican code is 1.4 for both dead and life loads.

It is important to highlight that the code defines the minimum concrete area of the column as:

$$A_g \geq P_u/0.5f_c'$$

In the next table are summarized the axial loads applied on each section of the column, and the required dimension according to the code.

Column	Fk (kN)	P (kN)	Pu (kN)	Ag (mm²)	b x h (m)	Ac (mm²)
Roof	428.25	428.25	599.55	47964	0.40 x 0.40	160000
3	373.45	801.70	1122.38	89790	0.40 x 0.40	160000
2	373.45	1175.15	1645.21	131617	0.40 x 0.40	160000
1	373.45	1548.60	2168.03	173443	0.40 x 0.45	180000
Ground	373.45	1922.04	2690.86	215269	0.50 x 0.45	225000

Table 24: Pre-dimensioning of the centered axial load column C5.

Fk is the value of the axial load for every story, P is the value of the axial load considered in the pre-dimensioning of the column, and Pu is the ultimate load that is obtained by multiplying the previous one by the load factor of 1.4.

Now it is important to include the self-weight of the column in the load considered for its design. On the next table are summarized the calculations for the pre-dimensioning of the column, with the self-weight considered.

COLUMNS			
B (m)	0.40	0.40	0.45
L (m)	0.40	0.45	0.50
Area (m2)	0.16	0.18	0.225
Inertia (m4)	0.00213	0.00304	0.00469
W [kN/m]	4.00	4.50	5.63

Table 25: Determination of the self-weight of the column

Col.	Height	Self-Weight	Fk (kN)	P (kN)	Pu (kN)	Ag (mm²)	b x h (m)	Ac (mm²)
Roof	3.06	12.2	440.5	440.5	616.7	49335	0.40 x 0.40	160000
3	3.06	12.2	385.7	826.2	1156.7	92532	0.40 x 0.40	160000
2	3.06	12.2	385.7	1211.9	1696.6	135729	0.40 x 0.40	160000
1	4.08	18.4	391.8	1603.7	2245.1	179612	0.40 x 0.45	180000
0	2.5	14.1	387.5	1991.2	2787.7	223013	0.50 x 0.45	225000

Table 26: Dimensioning of the centered axial load column C5.

For the dimensioning of the longitudinal reinforcement, the following considerations were taken:

- $As \geq 0.003\ Ag$
- $As \geq 0.10\ Pu/fy$

The next table summarizes the required longitudinal reinforcement requirements of the analyzed column:

Column	Ag (mm²)	As min		As (mm²)	
		ρs:0.003	0.10*Pu/fy		
Roof	160000	480	149.68	452.39	4 Φ 12
3	160000	480	280.74	452.39	4 Φ 12
2	160000	480	411.80	452.39	4 Φ 12
1	180000	540	544.94	678.58	6 Φ 12
0	225000	675	676.62	678.58	6 Φ 12

Table 27: Reinforcement dimensioning for the column C-5

4.5.1. Serviceability limit state verification

Under the hypothesis presented at the beginning of this chapter, it is possible to determine the stress on the materials according to the next equation:

$$\sigma_c = \frac{P}{A_g + \alpha_e A_s} \leq f_c^* = 20\ MPa$$

The stress service-ability state verification for the column C-5 is summarized in the next table:

Column	Ag (mm²)	As (mm²)	Aie (mm²)	P (kN)	σc (N/mm²)	< σadm
Roof	160000	452.39	164112.63	440.49	2.68	Ok
3	160000	452.39	164112.63	826.18	5.03	Ok
2	160000	452.39	164112.63	1211.87	7.38	Ok
1	180000	678.58	186168.95	1603.68	8.61	Ok
0	225000	678.58	231168.95	1991.19	8.61	Ok

Table 28: Column C5 SLS verification

4.5.2. Ultimate limit state verification

The translational equilibrium for the ultimate limit state is:

$$\frac{P_R}{F_R} = A_g f_c^* + A_s f_y \; Where \; F_R = 0.8$$

With the adopted dimensions and reinforcement arrangement, the resisted ultimate load of the column was calculated, the results can be seen on the next table:

Column	Ag (mm²)	As (mm²)	Pu (kN)	PR (kN)	PR/Pu
Roof	160000	452.39	616.69	2709.11	4.39
3	160000	452.39	1156.65	2709.11	2.34
2	160000	452.39	1696.62	2709.11	1.60
1	180000	678.58	2245.15	3103.66	1.38
0	225000	678.58	2787.66	3823.66	1.37

Table 29: Column C5 ULS verification

The next image illustrates the prescriptions given by the Mexican code for the transversal reinforcement detailing:

Cmin,b (mm)	14
Cmin,dur (mm)	15
ΔCdev. (mm)	10
Cnom (mm)	25
db,stirrup (mm)	**10**

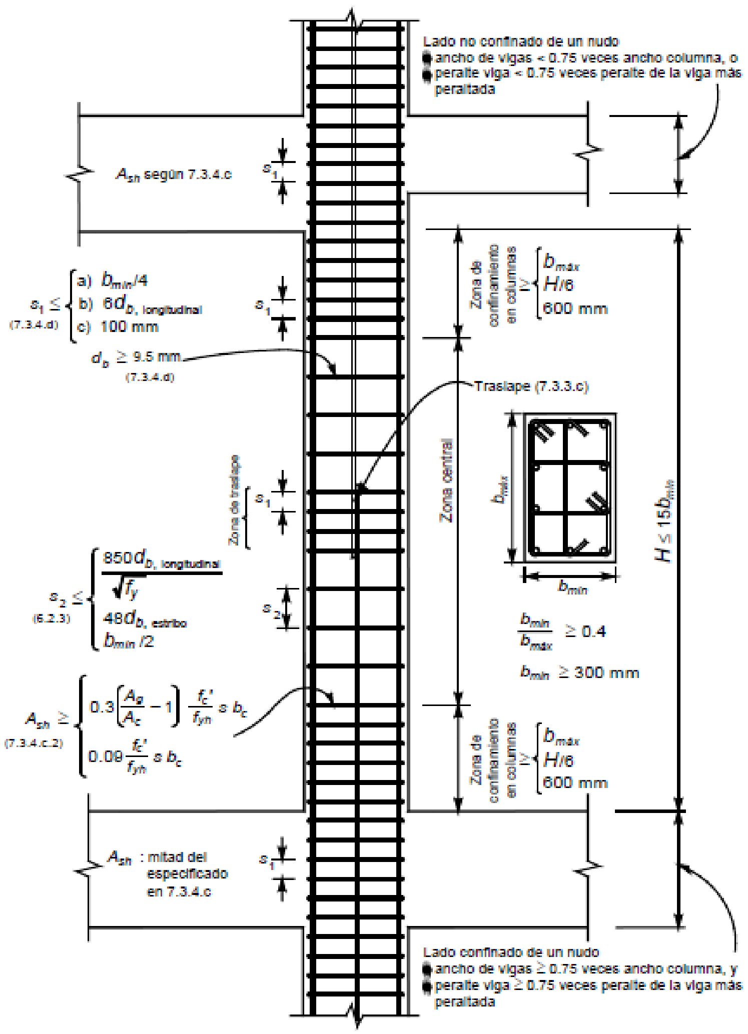


Figure 99: Detailing of members under flexo-compresion in a ductile frame.

On the next table it is possible to see the required space between the stirrups. It has to be reminded that the minimum diameter for them, according to the code is 10 mm. In all the cases, the spacing between the stirrups, in the zone of confinement is controlled by the longitudinal bar diameter.

Col.	Ag (mm²)	Ac (mm²)	s1 (mm)	s2 (mm)	Ash (mm²)			
					B 1		B 2	
Roof	160000	122500	72	200	140.43	2 Φ 10	140.43	2 Φ 10
3	160000	122500	72	200	140.43	2 Φ 10	140.43	2 Φ 10
2	160000	122500	72	200	140.43	2 Φ 10	140.43	2 Φ 10
1	180000	140000	72	200	137.62	2 Φ 10	157.08	3 Φ 10
0	225000	180000	72	225	157.08	2 Φ 10	176.94	3 Φ 10

Figure 100: Transversal reinforcement dimensioning for the column C5

For the columns with a height of 3.06 meters, those sections within a distance equal to 600 mm above and below the beams and slabs, stirrups of 10 mm will be placed at a separation of 70 mm. This distance applies also for the sections in which there is an overlap. For the others sections, the separation of the stirrups is increased to 200 mm.

For the column with a height of 4.08 meters, the distance in which the stirrups has to be located each 70 mm, is increased from 600 mm to 670 mm. Regarding the longitudinal reinforcement, for a bar of 12 mm, it is required an anchorage length of 200 mm and an overlap length of 422 mm.

5. Foundations

5.1. Soil characteristics

The subsoil of the city of Mexico has unique properties. The water content is greater than 400%, the plasticity index exceeds 300% and the compression ratio Cc can reach a value of 10, when in most of the soil is less than 1. The above, make of the lacustrine sediments of Mexico City as highly compressible. (Díaz-Rodríguez, 2006)

The soils of Mexico City are a heterogeneous mixture of sediments of volcanic and lacustrine origin, with a proportion and variety of microfossils (diatoms and ostracods) that add soluble compounds generated by altering their exoskeletons and form part of the microstructure of the soil. This influences their behavior so that it cannot be considered within a simple classification. (Díaz-Rodríguez, 2006)

Mexico City has been divided into three geotechnical zones: Zone I (hills), Zone II (Transition) and Zone III (Lake).

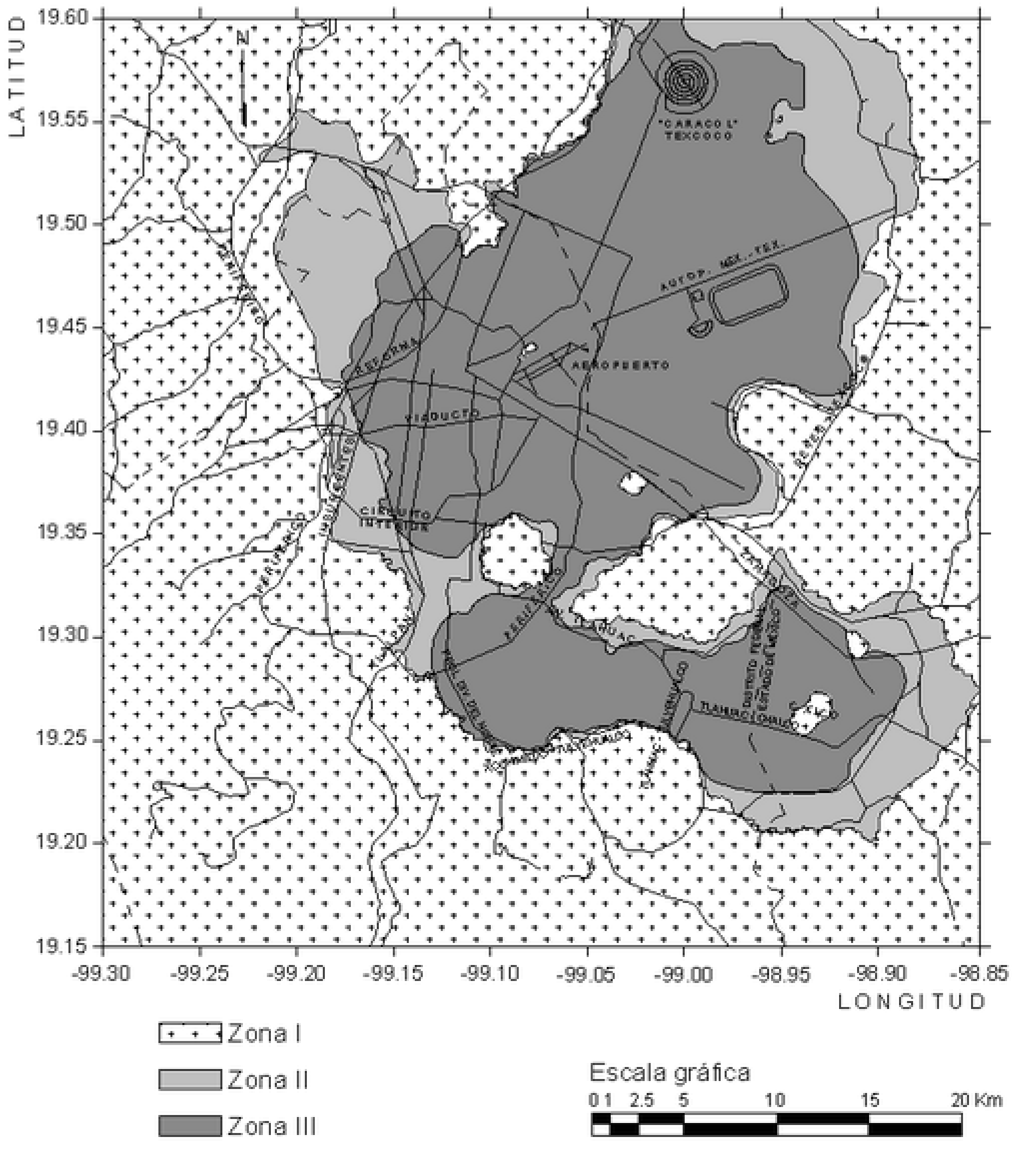


Figure 101: Geotechnical zoning of Mexico City

The building object of this study is located in the zone of the lake. In order to propose a foundation for the structure, it was decided to use the study of soil mechanics of a plot located in the same zone in which a school will be constructed. The study was taken from (Carrillo de Isolbi, 2015). The results of his study of mechanic of soils are shown in the next table.

Depth (m)	Description
From 0.00 to 0.70	Filling Material
From 0.70 to 1.80	Dark brown sandy loam of rigid consistency and high plasticity. It has the following characteristics: • Average water content of 70 to 100% • Liquid limit: 105.6%. • Plastic limit: 43.9%. • Percentage of fines: 70.9%
From 1.80 to 5.30	Fine dark brown colored sand with dense to very dense compactness. It has the following characteristics: • Average water content of 40 to 60% • Liquid limit: 286.4%. • Plastic limit of 61.0%. • Percentage of fine: 93.3%. • Solids density of 2.65. • Volumetric weight of 1.45 t/m3. • Void ratio of 2.25. • 92% degree of saturation. • Cohesion of 3.4 ton/m2, internal friction angle of 5 °, determined in not consolidated - undrained triaxle compression test. • Last resistance in simple compression test 7.41ton/m2.
From 5.30 to 11.80	Fine dark brown loamy sand with dense to very dense compactness. It has the following characteristics: • Average water content of 10 to 50% • Percentage of fines of 21.2 to 24.1%.
From 11.80 to 19.90	Greenish-gray sandy silt with stiff to very stiff consistency and high plasticity. It has the following characteristics: • Average water content of 50 to 250% • Fines percentage of 46.2 to 96.9% • Liquid limit of 71.1 to 72.8% • Plastic limit of 36.5 to 36.8% • Solids density of 2.62. • Volumetric weight of 1.18 t/m3. • Void ratio of 1.88 to 6.75. • Saturation degree of 94 to 97%. • Cohesion of 4.50 to 7.00ton / m2, internal friction angle of 11.0 to 33.0°, as determined in not consolidated - undrained triaxle compression test.

	• Ultimate resistance in simple compression test of 4.70 to 19.4 ton / m2.

Table 30: Stratigraphic profile

5.2. Proposed foundation

Considering that the regional subsidence in the area of the project is of significant magnitude, and that it is exacerbated by the continuous extraction of groundwater in all the city; the foundation of the structure, should be realized by means of a very rigid element that can sink at the same rate of regional subsidence, but have the possibility to redistribute their loads in a large contact area.

This is why, it was decided to use the example of the proposed foundation of (Carrillo de Isolbi, 2015), which consist on a foundation slab. It means a monolithic reinforced concrete box of 2.50 m of depth, with a slab at the bottom which contacts the surface of the soil, and a slab cover closing the hollow cells of the box.

It is important to remind that the settlement of this kind of foundations is reduced when the net pressure on the soil is decreased, which is done by increasing the embedment depth of the foundation Df. This increase is particularly important for slabs on soft clays where large settlements are expected consolidation, as in the case of Mexico City, were the more superficial layer of the soil has a better bearing capacity that the ones above it.

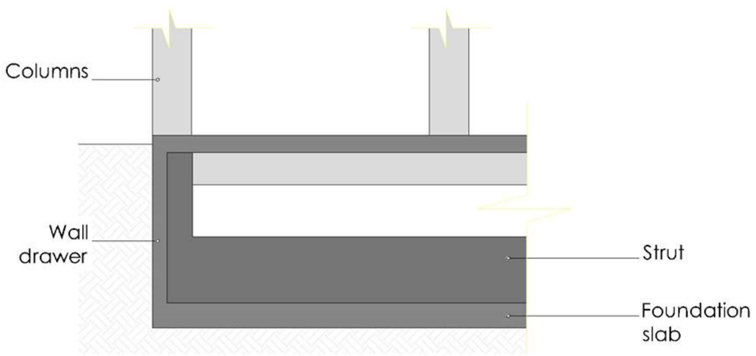


Figure 102: Scheme of a compensated slab foundation

For this project the hollow cells will be filled with low density polystyrene in order to avoid the flow of water inside the cells, due to the possibility that other waterproofing solutions cannot work very well with the sinking problems already described.

5.2.1. Failure limit state verification

The revision of the limit state of failure for the proposed foundation, was held as stipulated in the NTC-04 for foundation design with respect to foundations resting in purely cohesive soils.

$$\frac{\sum QF_c}{A} < C_u N_c F_R + P_v$$

Where:

- $\sum QF_c$ Is the sum of the vertical actions to take into account for the load combination considered in the foundation level, affected by its respective load factor in t/m2.
- A Is the area of the foundation in m2.
- P_v Is the total vertical pressure at the foundation depth caused by soil's own weight in t / m2.
- C_u Is the apparent cohesion determined by the non-consolidated non-drained triaxle test in t/m2.
- F_R Is a resistance coefficient equal to 0.70.
- N_c is the bearing coefficient given by the equation:

$$N_c = 5.14 * (1 + 0.25\, D_f/B + 0.25\, B/L)$$

In the next table are summarized the calculations done in order to verify the bearing capacity of the soil;

B (m)	L (m)	Df (m)	Nc	Cu (t/m2)	FR	Pv (t/m2)	q amd (t/m2)
11	27	2.5	5.96	2	0.7	3.5	11.84

Table 31: Allowable bearing capacity of the soil

$$\frac{\sum QF_c}{A} < 11.84\ t/m^2$$

5.2.2. Structural design of the foundation slab

The structural design of the foundation slab was performed by the conventional rigid method, presented in (Das, 1999).

The first step to develop was to calculate the axial loads of the different columns and walls of the structure by the method of the afferent areas. Thus, for each vertical element were assigned the dead and live loads of the structural and non-structural elements, according to the area around them.

Column	Afferent floor area (m2)				
	0	1	2	3	Roof
1A	4.97	4.97	0	0	0
1B	10	17.2	12.24	12.24	12.24
1C	9.85	12.23	23.79	23.79	23.79
1D	10.2	12.58	11.56	24.13	24.13
1E	14.52	29.03	0	29.03	29.03
1F	7.26	14.52	0	14.52	14.52
2A	15.67	15.67	0	0	0
2B	23.14	23.14	11.68	11.68	11.68
2C	16.46	11.68	16.46	16.46	16.46
3D	18.65	13.87	14.01	18.65	18.65
3E	23.86	23.86	18.45	23.86	23.86
3F	11.93	11.93	9.23	11.93	11.93
4A	10.99	10.99	0	0	0
4B	13.11	13.11	6.62	6.62	6.62
4C	15.66	15.66	15.66	15.66	11.14
4D	18.9	18.9	18.9	18.9	9.45
4E	19.7	19.7	19.7	19.7	9.85
4F	9.85	9.85	9.85	9.85	4.93
5C	4.52	4.52	4.52	4.52	0
5D	9.45	9.45	9.45	9.45	0
5E	9.85	9.85	9.85	9.85	0
5F	4.92	4.92	4.92	4.92	0

Table 32: Afferent areas for each vertical element

The geometrical properties of the foundation slab can be found in the next table:

Zone	1	2	Total
B (m)	10.703	16.6	
L (m)	9.05	12.6	
Area (m2)	96.86	209.17	306.03
X (m)	5.35	19	14.68
Y (m)	8.07	6.3	6.86
Ix (m4)	802.87	2832.83	3635.70
Iy (m4)	9355.69	8707.15	18062.85

Table 33: Geometrical properties of the foundation slab.

After having all the vertical loads, it was required to calculate the eccentricity of the loads on the slab with the next formulas:

$$e_x = x' - x$$

$$x' = \frac{Q_1 x_1' + Q_2 x_2' + Q_3 x_3' + \cdots}{Q}$$

$$e_y = y' - y$$

$$x' = \frac{Q_1 y'_1 + Q_2 y'_2 + Q_3 y'_3 + \cdots}{Q}$$

The next image corresponds to the plan of the foundation slab proposed.

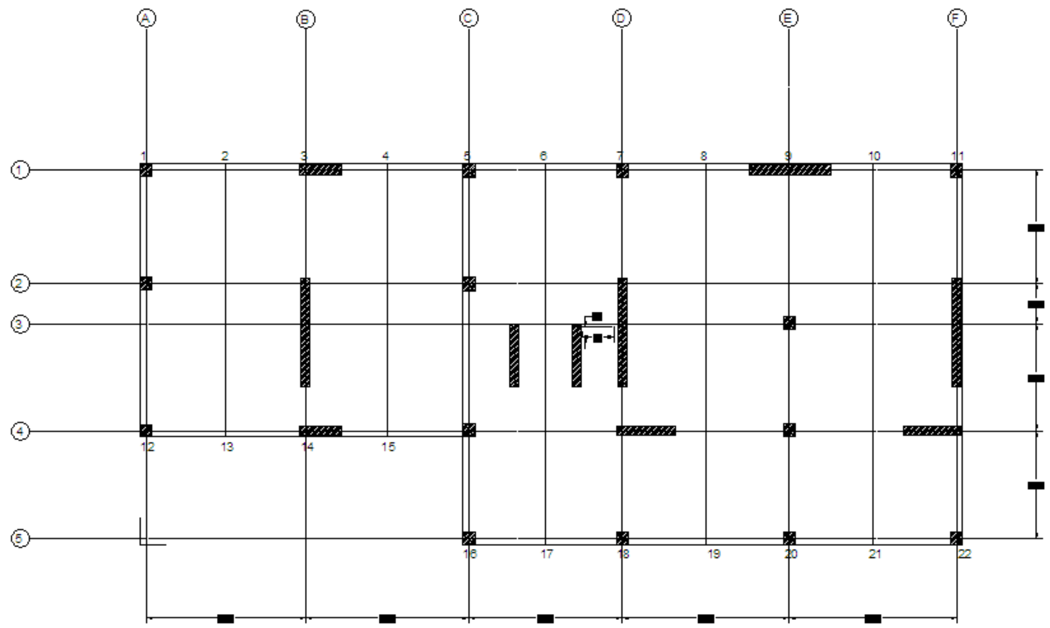


Figure 103: Foundation slab plan

In the next table are summarized the service dead and live loads for each column and wall at the level of the foundation, as well as their position in the Cartesian plane, and the multiplication of the load with their corresponding Cartesian coordinate.

Column	Dead loads (KN)	Live loads (KN)	Total load (KN)	X (m)	Y (m)	Q*X (KNm)	Q*X (KNm)
1A	100.66	56.16	156.82	0.20	12.40	31.36	1944.54
1B	544.69	288.37	833.06	6.00	12.40	4998.35	10329.93
1C	**588.52**	**392.36**	**980.88**	**10.90**	**12.40**	**10691.55**	**12162.87**
1D	559.13	335.43	894.56	16.00	12.40	14312.97	11092.56
1E	**863.32**	**417.31**	**1280.63**	**21.55**	**12.40**	**27597.51**	**15879.77**
1F	411.67	208.71	620.38	27.10	12.40	16812.39	7692.76
2A	196.46	177.06	373.52	0.20	8.65	74.70	3230.97
2B	795.75	393.44	1189.19	5.50	7.30	6540.56	8681.10
2C	547.90	347.35	895.25	10.90	8.65	9758.23	7743.92
3D	871.73	372.95	1244.69	16.00	7.30	19914.97	9086.21
3E	663.67	511.34	1175.01	21.55	7.30	25321.40	8577.55

3F	700.10	255.69	955.80	27.10	7.30	25902.08	6977.31
4A	157.24	124.18	281.42	0.20	3.75	56.28	1055.31
4B	446.18	222.93	669.11	6.00	3.75	4014.66	2509.16
4C	520.83	349.37	870.20	10.90	3.75	9485.16	3263.24
4D	679.84	417.66	1097.50	16.77	3.75	18405.10	4115.63
4E	550.97	435.34	986.31	21.55	3.75	21254.95	3698.66
4F	491.46	217.67	709.14	26.33	3.75	18671.53	2659.26
5C	189.38	97.62	287.00	10.90	0.20	3128.32	57.40
5D	306.14	204.10	510.25	16.00	0.20	8163.96	102.05
5E	315.02	212.74	527.76	21.55	0.20	11373.28	105.55
5F	199.35	106.26	305.62	27.10	0.20	8282.23	61.12

Table 34: Service load on the foundation and their localization on the Cartesian plane

The total service load is equal to 1684.4 tons, and with a load factor of 1.4, the ultimate load is 2358.2 tons.

The eccentricity of the loads resultant ant the moments created by them can be found in the next table:

X' (m)	15.72
Y' (m)	7.19
ex (m)	1.04
ey (m)	0.32
Load factor	1.40
Mx (ton*m)	766.21
My (ton*m)	2453.56

Table 35: Eccentricities of the vertical loads on the foundation slab.

The moments were calculated by ultimate load with their corresponding eccentricity.

After this, it was required to calculate the pressure q over the soil in the points 1 to 22 of the plan image. For that, the next equation was used:

$$q = \frac{Q}{A} + \frac{M_y x}{I_y} + \frac{M_x y}{I_x}$$

In the next formula is possible to find the values of the pressure that is doing the slab over the soil.

Point	Q/A (ton/m2)	X (m)	My*X/Iy (m)	Y (m)	Mx*Y/Ix (m)	q (ton/m2)
1	7.71	-15.52	-2.11	5.21	1.10	6.70
2	7.71	-12.62	-1.71	5.21	1.10	7.09
3	7.71	-9.72	-1.32	5.21	1.10	7.48
4	7.71	-7.27	-0.99	5.21	1.10	7.82
5	7.71	-4.82	-0.65	5.21	1.10	8.15
6	7.71	-2.27	-0.31	5.21	1.10	8.50
7	7.71	0.28	0.04	5.21	1.10	8.84
8	7.71	3.05	0.41	5.21	1.10	9.22

9	7.71	5.83	0.79	5.21	1.10	9.60
10	7.71	8.60	1.17	5.21	1.10	9.97
11	7.71	11.38	1.55	5.21	1.10	10.35
12	7.71	-15.52	-2.11	-3.44	-0.72	4.87
13	7.71	-12.62	-1.71	-3.44	-0.72	5.27
14	7.71	-9.72	-1.32	-3.44	-0.72	5.66
15	7.71	-7.27	-0.99	-3.44	-0.72	5.99
16	7.71	-4.82	-0.65	-6.99	-1.47	5.58
17	7.71	-2.27	-0.31	-6.99	-1.47	5.93
18	7.71	0.28	0.04	-6.99	-1.47	6.27
19	7.71	3.05	0.41	-6.99	-1.47	6.65
20	7.71	5.83	0.79	-6.99	-1.47	7.03
21	7.71	8.60	1.17	-6.99	-1.47	7.40
22	7.71	11.38	1.55	-6.99	-1.47	7.78

Table 36: Pressure of the slab over the soil verification

It is possible to see that the pressure over the soil is in all the cases lower than the admissible one, which is 11.84 ton /m2.

To determine the effective depth d of the slab, it was needed to check the shear due to diagonal tension near the more critical columns, according to the following equation:

$$U = b_o d\left[F_r\left(0.34\sqrt{f_c'}\right)\right]$$

Where:

- U is the factorized column load.
- F_r Is the reduction factor: 0.8 for shear.
- b_o is obtained according to the following scheme, according to the column:

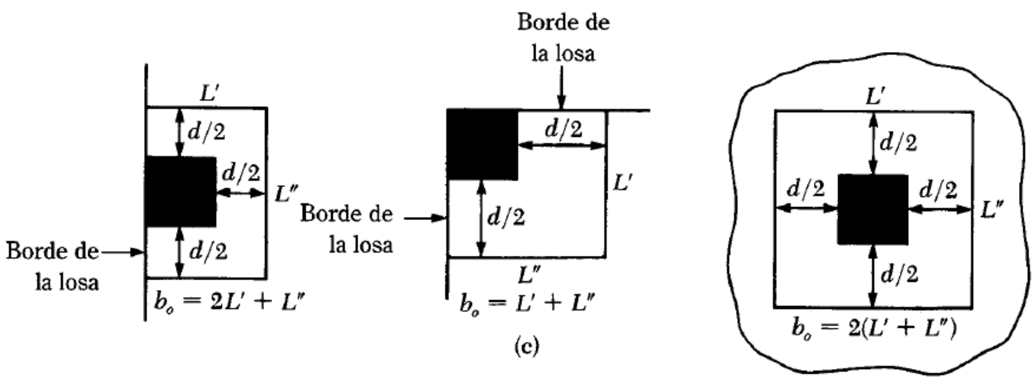


Figure 104; Determination of bo for the calculation of the shear capacity of the foundation slab. (Das, 1999)

Column	Pu (kN)			d (m)
Border column 1C	1373.23	<	1531.326	0.75
Border wall 1E	1792.88	<	1877.646	**0.83**
Inner column 3E	1645.01	<	1656.864	0.78

Table 37: Shear verification in the base of the vertical elements and calculation of the effective depth of the foundation.

The required effective depth d is 0.83 m. With a reinforcement bar of 25 mm and a cover of the steel of 70 mm, the total height of the slab is 0.925 m.

For the design of the slab it was divided in strips and the mean pressure over the soil was calculated for each of them, using the values obtained in the points previously calculated.

Mean reaction of the soil					
Strip	Width (m)	Length (m)	q1 (ton/m2)	q2 (ton/m2)	Soil reaction (ton)
1-2-12-13	2.85	9.05	6.89	5.07	154.29
2-3-4-13-14-15	5.35	9.05	7.46	5.64	317.26
4-5-6-17-16	5.25	12.6	8.15	5.75	459.96
6-7-8-17-18-19	5.32	12.6	8.85	6.28	507.25
8-9-10-19-20-21	**5.55**	**12.6**	**9.60**	**7.03**	**581.19**
10-11-21-22	2.98	12.6	10.16	7.59	333.29

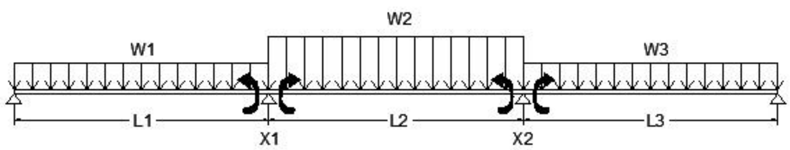
Table 38: mean reaction of the soil in the analyzed slab strips

The total load is 2353.24 ton.

For the dimensioning of the reinforcement of the foundation slab, the strip 8-9-10-19-20-21 was analyzed using the flexibility method, similar to the process developed for solving the beams. The geometrical properties of the slab strip analyzed can be found in the next table:

Slab strip 8-9-10-19-20-21	
B (m)	5.55
H (m)	0.93
A (m2)	5.13
I (m4)	0.3660

Table 39: Geometrical properties of the analyzed foundation slab strip



The system of equations of this foundation strip is the following:

$$\begin{vmatrix} \frac{L1}{3EI}+\frac{L2}{3EI} & \frac{L2}{6EI} \\ \frac{L2}{6EI} & \frac{L2}{3EI}+\frac{L3}{3EI} \end{vmatrix} \text{X} \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} -\frac{W1L1^3}{24EI}+\frac{W2L2^3}{24EI} \\ -\frac{W2L2^3}{24EI}+\frac{W3L3^3}{24EI} \end{vmatrix}$$

Where W1, W2 and W3 are the sum of the corresponding soil pressures for each span.

Span	**Length (m)**	**Pressure from the soil (Ton/m2)**	**Pressure from the soil (kN/m)**	**Q (kN/m)**	**Qu (kN/m)**
1	5.1	-6.85	-380.44	-380.44	-542.21
2	3.55	-6.09	-337.98	-337.98	-481.70
3	3.55	-5.56	-308.42	-308.42	-439.57

The systems of equations take the following values:

$$\begin{vmatrix} 2.88 & 0.59 \\ 0.59 & 2.37 \end{vmatrix} \text{X} \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} 3894.79 \\ 1717.36 \end{vmatrix} \qquad \begin{vmatrix} X1 \\ X2 \end{vmatrix} = \begin{vmatrix} 1266.88 \\ 408.92 \end{vmatrix}$$

In the next figure is represented the diagram of bending moments obtained for the analyzed slab strip.

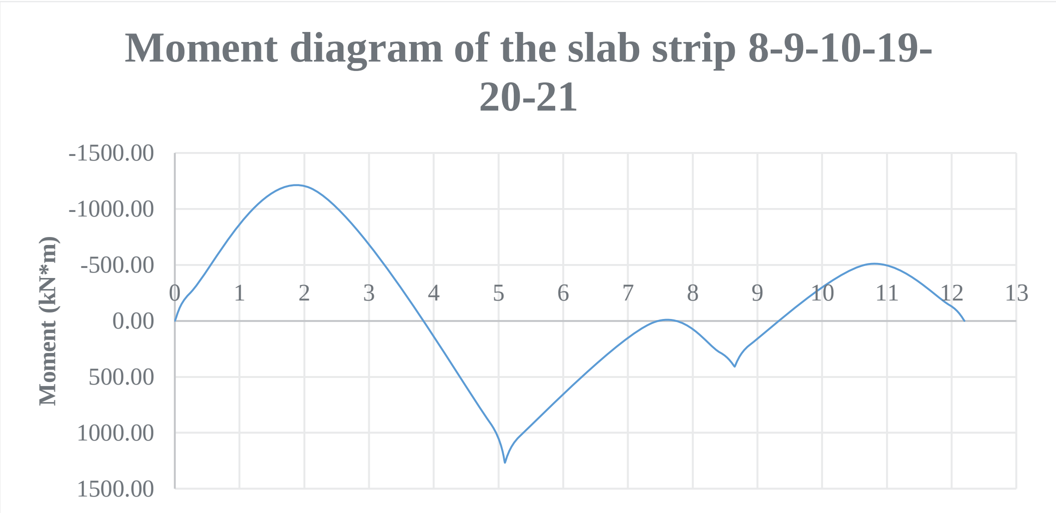


Figure 105: Diagram of bending moments of the analyzed foundation slab strip

Following the same equations already presented in the slab section, was realized the pre-dimensioning of the required area of longitudinal reinforcement for the analyzed bending moments in the most critical sections. On the following table, it is possible to see an example of obtained reinforcement area for the analyzed foundation strip, as well as the proposed selection of steel bars.

Position	As mm²	As n° Φ	mm²	x		x/d < 0.641	Mrd
0.00	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
2.09	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
5.10	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
7.38	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
8.65	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
10.69	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87
12.20	12335.95	26 Φ 25	12762.72	55.73		0.07	3807.87

Table 40: Dimensioning of the longitudinal reinforcement of the foundation Slab strip 8-9-10-19-20-21

It was possible to realize, that the design of the foundation slab was controlled by the determination of the effective depth according to the shear action created by the column loads on the slab. In terms bending moments, the longitudinal reinforcement is always the minimum required for the cross-section. Thus, bars of 25 mm diameter spaced 200 mm each.

Chapter V: Technological and building services design

1. Introduction

1.1. Project localization

The buildings object of the analysis and design of this chapter are located in Mexico City, at an altitude of 2230 m.a.s.l. and coordinates 19° 26′ 10″ N, 99° 4′ 19″ W.

1.2. Environmental conditions

The data here after presented correspond to the ones gathered during the period 1951-2010, on the weather station 00009068 PUENTE LA LLAVE, in the borough of Venustiano Carranza, Federal District. (CONAGUA, 2105)

The average data for the maximum normal temperature is 24°C, the minimum normal temperature is 6°C, and the mean normal temperature is 15°C. The normal yearly precipitation is 335.6 mm starting in June and ending in October, with most of the heavy rainfalls occurring daily on June, July and August, contributing to clean the air.

Month	Mean Temp.	Rain days	Foggy days	Days of hail	Thunderstorm days
January	12.1	1.5	0.1	0.0	0.5
February	14.1	1.1	0.0	0.0	0.3
March	15.9	1.4	0.0	0.0	0.0
April	17.1	4.1	0.0	0.0	0.2
May	17.3	6.5	0.0	0.1	0.0
June	16.6	11.9	0.1	0.2	0.2
July	15.7	14.1	0.1	0.1	0.8
August	15.7	11.7	0.0	0.0	0.4
September	15.3	8.6	0.1	0.0	0.4
October	15.0	4.3	0.2	0.0	0.7
November	13.3	1.1	0.3	0.0	1.6
December	12.0	1.2	0.7	0.0	0.8
Total	15.0	67.5	1.6	0.4	5.9

Table 41: Weather data from station 00009068 PUENTE LA LLAVE, Mexico City.

1.2.1. Maximum temperature

Month	Normal	Month max.	Year of max.	Day max.	Date of max.
January	21.2	28.1	1993	34.0	29/1993
February	23.4	26.2	1995	32.0	25/1997
March	26.0	29.7	1980	33.5	10/1980
April	27.0	30.6	1984	37.6	27/1993
May	26.9	30.6	1983	35.0	03/1983
June	25.5	28.7	1983	33.0	02/1980
July	23.9	27.7	1980	31.0	04/1980
August	24.1	27.2	1980	31.0	11/1980
September	23.4	26.7	1993	33.0	21/1988
October	23.7	27.4	1979	31.0	20/1979
November	22.0	25.4	1988	31.0	21/1989
December	20.6	23.2	1987	28.0	09/1993

Table 42: Maximum temperatures registered at weather station 00009068 PUENTE LA LLAVE, Mexico City.

1.2.2. Minimum temperature

Month	Normal	Month min.	Year of min.	Day min.	Date of min.
January	3.1	1.1	2003	-8.0	06/1994
February	4.7	2.1	2007	-1.0	01/1986
March	5.9	3.6	2007	-1.0	21/1986
April	7.2	3.6	2004	2.0	14/2008
May	7.7	3.7	2007	3.0	04/1995
June	7.7	3.5	2006	3.0	21/1988
July	7.4	3.5	2006	2.0	29/1997
August	7.3	3.6	2004	3.0	08/1994
September	7.2	3.0	1998	1.0	09/1988
October	6.3	2.5	2008	0.1	31/2008
November	4.5	1.0	2008	0.0	30/1989
December	3.4	0.6	2002	-0.8	05/1993

Table 43: Minimum temperatures registered at weather station 00009068 PUENTE LA LLAVE, Mexico City.

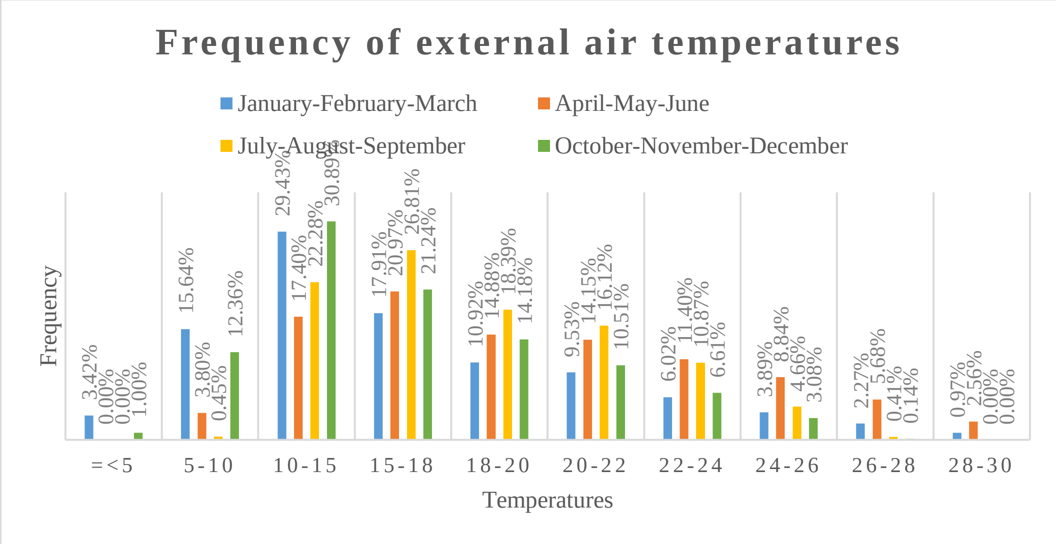


Figure 106: Frequency of external air temperatures

Looking at the frequency of the different external air temperatures, it is possible to realize that the weather is predominantly mild throughout the year. However, during the moths of April to June, the temperatures register higher pick values compared to the rest of the year. Summer temperatures are more moderate due to the presence of rainfall, as well as in autumn. During winter, the temperatures are low, but 80% of the hours remain above 10°C, and never go below zero.

1.2.3. Precipitation

Month	Normal	Month max.	Year of max.	Day max.	Date of max.
January	7.6	90.0	1993	42.0	05/1993
February	4.0	25.3	1981	18.5	22/1981
March	7.1	43.8	1978	32.4	16/1978
April	13.8	57.0	1985	29.1	12/1985
May	25.6	56.7	1979	20.0	13/1977
June	68.6	191.5	1986	65.0	19/1977
July	70.6	176.9	1984	37.1	23/1977
August	58.3	194.3	1976	52.4	14/1980
September	44.9	126.3	1977	44.6	26/1980
October	27.8	149.6	1978	32.3	03/1978
November	2.9	22.2	1980	11.6	21/1980
December	4.4.	38.1	1976	20.0	02/1976

Table 44: Precipitation values registered at weather station 00009068 PUENTE LA LLAVE, Mexico City.

1.2.4. Wind characteristics

The area where the former Lake Texcoco was located has a dry steppe climate, influenced by the eastern opening of the valley towards the great plains of Apan in the state of Hidalgo. The prevailing winds during the day and throughout the year come from the northeast, with surface average speeds of about 2 m / s. During the night, the cold winds from the mountains down into the valley.

In the dry season, during the first months of the year, strong afternoon winds from the northeast carry particles of areas lacking of vegetation or pavement causing local dust storms. During this same period, winds from the north and south occasionally clean the air at noon, establishing conditions of good visibility.

The extent of the urban sprawl and intense energy consumption that takes place within it, have significantly altered the microclimate of the valley. Currently, the heat island of the city marks differences of up to 12 degrees between city and suburban and rural areas on the periphery. This phenomenon causes upward movement of polluted air in the center of the valley, which has a chance to disperse or fall in the immediate vicinity of the city. (Estado de Mexico et al., 1990)

1.2.5. Solar radiation

In the Valley of Mexico the largest solar radiation is received from December to February, in the rest of the year and during the rainy season, cloud cover blocks out the sun. (Estado de Mexico et al., 1990).

From the following images of the global horizontal irradiation and the direct normal irradiation, it can be noted that Mexico City has a great potential for the use of solar energy.

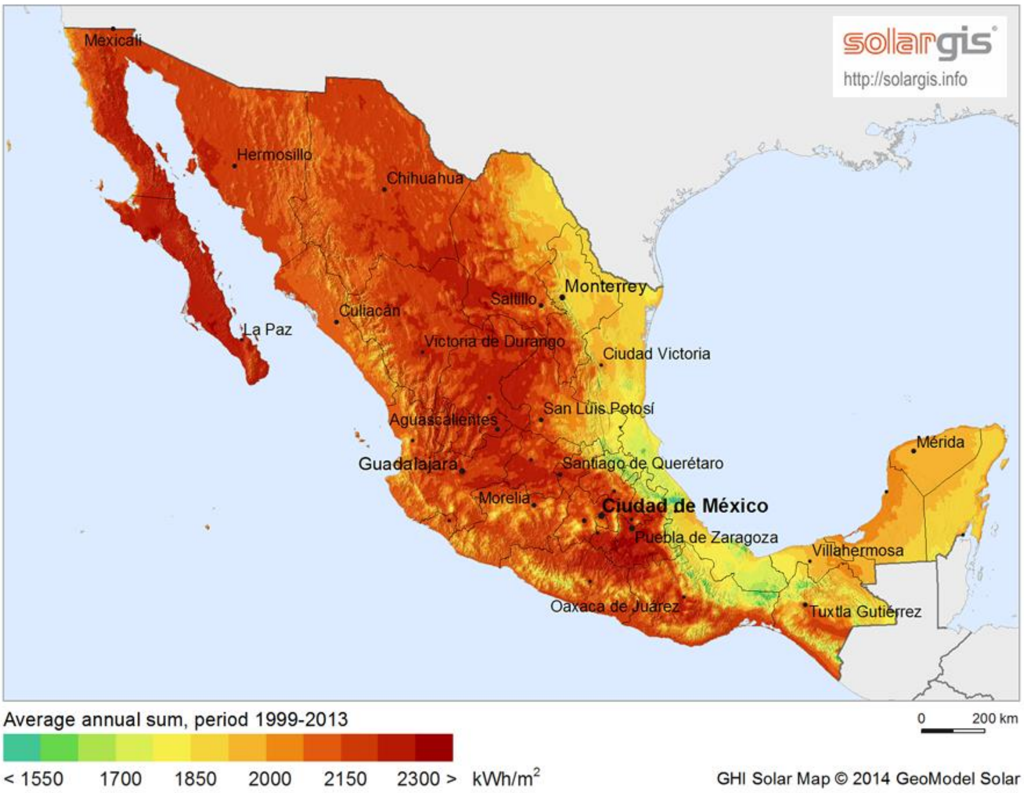


Figure 107: Global Horizontal Irradiation (GHI) for Mexico. Source: (GeoModel Solar, 2015)

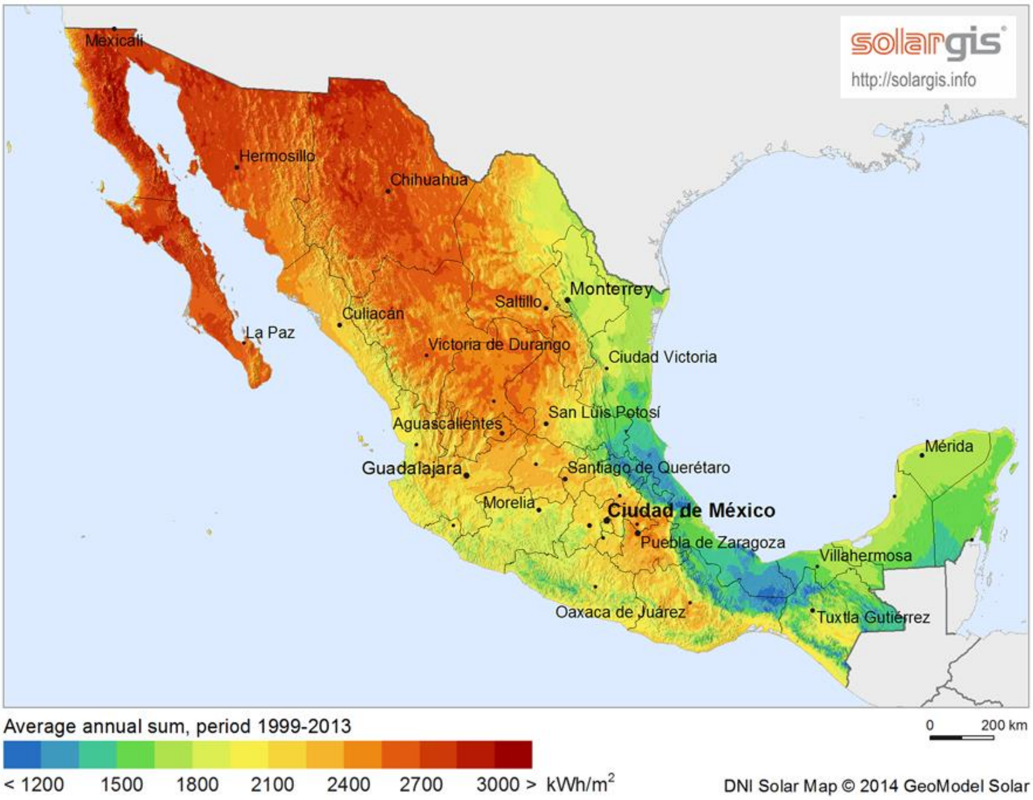


Figure 108: Direct Normal Irradiation (DNI). Source: (GeoModel Solar, 2015)

Solar Irradiance is a measure of how much solar power is striking a surface at a specific location. It varies throughout the year depending on the season, but also during the day depending of the sun's position and the clearness of the sky. The solar irradiance over a period of a single day is named solar insolation.

(Greenstream Publishing Limited., 2015) Has created a tool for calculation the irradiance of different cities around the world from data collated over a 22 year period to provide monthly average insolation figures, measured in kWh/m2/day.

Month	Opt. Ang	H Vertical 90°	H Best winter 34°	H Optimal 19°	H Best summer 4°	H Horizontal 0°
Jan	35°	4.85	6.23	5.78	5.00	4.74
Feb	27°	4.50	6.76	6.51	5.90	5.68
Mar	19°	3.47	6.77	6.88	6.61	6.47
Apr	11°	2.18	5.86	6.29	6.41	6.38
May	3°	1.75	5.14	5.79	6.16	6.21
Jun	-4°	2.43	5.30	5.59	5.61	5.57
Jul	3°	2.29	5.15	5.46	5.51	5.48
Aug	11°	1.83	4.73	5.14	5.31	5.31
Sep	19°	2.35	4.77	4.97	4.93	4.88
Oct	27°	3.34	5.38	5.33	5.00	4.87
Nov	35°	4.52	6.05	5.68	5.00	4.77
Dec	42°	4.47	5.71	5.29	4.57	4.34
Aver.	19°	3.17	5.65	5.73	5.50	5.39

Table 45: Mexico City Average Solar Insolation measured in kWh/m^2/day.

In order to present in a more clear way how the inclination of the solar panel influences on the average solar insolation that they receive during the year, a graph have been realized. On it, is possible to see that the highest values are obtained during the first months of the year, at the end of winter and the beginning of spring. This value is possible due to the high clearness of the sky during that period. In any case, the solar insolation is maintained at high levels throughout the year, at values that range from 5 to 7 kWh/m2/day when keeping the inclination of the panel at its optimal position, which for Mexico City is 19°. If higher values of solar insolation want to be achieved, it is possible to rotate the panels month by month to their specific optimal inclination values, already reported.

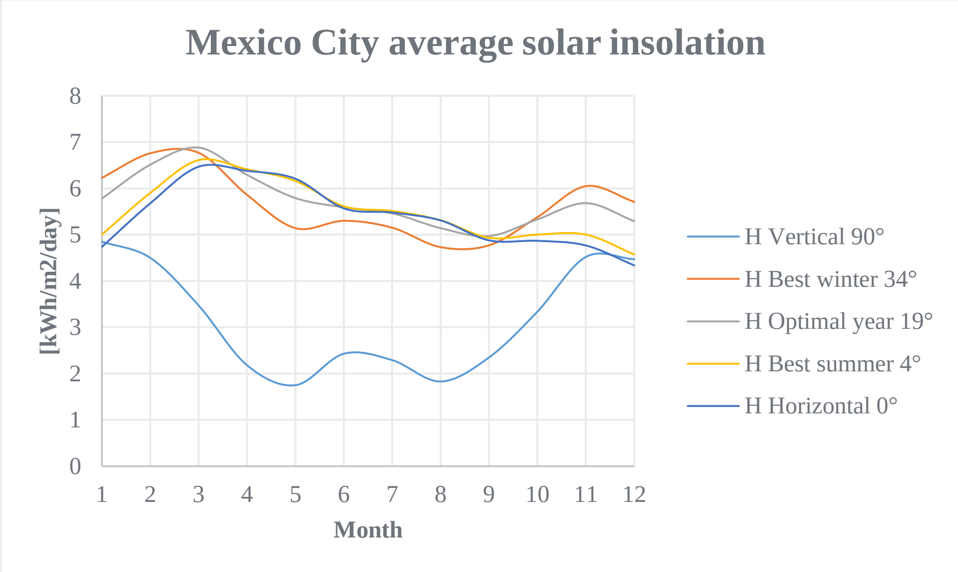


Figure 109: Mexico City Average Solar Insolation measured in kWh/m²/day.

1.3. Information analysis: SWOT

1.3.1. Strengths

- Possibility to work with the urban densities and building heights to modify the wind flow characteristics, such as its direction and velocity.
- Location of the building in front of a big open space that with a correct design can help to modify the microclimate characteristics of the zone.
- Liberty to work with the dimensions of the building and its inner spaces in order to take advantage of natural ventilation.

1.3.2. Weaknesses

- The urban masterplan do not let the possibility to orient the building to its optimum position.
- The amount of rainfall can limit the harvesting of water and force the designers to use specific species able to withstand drought.

1.3.3. Opportunities

- Mild temperatures throughout the year give the opportunity to work with natural ventilation and avoid the use of HVAC systems.
- The low temperatures of the nights can be harnessed to cool down spaces with high levels of internal gains such as restaurants or offices.
- The possibility to exploit the high levels of solar insolation for the production of domestic hot water and photovoltaic energy.

1.3.4. Threats

- The high levels of solar insolation can lead to problems of overheating and glare discomfort during the brightest and hottest days.
- The existing environmental conditions of the city such as the dust storms and the temperature inversions caused by the high levels of pollutants in the air can worsen the air quality and thereby discourage the use of natural ventilation.

2. Thermal analysis and design of the building envelope

2.1. Thermal comfort

Even if designing energy efficient buildings is a task of nowadays architects and engineers, it has to be reminded that buildings are designed for people, and that achieving thermal comfort is a paramount aspect. (Jankovic, 2012)

Thermal comfort is defined as a condition of mind that expresses satisfaction with the thermal environment. It is based on the equilibrium between heat gains inside human body and heat losses from the body to the environment. When the heat gain from metabolism is equal to the heat loss, the balance with the environment is achieved and that is felt as comfortable. (Jankovic, 2012)

Different aspects influence on how people react to the environment conditions of indoor spaces, and how they rate it as comfortable or not:

- Metabolic rate: is the internal heat production of the human body and is related to the activities that the person is developing.
- Resistance of clothing: is the capability of the clothes to resist the transfer of heat from the body to the environment. More insolated buildings will let the users to wear less.
- Air temperature: This temperature controls the conduction and convection mechanisms between the human body and the environment.
- Mean radiant temperature: It is an area-weighted average temperature of all internal surfaces in an internal space. This temperature controls the radiation heat transfer mechanism between the human body and the environment.
- Operative temperature: Is the average of the two previous temperatures.
- Air velocity: It influences thermal comfort in combination with air temperature and turbulence intensity.
- Air relative humidity: It can limit the evaporation heat transfer from the human body.

Thermal comfort can be assessed in two ways: the static approach, related with the Fanger statistical studies which follows the theory of thermal equilibrium of the human body; or the adaptive approach, based on a series of studies developed in real buildings, showing that people can tolerate temperatures that are out of the strict limits set by Fanger. It is used basically for buildings cooled naturally.

In order to choose one of this approaches, it is important to define if it is needed to use active systems for cooling, or instead, natural ventilation. An indicator of the cooling energy demand in given climate can be the cooling degree hours, although it should be noted that this value is also influenced by solar gains.

$$CDH = \sum_{k=1}^{N_{hours}} (T_{out,k} - T_{sp,k}) \; with \; T_{out,k} > 0$$

Where $\mathrm{T_{out,k}}$ is the outdoor air temperature in hour k and $\mathrm{T_{sp,k}}$ is the indoor design set point temperature, for example 26 °C. In the next table it is possible to compare the cooling degree hours for Mexico

City, compared with other cities. (Ramponia, Gaetanic, & Angelottic, 2014)

City	**Amsterdam**	**Milan**	**Rome**	**Mexico City**
CDH	154	815	1044	419

Table 46: Cooling degree hours for Mexico City

This results can be interpreted as a clear opportunity to use natural ventilation in order to cool down the building during the hottest days. In this sense, the adaptive approach for thermal comfort was chosen. It consist on setting the limits for the maximum and minimum comfortable temperatures, by correlating them with the external air temperature.

The limit temperatures for this approach are the followings:

$$\mathrm{Tmax} = 0.33 * \mathrm{Trm} = 18.8 + 3$$
$$\mathrm{Tmin} = 0.33\ \mathrm{Trm} + 18.8 - 3$$
$$\mathrm{Trm} = (1-\propto) * \mathrm{T}_{\mathrm{e(d-1)}} + \propto * \mathrm{T}_{\mathrm{rm-1}}$$

Where Te (a-1) is the temperature of the precedent day, Trm is the running mean temperature, T (rm-1) is the running mean temperature of the day before, and a is the velocity at which Trm variates with the external temperature, usually 0.8.

It is important to notice that for the calculation of the CDH, if instead of setting the design indoor temperature at 26 °C, it is set as the maximum admitted temperature for the adaptive comfort approach class II, the CDH will descend to just 76 hours, which means less than 1% of the year.

2.2. Analysis software: Trnsys 17

In order to investigate if the designed buildings are able to reach the required thermal comfort, the researchers have realized a thermal analysis using the software Trnsys17.

TRNSYS is an extremely flexible graphically based software environment used to simulate the behavior of transient systems. It has a modular the program.

TRNSYS is made up of two parts. The first is an engine that reads and processes the input file, iteratively solves the system, determines convergence, and plots system variables. The second part of TRNSYS is modular structure in which modules, called types, represent a specific component of an extensive library, each of which models the performance of one part of the system.

A dynamic simulation model is created by choosing the types which collectively describe the system that the users wish to simulate, and by 'writing' them up so as to achieve required information flow. In each time step, the program model executes the instructions from the 'writing' diagram, reads input weather data, applies them to the process model and generates output. (Jankovic, 2012)

2.3. Objectives of the analysis:

In order to develop this dynamic simulation and analysis, some objectives have to be fulfilled:

- Develop a dynamic simulation of a building in the context of Mexico City, and evaluate its thermal behavior throughout the year.
- Choose the best technology for the building envelope, in order to achieve thermal comfort and compare it with the materials that are commonly used in the building sector.
- Take advantage of the mild temperature of the outside environment to naturally ventilate the buildings.

2.4. Building object of the analysis:

The building object of this analysis is located in the southeast part of the public square. In four floors, several functions are developed, each of them with its own environmental requirements.

A three dimensional model was realized with the Sketchup plugin for Trnsys 17 named Trnsys 3d. On it, each office, shop, restaurant or apartment was modeled as a thermal zone. Elements such as the balconies, staircases, cantilevers, and other buildings are realized as 'shading groups'

Trnsys 3d helps the user to develop a simple model for a building in a very graphical way. Every thermal zone is delimited by closed surfaces such as walls, floors, roofs, ceilings, transparent or 'virtual' areas. For each surface, a relationship with the surrounding surfaces or external environment is stablished. And finally, the related surfaces are matched, in order that Transys 17 considers them as one single element when importing the 3D geometry.

The entire building was divided in 15 thermal zones. Their numerical name is composed by a first number which denote the floor level (from 0 to 3), and the second number corresponds to its position on each floor starting with 1 at the western part of the building.

Use	Zone	Volume (m3)	Area (m2)
Ground floor			
Kitchen of the restaurant	0_0	223.843	54.864
Ground floor of the restaurant	0_1	197.186	48.330
Lobby of the building (double height)	0_2	142.015	19.890
Retail shop	0_3	283.050	69.375
Retail shop	0_4	283.050	69.375
First floor			
First floor of the restaurant	1_1	180.938	59.130
Living room of a loft (double height)	1_3_A	132.467	21.645
Kitchen of a loft	1_3_B	120.579	39.405
Living room of a loft (double height)	1_4_A	132.467	21.645
Kitchen of a loft	1_4_B	120.579	39.405
Second floor			
Office	2_1	273.013	89.220
Upper floor of a loft corresponding to bedroom, studio and toilet	2_3	110.229	36.022
Upper floor of a loft corresponding to bedroom, studio and toilet	2_4	110.229	36.022
Third floor			
Apartment	3_1	273.013	89.220
Apartment	3_2	371.928	121.545

Table 47: Thermal zones

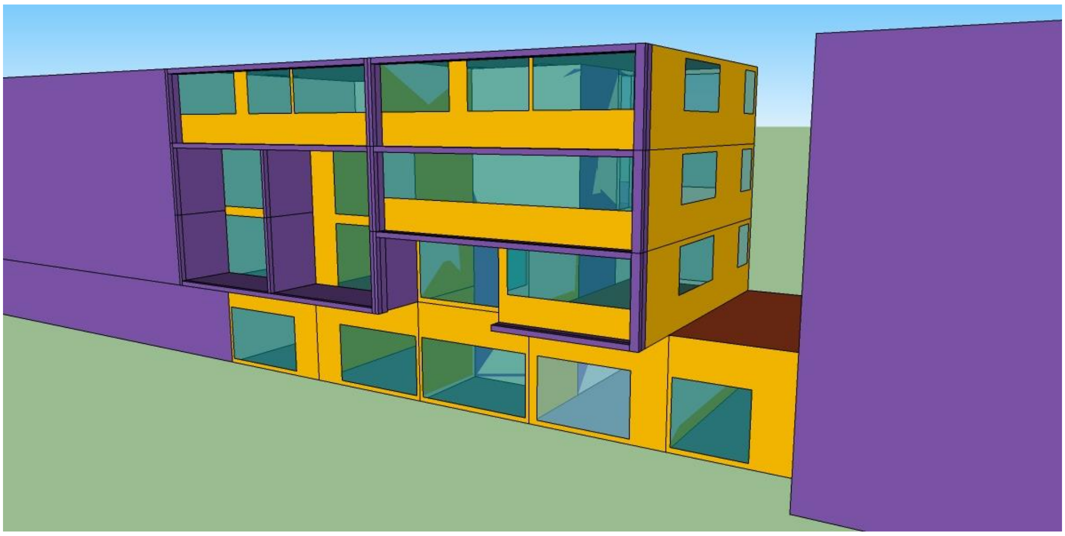


Figure 110: Front view of the 3D model realized on Trnsys 3d.

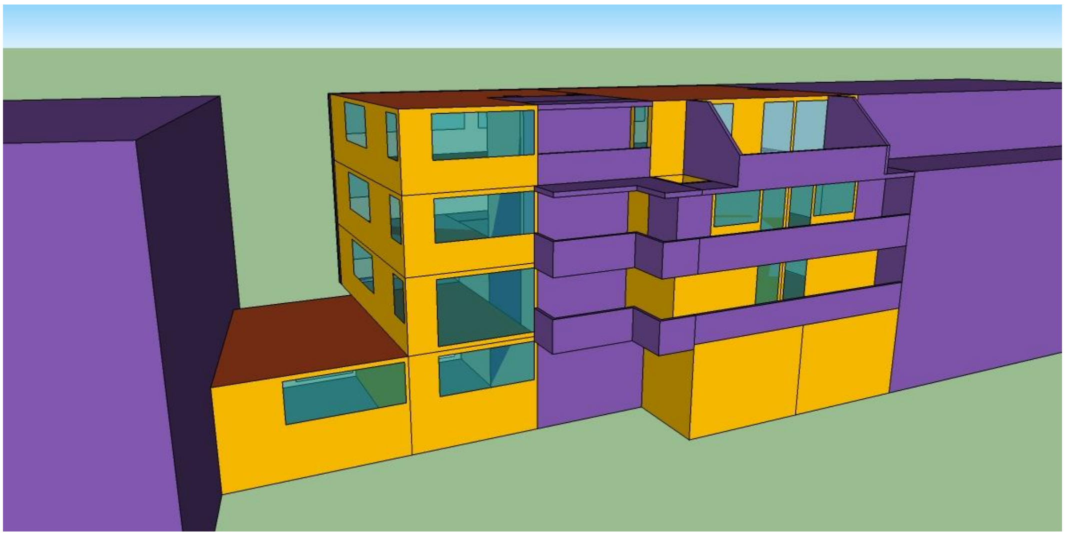


Figure 111: Back view of the 3D model realized on Trnsys 3d.

2.5. Building envelope alternatives

In order to analyze how the technology used for the building envelope determines the overall thermal behavior of the building, it was decided to carry out the simulations with technologies currently used in the modern buildings of Mexico City, and better performing materials, mostly used for achieving a better energy performance.

2.5.1. Current use technologies for the building

Nowadays, the construction sector of Mexico do not care about the thermal properties of the materials they use for their buildings.

However, many homes do not use any heating or cooling device. This is why it is important to know if the users are feeling comfortable inside this buildings, or if an improvement on the technologies have to be done. Currently, one can find the following technologies being used:

Clay bricks wall (V.C. 1)				
Description of the layer	Thickness [m]	(λ) [W/mK]	(c) [J/KgK]	(ρ) [Kg/m3]
Cementitious plaster	0.015	0.9	1000	1800
Clay bricks	0.12	0.78	940	1700
Cementitious plaster	0.015	0.9	1000	1800
Thermal transmittance (U) [W/m2K]		Thermal lag factor (φ) [h]		
2.80		4.36		

Table 48: Thermal properties of a wall V.C. 1

Lightened reinforced concrete slab (H.C.1)				
Description of the layer	Thickness [m]	(λ) [W/mK]	(c) [J/KgK]	(ρ) [Kg/m3]
Deko sky® (fiberglass)	0.016	0.032	850	105
EPS + RC joist	0.3	0.247	1383	329.9
Reinforced concrete	0.05	1.8	1000	2500
Cementitious mortar	0.03	1.4	1000	2000
Thermal transmittance (U) [W/m2K]		Thermal lag factor (φ) [h]		
0.52		11.53		

Table 49: Thermal properties of a lightened reinforced concrete slab H.C.1

2.5.2. Proposed technologies for the building

In order to achieve a more efficient envelope for the buildings, different material solutions are proposed for the external walls and roofs. Internal walls and slabs will be done as in the traditional ways already described.

Regarding the materials used on the external walls, it was considered that the first one that needed to be upgraded is the brick. An inquiry was carried out in order to find which bricks are sold in the Mexican market as improved in terms of their thermal properties.

Product name	Company	(λ) [W/mK]	Image
Ecoladrillo	Mexico EcoLadrillos	1.130	
Ecotec	ECT	0.580	
Miniblock ecotec	ECT	0.350	
Problock	Mexico EcoLadrillos	0.145	

Table 50: Upgraded bricks on the Mexican Market

It can be seen from the previous table that the better performing material in terms of thermal conductivity is the one named Problock. It is a lightweight, thermal and acoustic element used for building walls, made from a tough, durable and environmentally friendly cementitious mixture, to which are added light loads. Among its more interesting advantages are its low weight, and its high thermal resistance compared to other cement based blocks. Problock is a certified product by the ONNCCE under the law NOM-018-ENER-2011 as a thermal insulating material.

Problock wall (V.C. 2)				
Description of the layer	Thickness [m]	(λ) [W/mK]	(c) [J/KgK]	(ρ) [Kg/m3]
Cementitious plaster	0.015	0.9	1000	1800
Problock	0.12	0.145	840	1750
Cementitious plaster	0.015	0.9	1000	1800
Thermal transmittance (U) [W/m2K]		Thermal lag factor (φ) [h]		
0.97		8.36		

Table 51: Thermal properties of wall V.C. 2

A second step in order to improve the performance of the vertical enclosures is by the addition of an external insulating material. The material chosen for this purpose is Foamular®, a rigid extruded polystyrene foam distributed by FiberGlass of Mexico.

Problock wall + external XPS insulation (V.C. 3)				
Description of the layer	Thickness [m]	(λ) [W/mK]	(c) [J/KgK]	(ρ) [Kg/m3]
Cementitious plaster	0.015	0.9	1000	1800
Problock	0.12	0.145	840	1750
Foamular® XPS	0.051	0.029	1200	30
Cementitious plaster	0.015	0.9	1000	1800
Thermal transmittance (U) [W/m2K]		Thermal lag factor (φ) [h]		
0.36		10.75		

Table 52: Thermal properties wall V.C. 3

The third and final step in the process of betterment of the overall thermal performance of the building is the shift of the technology used for the roofs. The object in this case is to reduce the transmittance of energy coming through the most exposed surface of the building with the implementation of a green roof, with its well-known architectural, environmental and aesthetic advantages:

- Improvement of the weather and environmental conditions of the city as well as reduction of the heat island effect.
- Increment of the green surfaces on urban areas.
- Reduction of energy flows between the building and outside through the roof.
- Summer cooling due to evaporation of water on the substrate and from the biologic processes of the plants such as photosynthesis and evapotranspiration.
- Longer service life of the materials of the roof by protecting them from solar radiation and thermal stress.
- Reduction of the storms runoff, which lead to cheaper and more efficient drainage systems.

A green roof generally consist of:

- A mulch with native species and low maintenance.
- An organic or inorganic substrate, sufficient for vegetative development of species.
- Water retainer in the form of gel, synthetic panels or rock wool panels.

- Under the substrate a synthetic felt for retaining fine particles of the substrate.
- Optional thermal insulation depending on weather conditions.
- A waterproofing membrane, usually anti-root.
- Structural support.

The chosen vegetative species should be able to withstand extreme temperatures, long periods without contribution of water, high resistance to summer drought, capacity to grow in few deep soils and enough horizontal growth to cover all the surface. Some of the species identified that can fulfill this requirements are *agave attenuate, agave macroacantha, agave parryi, and agave potatorum* and *agave stricta*.

Despite Trnsys is a very advance tool, it is not still possible to simulate the behavior of a green roof under external energy loads. This due to the fact that the system of plants and substrate do not only work as a thermal insulation material but also are able to dissipate part of this energy by means of evaporation and transpiration processes.

On (Machado, Brito, & Neila, 2000) a study of different typologies of green roofs was developed in a partnership between private companies and the Universidad Politecnica de Madrid. The scope of this research was to calculate the equivalent thermal conductivity for the vegetative and substrate layers. For this, with the energy balance equation between the green roof and the environment, were calculated the values of the thermal conductivity for a period of 24 hours considering the temperatures of the hottest of July, a mild day of March and coldest day of January of the year 1997 in the city of Madrid. This yielded results for the three days chosen a value of O 12 W/m°C. This value have been chosen to be used for the analysis of the present project.

Green roof (H.C. 2)				
Description of the layer	Thickness [m]	(λ) [W/mK]	(c) [J/KgK]	(ρ) [Kg/m3]
Deko sky	0.016	0.032	850	105
EPS + RC joist	0.3	0.247	1383	329.9
Reinforced concrete	0.05	1.8	1000	2500
Cementitious mortar	0.03	1.4	1000	2000
Waterproofing	0.01	0.58	1140	1700
Anti-root membrane	0.005	0.19	650	100
Water retention panel	0.032	0.19	750	140
Natural aggregate	0.02	0.08	145	150
Sedum and agave plants + compost	0.18	0.12	1424	400

Thermal transmittance (U) [W/m2K]	Thermal lag factor (φ) [h]
0.26	22.35

Table 53: Thermal properties of green roof H.C. 2

2.5.3. Glazed surfaces

Two transparent enclosures were tested with the program:

- The currently used single glazed window with U-value of 5.68 $W/m^2 K$ and g-value of 0.855.
- Double glazed window with U-value of 5.83 $W/m^2 K$ and g-value of 0.755.

2.6. Dynamic analysis

2.6.1. Internal heat gains

The internal temperature in a building is a consequence of its tendency to stablish an equilibrium between heat gains and heat loses as a result of dynamic changes of external and internal influences. The building heat balance is influenced by three sources, the external heat gains, the internal heat gains and the auxiliary heating of cooling.

Considering that each of the thermal zones have different uses, for each of them were assigned their corresponding internal heat gains, based on the area of the zone and the schedule of use.

Lighting and people internal heat gains are assigned inside the program by changing the expected occupancy density, activity type and recommended lighting levels for each space and use. In terms of the internal gains due to equipment or appliances, the following values were used:

- Restaurant kitchen: 22.7 w/m2.
- Restaurant: 10.7 W/m2.
- Commerce: 10.7 w/m2.
- Office: 3.4 w/m2.
- Apartments: 400 W/person.

2.6.2. Ventilation

As in service conditions ventilation is necessary to keep comfortable and healthy spaces, it must be considered on the model. Taking into account that the climate conditions of Mexico City allow the utilization of natural ventilation, it is desired for this project to explode this alternative at its maximum in order to reduce the necessity to external energy sources. However, it is not possible to make a simulation of the wind flow inside the spaces on Trnsys 17. For this reason, some basic ideas were applied in order to guarantee that natural ventilation will occur in the designed buildings:

- Use of thermal mass: As night time air in a temperate climate is much colder that day time during most of the year, thermal mass will let the possibility to discharge during night the heat absorpted during the day by means of night time ventilation.
- Building geometry: Natural ventilation works in buildings up to 12 meters depth with windows in the opposite sides, with typical ceilings height of 3 meters. When only windows can be found on one of the facades, a maximum depth of 6 meters or a higher ceiling height is needed.
- Control temperature: Considering the different seasons and scenarios, it is required that in the case that people cannot operate by themselves the building openings, a control temperature is required in order to maintain ventilation and temperature in comfortable conditions.

In order to consider the ventilation inside the dynamic model realized on Transys 17, a volume of air changes per hour has to be provided (ACH). Usually, the monthly average ACH for pure wind-driven cross-ventilation in office buildings can vary from 11.7 to 8.0 to 4.7 h^{-1} assuming an upstream wind profile for country, urban and city terrain, respectively (Ramponia, Gaetanic, & Angelottic, 2014).

The ventilation rates considered on transys are:

- For the residences, 0.3 volumes per hour when the outside temperature is not comfortable, and 4.7 volumes per hour when the outside temperature is comfortable.
- For all the other zones, 0.7 volumes per hour when the outside temperature is not comfortable, and 4.0 volumes per hour when the outside temperature is comfortable.

2.6.3. Influence of the building envelope in the thermal behavior of the building

After having assigned the different material properties for the closure elements of each of the thermal zones of the model, a series of simulations where carried out varying always one parameter. In this way it would be possible to determine how the improvement on the building technologies affects the indoor environmental conditions. In total 10 simulations were developed:

Sim	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Wall	v.c. 1	v.c. 1	v.c. 1	v.c. 2	v.c. 1	v.c. 2	v.c. 1	v.c. 2	v.c. 3	v.c. 3
Roof	h.c. 1	h.c. 1	h.c. 2	h.c. 2	h.c. 2	h.c. 2	h.c. 1	h.c. 1	h.c. 2	h.c. 2
Glass	2	1	1	1	1	1	1	1	1	2
Vent	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes

Table 54: Series of dynamic simulations on Trnsys 17

In order to test the reliability of the model, the first four simulations were carried out without ventilation, just changing the three first parameters. In this way it was possible to realize how the introduction of a better performing brick or window was enough for increasing the indoor temperatures as expected.

After having verified that the model is reliable, it is important to know how the behavior of the building is when it is built with the current use construction technologies, which means, with no thermal efficient materials.

In the next page are presented three graphs that register the distribution of frequencies of the indoor air temperatures for the different zones. From them it is possible to see that all the zones are between 20 and 26 °C in a range of 70 to 95% of the hours of the year. With the coldest zones located on the ground floor, especially on the zones 0_3 and 0_4 that correspond to the retail uses, which are characterized by lower equipment heat gains and are influenced by its vicinity to the ground, which acts as a heat reservoir at almost constant temperatures. On the other hand, the zones that correspond to the restaurant, present overheating with almost 10% of the hours over 27 °C, due to the high internal heat gains.

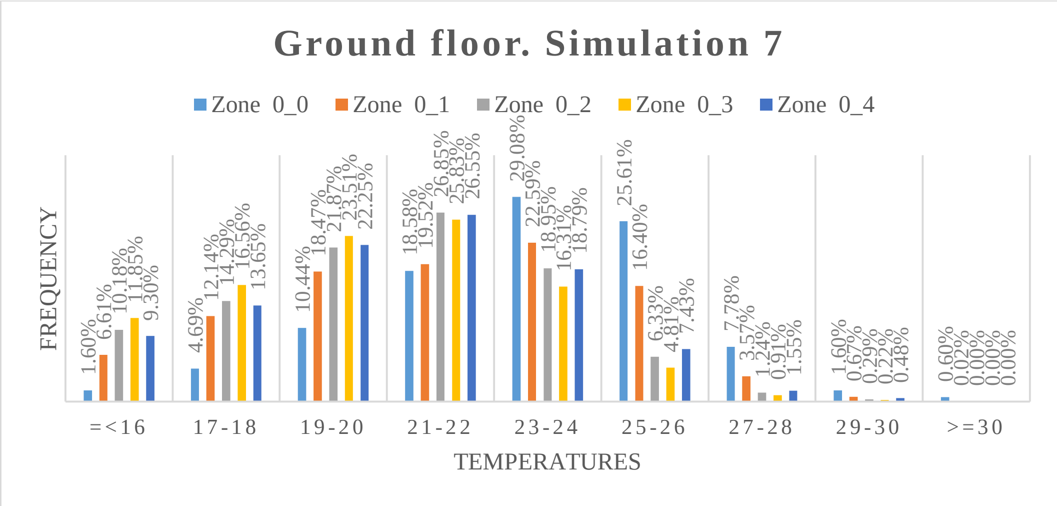


Figure 112: Frequencies of internal air temperatures for the ground floor. Simulation case 7

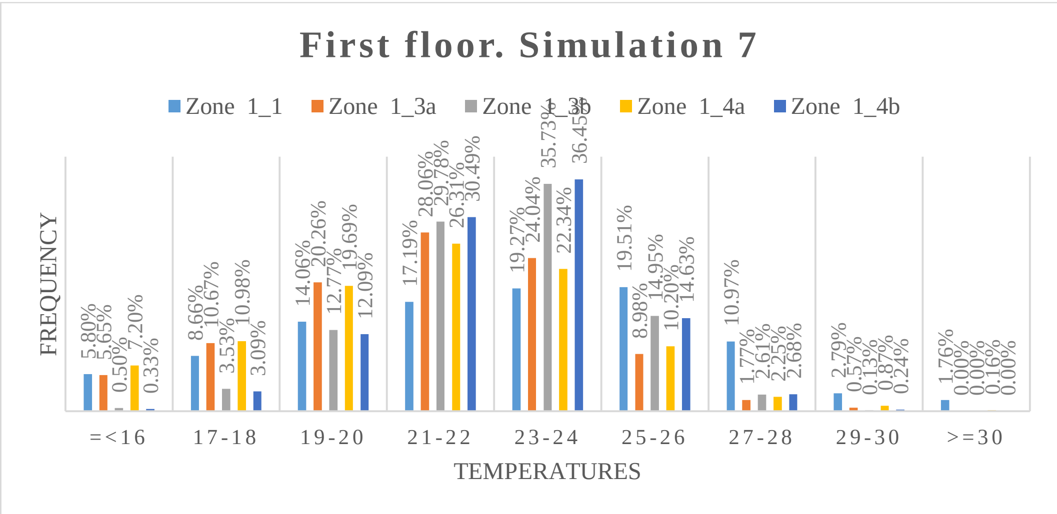


Figure 113: Frequencies of internal air temperatures for the first floor. Simulation case 7

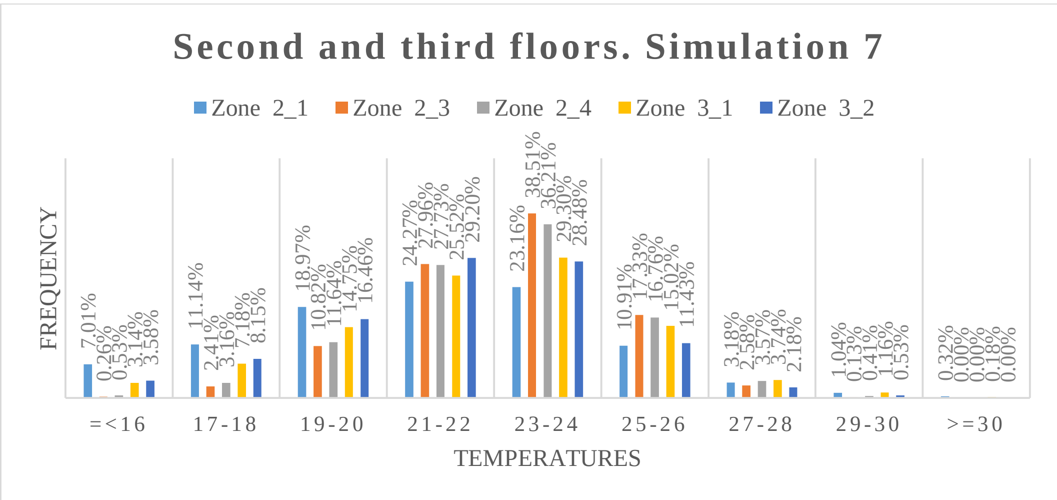


Figure 114: Frequencies of internal air temperatures for the second and third floors. Simulation case 7

The spaces that correspond to the loft are the ones which reach the most comfortable temperatures, being above 90% of the year between 20 and 26 °C.

The upper floors, benefit from higher solar heat gains, which make possible that the range of temperatures moves towards warmer temperatures without arriving to overheating.

After this analysis, it is important to notice that the only zone which might present problems due to overheating is the restaurant. However, due to the bad performance of the building envelope, uncomfortable cold temperatures during winter or just at nights can be felt by the users.

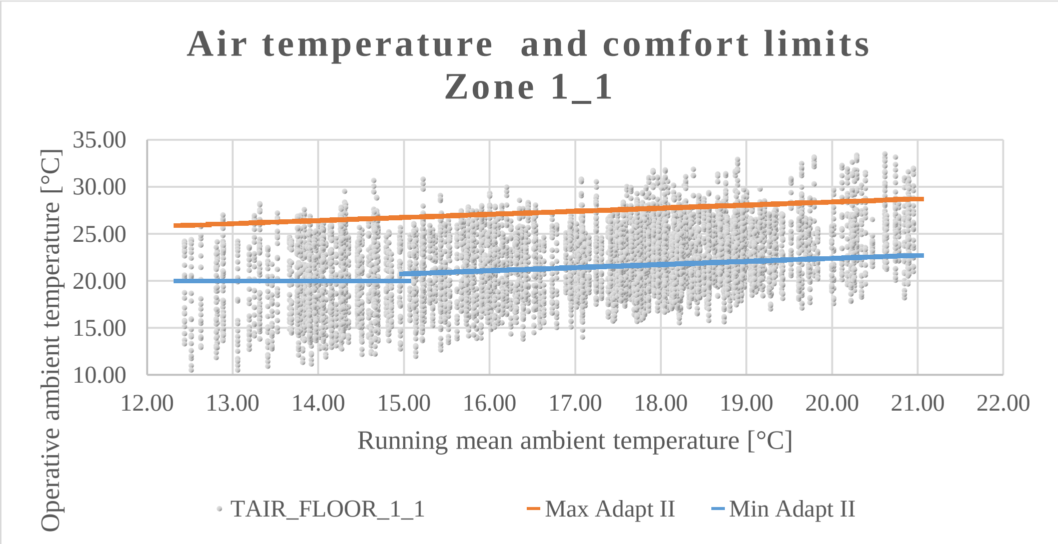


Figure 115: Operative ambient temperature of the zone 1_1 (restaurant) in relation to the outside mean ambient temperature for the simulation case 7.

On the following graph it is possible to see the thermal behavior of the most critical thermal zone of the building, which corresponds to the first floor of the restaurant. It is notable how for a mild day, almost the three technology choices have more or less the same temperatures, with values closer to the external ones in the case of the traditional brick walls, and with the highest values for the combination of Problock and XPS. However, there is a more notable difference on the pick temperatures, both highest and lowest.

When adding a double glazing to the wall type V.C.3, a different result is obtained, in this case, the lowest temperatures go up almost 5°C meanwhile the highest only increase 1°C compared to the same building with just single glazed windows. This result remarks the idea that with a better insulated envelope more stable and comfortable temperatures are reached.

It is important to state however, that this result is obtained also thanks to the use of ventilation rates in accordance to the external air temperature. This is why, when external air is at temperatures lower than 20 °C, the ventilation is kept at its minimums in order just to provide the necessary air for keeping it at high levels of quality. When the outside temperatures are equal to the ones desired inside, the openings are widened, in order to avoid the process of overheating that typical of a more insulated building. This process can be controlled either by special technologies, or by the user itself.

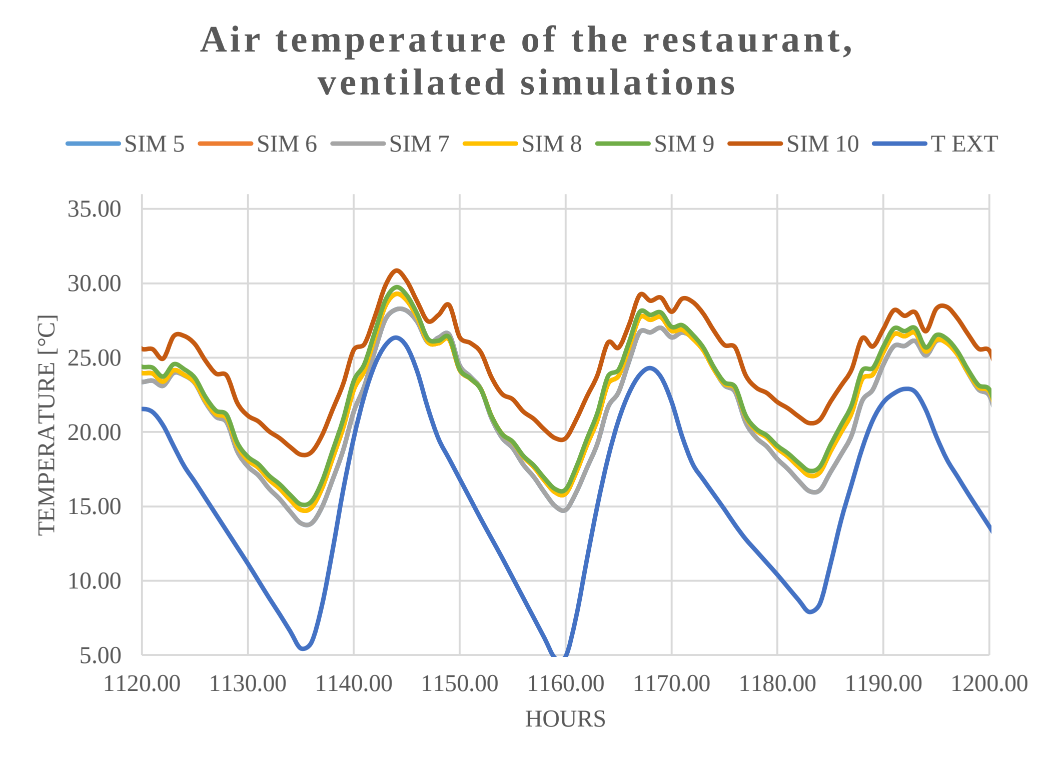


Figure 116: Air temperature of the restaurant on a day of February for different technology simulations.

On the next graph are presented the recorded indoor temperatures for the two zones of the last floors at two simulation cases. Simulation case 6 corresponds to a problock envelope combined with a green roof and single glazing, the simulation case 8 corresponds to a problock envelope with a concrete slab roof and single glazing. It is possible to see how the utilization of the green roof only represents a reduction on the temperatures of 0.3 °C. However this might be due to the fact that the slab is lightened with expanded polystyrene which already works as a high insulating material.

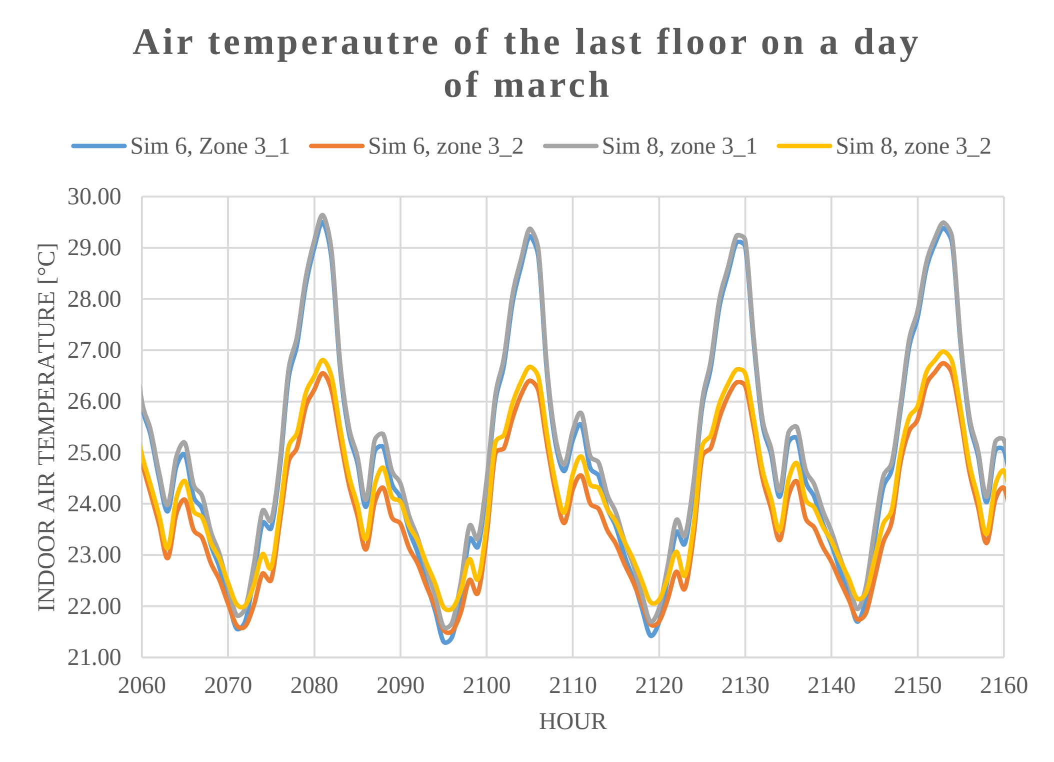


Figure 117: Influence of the green roof on the indoor temperature of the last floor.

The next table shows how the utilization of better performing technologies for the external envelope can improve the thermal behavior of a building, to a more comfortable one.

Zone	Simulation 7			Simulation 10			Improvement
	% days below	% days comfort	% days above	% days below	% days comfort	% days above	
0_0	28%	69%	3%	3%	89%	8%	20%
0_1	51%	49%	1%	39%	60%	1%	12%
0_2	67%	33%	0%	49%	50%	1%	17%
0_3	72%	28%	0%	68%	31%	0%	4%
0_4	66%	34%	0%	65%	35%	0%	1%
1_1	41%	53%	6%	8%	72%	21%	19%
1_3_A	57%	42%	0%	24%	75%	1%	33%
1_3_B	34%	66%	0%	2%	98%	1%	32%
1_4_A	57%	42%	1%	25%	74%	1%	32%
1_4_B	33%	67%	0%	1%	99%	0%	31%
2_1	54%	44%	1%	23%	74%	3%	30%
2_3	29%	71%	0%	1%	98%	2%	27%
2_4	32%	68%	0%	1%	97%	2%	29%
3_1	42%	57%	1%	4%	93%	3%	36%
3_2	47%	52%	0%	15%	85%	0%	32%

Figure 118: Comparison between current use technologies and technology proposed for the building.

In the next two graph, it is possible to realize also how the use of a more insulated building envelope can reduce the variability of the indoor temperatures and minimize the days which might be considered as cold for the users. However, it also causes overheating in two zones of the restaurant: the kitchen and the upper floor during the warmer days.

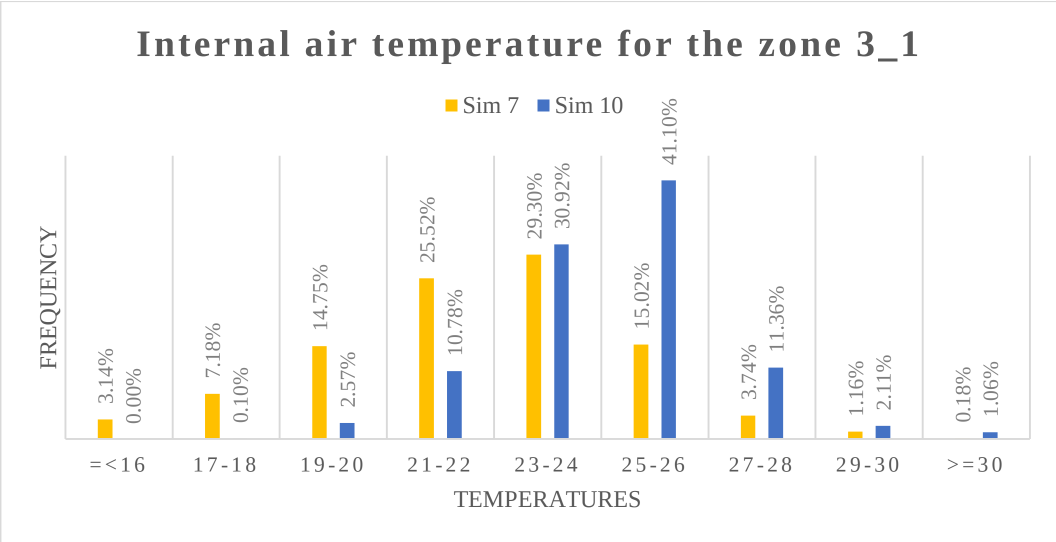


Figure 119: Frequency of air temperature in the zone 3_1 for simulations 7 and 10.

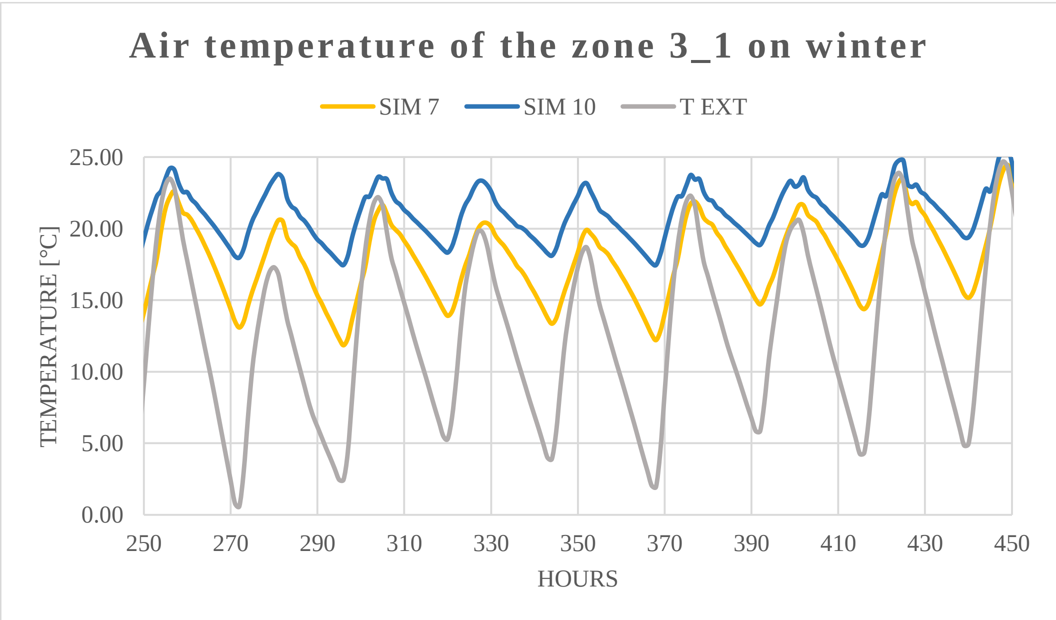


Figure 120: Air temperatures on winter for zone 3_1, simulations 7 and 10.

2.6.4. Influence of the shading devices in the thermal behavior of the building

After having analyzed the advantages of choosing a better performing building envelope for the achievement of more comfortable spaces, the technology combination of the simulation case 10, which corresponds to the wall made of Problock and external extruded polystyrene, green roof and double glazing, have been selected.

Despite of the fact that the main goal of having thermal comfort most of the time of the year on the different zones of the building has been achieved, one main aspect still raise concerns: the problem of overheating during the hottest moths of the year.

It was possible to realize that in many of the thermal zones are present very high temperatures around 27 and 28 °C. Even when this values are still inside the comfort range, the percentage of them has increased compared to the cases of non performing building envelopes.

The zone 1_1 is the most critical one in terms of overheating, with 21% of the hours of the year with temperatures above the highest admitted temperature.

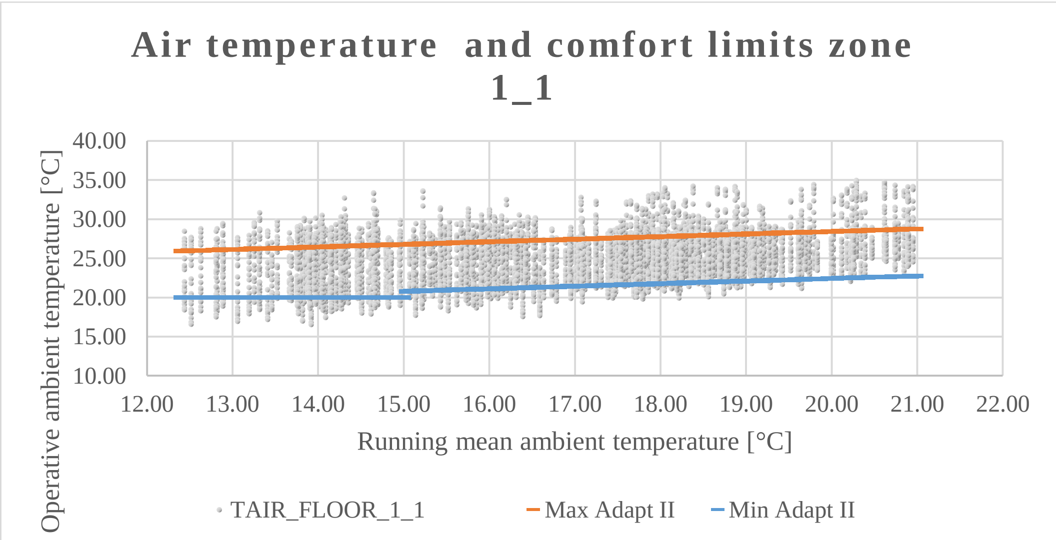
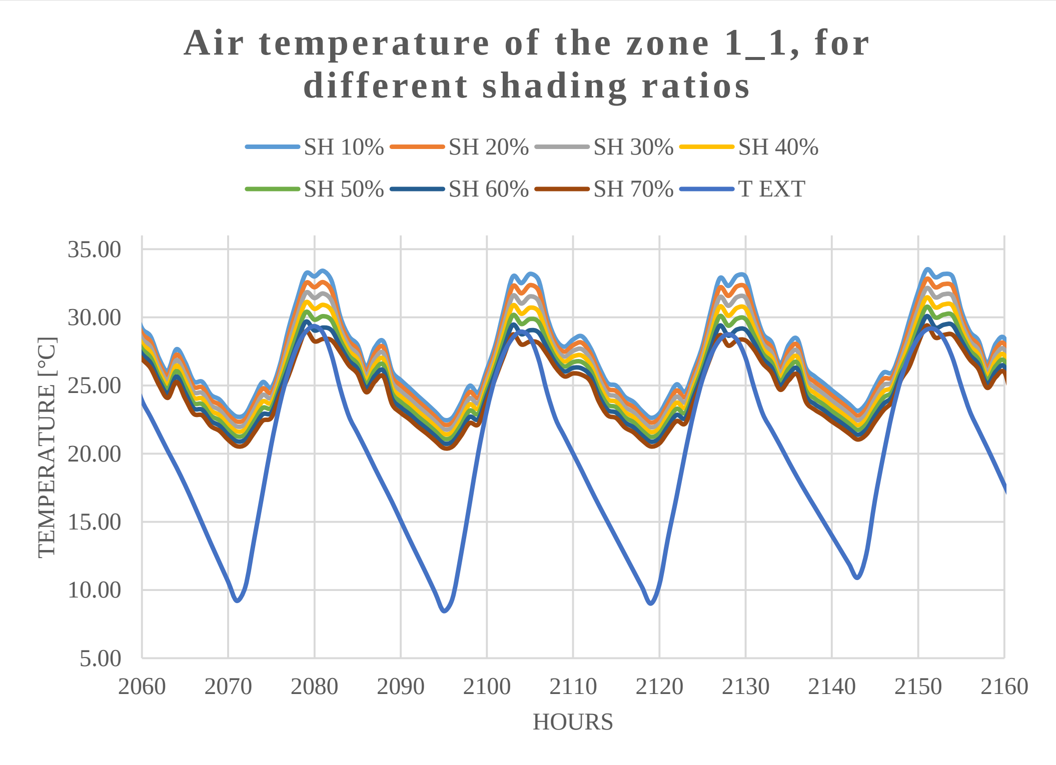


Figure 121: Operative ambient temperature of the zone 1_1 (restaurant) in relation to the outside mean ambient temperature for the simulation case 10.

A solution for this problem is the implementation of solar shading devices over the glazed surfaces in order to minimize the external heat gains coming from the excessive sun radiation that characterize the hottest seasons.

A series of simulations were carried out for the selected building envelope technologies with different shading ratios, from 10% to a maximum 70%. The results can be seen in the following graph:



It is notable that with an increment of 10% in the density of the shading it is possible to lower down the indoor temperature of the zone in almost 0.5 °C, reaching to a maximum of 4 °C for a shading of 70% of opacity.

Another interesting aspect to highlight of the previous graph is that with values of shading opacity of 60% or more, it is possible to have indoor temperatures lower than the registered outside during the hottest picks of the day.

The next graph represents how by using a shading of 70% over the glazed surfaces helps to reduce the overheating that characterized the zone 1_1, which corresponds to the upper floor of the restaurant. Now it has passed from 21% of hours above the thermal comfort limit to just 2%. However, as Transys 17 sets the use of shading according to the levels of solar radiation coming from its environmental data, it also happens that shading is used during the coldest days of the years when clear sky is present, as is very common in Mexico City.

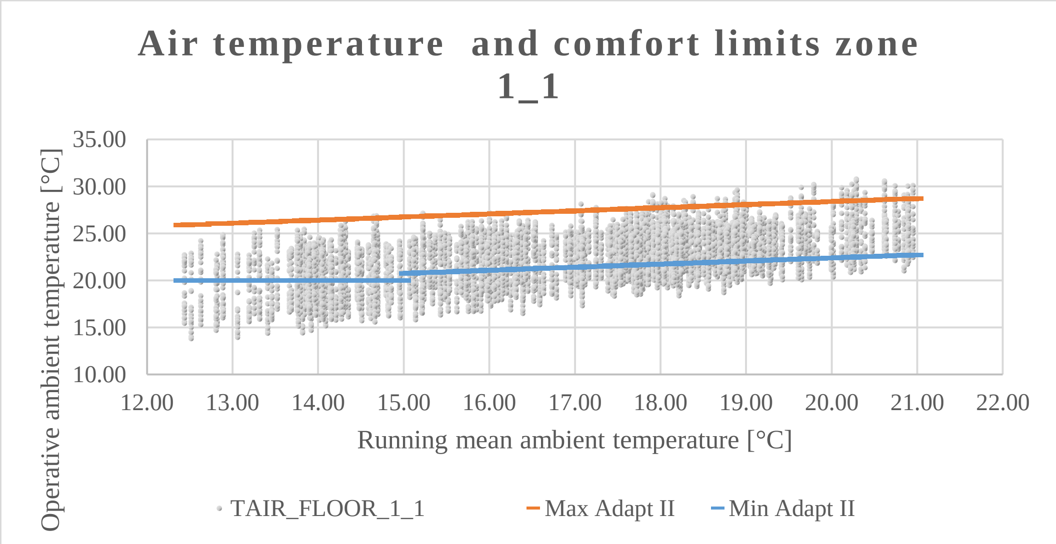


Figure 122: Operative ambient temperature of the zone 1_1 (restaurant) in relation to the outside mean ambient temperature for a shading of 70%

This situation stress the necessity to use the shading devices only during the hot months of the year, or at least partially in order to control just visual discomfort caused by glare.

2.7. Technological solution adopted

After having exposed the different analysis that have been carried out in order to determine a suitable building envelope technology for a low-rise mixed-use building located in Mexico City; it has been determined that the best solution, for this project is:

- Vertical closure elements build with problock cement based blocks of 12 cm width with an external layer of 5 cm of extruded polystyrene.
- Green roof.
- Double glazing windows.
- Shading devices operated by users.

3. *Solar analysis and shading design*

3.1. Horizontal and vertical fixed fins

The sun path diagram gives the information of solar angles for different times of the day and different moths of the year for particular latitudes. With this tool, it was possible to see how the use of overhangs and vertical fins could help to create shade over the building, and most importantly, over the glazed surfaces.

As it has been said before, the most critical months in terms of sun exposure and high temperatures are the ones that correspond to the spring and early summer seasons, due to their lack of rainfalls. In the next table are presented the different angles of azimuth and altitude of the sun, for specific days of the most critical 4 months of the year:

	22 of March		22 of April		22 of May		22 of June	
Local	Azi. [°]	Alt. [°]	Azi. [°]	Alt. [°]	Azi. [°]	Alt. [°]	Azi. [°]	Alt. [°]
7:00	91.3	4.0	80.8	9.7	72.8	12.6	69.2	12.4
7:30	93.8	11.1	83.1	16.7	74.7	19.4	71.1	19.0
8:00	96.4	18.1	85.3	23.8	76.5	26.3	72.6	25.8
8:30	99.3	25.1	87.6	30.8	78.1	33.2	74.0	32.5
9:00	102.6	32.0	89.9	37.9	79.6	40.1	75.1	39.4
9:30	106.3	38.9	92.6	45.0	80.9	47.1	76.0	46.2
10:00	110.9	45.6	95.6	52.0	82.1	54.1	76.5	53.1
10:30	116.6	52.1	99.5	59.0	83.2	61.1	76.5	60.0
11:00	124.3	58.2	104.9	66.0	84.0	68.1	75.6	66.8
11:30	134.9	63.7	113.5	72.6	84.4	75.2	72.7	73.6
12:00	149.9	68.0	130.8	78.7	83.0	82.2	63.9	80.2
12:30	170.0	70.5	171.0	82.3	41.9	89.0	24.9	85.5
13:00	-167.5	70.3	-140.5	80.3	-82.0	83.6	-50.5	83.5
13:30	-147.9	67.6	-117.8	74.7	-84.3	76.6	-69.2	77.3
14:00	-133.5	63.1	-107.2	68.2	-84.2	69.5	-74.4	70.6
14:30	-123.3	57.5	-101.0	61.3	-83.4	62.5	-76.2	63.7
15:00	-115.9	51.4	-96.8	54.3	-82.4	55.5	-76.6	56.8
15:30	-110.3	44.9	-93.5	47.3	-81.2	48.5	-76.3	50.0
16:00	-105.8	38.1	-90.8	40.2	-79.8	41.5	-75.6	43.1
16:30	-102.2	31.3	-88.3	33.1	-78.4	34.5	-74.6	36.3
17:00	-99.0	24.3	-86.0	26.1	-76.8	27.6	-73.4	29.4
17:30	-96.1	17.3	-83.8	19.0	-75.1	20.8	-71.9	22.7
18:00	-93.5	10.3	-81.5	12.0	-73.2	14.0	-70.3	16.0
18:30	-91.0	3.2	-79.2	5.0	-71.1	7.2	-68.3	9.4

Table 55: Sun path for the hottest months of the year.

With this information, it is possible to check at which moments of the day the proposed vertical and horizontal fins are fulfilling its purpose.

It has to be stated at this point that the architectural design contemplates the use of three lengths for the fins (equal length for horizontal and vertical). The main idea is to check which the required length is for them for a window of 1.6 meters height and a 5.4 meters length:

Hours shaded by a 50 cm fin.
Hours shaded by a 120 cm fin.
Hours shaded by a 180 cm fin.

Local	North façade			South façade		
	Hor. [m]	Vert. [m]	Fins L [m]	Hor. [m]	Vert. [m]	Fins L [m]
7:00	7.16	2.09	2.09	22.88	0.12	0.12
7:30	4.54	1.88	1.88	8.16	0.37	0.37
8:00	3.24	1.72	1.72	4.90	0.62	0.62
8:30	2.45	1.58	1.58	3.42	0.90	0.90
9:00	1.90	1.46	1.46	2.56	1.23	1.23
9:30	1.49	1.37	1.37	1.60	1.61	1.60
10:00	1.16	1.32	1.16	1.25	2.10	1.25
10:30	0.88	1.32	0.88	0.96	2.75	0.96
11:00	0.64	1.41	0.64	0.71	3.75	0.71
11:30	0.42	1.71	0.42	0.50	5.48	0.50
12:00	0.22	2.69	0.22	0.32	9.49	0.32
12:30	0.03	11.85	0.03	0.22	34.73	0.22
13:00	0.18	4.53	0.18	0.27	24.81	0.27
13:30	0.36	2.09	0.36	0.44	8.77	0.44
14:00	0.56	1.54	0.56	0.64	5.22	0.64
14:30	0.79	1.35	0.79	0.88	3.61	0.88
15:00	1.05	1.31	1.05	1.15	2.67	1.15
15:30	1.34	1.34	1.34	1.48	2.03	1.48
16:00	1.71	1.41	1.41	1.89	1.56	1.56
16:30	2.18	1.51	1.51	2.63	1.19	1.19
17:00	2.84	1.64	1.64	3.54	0.87	0.87
17:30	3.82	1.80	1.80	5.14	0.59	0.59
18:00	5.58	1.97	1.97	8.80	0.34	0.34
18:30	9.66	2.19	2.19	28.62	0.10	0.10

Table 56: Required length for fixed fins for different times of the day

The 50 cm fins are located over all the windows facing north and south providing full shade for two hours at midday. 120 cm is the length of the horizontal overhang located at the rear façade of most of the designed buildings, which acts as a corridor that gives access to the different dwellings. For the specific case of the building studied, it is located facing south, giving full shade to the spaces behind for almost 5 hours. Finally, 180 cm is the length of the cantilevers that serve ass balconies for the lofts and apartments that face the main public square; in this case full shade is provided during all day, protecting efficiently from direct sun exposure the double height glazed surfaces.

3.2. Operable outdoor awning blinds

It is important to take in mind that for the east and west facades of the buildings it is quite difficult to provide shade with fixed vertical or horizontal fins without blocking too much the sunlight or external views. A solution for this problem is to use operable outdoor waning blinds. This devices will be installed not only on the mentioned façade, but also on the ones facing north and south due to the following advantages:

- Possibility to give to the users the control the amount of shade or sunlight they want on their indoor spaces.
- Ability to provide shade in the hours in which the vertical and horizontal fins are not enough, in order to lower the indoor air temperatures during the warm days.
- Flexibility to permit the entrance of sunlight on overcast days or to heat up the buildings on winter.
- Sense of privacy for the users of the buildings.
- Opportunity to provide character, style and movement to the building façade.

Figure 123: Example of operable outdoor awning blinds

For the awning blinds, the researchers have chosen the Mermet® fabrics, which are flexible printable supports that can be structured and personalized using different painting processes, and fulfil as well all of the building's requirements regardless of its use (office building or residential building, shops, museums, exhibition halls, hotels, restaurants, etc.).

Figure 124: Example of printable Mermet® fabrics

This specific kind of fabric produced by Mermet® can be found in 48 different colors and help to control heat and glare by reflecting up to 90% of the solar radiation. It has the following technical characteristics:

- Composition: 42% Fibreglass - 58 % PVC
- Weight: 520 g/m² ± 5%
- Thickness: 0.75 mm ± 5%
- Visible transmittance: 10-16 %
- Internal solar factor (gv=0.59) gtot: 0.40 – 0.44
- External solar factor (gv=0.59) gtot: 0.16 – 0.19

3.3. Visual comfort: natural daylight and glare

Sunlight is defined as the direct unobstructed light coming from the sun. Daylight is a combination of direct sunlight, sunlight diffused through clouds, and sunlight reflected from the water, ground, plants and other objects (Jankovic, 2012).

Human light not only has an aesthetic or emotional meaning for humans, but it also stimulates the creation of a hormone called melatonin, able to regulate the body's biological clock and make us sleep when produced.

As a natural renewable resource, daylight can reduce considerably the energy consumption in buildings. It also influences human wellbeing by making indoor spaces heathy and enjoyable. It is therefore important to design buildings that maximize the use of light (Jankovic, 2012).

The main objective of daylight design is to maximize visual comfort and minimize energy use. Daylight can be measured by the following units:

Candela: is the luminous intensity, in a given direction of a source that emits monochromatic radiation of frequency 540 x 1012 hertz ant that has a radiant intensity in that direction of 1/683 watt per steradian.

Lumen: is the unit of measurement of luminous flux, is a rate of energy flow per unit of time per unit of area across a surface, 1 lm= 1 cd.sr.

Lux: is the unit of measurement of illuminance, is the luminance per unit of area lx=lm/m2.

Regarding visual comfort it has to be said that the human eye is adaptable to illuminance ranging between 100,000 lx and 0.1 lx, but it needs some time to adjust. Simultaneous occurrence of radically different illuminances will cause some discomfort. Poor lighting conditions for specific tasks will cause discomfort also. In order to provide visual comfort in internal environments, suitable illumination must be provided, avoiding different illuminances (glare).

The fundamental aspects to be considered when designing a lit environment are:

- Distribution of luminance.
- Illuminance.
- Uniformity of illuminance.
- Glare.
- Light directioning.
- Color temperature.
- Adverse health effects

Considering that daylight is the best and easiest way to achieve visual comfort; on this project, the first four aspects are considered of fundamental importance when dealing with natural lighting.

3.3.1. Distribution of luminance

The distribution of luminance on a space conditions the adaptability of the human eye, which ends up affecting the visibility of a task. Luminance is the energy emitted or reflected towards the eye of the observer (measured in cd/m2).

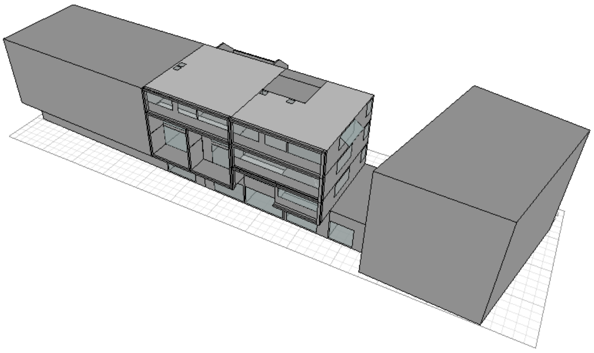
The distribution of luminance can affect also the visual comfort. For This reason the following circumstances must be avoided:

- Too high luminance that can cause glare.
- Too high contrast of luminance, which can cause fatigue to the eye.
- Too low luminance or contrasts of luminance which might create a poor environment.

An acceptable equilibrium of luminance between the task and the surrounding space can be 1:20 between the light source and the environment, with a maximum acceptable contrast of 1:40. However, it must be said that luminance lower than 1 cd/m2 are saw as black objects, and those higher than 500 cd/m2 are seen as dazzling (Comité Español de Iluminación, 2005).

In order to assess the distribution of luminance inside the building object of this research, a model was realized in Ecotec. The indoor luminance distribution was tested with Desktop Radiance tool for Ecotec in one of the apartments of the last floor, in a space that has windows towards the north and west.

The luminance was tested at 21st of January with a clear sky, during the sunset time when light enters almost horizontally thought the west window.



The first image that can be seen coming up next is the case in which the operable awning blinds are up. It is possible to see how the windows have excessive levels of light reaching the 2000 cd/m2, especially in the areas where it is possible to see the sky. This result is showing how it is important to shade the windows in order to prevent glare.

The second image corresponds to the case in which an awning blind with a visible transmittance of 16% is partially lowered in the west window. It is possible to see how with the help of this fabric the levels if illuminance decrease in almost 75% to values lower than 500 cd/m2. This demonstrates that with the use of blind awnings, people inside the building can adapt their spaces to the external environmental conditions, in order to reach visual and thermal comfort without the need of external energy sources.

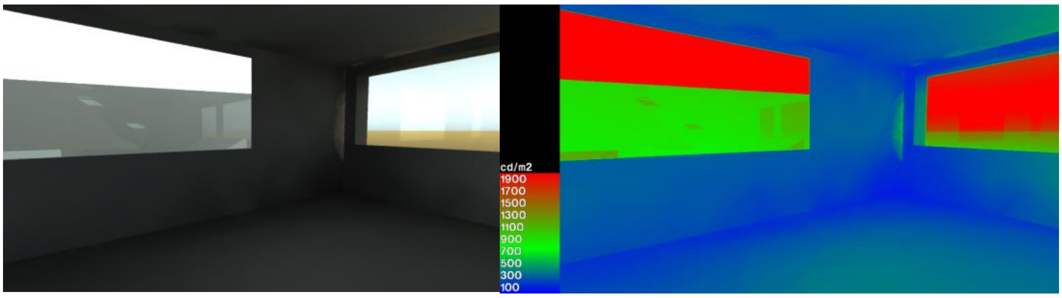


Figure 125: Distribution of luminance without shading devices.

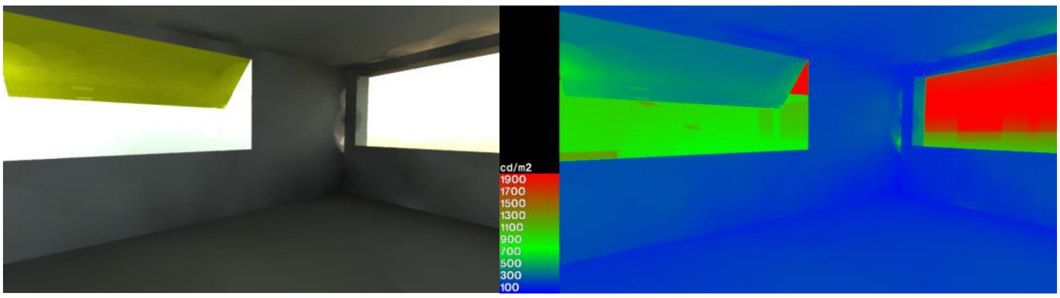


Figure 126: Distribution of luminance when using external awning blinds.

3.3.2. Illuminance requirements

Illuminance and the way it is distributed in a space has a great impact in the way a person perceives and realize a visual task in a fast, secure and comfortable way. (Gobierno del Distrito Federal, 2004) Has stipulated a set of minimum levels of illuminance for indoor spaces according to their use:

- Residential: 50 lux.
- Commerce: 250 lux.
- Offices: From 100 lux to 500 lux depending on the necessity to appreciate details.
- Restaurants: 50 lux to 250 lux in the dining area, 200 lux in the kitchen.

Using the Desktop radiance, the researchers have tested the distribution of Illuminance inside the upper floor of the restaurant on a cloudy winter day at three different hours. The results can be seen in the following images.

It is notable that even for a cloudy day the restaurant is a lit space. Looking at the images that correspond to the test at 9.00 and 13.00, it is possible to see that almost everywhere the levels of Illuminance are above 250 lux. Instead, for the image of 17.00 the values are just around the 250 lux, which is in any case enough, considering the minimum required for the norm.

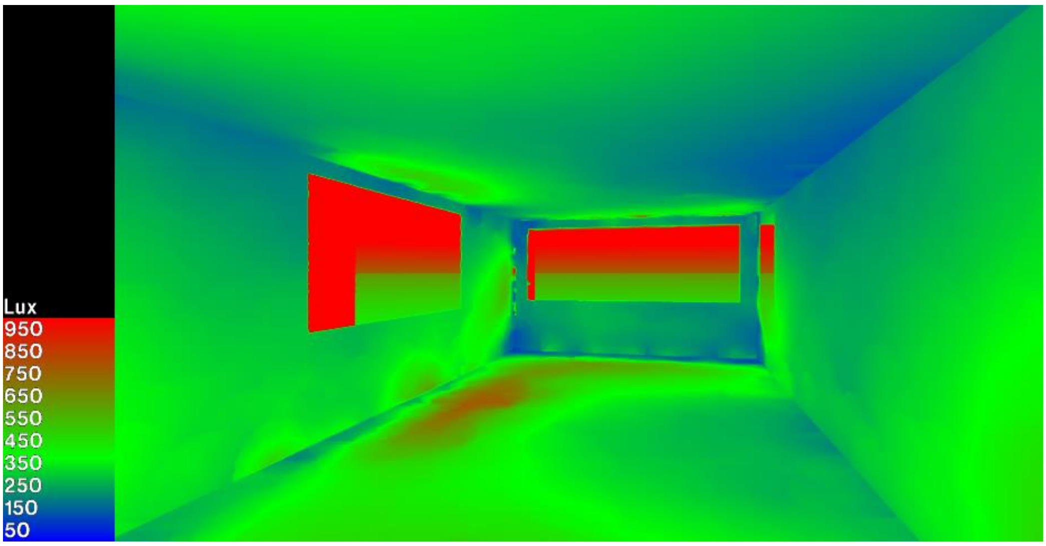


Figure 127: Illuminance of the restaurant at 9.00 during a winter cloudy day.

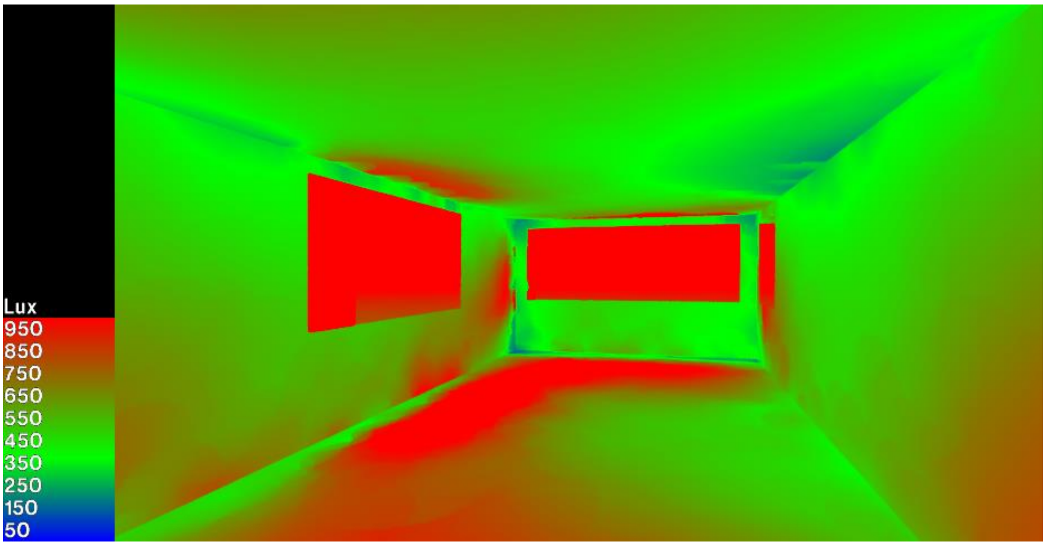


Figure 128: Illuminance of the restaurant at 13.00 during a winter cloudy day

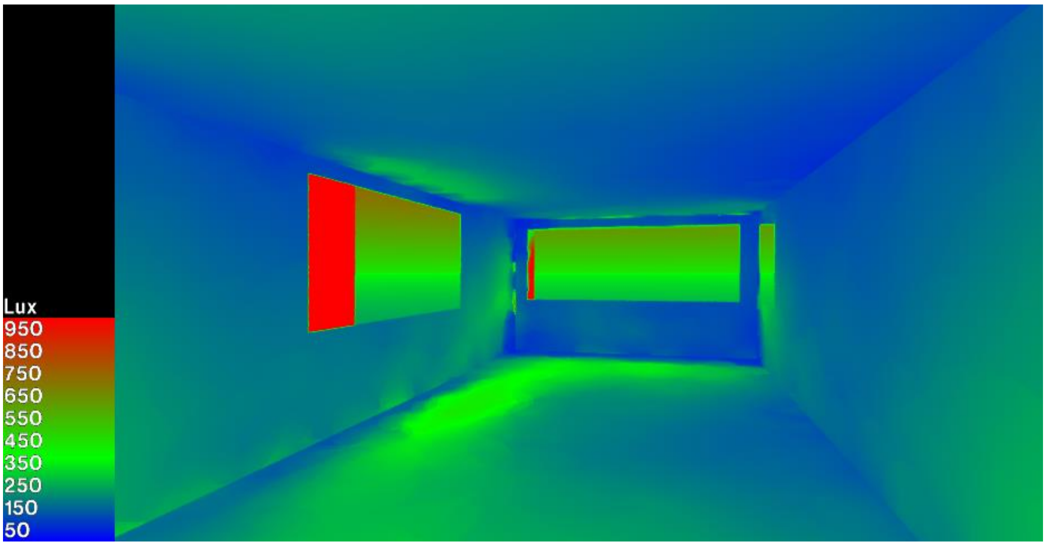


Figure 129: Illuminance of the restaurant at 17.00 at a winter cloudy day.

4. Domestic hot water

The design and optimization of the solar thermal power installation was realized using the software T * SOL®. As in the free trial version is not allowed to use the climatologic data of Mexico City, the city of Kinshasa in Democratic Republic of the Congo was chosen, due to its similar total annual global irradiation.

Taking into account that it is not possible to realize the calculation directly with the real location of the project, it was decided to perform an online solar calculation of the same software provider, where Mexico City is available (Valentin Software GmbH, 2105).

The analysis was performed using both software in order to compare them, and see if it was accurate to use another location with similar annual global irradiation. A scheme of the domestic hot water model is presented in the next image:

The system was designed for an average daily consumption of 160 l/person, a volume flow rate of 40 l/h/m² of solar panel. The desired domestic hot water temperature was set at 50°C in order to reduce the risk to have legionella in the storage tank. (Lévesque, Lavoie, & Joly, 2004) States that the risk to have that bacteria in the storage can be lowered by setting the heaters at 60°C, but with a hot water temperature at the ending tap of 49°C.

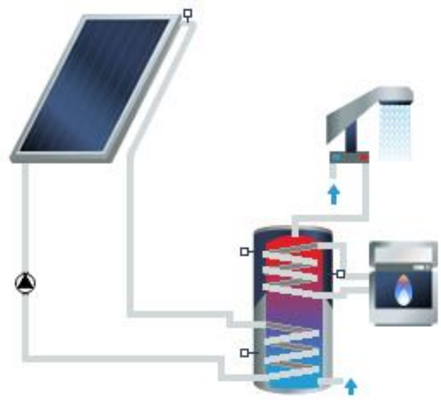


*Figure 130: Scheme of the DHW model in T * SOL®*

The collectors will be tilted at 20° from the horizontal plane facing the south. As it has been found that for a fixed inclination, in this way they are having the maximum efficiency all along the year.

As the on-line solar calculator is not allowed for a large number of people. It was decided to take as reference 10 people, and then extrapolate them for the requirements of the project. The system for this amount of people requires a generic flat-plate collector area of 6 m², with an angle of tilting of 20°, for a domestic hot water temperature of 50°C and a storage tank of 1000 liters. The obtained results for this first approach are:

- Solar radiation onto the tilted surface of the collector absorber surface, over one year: 11.854 kWh/year.
- Solar system's available energy: 6.002 kWh/year.
- Percentage of the total energy requirement produced by the solar system (solar fraction): 89 %.
- CO^2 emissions avoided by use of the system: 1584 kg/year.

For the analyzed building of this chapter which corresponds to 4 residential units, 1 office, 3 shops and a restaurant, the required capacity of the system was set for 40 people. From the first approach, it is possible to say that the system will require 24 m^2 of flat-plate collectors and a storage tank of 4000 liters.

When using the software T * SOL®. The chosen solar collector was the Genersys 1000-4. It is a flat-plate, vertically-mounted type collector without collection pipes, intended for applications in smaller systems equipped with circulating pumps. It consists of a one-piece forged metal casing to which safety solar glass is fixed by means of a frame made from non-corrosive aluminum profile. The technical characteristics of this solar collector are:

- Gross surface area: 2.03 m2
- Absorbing Surface: 1.76 m2
- Linkage dimension: 1040 x 2040mm
- Cover glass: Safety solar glass 4mm thick.
- Solar absorptivity: αM1.5 Min. 0.96
- Thermal emissivity: ε82oC Max. 0.14
- Optical efficiency: 81%
- Specific heat capacity: 5670 Ws/(m^2K)

The one-way length of the piping was supposed as 25 m for the inside piping, and 2 m for the external one. The minimum cold water temperature was assumed as 7°C in February and the maximum as 12°C in august.

From the following results of the annual simulation done with the second approach it was possible to see that it was quite accurate to use the location of Kinshasa for the dynamic simulation:

- Installed collector power: 21.28 kW.
- Number of flat-plate collectors: 15.
- Installed solar surface area (gross): 30.41 m^2.
- Irradiation on to collector surface (active): 1546.74 kWh/ m^2.
- Energy delivered by the collectors: 715.04 kWh/ m^2.
- Energy delivered by the collector loop: 651.77 kWh/ m^2.
- DHW heating energy supply: 16.77 MWh
- Energy from auxiliary heating: 2122.3 kWh
- Natural gas savings: 2890 m^3.
- CO2 emissions avoided: 6111.41 kg.
- DHW solar fraction: 88.6%
- System efficiency: 40.2%
- Dual coil indirect hot water tank of 4 m^3.

In the next graph it is possible to see how is the behavior of the system in terms of savings of natural gas in m3, CO2 emissions avoided in Kg, solar fraction, system efficiency, solar contribution to domestic hot water in MWh, energy auxiliary heating in MWh

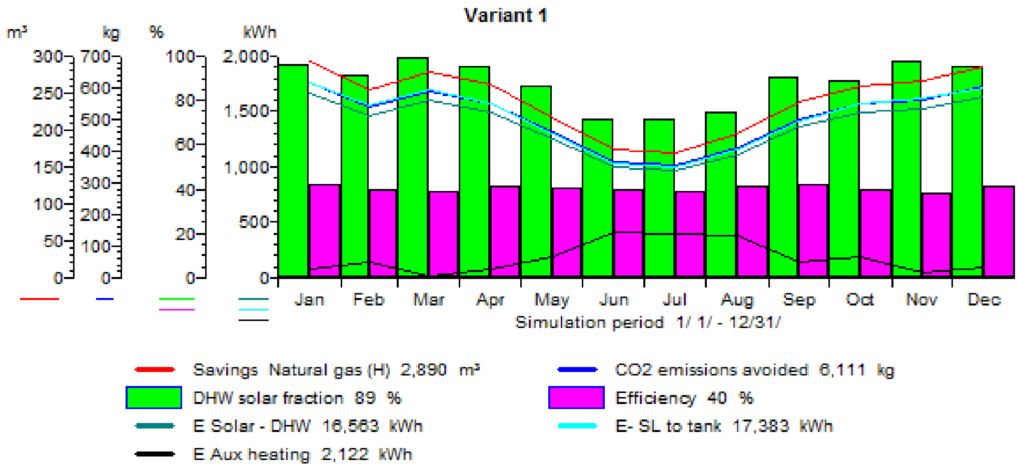


Figure 131: General results of the dynamic simulation for the dimensioning of the solar thermal panels.

The next graph describes the solar energy consumption as a percentage of the total consumption, it is possible to see that is on summer when the solar energy is at its lowest levels, due to the high cloudiness that characterizes this period.

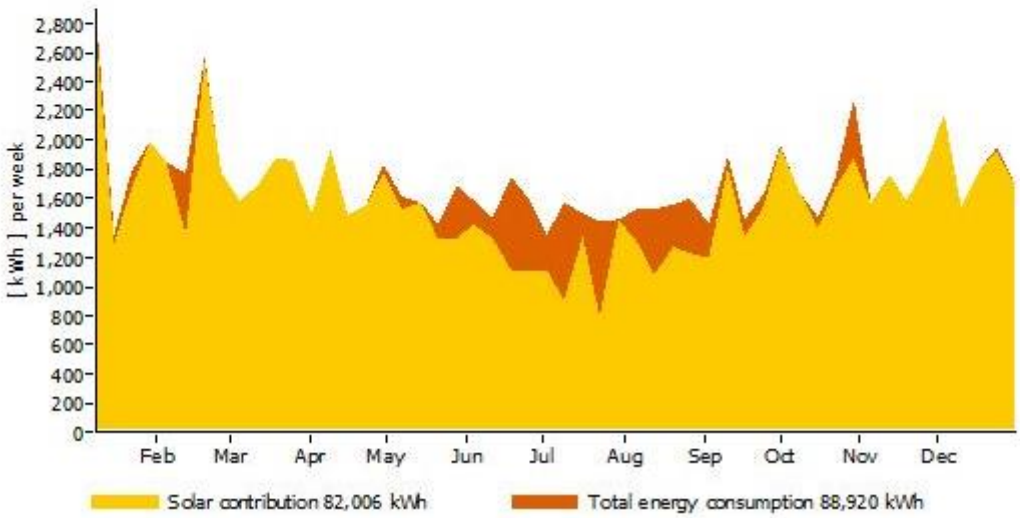


Figure 132: Solar energy consumption as a percentage of total consumption.

The result of the energy balance of the DHW system are presented in the next table:

1	Irradiation on the collector surface	41,252 kWh
1.1	Optical collector losses	11,345 kWh
1.2	Thermal collector losses	10,837 kWh
2	Energy from collector array (before piping)	19,070 kWh
2.1	Solar energy to storage tank	17,383 kWh
2.5	Internal piping losses	1,552 kWh
2.6	External piping losses	136 kWh
3.1	Tank losses	2,735 kWh
6	Final energy	3,859 kWh
6.1	Supplementary energy to tank	2,122 kWh
6.5	Electric element	0 kWh
9	DHW energy from tank	16,773 kWh

Table 57: Energy balance of the DHW system.

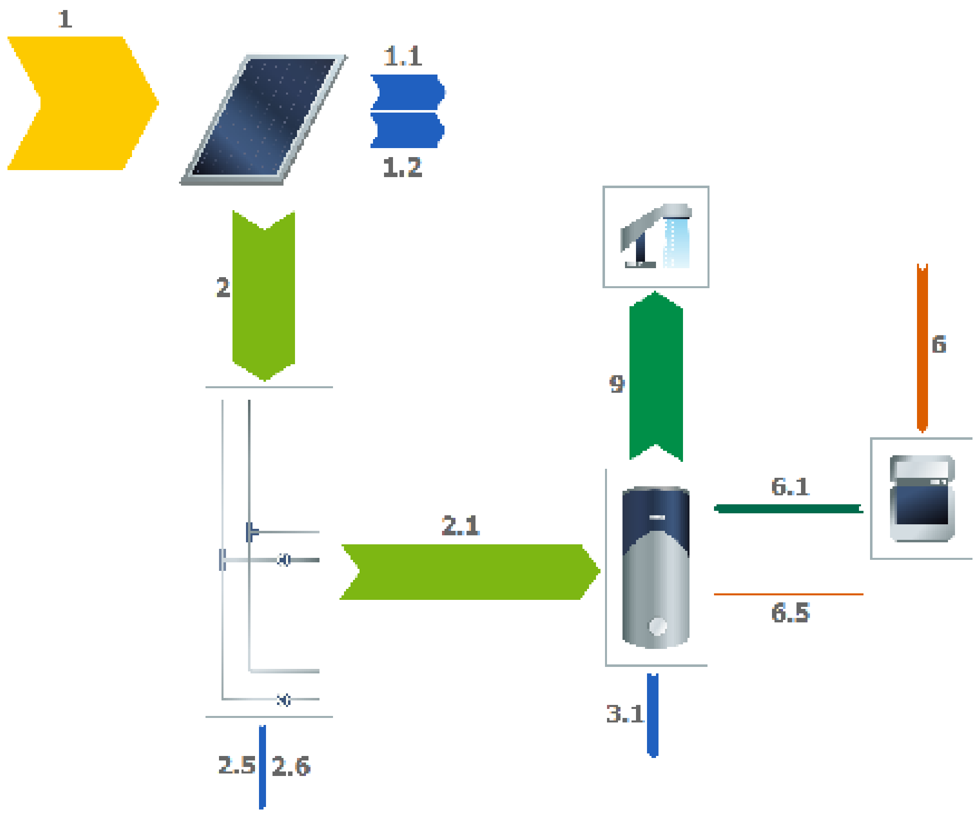


Figure 133: Scheme of the energy balance of the DHW system

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