The recovery of the public space in a context of high density: Implementation of Barcelona's case

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Abstract

In the last couple of centuries, Europe has faced rapid urbanization of cities with accommodating the incoming population from rural areas. Although metropolitan regions represent a tremendous take on economic growth, they are compromising the future generations to meet their own needs; hence, today's cities are not sustainable. One of the aspects diminishing the quality life of city inhabitants is the scarcity of public space in the context of high-density population. This space is occupied by cars, which left out the citizens from the streets and contributed to the unhealthiest environment conditions. This thesis focuses on the study of public space insufficiency in Barcelona's compact city, where this critical situation is linked to the misinterpretation of Cerdà's expansion plan. The thesis presents the Superblock implementation case in Barcelona, as the solution examined to gain back these spaces once lost. Nonetheless, this new urban model is a pretentious project; each Superblock's sustainability achievement should be meaningfully evaluated to prioritize those areas most in need. It is considered decision-making tools, in specific the MIVES multi-criteria analysis, as the methodology suggested to assess the sustainability of the proposed developments. This methodology helps set an order of the alternatives contemplated based on a sustainability level. Thus, it provides a desirable prioritization list of the Superblocks that should be implemented first.

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1. Introduction

The concept of a City is considerably old; however, it was not after the Industrial Revolution that cities emerged as the centres of population growth and productivity. In 1950 the percentage of the population living in cities was around 30 percent; it increased to 55 percent by 2018 (Department of Economic and Social Affairs, 2018). The possibilities of employment, the easy access to goods and services, and the wealth creation capacity are under the main reasons for the city’s magnetism. This demographic escalation altered the way of living, working, and traveling.

Despite the gimmicks of the cities, when space's distribution is not done correctly, the counter-effects of urban life cannot be neglected. Sedentary lifestyle, environmental pollution, scarcity of green and public spaces have a tremendous repercussion on health and mortality. The analysis carried out by the Global Burden of Disease of 2013 attributed almost 5 million deaths to air pollution (Forouzanfar *et al.*, 2015). However, new studies by the European Health Journal estimate the global mortality due to ambient air pollution at 8.79 million in 2015 (Lelieveld *et al.*, 2019). In a depth examination of Barcelona, the rate of premature mortality related to environmental and physical activity factors is of 20 percent each year (Mueller *et al.*, 2017).

Lancet and University College London Institute for Global Health Commission declared climate change as the most significant global health threat of the 21st century (Costello *et al.*, 2009). All issues mentioned representing an enormous, demanding challenge that can easily be linked to city's urban and transport planning of cities. The influence of cars over city planning, where the non-presence of the automobile is barely unimaginable, is highly responsible for the sedentary life and high levels of environmental pollution. Public space is devoted to cars, limiting access to other purposes apart from transport infrastructures. Nevertheless, the rising demand for a functional transport system is quintessential for economic growth.

It is clear the need to correct the equilibrium of public space use. Space must be divided to assist as the common ground for social and cultural activities and maintain the flow channels. The construction of culture is mainly built on the streets complemented by squares and markets acting as meeting points. Thus, the mobility must deviate towards a public and active eco-friendly model, efficiently enough to stimulate the private users to change their means of transport. It is the only solution for the coexistence of the private and public use of the space.

A big personality in ecological urbanism for the case in Barcelona is Salvador Rueda, director of the Urban Ecology Agency of Barcelona. He defined in great detail the principles of the ecosystem urbanism. The concept acquired importance as the city became the natural habitat of humankind. However, the city ecosystem of a city is far from being comparable to a natural one; hence, it needs a particular ecological urban system.

This idea determines to fight with the proper tools for the challenges of the new century. The main ideas can be summarized on six theoretical variables named “six Ds” as all words start with the letter D. These variables are density, diversity, design, destination accessibility, distance to transit, and demand management (Ewing and Cervero, 2010). For the case of Barcelona, it translates into the Superblock model, a fitting solution to endeavour the incoming threats of climate change, poor living standards, and other problems of today’s cities.

A compact city like Barcelona has a high population density, with good destination accessibility and great diversity. Like any other typology, it has its strengths and flaws. However, compact cities have tremendous potential to shift towards a sustainable city. The coalescence of diversity and density reduces the travel distances as the different destinations are closer to their origins. With the proper urban design, it would encourage civilians to use other systems of transport rather than private cars, or even better to walk. The practical strategies applied by a handful of cities like Oslo, Hamburg, or Helsinki are to reduce car usage by several policies restricting the use of it and, by exchange, invest in cycling infrastructure and pedestrianize their streets (Nieuwenhuijsen and Khreis, 2018).

Along with these mechanisms of the ecosystem urbanism, Barcelona is trying to implement the so-called Superblock model. The objective is to recover the public space, that car once took from its inhabitants, by enhancing the characteristics of a complex city through the definition of partly independent urban cells within the city, aiming to obtain the desired sustainable city of the future, the key to achieving a high-quality life.

Thus, this thesis focuses on the case of Barcelona, particularly the Superblock urban model implementation. Understand what bases the model was designed, how this can bring back the public space to its citizens, and how the big city's adverse effects are reduced without losing mobility. Moreover, different alternatives will be studied to discern the benefits of each aspect of the model, and what manner the location of the alternative influences it, to pose a decision-making model prioritizing the alternative to implement.

1.1. Background

A city is constructed balanced on the disposition of private and public space. The street is the element that delimits the private and defines the public space, occupying between 25% to 40% of it. The primary function of streets is the mobility system that connects urban function locations; it constructs a network that enables one to go from one destination to another. Despite being their reason for existence, it does not mean it is the only purpose, there are other functionalities where today’s information and technology era may seem irrelevant, but socially speaking, they are indispensable. Amongst these activities, streets serve as a space for social relations built on face-to-face interaction, cultural transmission, and the generation of open space in urban areas that facilitates it. Nevertheless, for the time being, streets represent 60 percent of the public space in Barcelona, where 85 percent of the street is dedicated to mobility (Rueda, 2017).

The amount of space devoted to the cars lies in the consumer preference over the modes of transport, which at the same time the inclination upon cars is built due to shape and land use characteristics focus (Nieuwenhuijsen and Khreis, 2018). This issue is not new; for instance, the last few mayors of Barcelona reduced parking spots in public areas. The actual number of parking spaces has been reduced to 110 529, a 44% reduction from the highest number in 2004 of 197 533 parking spaces (fig. 1-1)(Márquez Daniel, 2019).

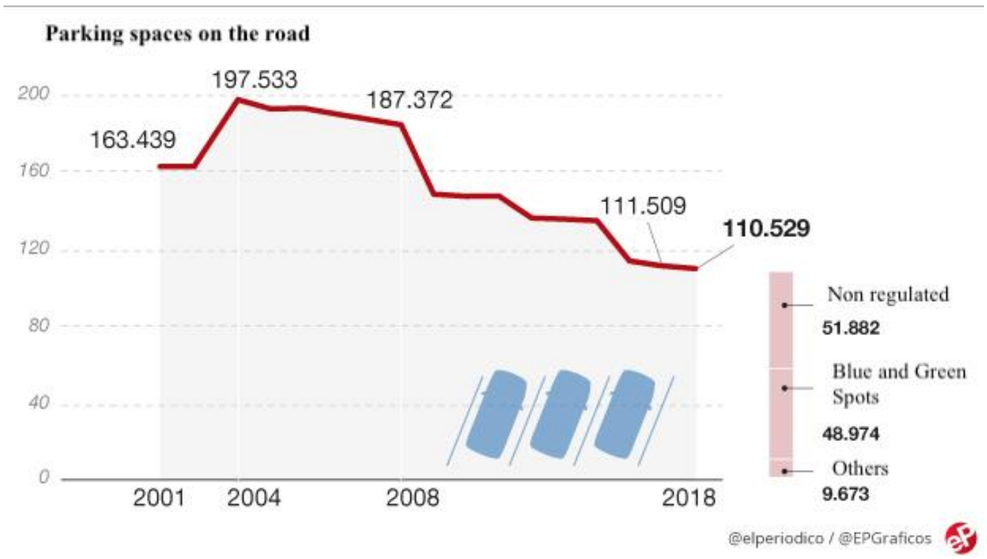

Figure 1-1: Parking spots on the streets of Barcelona. (elPeriodico, 2019)

In 2017 from the total amount of travels, internal-internal and internal-external, in the city of Barcelona, 24.6% were private modes of transport, and 67.7% of these travels were done using cars (fig. 1-2). Although the tendency shows a decrease in car-dependency, it is still far from 21% for 2018 proposed by the Urban Mobility Plan of Barcelona (Ajuntament de Barcelona, 2014).

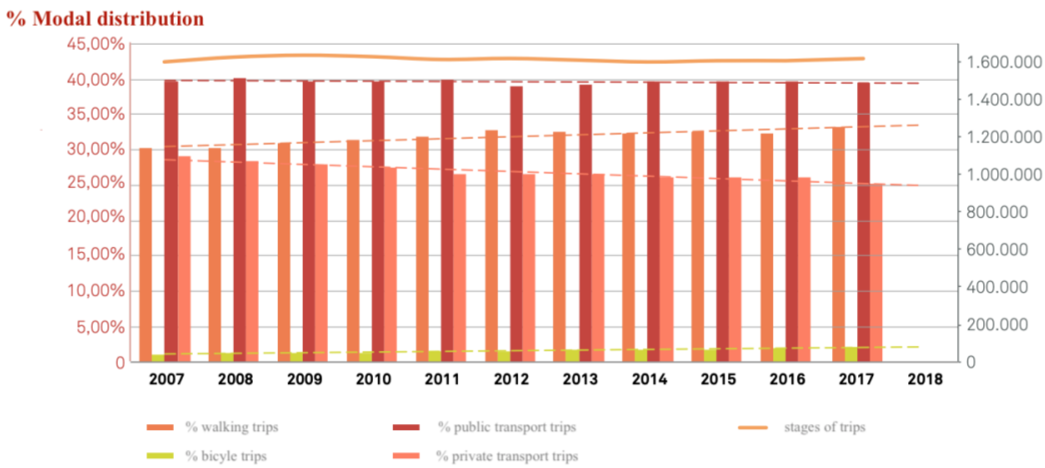

Figure 1-2: Modal distribution over 10 years (Ajuntament de Barcelona, 2017)

These trends, prone to a more public and active way of transport, have become a challenging target for policymakers on urban transport systems. Barcelona’s new bus network is an example of this shift. The old network had 211,72 km of bus lanes characterised with 101 routes and 2590 stops. It was not until 2012 that the project named Nova *Xarxa de Bus de Barcelona* took off. This new network would introduce 28 high-performance bus lines: 17 vertical (sea-mountain), eight horizontal (Llobregat-Besos), and three diagonal. Maintaining 20 lanes from the old 63 networks.(Barcelona City Council & TMB, 2019). Straightening the arteries to take advantage of Barcelona’s street orthogonality., and avoiding meandering journeys as they slow down routes, making and overall faster, more comfortable, and more sustainable service. Next two figures (fig 1-3 & 1-4) illustrates the old and the new bus lanes:

Figure 1-3: Map of Barcelona's bus network

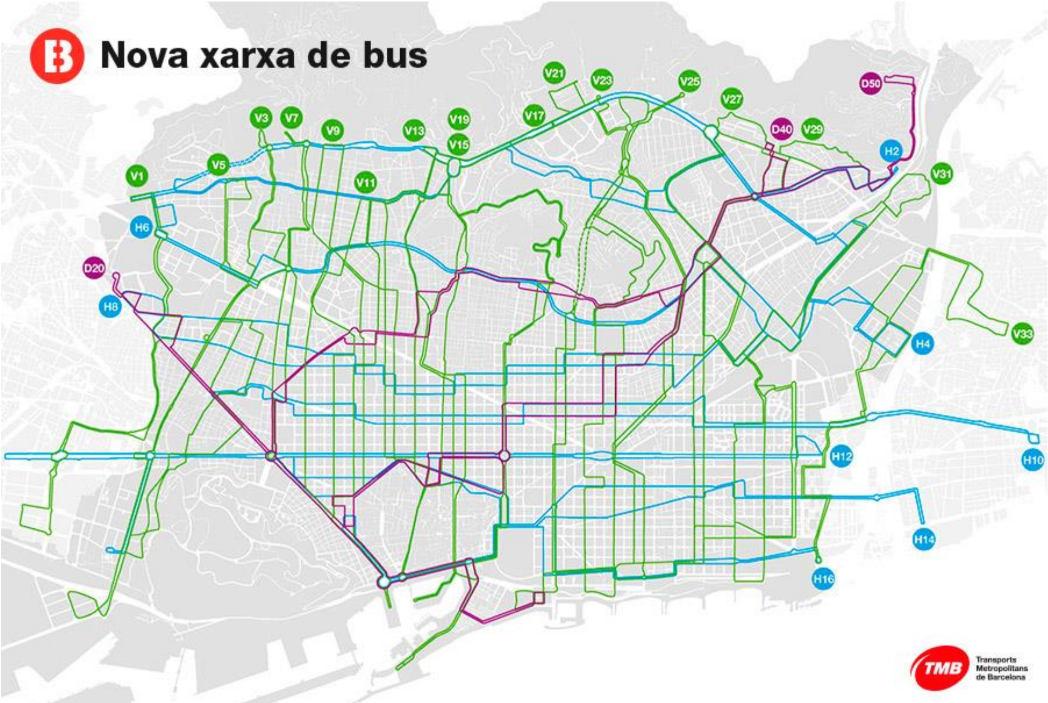

Figure 1-4: New bus network of Barcelona

A concept of importance for achieving sustainable urban models is the proximity of a spatial context (Marquet and Miralles-Guasch, 2014). Closer destinations to jobs, schools, and services, cut down the use of motorized transport for the benefit of walking or cycling. Barcelona is a compact city with tremendous potential to turn into a greener city. Reisi et al. (2016) studied different urban developments in Melbourne, which showed that a more compact development results in less car travel and, consequently, more sustainable transportation mode.

Following this path of greener cities and the appearance of technology as a means to an end, smart cities are another uprising concept that comprises all aspects mentioned using new technology to achieve the objectives. A project called mySMARTLife, initiated in December 2016, combined a consortium of 28 partners from 7 different countries to reduce greenhouse gas emissions, promote renewable energy resources and mobility to ascend the city living standards (Knieling and Lange, 2019). Amongst the cities involved, the case of Hamburg (Germany) promotes the e-mobility and to convert 40% of the city into the car-free city pedestrian zone within the next two decades (Nuwer, 2014).

1.2. Research motivation

One of the author's primary interest on the topic was the book *El Dominio Mundial: Elementos del Poder y claves geopolíticas* (Baños, 2018). After reading the book, the concern of how future cities will be able to absorb the incoming population, as it is foreseen to grow from an actual 55% to 68% by 2050 (United Nations, 2018), brought the first motivation to endeavour the research proposed. However, Europe already has a large population living in urban areas, but the conflict does not end there as Baños says:

« Problems do not go away once reached the city; new social deficiencies emerge (slums, unemployment, lack of resources, solitariness…). […] From 2008, there is a more urban population in the world than rural, and the tendency is to continue in the following decades. Hence, from the premise that a higher number of people suggest major inequalities, cities will be more conflictive. »

Thus, the curiosity shifted towards the enhancement of the living conditions, as the time of an apparent climate change, and the unflagging globalization accentuates the spread of viral diseases jeopardising citizens in congested areas.

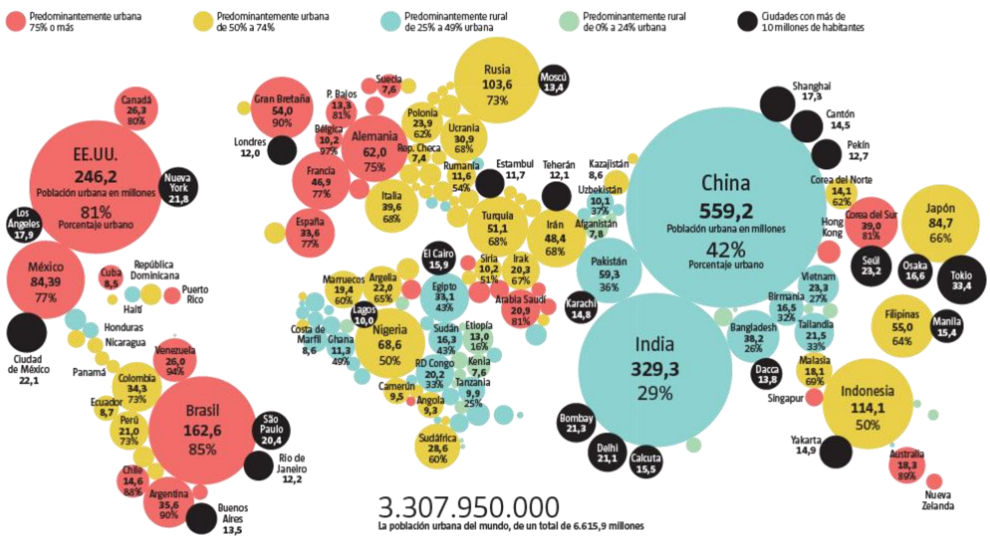

Figure 1-5: Urban map 20th century. (la Vanguardia)

Another philosophical driving force to study the recovery of public space is the dichotomy between private and public space. Although conceptually streets belong to the public domain, private vehicles occupy a massive extension of them. Therefore, streets lost their character of public space to become the spot for those who own a car. Also, they represent a burden to the eradication of pollution. The Superblock proposal of Salvador Rueda is an appealing idea that merges all previous concerns, hence evaluating the different alternatives in terms of the stated concepts that come out to be a fascinating job.

1.3. Objectives

This thesis aims to determine the sustainability level of public investment urban plans and provide a robust assessment on where to allocate the funds, so it delivers the most significant benefit.

To reach the stated goal of this thesis, the author has set up the following objectives:

- Examine the needs and benefits of the recovery of public space for the city inhabitant. Why there must be a change in urbanism approach towards smart ecosystemic urbanism.
- Discern the reasons behind the empowerment of the car over any other mode of transport. The influence of the transition from modern Barcelona urbanism of Barcelona to where it is today.
- Analyse the solutions proposed for the recovery of the public space and how this contributes to improving the living standards of situations with a high-density population.
- Determine decision-making models for the implementation of sustainable urban public projects, particularly for the Superblock program in Barcelona.
- Perform an analysis, with the help of the MIVES decision-making model, on a preselection of different Superblocks of Barcelona, to compare and prioritize the most beneficial alternative in terms of sustainability, and consequently the ones with the most significant pay off for the citizens.

1.4. Approach

The author's research purpose is to build an effective mechanism to designate public funding, in the current circumstances of tactical urbanism in the city of Barcelona, to those alternatives that contribute on a higher proportion to the recovery of the public space, determined by the level of sustainability contribution. Furthermore, a consequential approach is to propose the use of decision-making methodologies to optimize the use of capital on administration projects.

There is a relatively amount of methodologies used to make decisions on a wide variety of fields. Multi-criteria decision analysis and, in specific the MIVES multi-criteria approach, thoroughly described, later on, is the one considered to endeavour the study over the alternatives. The addition of the already functioning Poblenou Superblock added amidst the alternatives, is used to compare and guarantee the required accuracy of the outcome.

A handful of sources have been used to obtain the required data throughout the study of the different alternatives. Quantitative secondary data is the predominant character of information, such as density population, gross domestic product, green space, being the City Hall, and the Urban Ecology Agency of Barcelona, the principal information resource.

For boundary condition data used to homogenise each alternative's character, the two sources cited work in collaboration to elaborate a diagnostic report for each region. The household income, the density population, or the current sustainability level is gathered, form this report explicitly, to compute the homogenization coefficient. The values of municipal money investments are directly acquired from the City Hall report 2016-2019.

Then, the following sections use data from the same organizations, which develop each Superblock's action plan with detailed information from the works done to the new transport type of lines and the budget.

1.5. Thesis structure

The thesis is structured in two major divisions, a first more theoretically focused on urbanism and decision-making methodologies and the second one concerning the appliance of one of those methodologies on an ongoing plan of reshaping Barcelona’s mobility to recover public space for the citizens.

Firstly, the presentation of the progression of Barcelona’s Urbanism over the modern era sets a basis for figuring out how Cerda’s original plan's misinterpretation leads to a shortage of green and public space. So, the proposal of the Superblock model is analysed as a plausible solution. A final section in the matter of decision-making methodologies is posed to introduce the tools that will be used, moving onto the practical side of the thesis.

Secondly, the main body of the thesis is applying the MIVES methodology upon the Superblock model. The approach is adapted to harmonize the heterogeneity of the alternatives, following a similar structure to what Pujadas et al. (2017) did to apply the methodology to public investment prioritization. Then, it ensures a compelling comparison between the alternatives that have a major impact on sustainability in the different regions of Barcelona.

Finally, the conclusions discuss the reason behind the results from the methodology and a summary of the whole thesis, the possible reasons that contribute to the final ranking decision, the different outcomes from the sensitivity analysis, and how the high-density situation is addressed.

2. Theoretical (or model) framework

2.1. Barcelona's Urbanism

Urbanism is an antique field of study, but it was not until the Industrial Revolution that it had the means to achieve solutions to the global and systematic problems in cities and be conceived as the image of the modern contemporary cities (Baños, 2018). The work of *Ildefons Cerdà* in *La Teoria General de la Urbanización* in 1867, is named the first treaty in urbanism that marks the beginnings of urbanism as a science. Cerdà planned the rehabilitation and expansion project of Barcelona in 1859, known as the Eixample, that put the city as the pioneer of the modern urbanism. The magnificence of Cerdà's work relies on the acknowledgement of the pathologies in the old city and his active approach to solving these problems (Universidad Autónoma Metropolitana, 2004).

Through those years of industrialization, the old walled town of Barcelona experienced overnight population growth. This outrageous increment reaching to 859 inhabitants per hectare put Barcelona as one of the highest densified cities in Europe. Moreover, most impoverished hygienic living conditions lead to a dreadful rate of mortality. Influenced by this situation, one of the elements that would act as a backbone on Cerda's theory was the rehabilitation of the hygienic conditions. He studied in depth the quality of life inside the walled town, with the help of one of the first demographic statistics done by Laureà Figueroa. Once he understands the needs of a future Barcelona, Cerdà presents feasible solutions executed with a meticulous topographic study to where the city expansion will be located (fig. 2-1). Other dynamic forces to the extension project were the research of the house typology and the integration of the divergent modes of transport (walking, carriages, equestrian, and locomotion) (Tarragó, 1994).

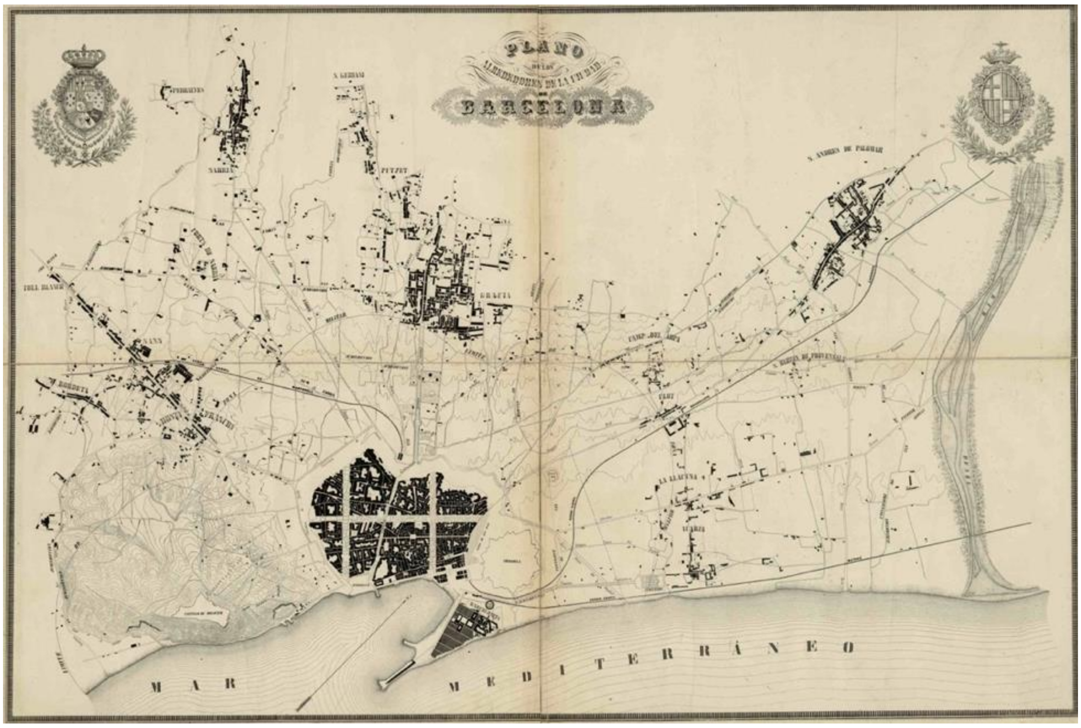

Figure 2-1: Topographic map. Source: Historical Archive of the City

Thus, considering the circulation in the future expansion, while the expansion of the new modes of transport is taking place, Cerda anticipates the problems it can engender by suggesting streets of 20 meters width and foremost the chamfers in the street corners. The proposal had a firmly established hierarchization of the streets, diversifying the street functionality to the number of transit modes, assigning a bigger space for pedestrian (loaded and non-loaded), carriages, and smaller spaces dedicated to steam engine machines (fig. 2-2) (Busquets Grau, 1992). For a future primary circulation, he planned the execution of three principal communication channels with a 50 meters width coming from the harbour and a fourth crossing every one of them. These three streets are renowned as *Paral·lel, la Rambla* (together with *Passeig de Gràcia, Major de Gràcia, Bonanova to Sarrià*) and *Meridiana,* with *Gran Via* linking road intersecting them.

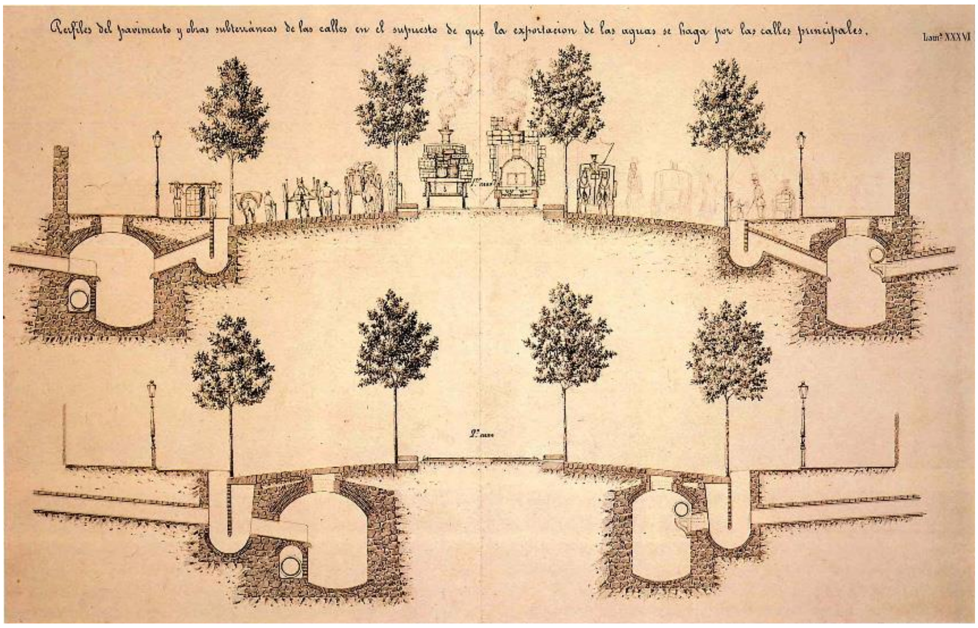

Figure 2-2: Street section with 35m width. Preliminary design. Source: History Museum of Barcelona City

The system of streets described reached the final unifying element by extending the project to the entire plain of Barcelona. The sketch (fig. 2-3) was based on a system of blocks with 113,3 meters wide and a street of 20 meters, a trace that gathers the benefits of a circulatory order, the flexibility of the orthogonal grid, and the sufficient amplitude to recover the habitable conditions.

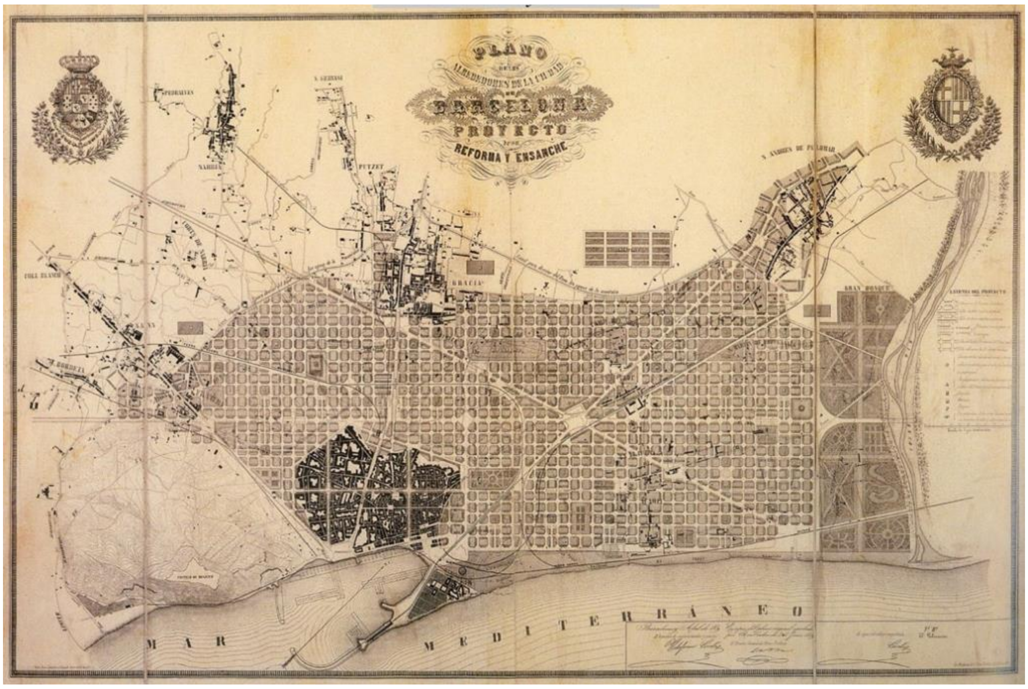

Figure 2-3: Cerda's original project. Source: History Museum of Barcelona City

Linking the concept of the importance of a diverse city with multiple functionalities on a nearby range, Cerdà's draw the interurban morphology with a consecutive subdivision, where each area of 5x5 blocks had the primary needs served (church, school, kindergarten, and squares). On a larger scale (10x10 blocks) included the presence of a street market, and the construction of two suburban parks appeared on a section of 20x20 blocks. In the next illustration (fig. 2-4), the purple blocks represent administrative buildings, the green areas are parks, the yellow ones are hospitals, and the graveyard is the red rectangle. Emphasize the theoretical character of this drawing from 1859 Cerda's project (Tarragó, 1994).

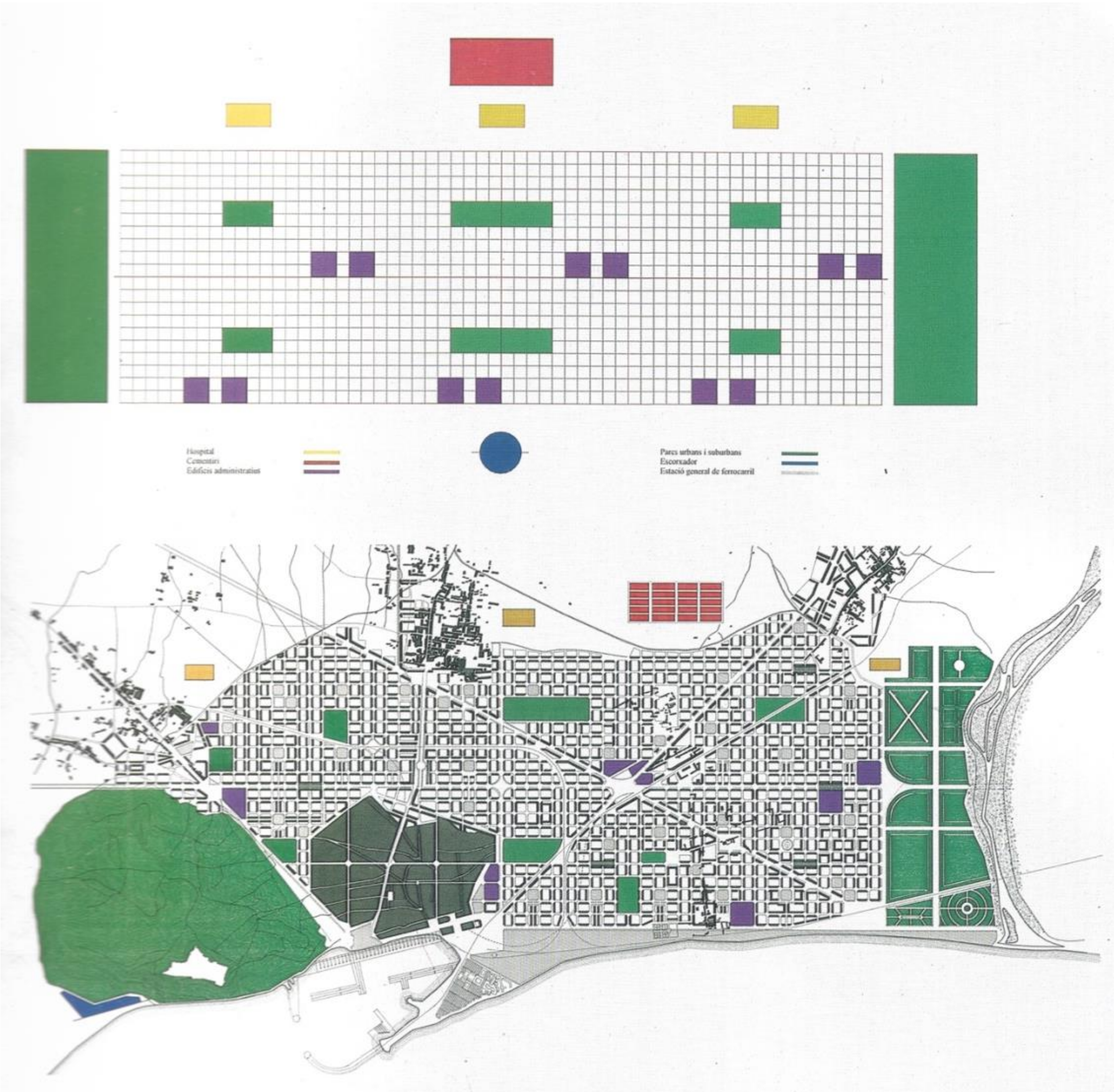

Figure 2-4: Theoretical scheme of 1859 city project (Tarragó, 1994).

The significance of this work represents the first urban approach from a sociological standpoint. The demographic and density problems, the statistical mortality rate due to the hygienic conditions, are for the first time being analysed. However, these issues did not eventually become the final plan, transmitting them to today's problems. The reason for this failure plan could be related to financial obstacles and a lack of a leading officer managing the constructions, which lead to an anarchic development modifying the urbanistic schemes. Aside from the reduction of public areas, a critical circumstance was the construction on the block's four façades, against the preliminary design of the assembly of only two façades, which represented an increase in the population density (Baldellou, 1978).

Over the next decades, the necessity to recover the original plan was striking, and a few proposals were made. One of the most known urban projects, revising the work of Cerdà was the *Pla Macià*, composed by the famous Swiss-French architect Le Corbusier and P. Jeanneret in collaboration with GATCPAC ("Grupo de Artistas y Técnicos Catalanes Para la Arquitectura Contemporánea"). Both architects, distinguished by their rationalism approached, saw their colleagues' work as an incredible opportunity to attempt merging two basic urban layouts, a general linear structure with a radial structure connecting Barcelona harbour with the historic corridor from *Vallès*. The plan had five essential points: zoning the city upon diverse functionalities with a major division on housing and industry; sanitation of the old town; limitation of Cerda's plan; linking the city to the sea; and new municipal ordinances. Similarly, to Cerdà's work, the *Pla Macià* was never reached. However, they set a concept of a new urban module of 400x400 meters (fig. 2-5), that would serve as a base for new plans (Tarragó, 1980).

Figure 2-5: Macià's Plan, 1932-1935.(GATCPAC, 1934)

This concept of a new unit cell was re-examined with the proposal of Antoni Bonet, the forerunner of the superblock concept. A year before the centenary of Cerda's work of 1859, he wrote a letter to the Director of urbanism and prestigious architectural journal (Bonet Castellana, 1958):

> *« Dear Friend: […] It came up to that Barcelona, to commemorate the centenary, constructs a housing sector in accordance with the truth Cerdà's Plan. […] Regarding that the city could exhibit in the future, a taste of what it should have been the actual Barcelona. »*

2.2. Superblock model

Bonet studied, along with the assembly of architects GATEPAC ("Grupo de Artistas y Técnicos Españoles Para la Arquitectura Contemporánea"), Cerda's idea of the rational block and proposed the new interpretation under the name of superblock (Baldellou, 1978).

In the letter mentioned, Bonet addresses the lack of interpretation of Cerda's work, thus the degeneration of Barcelona's urbanism. He foresees the negative impact of the transformation of the classical street, a consequence of the uprising of the car-dominance. To avoid the inevitable dark future of European cities, Bonet suggests choosing a sector of 9 blocks on the Example, a square of 3 blocks per side, with either two or the four sides of the square for fast traffic vehicles. He stated the basic principles of the superblock concept, encouraging the future urbanists to work over that. (Bonet Castellana, 1958).

Again, following the pattern of previous ideas, the motion did not prevail, and the automobile expanded to today's degree. From a Cerdà's perspective, the pedestrian space on the street would represent the 70% percent (14m from a 20m street width) (Tarragó, 1994). In some way, it evolved in the opposite direction, where today, 85 percent of the street is occupied by cars. The current city framework is based on the General Metropolitan Plan of 1977, where the Eixample morphology had nothing to do with the former plan.

Consequently, the initial concerns of hygienic conditions in densified cities were never tackled. On the contrary, the rise of technology and making the car more accessible to medium and lower classes worsen the damage caused to the population health. The never rethought model was now in need of a re-examination. Salvador Rueda took up the Superblock concept model with a small switch built on the Ecosystemic Urbanism principles, which would not only allow the city to become sustainable but also to put back the *intervia* (space between streets) as the vital element as Cerda intended.

Retaking the “six Ds” concept, the principals of this Ecosystemic Urbanism are based on a city with a balanced system of proportions of these variables. Proximity is increased in compact cities (high density) with a great diversity of uses. With the appropriate design and destination accessibility, the use of public modes is favoured by accomplishing a redistribution of the public space, making the city more sustainable.

The Ecosystemic Urbanism goes beyond the Superblock model; it introduces a three-dimensional mobility urban plan. The vast majority of transportation networks live on a two-dimensional space, adding an extra dimension by using the underground depth opens a whole new perspective to create efficient networks to move around cities. It is an appealing subject matter, but out of the scope of this thesis.

This new model, based on a new urban cell of 400mx400m with the same dimensions of Le Corbusier’s design, is composed of nine blocks of 113x113m. The idea was thought for the orthogonal plane of the Eixample district; however, the adaptative capacity of the new urban cell tolerates the accommodation throughout the different morphologies of the city (Rueda, 2018). This feature is remarkable; besides integrating Barcelona's entire city, the model is extrapolated to other cities. For instance, the city of Vitoria-Gasteiz put a Central Superblock winning the European Green Capital Award in 2012.

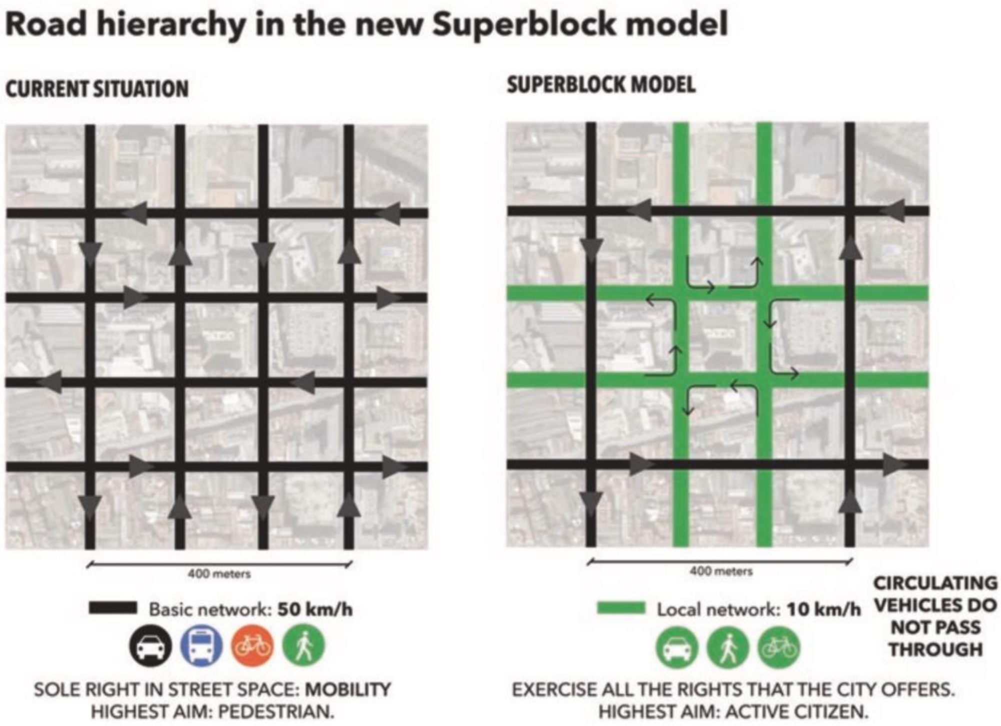

Figure 2-6: Networks scheme, current and future, based on superblocks. Source: BCNecologia.

Spatial hierarchisation is fundamental in this new urban cell. On this argument lies the new dimensions for the superblock. An average person walks at about 4 km/h, the time needed to walk around the block is similar to what a car needs to go around a superblock at an average speed of 20 km/h (the average urban speed in Barcelona). Therefore, the interior of the cell is left for civic and green purposes, and the perimeter, a set of primary roads, as it is shown in figure 2-6.

The maximum speed of the primary roads is 50 km/h, while the interior roads the speed is limited to 10 or 20 km/h. A Superblock is designed for car to go from A to B; both points outside a superblock unit, cannot use the interior as a shortcut. The right side of figure 2-6 shows the cases in which a car is authorized to use the *intervia*, limiting the movements only if either the origin or destination is inside the cell (Rueda, 2018).

The model grants a public space to cultivate new socio-cultural relationships, stimulate new functionalities, which enhances the diversity and complexity of the streets. It must be understood as an entire interdependent network instead of isolated urban cells. Once the complete orthogonal network of superblocks is achieved, it will represent a 61% (fig.

2-7 & 2-8) of basic road length from the current network, representing a total of 15 million square meters dedicated to mobility. On the contrary, the gain in public space for the citizen benefit will be almost 70 percent.

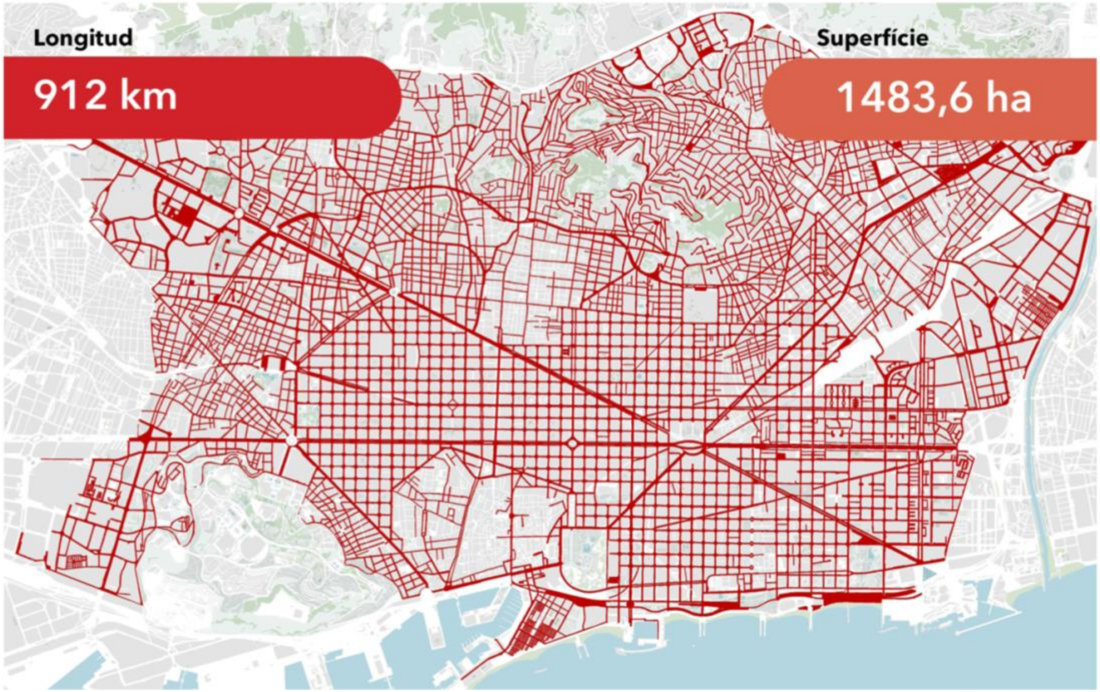

Figure 2-7: Current situation of Barcelona road network (Rueda, 2018).

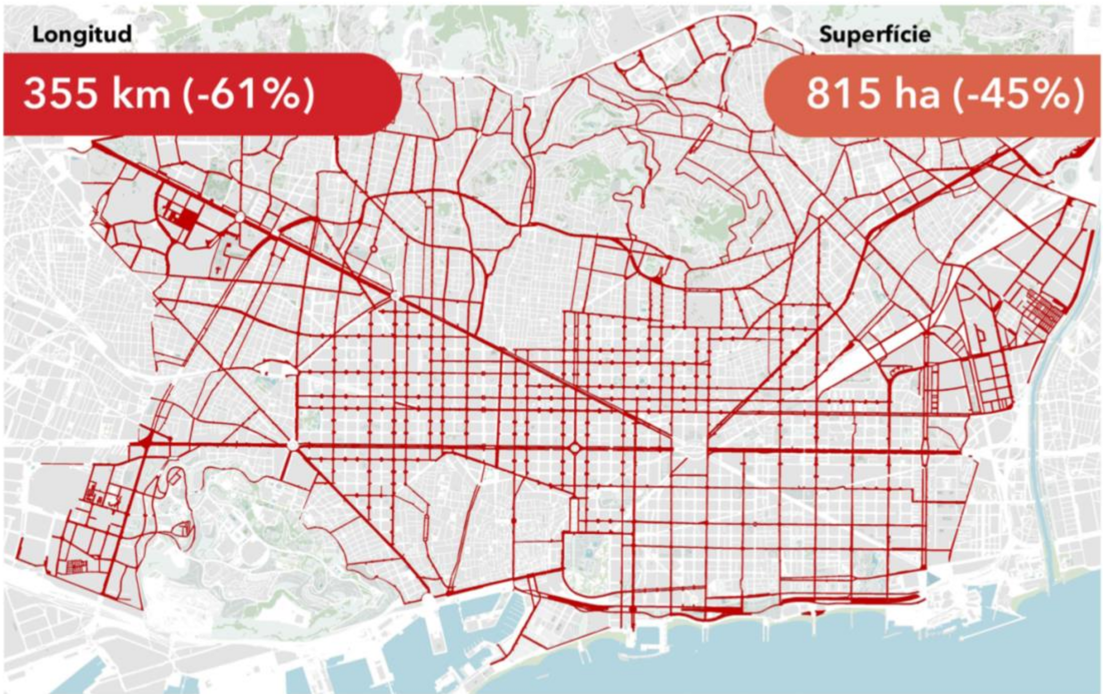

Figure 2-8: Future Superblock road network scenario (Rueda, 2018).

One could think that by reducing the basic road network to such extent, it would imply an escalation of the traffic levels. It is not far from the truth; however, by reducing 13% of the circulation vehicles, the level is maintained. The Sustainable Urban Mobility Plan of Barcelona goes further by proposing a decline of 21%, which means that instead of incrementing, the traffic level is enhanced.

The use of public transport must be improved, so the non-user is stimulated to change the mode of transports to achieve such desirable numbers. The problem of Barcelona's bus network is that it has been built overlapping the ancient tram network and progressively extended as a result of city expansion and the consequent increase in demand, yielding on an unplanned inefficient system. Meanwhile, other PT (public transport) modes were spawned (metro, *Ferrocarrils de la Generalitat de Catalunya*, *Rodalies*, *Bicing*, and taxis) lessening bus users. Hence, in 2012 the Transports Metropolitans de Barcelona (TMB), with the idea of greater efficiency and to arrange an understandable bus network, kicked off an ambitious new orthogonal bus network based on the superblock model (fig. 2-9), which will make of the bus a decent competitor amongst the other modes of transport.

Figure 2-9: Barcelona's new orthogonal bus network.(Barcelona City Council & TMB, 2019)

Regarding the environmental issues, with the desired cutback in-vehicle circulation, the degree of pollution will diminish below allowable limits. The estimations show that the number of people exposed to acceptable levels of pollution and noise will rise from 56% to 94% and 54% to 73,5%, respectively (fig. 2-10) (Rueda, 2017).

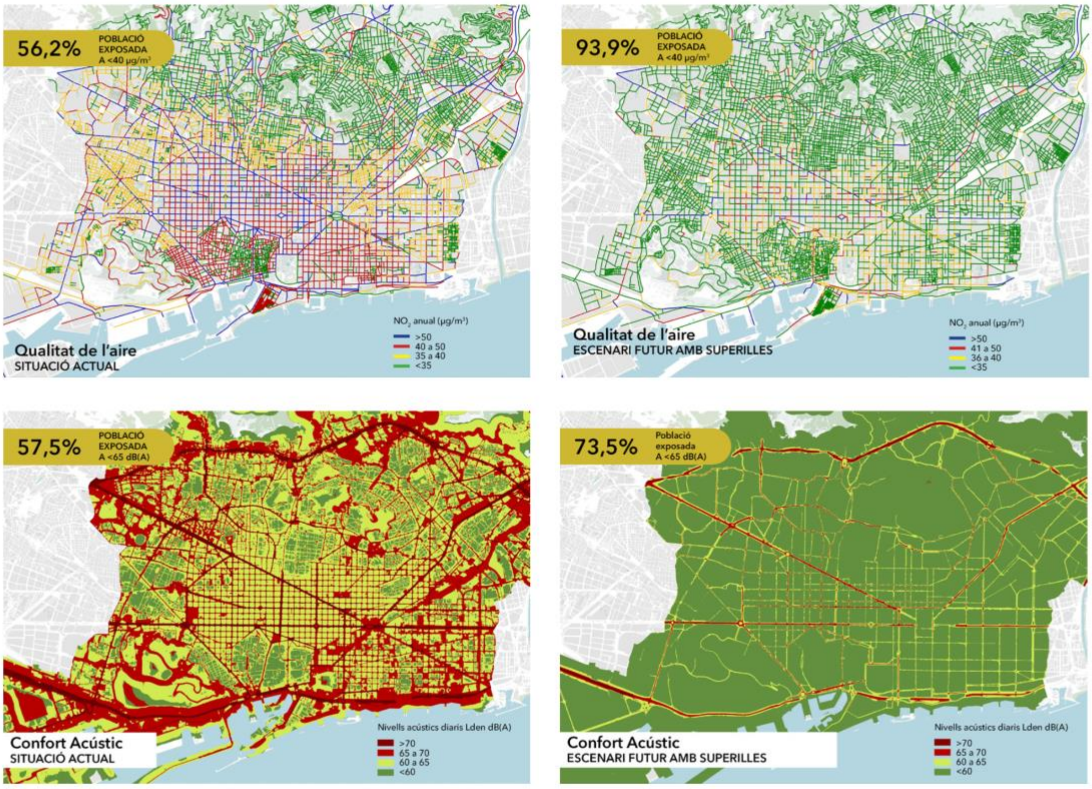

Figure 2-10: Air and noise quality before and after the Superblock implementation (Rueda, 2018).

One of the elements aiming to reduce pollution is the potential recovery of green space, where it is far from what Cerdà's or Macià's plan proposed initially (fig. 2-11). It will not only diminish carbon dioxide emission but also increase soil permeability forestalling flooding risk. Moreover, the presence of parks and other open areas comes along with the decline of hellish temperatures.

From another standpoint, the new Superblock model represents an upturn condition of the corrected compactness, a concept rating the built-up volume, and open space (later used in the practical part). The square meters of green space for inhabitant grows from 2,7 to 6,3 square meters per inhabitant, mainly due to the appearance of four new squares of 1900 m^2 inside the 3x3 Superblock Intervia (Rueda, 2018).

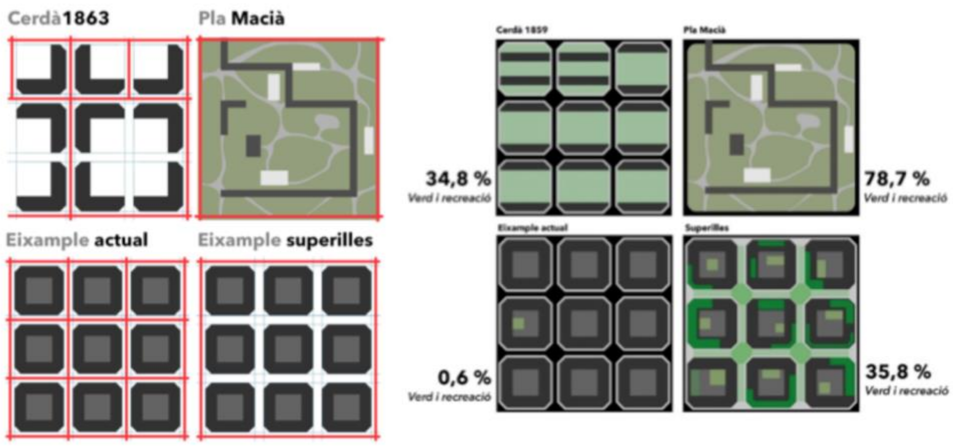

Figure 2-11: Intervia from Cerdà's plan, Macià's plan, the current situation, and the future Superblock.

One of the first implemented Superblocks was the one in *Vila de Gràcia* in 2003, which initiated the debate over the efficiency of this new model. One thing was clear; all streets are different, even in the *Eixample,* where the streets have diverse levels of connectivity. Then, it was essential to define the first lines of action to attain the Superblock model, which arose in the Urban Mobility Plan of Barcelona (PMU) from 2013 to 2018. This plan reconsiders the current urban plan, looking to harmonize all transportation modes in this future model. The PMU develops the actions towards more sustainable mobility.

2.3. Current situation of Superblock in Barcelona: PMU 2013-2018.

Oriented upon the public space recovery for the citizen, together with the operation of sustainable transport means, the PMU Barcelona 2013-2018 depicts the redesign of the city. The plan defines four strategic mobility objectives: safety reducing accidents, equitable with all transport types, the efficiency of the system, and sustainable mobility, reducing noise and air pollution. Hence the plan approaches these objectives based on the Superblock model, the configuration of a new bus network alongside the generation of new bike lanes.

The plan delineates three Superblock stages. In the first stage, air quality is not a target, whereas, in the second and third stages, it stipulates the European air quality standards. The use of new technologies, for instance, electric vehicles, is where the lasts stages differ. The latter is the desirable one; it focuses on social and environmental issues without a drastic erosion of mobility (21% reduction of the private vehicle).

From all districts of Barcelona, the *Eixample* has a particular interest for several reasons. The two principles are the idyllic shape for the Superblocks implementation, with an extended orthogonal street grid, which is one of the most densified areas of the city. The latter is crucial for the thesis author, as the recovery of public space in a context of high-density is paramount.

Another asset of the Eixample is its lower street slopes, which enhances bike accessibility, an ingenious solution with great potential in high-density environments. To make use of this circumstance, PMU proposes not only the construction of new bike lanes but also the increase in the number of bicing parking (the bicycle sharing system in Barcelona), bringing closer the access to the service.

The car road parking spots is a controversial topic addressed in the PMU, decreasing the number of places to park in the street is a downside from mobility and economic standpoint. However, from the perspective of street spaced gained is very attractive, forcing the use of public or active means of transport.

Then, the next chapter section explains the problem of the superblock implementation in the Eixample district. In particular, the works carried out in the regions around Girona Street, Consell de Cent-Germanetes, and Poblenou, where the alternatives selected, later specified on the methodological part, are located. The selection of these alternatives is also further explained in the second part of this thesis.

A series of actors are involved in the project, from neighbours, entities, and districts to the City Hall, the Urban Ecology Agency of Barcelona, and experts in the field, which provides a detailed action plan for these specific places. This collaboration results in participatory action plans, where the processes that will be executed are defined.

2.4.Problematic of the superblock implementation

The Superblock program sets three levels of works: a functional (or basic) level, where the functional mobility of the streets is changed, a tactic level, referred to the recovery works of the public space, and a structuring level, which changes the functionality of the public space to consolidate the previous ones. The process to define and implement the actions in each level is distributed in two phases, where they are divided into two and three subphases, respectively (fig 2-12).

The first one has the objective to define the action plan, where the Superblock will be placed through the neighbours' participation. An initial diagnosis of the region (subphase A) gathers information about the characteristics of the current public space situation and estimates its sustainability level. This phase ends with the definition of the Action Plan (subphase B), with all actions proposed for the region under study.

The second one is related to the prioritization, definition, and implementation of the works. These three steps, in that order, are divided into the subphases C to E. The subphase C has a similar purpose to the later application of the methodology, with the difference that MIVES considers the prioritization amongst several Superblock, whereas, this subphase is regarding the actions taken inside one alternative.

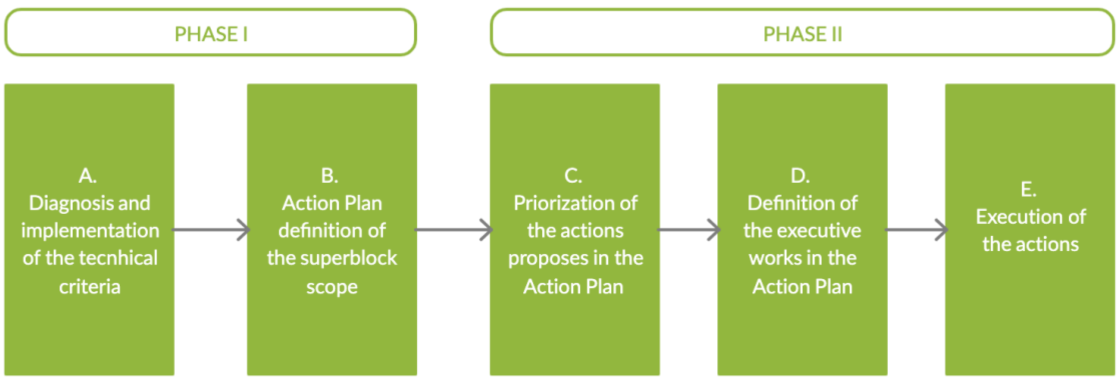

Figure 2-12: Phases of the implementation process

One of the preliminary conditions to the selection of the alternatives, later explained is the location of those between phases I and II. Then, hereunder is explained the current situation and actions planned for the recovery of the public space, on the regions around *Consell de Cent-Germanetes*, and *Girona* Street which are in that situation.

The first region of *Consell de Cent-Germanetes* has 86 287 m_2 of recreation and green space and a total of 136 777 m_2 of public space (sidewalks) (fig. 2-13). With a mean density population of 380 inhabitants per hectare, the recreation and green space per inhabitant is 2,23 m_2, which is on the mid-table value of all districts. The alterations on the functional mobility will allow the generation of a series of "civic axis" (fig. 2-14), which will increment accessibility to public space with pedestrians' elevated flux, functional connectivity between parks and squares, and to the public transport. That is why this typology is an excellent candidate for the improvement of the social and environmental conditions.

Figure 2-13: Current state of the Public Space in Consell de Cent-Germanetes (Ajuntament de Barcelona,2018)

Figure 2-14: "Civic Axis" proposal in Consell de Cent-Germanetes (Ajuntament de Barcelona,2018)

This new distribution represents a gain of 37 706 square meters of public space. The mobility preference is modified for the benefit of the pedestrian, allowing transit only to access housing and business on those streets named as neighbour roads (fig. 2-14). The next figure (fig. 2-15) illustrates an example, a section of Borrell Street, of the works proposed to reduce traffic and transform it onto a pedestrian street:

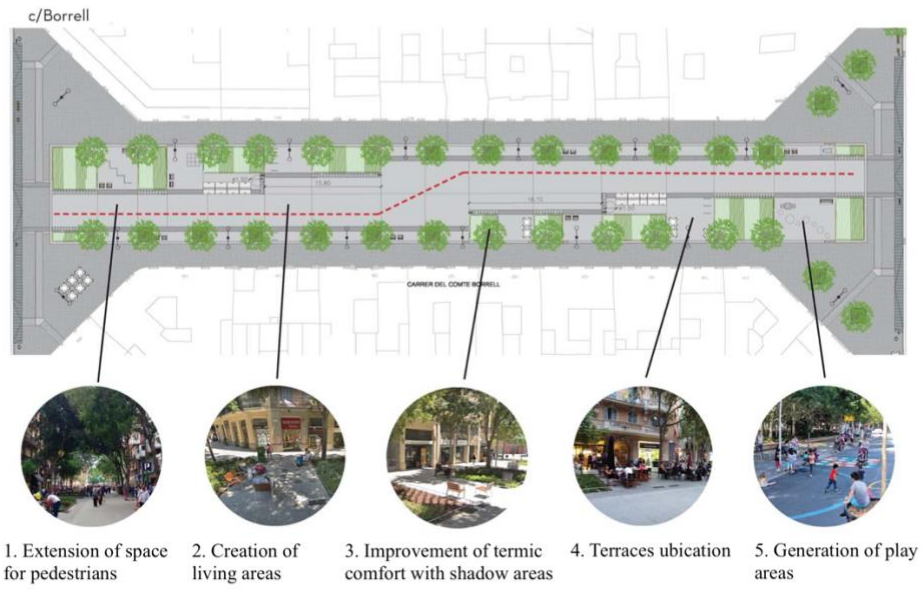

Figure 2-15: Pedestrian section of Borrel street (Ajuntament de Barcelona,2018)

The second region of *Girona* Street has 5 165 m2 of recreation and green space and a total of 120 213 m2 of public space (sidewalks) (fig. 2-16). With a mean density population of 284 inhabitants per hectare, the recreation and green space per inhabitant is 0,59 m2, which is the worst value of all districts. Analogously, the generation of a series of "civic axis" (fig. 2-16) will increment accessibility to public space. The amount of space gained is 39 962 square meters.

Figure 2-16: Current public space state versus "Civic Axis" proposal (Ajuntament de Barcelona, 2018)

The next figure (fig. 2-17) illustrates a type of works proposed to transform a Girona Street chamfer onto a pedestrian area, where cars are permitted to access a limited range of movement:

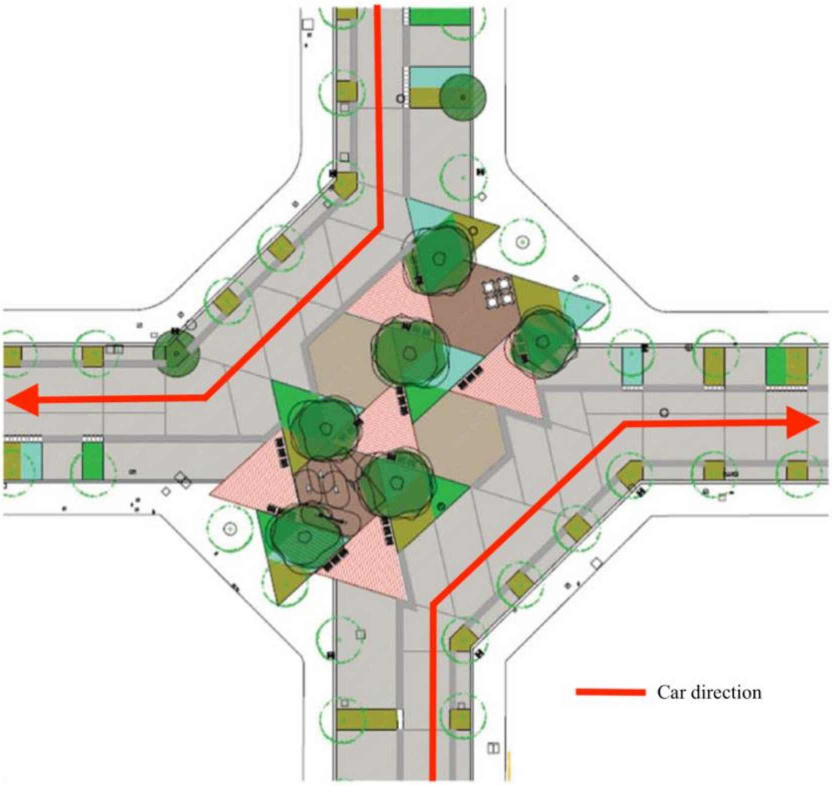

Figure 2-17: Pedestrian Chamfer of Girona Street (Ajuntament de Barcelona, 2018)

These works, above exposed, represent the Superblock model's central intentionality, where a new hierarchization of the streets can bring back the pedestrian as the main actor, where everything else circulates around. Now that its actions and solutions are presented, the following sections endeavour the task to study the level of sustainability, based on several aspects, of all alternatives considered. From the decision-making methodologies currently used, the MIVES Multi-criteria methodology is selected. A previous presentation of decision-making methodologies is exposed below.

3. Decision-Making methodologies

Urban sustainability is progressively becoming essential as cities grow. However, investment in urban projects reaches a ceiling as the resources are limited. It is inconceivable to accomplish all proposed projects of all agencies and stakeholders might propose. The enormous disparity between the investment needs and the public funds makes it inevitable to select and identify those that maximize the goals of sustainable projects.

The act of choosing is quintessential in a wide variety of fields (economy, sociology, or technology), "to choose" accurately demands of knowledge and understanding. Today's access to information has elevated the decision making to a degree of significant complexity, integrating all variables that can alter the outcomes of the problems alternative can be troublesome (Robusté and Gonzáles, 2017).

In the case of urban planning, where the decision-making is left to the governmental institutions, the extent of complex information should be treated to assure rational and comprehensible criteria to facilitate the decision. The most common form of decision-making analysis, used by the public sector, is monetary-based techniques. These techniques are exact in economic terms, for instance, cost-benefit analysis (CBA); however, they are mostly inaccurate in terms of social and environmental points of view. In most cases, financial analysis is more than enough, but a sustainable urban planning model should encompass the three sustainability dimensions: social development, economic development, and environmental protection (United Nations, 2005). When these dimensions are paramount, a Multi-criteria analysis (MCA) is convenient, capable of transforming subjective aspects of a sustainable project to rational variables (Pujadas *et al.*, 2017).

Multi-criteria decision analysis is a set of different tools and techniques that aids in considering the multidimensional aspects within the potential alternatives to solve a problem. It ranks the different alternatives from the most favourable to the least favourable, diminishing the decision's intricacy. Depending on the number of alternatives, these Multi-Criteria Decision Making (MCDM) problems can be categorized in evaluation problems, where the number of alternatives is finite, or design problems, where the alternatives are either infinite or uncountable.

Once the problem is categorized, choosing one MCDM methodologies depends on the field of study or application, using one or the other depends upon the study's matter. For instance, in science and forecasting technologies, the Delphi method is precise, summons diverse opinions from experts without any physical meeting required, consists of a series of anonymous surveys using statistics to give results feedback. However, it does not mean that each methodology should only be used in one care or another, they are adaptable, and the decision-maker needs to find the one that suits best for the purpose.

For example, there are hundreds of methodologies that can be used in studies on water management, from Multi-Attribute Utility Theory to Goal Programming, to PROMETEUS. All these options have their advantages and downsides, finding the appropriate one is foremost to succeed in ranking the alternatives considered.

Some researchers from Spanish universities (UPC and UPV) develop a methodology to assess sustainability in construction. MIVES, the methodology's name, combines the Multi-Attribute Utility Theory method with the Analytic Hierarchy Process (AHP). The general procedure allows it to be used in different fields of study, and since one of the objectives is to determine an MCDM to evaluate the sustainability of some Superblocks alternatives in Barcelona, MIVES is the approach selected. The next chapter explains how this method works and goes into detail on the implementation procedure.

4. MIVES Methodology

The Integrated Value Model for Sustainable Assessment (*Modelo Integrado de Valor para una Evaluación Sostenible* – MIVES) a decision-making model is an evaluation Multi-Criteria Decision-Making (MCDM) type of problem. A defined number of feasible alternatives to the problem, which they can either be postulated before the delimitation of the decision or after the weight assignation. Nevertheless, what characterizes MIVES from other methodologies is the valuation model's proposal previous to the creation and evaluation of the alternatives.

The following steps described upon the MIVES methodology are taken from the *Manual MIVES – Evaluación de Sostenibilidad en Ingenieria Civil* from UPC, provided by professor Miquel Estrada. Moreover, Pujadas et al. (2017) paper on the MIVES approach for prioritizing public investment projects will be used as a guide throughout the next chapters regarding the application of the methodology to the case of Barcelona Superblocks.

The model involves a multi-attribute utility theory (MAUT) and analytic hierarchy process (AHP) to standardize the sustainability objective into some variables (requirements, criteria, and indicators) through a value function and assignation of weights. The use of this value function, the heterogeneity of the different variables, is homogenized to achieve a rational assessment.

The end goal of the model is to either find the best alternative, sort the alternatives, or classify them (Pujadas et al., 2017). Although the end goal of the model could be to find the best alternative that solves the problem, another possibility could be to sort the alternatives. “Sorting” orders the different options, depending on the priority, so that the decision-maker can determine which one is better to start. The entire procedure follows these steps:

1. Define the problem: Describe the problem, the limits and boundaries, and who will make the final decision.

2. Requirements tree: The aspects of sustainability are introduced in the requirement tree, where requirements, criteria, and indicators are shaped.

3. Value function: The creation of these functions allows us to obtain a value between 0 and 1 of all criteria defined in the tree.

4. Weighting: By designating weights, a preference is brought into the aspects to manifest the importance of each requirement.

5. Definition of the alternatives: The different alternatives are defined. In the case of a previous definition of them, any evaluation ought to be avoided. Most of the "sorting problems" the alternatives are defined in advance.

6. Valuation of the alternatives: It is obtained the value index of each alternative.

7. Results: Make the decision.

If a sensitivity analysis and a comparison of the results are added to the process, it will build up the model's robustness. The sensitivity analysis consists of observing the change in each alternative's value index by varying the weighting or value functions. Finally, comparing the results would allow seeing if the decision is close to the expectations.

4.1. Statement of the problem

4.1.1. System Boundaries

To help analyse the methodology, it structures the boundaries of the system in three axes: components of the alternatives, requirements, and lifecycle. Different components of the alternatives and their lifecycle can be analysed under the requirement tree with this three-dimensional structure.

For the study, the methodology is structured in one dimension. There is just one component per alternative, which is the entire alternative being analysed at one, and the lifecycle goes from the initial state to the long-term state after the construction of the alternative.

4.1.2. Boundary Conditions

In the decision-making problem, the alternatives' initial circumstances can countereffect upon the interest of the analysis elements that can influence ranges from economic agents or geographic attributes, to demographic data. In the case of the superblocks, the impact on the population can differ depending on the alternative location. Then, identical boundary conditions are necessary, so the problem is comparable, some of these conditions act as a filter for the alternatives where they cannot be above or under a certain threshold, or attribute requirements. As for the Superblocks, there are a distinctive definite number of alternatives; their idiosyncrasy disrupts the implementation of restrictive conditions. Consequently, a preliminary selection analysis of the alternatives will be performed to reduce the magnitude of the project and stick to the scope of the study, thereupon a homogenization coefficient (HC) (Pardo-Bosch and Aguado, 2016) will be introduced to make the alternatives comparable between them.

Firstly, the only alternatives considered will be those neighbourhoods that make up the district of Eixample. Despite the flexibility of the Superblock to adapt throughout the city of Barcelona, the original superblock concept was based on the famous orthogonal grid planned by Ildefons Cerdà. With a focus on this grid, the initial condition is that the alternatives selected must be inside the district of the Eixample. There are other districts with the distinguished grid, but the Eixample is the only district entirely orthogonal. Hence, it fulfils the comparable requirement.

Furthermore, the Eixample district has one of the highest population densities of Barcelona, targeting those areas in a high-density context. The district comprises the neighbourhoods: *Dreta de l'Eixample, Antiga Esquerra de l'Eixample, Nova Esquerra de l'Eixample, Fort Pienc, Sagrada Familia and Sant Antoni*. The following fig 4-1 locates the neighbourhoods on a Barcelona map.

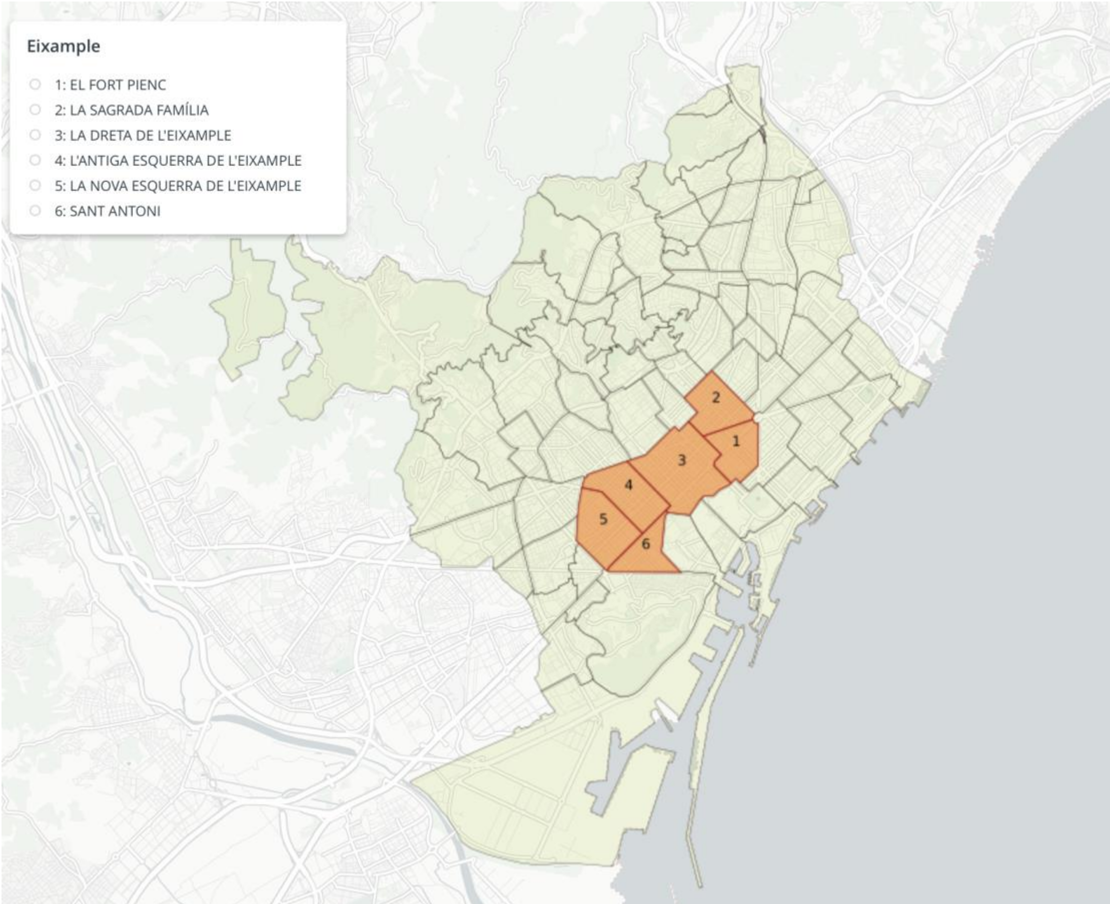

Figure 4-1: Eixample district divided by neighbourhoods

Secondly, the following condition is to consider those areas in between the first and the second phases (Phase 1.B). Those superblocks are entering the prioritization step, where their actions feasibility is being analysed upon the degree of their needs. These needs are the indicators that will be used in this methodology. It will then help dismiss the alternatives that are either not yet being studied or are under execution. The next map shows the different areas where the superblocks have been proposed and their actual phase (fig 4-2). The red areas refer to those regions in between phases.

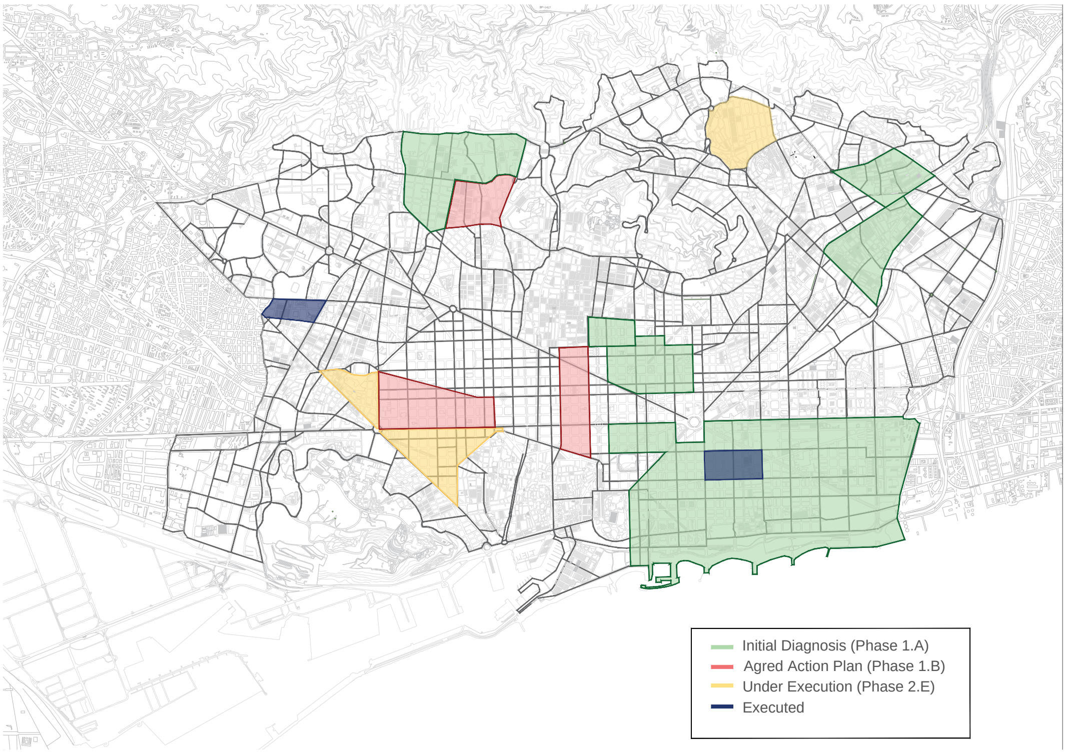

Figure 4-2: Map of the superblock under study. (Own source)

Two areas regarding the district of the Eixample, at the moment, have their Action Plans defined. They are the two red sections in the Eixample district marked in the previous map. The left one is the zone of the streets *Consell de Cent – Germanetes*, and the right one corresponds to *Girona Street's* surroundings.

The last condition, similar to the first one, consists of selecting those alternatives that follow the traditional definition of the 3x3 blocks inside the previously mentioned areas. By selecting only those alternatives that maintain the initial description of a superblock, it increases the homogeneity. These are three alternatives for the area of *Consell de Cent – Germanetes* (fig. 4-3) and one alternative around the area of *Girona* Street (fig.4-4). The figures below illustrate these alternatives, where the red lines correspond to the basic type of road, and the light blue dashed lines represent the alternatives.

Figure 4-3: Superblock area of Consell de Cent – Germanetes. (Agència d'Ecologia Urbana de Barcelona, 2016)

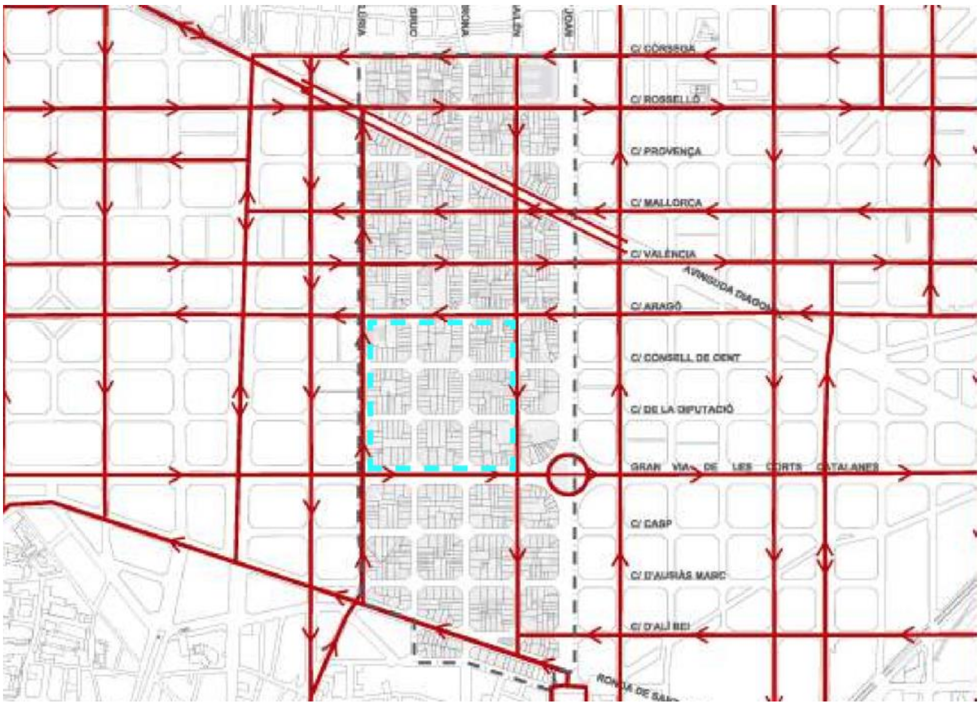

Figure 4-4: Superblock area of Girona Street. (Agència d'Ecologia Urbana de Barcelona, 2016)

A final consideration is the addition of an already functioning Superblock located in *Poblenou (fig 4-6).* As mentioned, the point is to use it as a reference to assure the precise accuracy of the outcome, comparing the actual benefits of one of the options, the interpretation is put into perspective and grants substantial meaning to the final results.

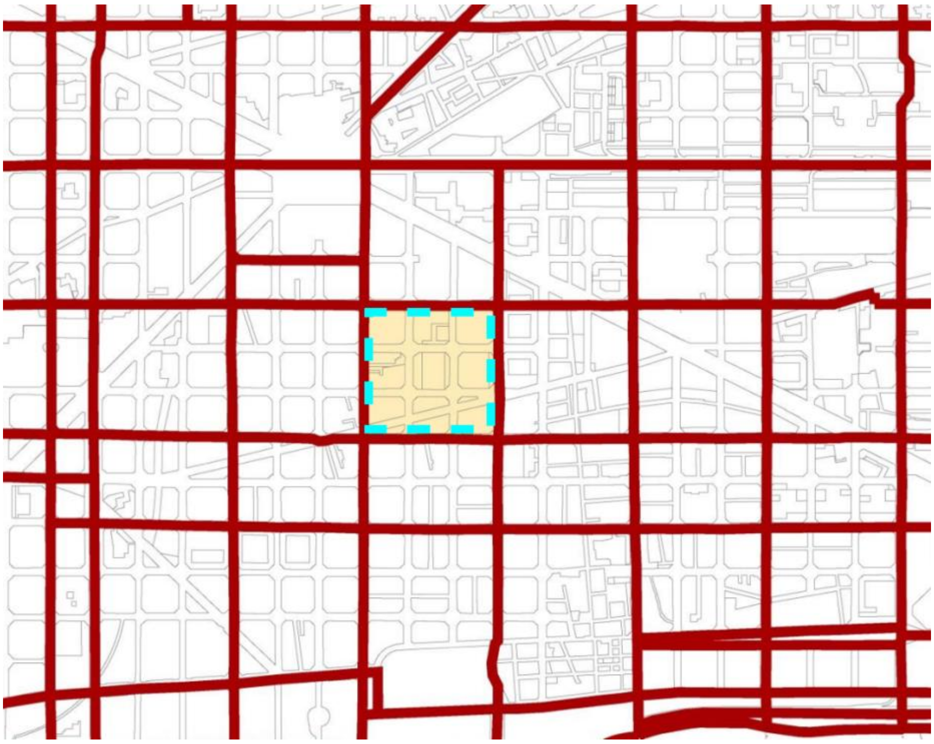

Figure 4-5: Poblenou Superblock.(Agència d'Ecologia Urbana de Barcelona, 2015)

4.1.3. Superblock area of Girona Street: Alternative 1 (Aragó – GV de les Corts Catalanes)

This first area is located on the most centric part of Barcelona, in the neighbourhood of *La Dreta de l'Eixample*, with a surface of 212 hectares. It has a desirable density in terms of environmental sustainability, not too dense because it implies a lack of public space and is not too empty, requiring a higher consumption of resources. The investment in the superblock area during the previous years from 2016 and 2019 is estimated as a spatially proportional fraction from the total investment done in the neighbourhood of *La Dreta de l'Eixample.* The household income is provided by the City Hall report of 2017 published in 2018; this is the last year with available data distributed by neighbourhoods (Ajuntament de Barcelona, 2018) (table 4-1).

Table 4-1: Data regarding alternative 1 (Agència d'Ecologia Urbana de Barcelona, 2016)

Alternative 1	Proportional Investment (€)	Inhabitants	Pop. Density (inhab./ha)	HouseHold Income
Aragó - GV les Corts Catalanes	403534	4210	263	175,9

The diagnostic report by the Urban Ecology Agency of Barcelona draws this first alternative, inside some Superblock that together sums a total of 86 hectares. The next figure (fig. 4-6) displays the area of *Girona* Street Superblock concerning the density of each block, where the blue square points out the dimensions of alternative 1.

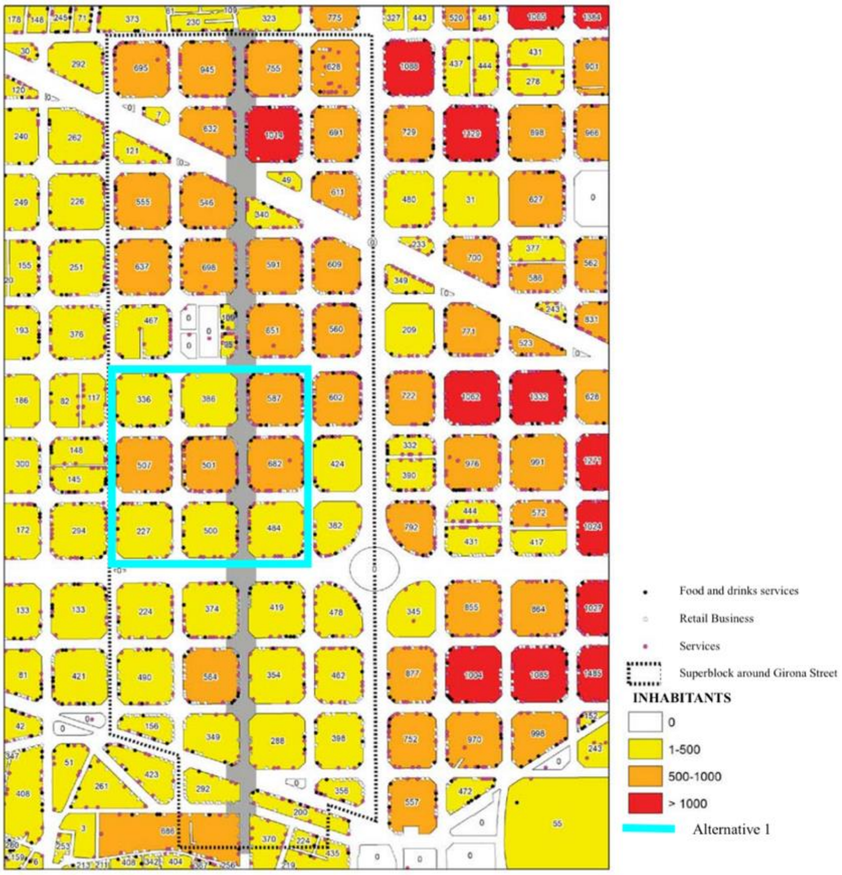

Figure 4-6: Population density alternative 1 (Agència d'Ecologia Urbana de Barcelona, 2016)

4.1.4. Superblock area of Consell de Cent – Germanetes: Alternative 2 (Entença – Viladomat), 3 (Parc Joan Miró) & 4 (Comte d'Urgell-Montaner)

This second area of *Consell de Cent – Germanetes* encompasses the next three alternatives considered (fig 4-7). The scope of the diagnostic report is located on the west side of two neighbourhoods: *La Nova Esquerra de l'Eixample & Antiga Esquerra de l'Eixample*. The third alternative has the particularity of the presence of an urban park (*Parc Joan Miró*) and the *Las Arenas* mall. Despite the population densities varying along with the alternatives, they are higher than the first one, enhancing the complexity of uses, and bringing a shortage of public spaces and services. The household income in the neighbourhood is obtained from the previously reported mentioned (table 4-2).

Table 4-2: Data regarding alternatives 2, 3 & 4 (Agència d'Ecologia Urbana de Barcelona, 2014)

Neighbourhood	Alternatives	Proportional Investment (€)	Inhabitants	Pop. Density	HouseHold Income
La Nova Esquerra de l'Eixample	Parc Joan Miró (3)	2948881	3394	212	110,2
	Entença - Viladomat (2)	2948881	8280	545	110,2
L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner (4)	2751297	6622	414	137,2

Figure 4-7: Superblock alternative 2, 3 and 4 (Agència d'Ecologia Urbana de Barcelona, 2014)

4.1.5. Superblock area of Poblenou: Alternative 5 (Badajoz-Llacuna)

The superblock of this last alternative has already been constructed. As previously remarked in this thesis's approach, the reason is to provide a reference to ensure the accuracy of the outcomes.

Table 4-3: Data Alternative 5 (Agència d'Ecologia Urbana de Barcelona, 2015)

Alternative 1	Proportional Investment (€)	Inhabitants	Pop. Density (inhab./ha)	HouseHold Income
Badajoz - Llacuna	13605114	2176	136	100,4

Figure 4-8: Alternative 5 (Agència d'Ecologia Urbana de Barcelona, 2015)

4.1.6. Homogenization Coefficient

The alternatives are located in different zones of Barcelona, which impairs the compatibility as their initial conditions are dissimilar. The coefficient evaluates four independent but complementary variables, with the aim to decrease the heterogeneity to allow their comparison and ensure the accuracy and representativeness. Each variable is assigned a value ranging between 1 to 5 points (Williams, 2009), according to the next table (table 4-4). The variables derive four strategic questions that depict their social necessity (Pardo-Bosch and Aguado, 2016).

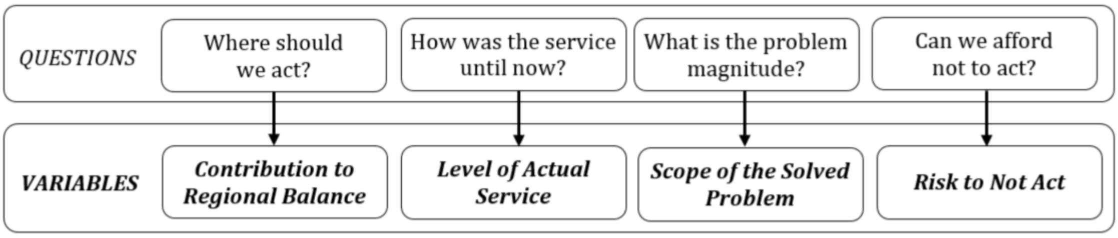

Figure 4-9: Questions and their respective variables to build the HC.(Pardo-Bosch and Aguado, 2016)

Table 4-4: Attributes

Variable						**Grade**
CBR			**InD**			
			55 % < AID			5
			35 % < AID ≤ 55 %			4
			15 % < AID ≤ 35 %			3
			5% < AID ≤ 15 %			2
			AID ≤ - 5 %			1
LAS	**SaI**			**CI**		
	α_1= 0.5	Sidewalk width	Slope	α_2= 0.5	IMD veh/dia	
		<1,8	> 6		> 15 000	5
		<1,8	⋜ 6		5 000 - 15 000	4
		⋝ 1,8 a 2,5	⋜ 6		3 000 - 5 000	3
		⋝ 2,5 a 3,7	⋜ 6		< 3000	2
		⋝ 3,7	⋜ 6		0	1
SSP	**PoS**		**SoS**			
	β_1=0.5		β_2=0.5			
		> 8000		Excellent (A)		5
		6 000 - 8 000		Notable (B)		4
		4 000 - 6 000		Suficient (C)		3
		2 000 - 4 000		Insuficient (D)		2
		< 2 000		Very Insuficient €		1
RNA			**PEI**			
			$N0_2$ Concentration (µg $N0_2/m^3$)			
			> 50			5
			40 - 50			4
			35 - 40			3
			30 - 35			2
			< 30			1

The Contribution to Regional Balance (CRB) assesses the status of the public investment in a specific zone, weighted upon the level of influence (area, income, population). The spatial area is almost the same for all alternatives, with a value of 16 ha, it will not be taken into account. The variable intends to readjust any possible unbalanced distribution of investments through the computation of the area's investment deficit (AID). Hence, the higher the superblock's preference, the higher the deficit rate, the bigger the final grade.

Then, the factors considered are the GDP (*TI*), the population (*Pop*), and the public investment (PI). Sub-index "T" refers to the entire city while sub-index *"i*" indicates the area under consideration.

$$ZID = \left(1 - \frac{\frac{PI_i}{PI_T}}{\frac{Pop_i}{2Pop_T} + \frac{GDP_i}{2GDP_T}}\right) * 100$$

Equation 4-1: CRB

Table 4-5: CBR Values of each alternative

Constribution to Regional Balance (CBR)							
District	Neighbourhood	Alternative	Proportional Investment (€)	Pop (inhab)	PIB	ZID (%)	Grade (1 to 5)
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	2948881	3394	180082991	-20,6	1
		Entença - Viladomat	2948881	8713	462304978	53,0	4
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	2751297	6622	437444086	48,9	4
	La Dreta de l'Eixample	Aragó - GV les Corts Catalanes	403534	4210	356555547	89,9	5
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	13605114	2176	105189373	-810	1

The Level of Actual Service (LAS) evaluates the alternatives in terms of the services offered and access to those services. For this reason, the variable is studied by two concepts: The Sidewalk Accessibility level (SAl); and the Congestion level (Cl). Weighting both concepts, the LAS is obtained with the following equation:

$$LAS = \alpha_1 SAl + \alpha_2 Cl\,; \alpha_1 = \alpha_2 = 0{,}5$$

Equation 4-2: Sal

The Sidewalk Accessibility measures the features in terms of width and slope of the street sidewalks; if the street dimensions are in the right conditions (width more excellent than 3,7 meters and a slope smaller than 6 %), it is considered to have the lowest mark. The characteristics of the *Eixample* district, with full streets and natural topography, contribute to general low grading.

Table 4-6: Sidewalk Accessibility level (SAl)

Sidewalk Accessibility Level (SAl)					
District	Neighbourhood	Alternative	Sidewalk and/or crosswalk width	Slope	Grade (1 to 5)
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	$\geq$ 3	$\leq$ 6	2
		Entença - Viladomat	$\geq$ 3,7	$\leq$ 6	1
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	$\geq$ 3,7	$\leq$ 6	1
	La Dreta de l'Eixample	Aragó - GV les Corts Catalanes	$\geq$ 3,7	$\leq$ 6	1
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	$\geq$ 2,5 a 3,7	$\leq$ 6	2

The Congestion level evaluates the number of vehicles traveling through the streets of the different alternatives. To be computed, the Daily Mean Intensity of vehicles (IMD – Intensidad Media Diaria (Veh/per day)) is used. The bigger the intensity, the highest preference of the Superblock.

Table 4-7: Congestion level (Cl)

Congestion level (Cl)				
District	Neighbourhood	Alternative	IMD	Slope
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	5 000 - 15 000	4
		Entença - Viladomat	5 000 - 15 000	4
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	> 15 000	5
	La Dreta de l'Eixample	Aragó - GV les Corts Catala	> 15 000	5
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	5 000 - 15 000	4

The Scope of the Problem Solved (SPS) classifies the scale of the investment project with the measurement of two notions: the population that can benefit (PoS); and the Corrected Compactness (CC). Analogously, the equation to obtain the final value is a weighted sum of the two notions:

$$SSP = \beta_1 PoS + \beta_2 CC \ \ ; \beta_1 = \beta_2 = 0{,}5$$

Equation 4-3: SSP

The more population that can benefit from the implementation of the service, the greater the score, as it would mean a bigger impact. This notion presents the greatest differences amongst the alternatives due to the dissimilarities in the density population of the territory.

In a similar manner, the Corrected Compactness notion refers to the relation between the built-up volume and the green, liveable space. It is an important concept, once defined by Cerdà, where the dichotomy between private and public space was essential to his city planning. The smaller relation the greater the living space, the smaller the overall grade, because if there is a good compactness relation, the problem of the scope is smaller.

Table 4-8: PoS and CC Values

Scope of the Problem Solved (PSP)						
District	Neighbourhood	Alternative	PoS (inhab)	Grade (1 to 5)	CC	Grade (1 to 5)
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	3394	2	10 to 20	2
		Entença - Viladomat	8713	5	50 to 100	4
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	6622	4	50 to 100	4
	La Dreta de l'Eixample	Aragó - GV les Corts Catalanes	4210	3	50 to 100	4
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	2176	2	20 to 50	3

The Risk to Not Act (RNA) evaluates the level of pollution exposure (PEl) of each alternative, which is somewhat related to the mortality due to ambient pollution. It is measured with the air quality, the higher concentration of $N0_2$ will reflect a higher risk if any action is done, thus scored with a higher value. The values obtained indicate the significant importance of acting on all Barcelona, as the levels of ambient pollution are severe for most of the territory.

Table 4-9: Risk Not to Act

Risk Not to Act (RNA)				
DISTRICT	Neighbourhood	Alternative	$N0_2$ Concentration ($\mu g\ N0_2/m^3$)	Grade (1 to 5)
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	40 - 50	4
		Entença - Viladomat	> 50	5
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	> 50	5
	La Dreta de l'Eixample	Aragó - GV les Corts Catalanes	> 50	5
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	40 - 50	4

The final value of the Homogenization Coefficient (HC) for each alternative (table 4-10) is computed as a weighted sum of each variable (w_{HC_i}), based on the level of importance. The weights assigned are based on the relevance of the author's interest in this thesis. Thus, being the density (SPS) and ambient pollution (RNA) the most important, in that order, they will weight 0.4 and 0.3, respectively. Followed by the level of service (LAS) with 0.2, and finally, the contribution to regional balance (CBR) with 0.1. The final equation (eq. 4-4) appears as:

$$HC = w_{HC_1} CBR + w_{HC_2} LAS + \ w_{HC_3}\ SSP + \ \ w_{HC_4} RNA$$

Equation 4-4: Final computation of the HC

Table 4-10: Homogenization Coefficient

		Homogenization Coefficient					
District	Neighbourhood	Alternative	CBR	LAS	SPS	RNA	HC
EIXAMPLE	La Nova Esquerra de l'Eixample	Parc Joan Miró	1	3	2	4	2,7
		Entença - Viladomat	4	2,5	4,5	5	4,2
	L'Antigua Esquerra de l'Eixample	Comte d'Urgell - Montaner	4	3	4	5	4,1
	La Dreta de l'Eixample	Aragó - GV les Corts Catalanes	5	3	3,5	5	4
SANT MARTÍ	El Parc i la Llacuna del Poble Nou	Badajoz - Llacuna	1	3	2,5	4	2,9

The coefficient indicates the necessity of each alternative; however, it does not mean it has to be the more sustainable option; therefore, it may not be prioritized. An array of reasons could lead to non-sustainable or, in other words, non-cost-beneficial, but a possible solution could be the redesign of the proposal. The following steps will lead to the listing of the higher sustainability contribution of each project.

4.2.Requirements tree

The requirements tree consists of three-level structures with all aspects under consideration. On the first level, the requirements represent the main topics evaluated, on a second level, more detailed criteria, and finally, the indicators, which are the variables that will be directly measured. The selection of the most deterministic powerful indicators will contribute to the representativeness and credibility of the sustainability level reach by each Superblock. The next table illustrates these indicators (table 4-11).

Table 4-11: Requirement Tree

Requirements	Criteria	Indicators
Social	Tactical Measures	Public Space Gained (PSG)
	Structuring Measures	meters of Parking Spots Reduced (mPSR)
		Diversity of Uses (DoU)
	Functional Measures	Bus Mobility (BM)
		Bike Mobility (BiM)
Economical	Investment	Unitary Cost (UC)
	Economy Impact	Effect on Local Commerce (ElC)
Environmental	Pollution	Daily Congestion Improvement (DCI)
		Peak Congestion Improvement (PCI)

In this section the requirement tree is only presented. Then, in the value function definition, each indicator is explained in detailed, and their equation to be evaluated.

4.3. Value function

Each indicator has a different character; they could differ in magnitude, units, or even the type of data (qualitative or quantitative), making them not comparable on the first level. The objective of the value function is to standardize these different evaluation methods to a unidimensional variable number between 0 and 1, hence, to make them comparable.

All indicators evaluated have a specific function obtained from a generic equation, which is defined based on five parameters: K_i; C_i; X_{max}; X_{min}; and P_i (eq. 4-5) (Alarcon *et al.*, 2011). The variation of these parameters will result in different shapes: convex, concave, lineal or shape S.

$$V_{ind} = B\left[1 - e^{-K_i\left(\frac{(|X-X_{min}|)}{C_i}\right)^{P_i}}\right]$$

Equation 4-5: Value function

Where: X_{min} is the minimum x-axis, 0 for increasing functions; X is the quantification of the indicator under evaluation; P_i is a shape factor that defines whether the curve is concave, convex, linear or an "S" shape ($P_i < 1$: concave; $P_i > 1$ convex and S shape; $P_i = 1$ straight lines); C_i and K_i approximate the x-axis and the ordinate of the inflection point respectively. B_i: is the factor that allows the function to be maintained within the range of 0 and 1 (eq. 4-6).

$$B = \left[1 - e^{-K_i\left(\frac{(|X_{max}-X_{min}|)}{C_i}\right)^{P_i}}\right]^{-1}$$

Equation 4-6: B factor

Where: X_{max} is the maximum x-axis, 1 for increasing functions. In the case of using decreasing functions, the only change of variables is that X_{max} is substituted for X_{min} and vice versa. The fact that a function is decreasing or increasing will depend on the indicator and the measurement method. Then, defining the tendency, the maximum and minimum satisfaction, and the shape of the value function will provide the mathematical expression for each indicator.

4.3.1. Value function definition:

The first thing to define is the tendency of the function. This will depend upon the nature of the indicator. That is to say if the indicator is indirectly proportional to satisfaction, the function decreases, and if it is directly proportional, it increases. In this case, the number of parking spots is a decreasing function; the maximum satisfaction level (X_{max}) is reached when 0 spots are measured in one alternative.

Defining the maximum (X_{max}) or minimum (X_{min}) satisfaction marks the lower and upper limits of the abscissa axis. They represent the 0 and 1, respectively, on the coordinate axis for an increasing function. They can be fixed according to rules and regulations, experience with previous projects, or the limits obtained in measuring the indicators. These are three different options; it does not mean that the maximum and minimum values measured are always the boundaries of the x-axis (Alarcon *et al.*, 2011).

The next defining factor is the shape of the function. It shows the worth associated with a certain level of satisfaction reached. For instance, a concave curve (fig. 4-10 (a)) implies bigger increments to produce any satisfaction. A reason to select this type of curve is when obtaining a maximum level of satisfaction is paramount, environmental indicators are a good example.

The convex shape (fig. 4-10 (b)) has the opposite meaning; satisfaction with small changes is immediately perceived, used with the high impetus for improvement.

The S shape (fig. 4-10 (c)) is a mixture of concave and convex, alterations near the limits are not felt in satisfaction, it is a good option for alternatives indicator value ranged in the middle.

Finally, linear functions (fig. 4-10 (d)) have a constant relationship between changes in the indicator and satisfaction level, variables with no explicit form use this shape by default.

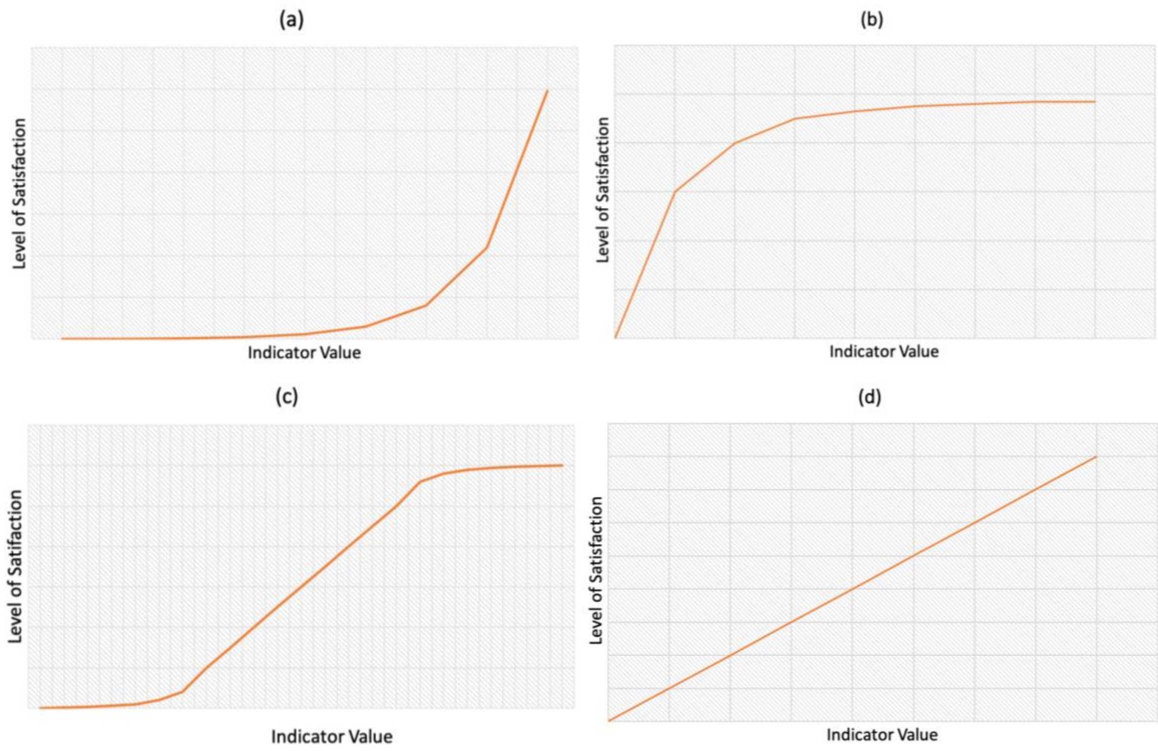

Figure 4-10: Value function shape

The different shapes of the value function explained are given by the parameters already mentioned. They are interdependent; the influence of each parameter will depend on the rest. A specific range of parameter values related to the shape they provide cannot be given. However, in general terms, higher values of P produce concave or S shapes, and smaller values are convex (magnitudes of 1-10). A 0 K value represents a linear function, followed by S shapes and concave, and as the value increases a convex shape is produced (magnitudes of 0-10).

4.3.2. Environmental Requirement:

This criterion is directly related to the sustainability evaluation; the two indicators measured are the Daily Congestion Improvement (DCI) and the Peak Congestion Improvement (PCI). A regular cutback of car presence is related to air pollution. In the long term, the levels of pollution will decline, whereas a peak congestion reduction considers the decrease in high decibels generated during rush hour. Both have concave value functions with an indicator measurement and parameters shown below (eq. 4-7) (table 4-12).

$$DCI_i = \left|\Delta IMD_i\left(\frac{veh}{d}\right)\right| HC_i;\ PCI_i = \left|\Delta IMD_i\left(\frac{veh}{d}\right)\right| HC_i;$$

$$\Delta IMD_i\left(\frac{veh}{d}\right) = IMD_{lt} - IMD_{sa} =$$

$$= \left(\frac{IMD_{br}\, ns_{br} + IMD_{lr}\, ns_{lr} + IMD_{nr}\, ns_{nr}}{\sum ns_i}\right)_{lt} - \left(\frac{IMD_{br}\, ns_{br} + IMD_{lr}\, ns_{lr} + IMD_{nr}\, ns_{nr}}{\sum ns_i}\right)_{sa}$$

Equation 4-7: DCl and PCl indicator equation

Table 4-12: Environmental Indicators Parameters

Parameters	DCI	PCI
Xmin	0	0
Xmax	30000	40
Ki	0,20	0,1
Ci	20000	30
Pi	3	3
B	2,04	4,74

Setting the parameters to the general equation for both indicators, the value functions obtained are (fig. 4-11 & 4-12):

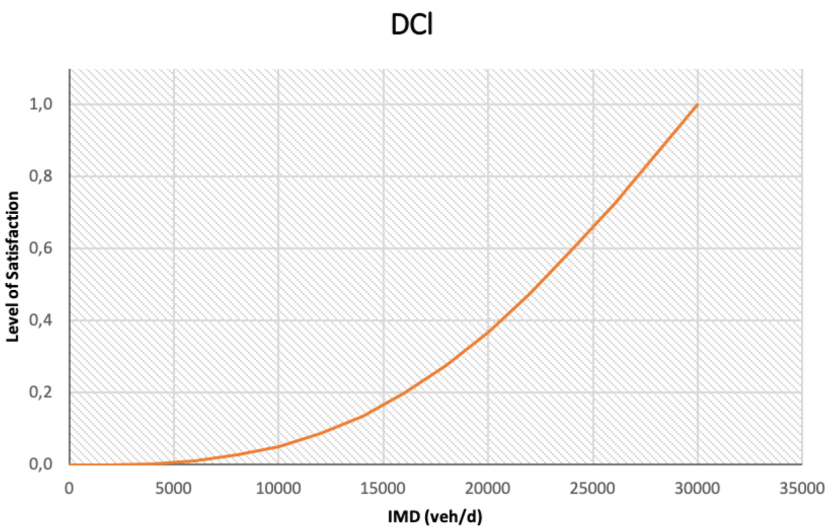

Figure 4-11: DCI value function

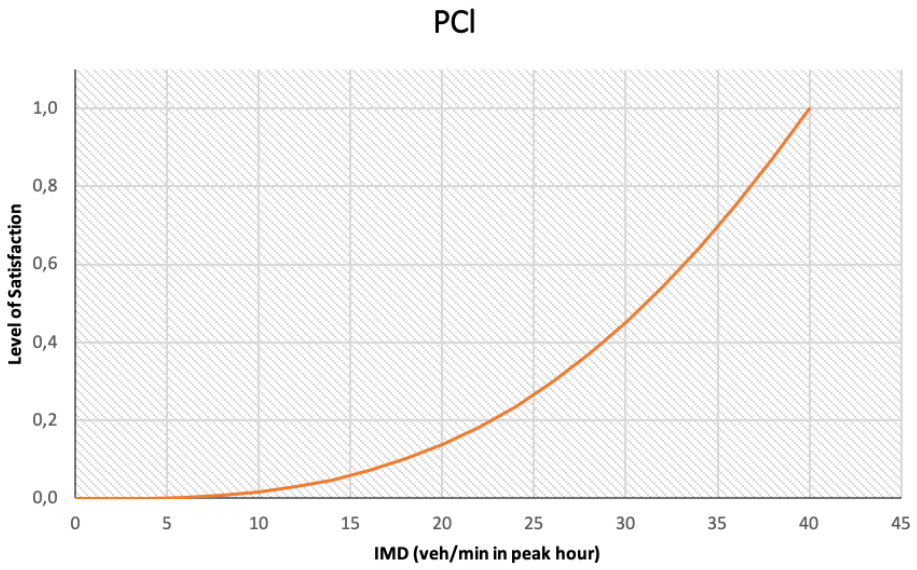

Figure 4-12: PCl value function

Table 4-13: Results of the Value function for each alternative

Alternatives	DCl	PCl
Parc Joan Miró	0,02	0,02
Entença - Viladomat	0,27	0,21
Comte d'Urgell - Montaner	0,73	0,58
Aragó - GV les Corts Catalanes	0,14	0,07
Badajoz - Llacuna	0,00	0,01

4.3.3. Social Requirement:

The social requirement is paramount for this thesis's purposes, as it is based on the study of public space recovery. It is branched in three criteria: tactical, structuring and functional measures.

Tactical measures refer to the improvements on the habitability of the public space regarded as the most important of all criteria. Evaluating the Public Space Gained (PSG) is set as the indicator, computing the space gained in each street of the alternatives (eq.4-8).

$$PSG_i = GpS_i * nS_i * HC_i$$

Equation 4-8: Public Space Gained

Where: GpS (Gained per Street) is the public space gained per street in each alternative; nS the number of streets gained; and HC the homogeneity coefficient.

Structuring measures refer to the re-urbanisation works affecting the functional uses of the space. To evaluate it, two indicators are used, the meters of Parking Spots Reduced (mPSR) and the Diversity of Uses (DoU). The case of parking spots reduced is considered as a decreasing function; the more reduction of places to park is considered as less satisfactory. It may seem contradictory to the fact that public space is gained if the number of spots to park is reduced. However, this criterion evaluates the functionality of the space, and if it was not considered a decreasing function, the same aspect (gained of space) would be considered twice. The second indicator measures to concepts, the variety of uses (cultural, social, religious, etc.) and the total amount of spaces devoted to different uses. Both indicators are computed with the following equations:

$$mPSR_i = \frac{cBZ * rBZ + cGZ * rGZ + cMZ * rMZ}{HC_i}$$

$$DoU_i = \left(\beta_1 \left(\frac{n_i DU}{n_t DU} \right) + \beta_2 \left(\frac{n_i U}{n_t U} \right) \right) HC_i$$

Equation 4-9: Parking Spots Reduced and Diversity of Uses

Where for the mPRS equation: cBZ and rBZ refer to the current reduction of blue zones; analogously cGZ, rGZ, and cMZ, rMZ represents the current and reduction spaces for the green zones (GZ) and the motorbike zones (MB), measured in meters. The total meters reduced is then divided by the homogeneity coefficient, as it is a decreasing function.

Moreover, for DoU equation: niDU and ntDU refer to the number of different uses in each alternative and the total number of possible different uses respectively; analogously niU ntU are for the number of uses. Both variables are weighted (β_i), where the different uses represent 70% and the total number the 30%.

Functional measures evaluate the alteration on the functionality of the public and active modes of mobility (bus and bike). The indicators to calculate it are the enhancement of Bus and Bike Mobility (BM & BiM). To measure the indicators, the addition of new lanes and new stations for both modes of transport has been studied. However, in bus mobility, the study does not show any new lanes or stations in any of the alternatives. Thus, the Bike Mobility (eq. 4-10) will represent the totality of the functional measure criterion.

$$BiM_i = \left(\frac{\Delta Bl}{cBl} + \frac{\Delta Bs}{cBs}\right) HC_i$$

Equation 4-10: BiM

Where the BiM is computed with the summation of the percentual increment on bike lanes (ΔBl) and bike stations (ΔBs) times the homogeneity coefficient.

The parameters used for each indicator are set to provide a distinct shape to each function (table 4-14). The Public Spaced Gained indicator is considered to have a smooth S shape (fig.4-13), as the greater satisfaction is experienced with a balanced amount of space gained, smaller or bigger increments do not produce a substantial increase in satisfaction. Due to the small changes on Bike Mobility, the function has a convex shape (fig.4-14), where the tiny positive modifications are well received. The Parking Spots Reduced are represented with a decreasing convex function (fig.4-15). Finally, the Diversity of Uses indicator has a linear relationship with satisfaction (fig.4-16).

Table 4-14: Social Indicators Parameters

	PSG	BiM	mPSR	DoU
Xmin	0	0	300	1,5
Xmax	45000	400	0	3
Ki	0,2	1,5	2	0
Ci	20000	75	100	2,25
Pi	4	0,5	0,5	1
B	1,01	1,03	1,03	1500,50

Applying the parameters, the value functions obtained are the following:

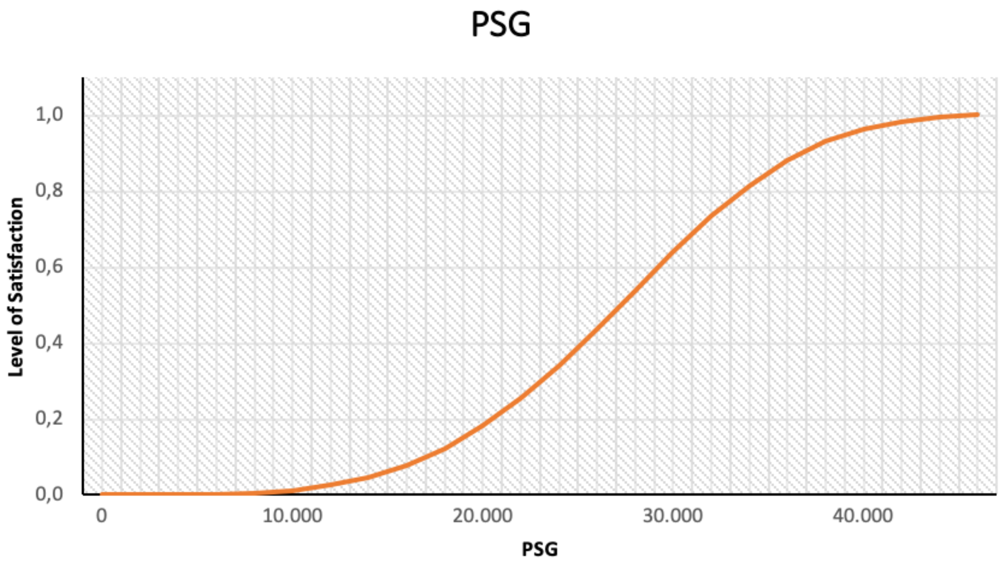

Figure 4-13: PSG Value function

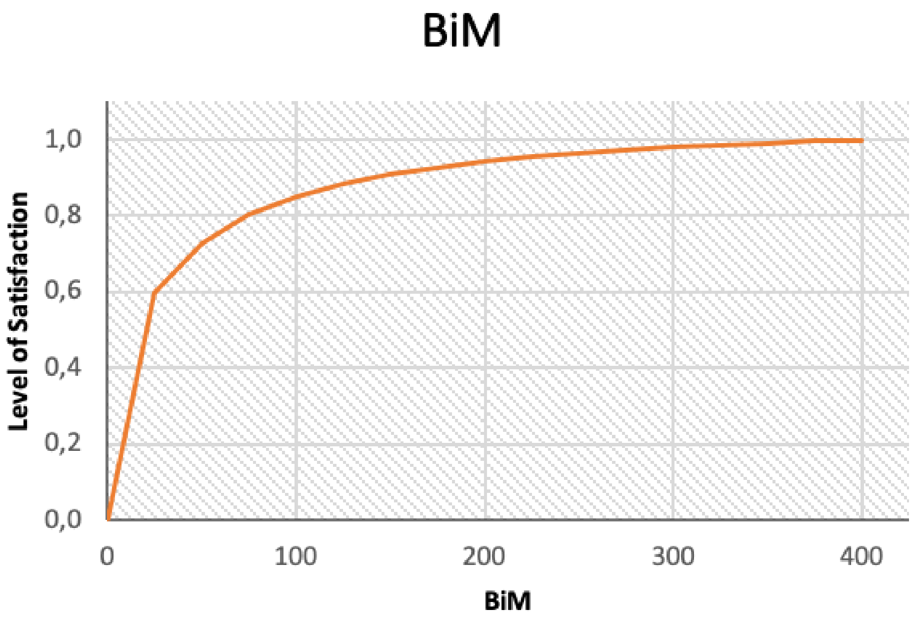

Figure 4-14: BiM Value function

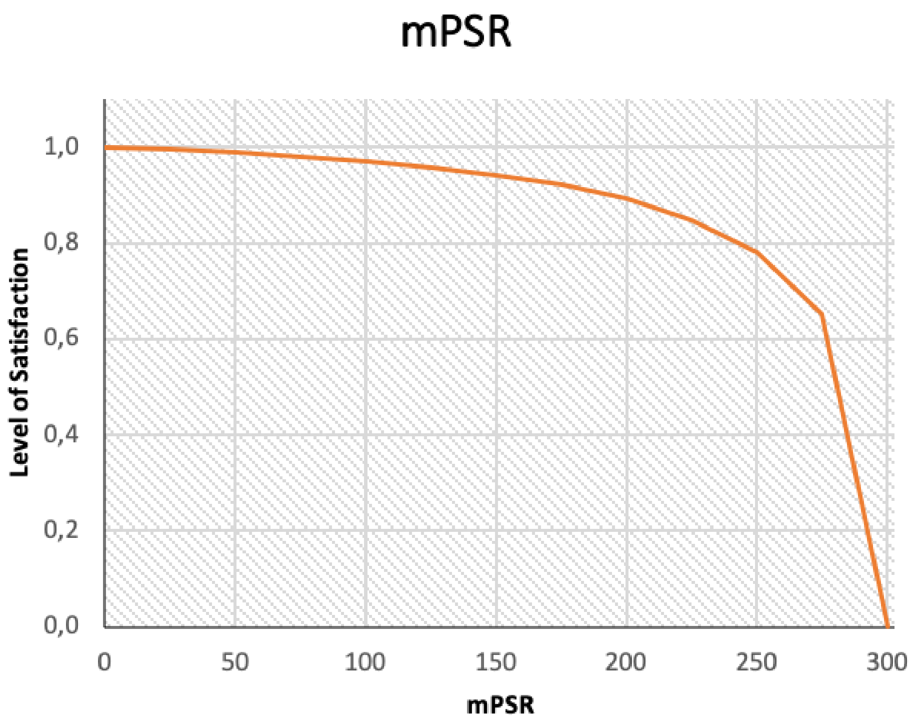

Figure 4-15: mPSR Value function

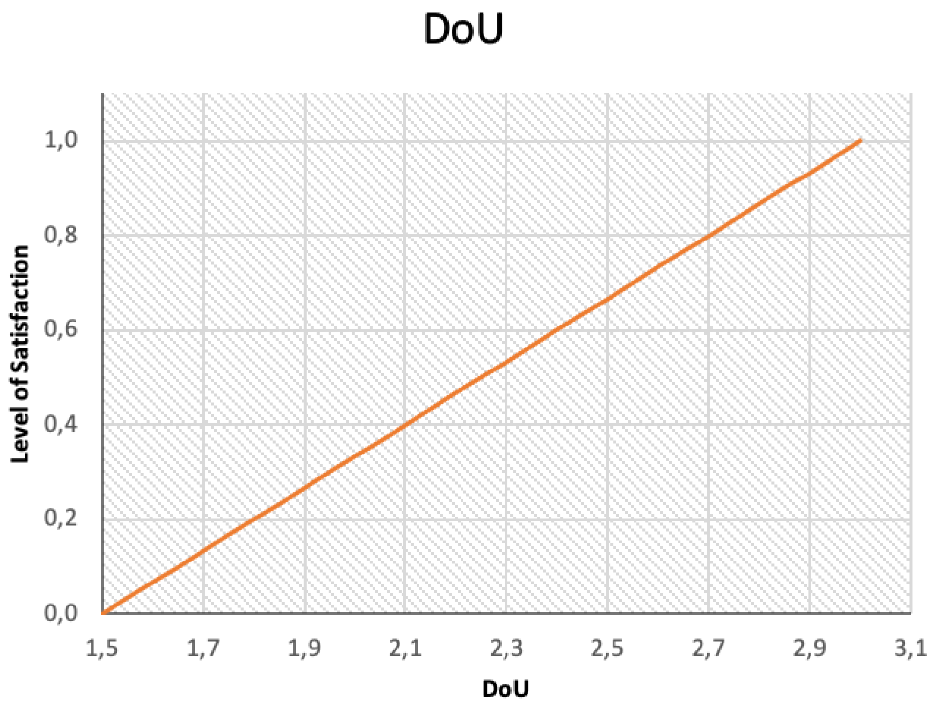

Figure 4-16: DoU Value function

4.3.4. Economical Requirement:

The economic requirement evaluates the different monetary impacts caused, based on the cost of construction and the economic benefits. For the computation of the requirement, two criteria are studied: the economic impact on local commerce and the unitary cost of the alternative. The unitary cost indicator may not be influential for the citizen viewpoint, but in terms of decision-makers it could be considered decisive, then it is important to take it into account

First, the satisfaction on the economic impact criterion is analysed through the effect on local commerce (ElC) if the loading and unloading points are reduced (table 4-15). The effect of decreasing 3 points on a high trading concentration is not the same that in a low concentration area, thus the satisfaction produced is different.

Table 4-15: ElC evaluation

	ElC
Very Positive	5
Positive	4
Indiffenent	3
Negative	2
Very Negative	1

Secondly, the unitary cost (UC) is computed as the summation of all priority works prices done in each alternative separately. In this particular case, the value is divided by the homogeneity coefficient because the final value of the cost is directly proportional to the monetary cost and indirectly proportional to the need for the infrastructure.

$$UC_i = \frac{TotalCost_i(M€)}{HC_i}$$

Equation 4-11: Unitary Cost

The parameters used for each indicator set two distinct shapes to each value function (table 4-). The Effect on the local Commerce (ELC) indicator is considered to have a sharp S shape (fig.4-), as the first effects are adverse, which produces a null satisfaction, the satisfaction increases sharply as the effects go from negative to positive. The Unitary Cost has a decreasing linear relationship (fig.4 with satisfaction produced to the decision-maker.

Table 4-16: Economic Indicators Parameters

Parameters	ElC	UC
Xmin	0	1
Xmax	5	0
Ki	0,1	0,0
Ci	2,5	0,5
Pi	7	1
B	1,0	5000,5

Applying the parameters, the value function obtained are the following:

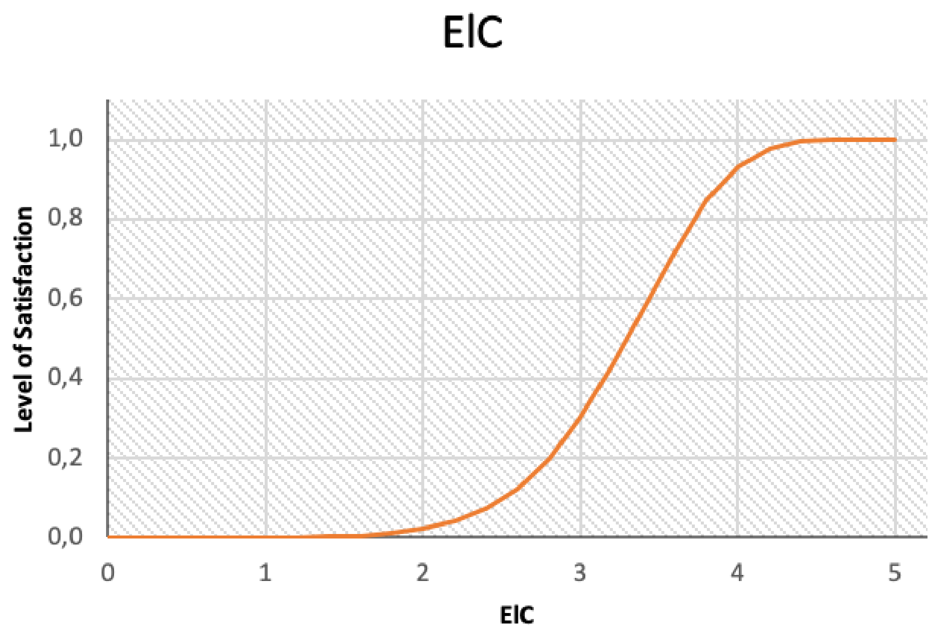

Figure 4-17: EIC Value function

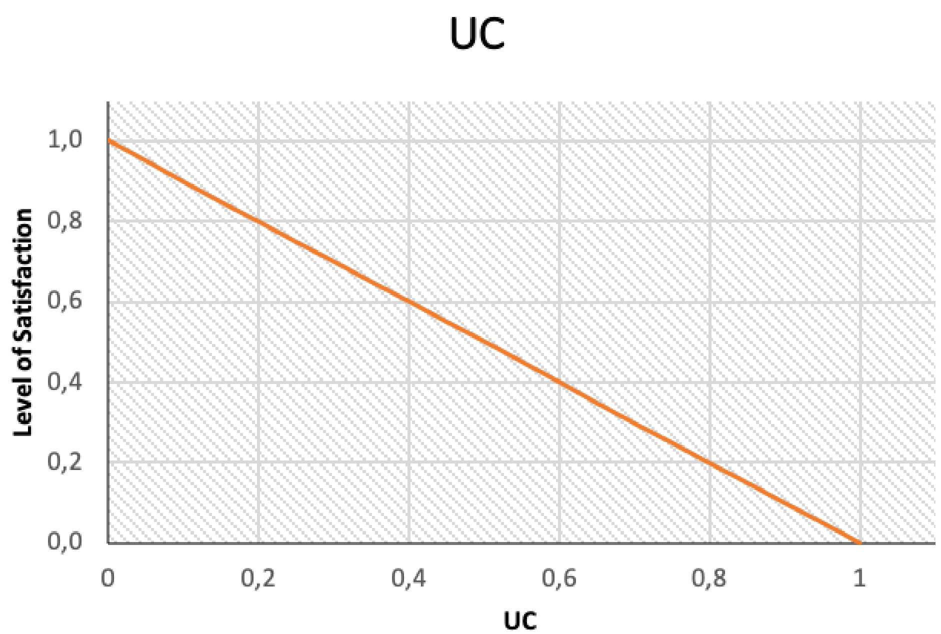

Figure 4-18: UC Value function

4.3.5. Final Results:

The values obtained for each alternative on all indicators are:

Table 4-17: Indicators Results on each alternative

	Environmental Requirement		Social Requirement				Economical Requirement	
Alternative	DCI	PCI	PSG	BiM	mPSR	DoU	EIC	UC
Parc Joan Miró	0,02	0,02	0,01	0,71	0,94	0,24	0,30	0,66
Entença - Viladomat	0,27	0,21	0,93	0,00	0,93	0,93	0,02	0,68
Comte d'Urgell - Montaner	0,73	0,58	0,91	0,95	0,98	0,15	0,00	0,98
Aragó - GV les Corts Catalanes	0,14	0,07	0,98	0,81	0,45	0,53	0,02	0,29
Badajoz - Llacuna	0,00	0,01	0,39	0,99	0,98	0,78	1,00	0,49

The next figure (fig. 4-19) is a more visual representation of the function values results for each indicator:

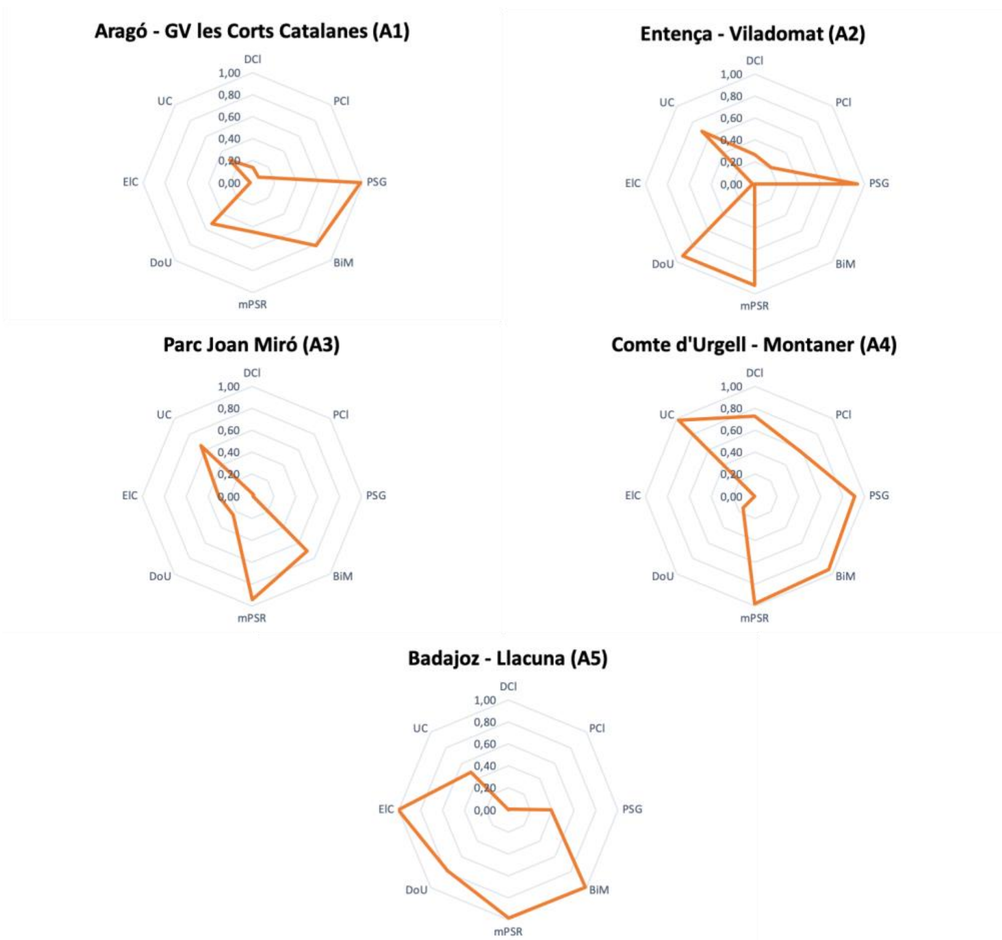

Figure 4-19: Radar charts for the value function results of each indicator

4.4. Assignation of weights

Each requirement, criteria and indicators, on a decision-making problem, has their relative grade of importance, which varies upon the goals and interests of the decision-maker. The author's focal interest is the recovery of public space in a densified context; thus, indicators related to the density and public space use will prevail over the others. Assigning weights to each branch of the requirement tree reflects those concerns.

It could be directly assigned for a reduced number of elements; however, for a more sophisticated requirement tree, the Analytic Hierarchy Process (AHP) (Saaty, 1980) is more appropriate. Through a series of pairwise comparisons, the AHP process generates a comparison matrix to compute the requirement tree's weights. Moreover, it checks any inconsistency that may arise for matrixes bigger than 2x2. The process is first applied independently to indicators from the same criteria, then to criteria from the same requirement, and finally to the three principal requirements.

Table 4-18: Comparison scale by Saaty (1980)

Comparison of indicator *i* with respect to indicator *j*		
Intensity of imporance indicator i	Definition	Intensity of imporance indicator j
1	Equal Importance	1
3	Moderate importance of i over j	1/3
5	Strong importance of i over j	1/5
7	Very strong importance of i over j	1/7
9	Extreme importance of i over j	1/9

The previous scale (table 4-18), presented by Saaty (1980), is used to build the matrixes upon the level of importance between the elements compared, allowing the use of intermediate values. So, from the requirement tree (table 4-11), a series of matrixes are developed (appendix A). From there, the eigenvector of the maximum eigenvalue of each matrix represents the weights of their corresponding indicators, criteria, and requirements.

For instance, diminishing the daily congestion level has a greater influence on pollution levels, since it represents a higher volume of cars. Thus, the Daily Congestion Level (DCl) is considered to have substantial importance over the Peak Congestion Level (PCl), which is both indicators of the environmental requirement. Then, the following matrix is built (fig. 4-20):

$$\begin{vmatrix} 1 & 5 \\ 1/5 & 1 \end{vmatrix}$$

Figure 4-20: Comparison Matrix (DCl versus PCl)

The term "*i*" (DCl) is compared with the term "*j*" (PCl), then the diagonal is one since comparing one element to itself; the level of importance is the same. The term a_{ij} compares DCl over PCl, which is said to be of stronger importance, hence a value 5. Then, the term a_{ji} is the inverse. The maximum and only eigenvalue is 2, with an eigenvector (1;0,2), meaning that PCl has a relative weight of 0,83 and DCl of 0,17.

Analogously, the process is applied to two more homogeneous indicators, functional and structuring measures; two sets of criteria, social and economic; and a final one for the three requirements, with the final result of percentual weights:

Table 4-19: Weights of the tree requirement

Requirements (weight%)	**Criteria (weight%)**	**Indicators (weight%)**
Social (76%)	Tactical Measures (77,16%)	Public Space Gained (100%)
	Structuring Measures (17,36%)	meters of Parking Spots Reduced (12,5%)
		Diversity of Uses (87,5%)
	Functional Measures (5,48%)	Bus Mobility (0%)
		Bike Mobility (100)
Economical (9%)	Investment (10%)	Unitary Cost (100%)
	Economy Impact (90%)	Effect on Local Commerce (100%)
Environmental (15%)	Pollution (100%)	Daily Congestion Improvement (83%)
		Peak Congestion Improvement (17%)

As mentioned, some inconsistencies in weight computation can appear. To check them, Saaty (1980) introduced the Consistency Ratio (CR); if this ratio exceeds 10%, some revision may be need it. The CR is the ratio between the Consistency Index (CI) and the Random Index (RI) (eq. 4-12).

$$CR = \frac{CI}{RI} = \frac{\frac{\lambda_{max} - n}{n - 1}}{RI} < 0.1$$

Equation 4-12: Consistency Ratio

Where: λ_{max} is the largest eigenvalue; and "n" the size of the matrix. The RI is the mean value of all CI of a matrix generated randomly (table in appendix A).

For the indicator matrix and economic criteria matrix, the size is two, and their maximum eigenvalue is also 2. Therefore, the Consistency Index (CI) is null, and no inconsistencies are found. The social criteria matrix and the requirement matrix have a size of 3, with a RI of 0,525 (table 4-20), and a maximum eigenvalue of 3,2 and 3,03, respectively.

Applying the Consistency Ratio, some inconsistencies are obtained for the social criteria matrix, with a CR of 0.19. This means that if, for example, “A” criterion is four times “B” and “B” is two times “C”, then “A” is eight times “C”. However, the weights obtained do not reflect these relationships. After a revision, the new matrix is consistent, with an eigenvalue of 3,1, and the new social criteria weights are:

Table 4-20: Final Social criteria Weights

Criteria (weight%)
Tactical Measures (61,35%)
Structuring Measures (33,13%)
Functional Measures (5,52%)

4.5. Evaluate and assess the alternatives

Once the value function and weights are defined, the evaluation can be done, and the Prioritization Index (PI) of each alternative is obtained (eq. 4-13).

$$PI_i = 100 \sum (w_{R_h} \times w_{C_j} \times w_{I_l} \times Vf_l)$$

Equation 4-13: Prioritization Index

Where: $(w_{R_h}; w_{C_j}; w_{I_l})$ are the relative weights of each requirement, criteria and indicator, and Vf_l the value function of each indicator.

The Prioritization Index goes from the highest priority (100) to the lowest one (0). Fig. 4-21 shows the results of applying the Prioritization Index to the alternatives presented in previous chapters.

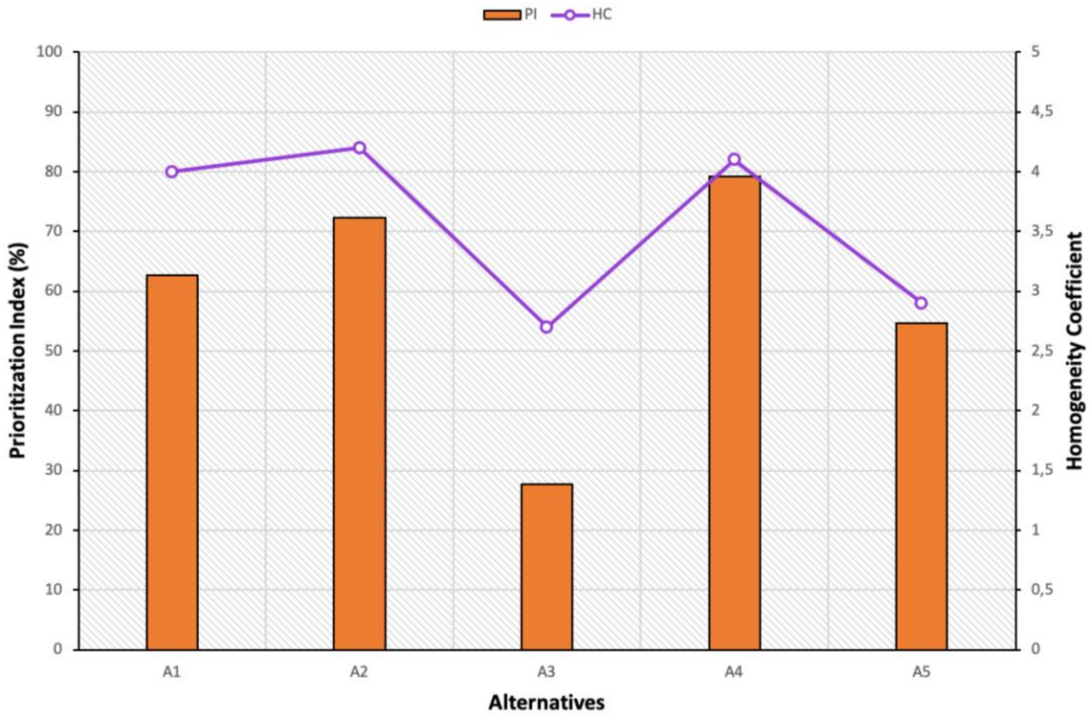

Figure 4-21: Prioritization Index of the Superblock Alternatives

The results showed that the Superblock *Comte d'Urgell-Montaner* (A4) is ranked as the highest priority alternative, followed by *Entença -Viladomat* (A2), *Aragó – GV de les Corts Catalanes* (A1), *Badajoz – Llacuna* (A5), and lastly the lowest-ranked alternative is *Parc Joan Miró* (A3). However, these results are highly influenced by the decision-maker interests, as they are defined in advanced. These interests are represented by the homogeneity coefficient and the parameter weights. In this case, it is easy to see the influential power of the homogeneity coefficient, as the prioritization ranking follows a similar pattern (fig.4-21).

4.6. Sensitivity Analysis

The sensitivity analysis, mentioned beforehand, adds strength to the results obtained. It analyses how the prioritization ranking would vary if the HC or the parameter weights changes. Considerable alterations on the final results due to a variation on the HC would reaffirm this coefficient's influential power. Meanwhile, if the alterations are shown when the parameter weights are changed would mean that the author’s established interests have a great significance.

On the one hand, it is carried out two sensitivity analyses altering the homogeneity coefficients. First, set them to equal value for all alternatives (SA1), and then rearrange the preference so that the order is reversed (SA2). When altering these weights, the value function parameters (X_{max}, X_{min}, P, C, and K) must be changed accordingly.

On the other hand, three sensitivity analyses are also carried out, changing the weights in this case only from the requirements, not the indicators or the criteria. A first balanced distribution is studied (SA3), a second one assigning bigger weight to the environmental requirement (SA4) and a final one with more significant weight to the economic requirement (SA5).

To avoid tediousness, all value functions, and the relative weights used in each analysis will be shown in appendix B. The following figures will only represent the final results obtained from the sensitivity analyses and the comparison with the original result.

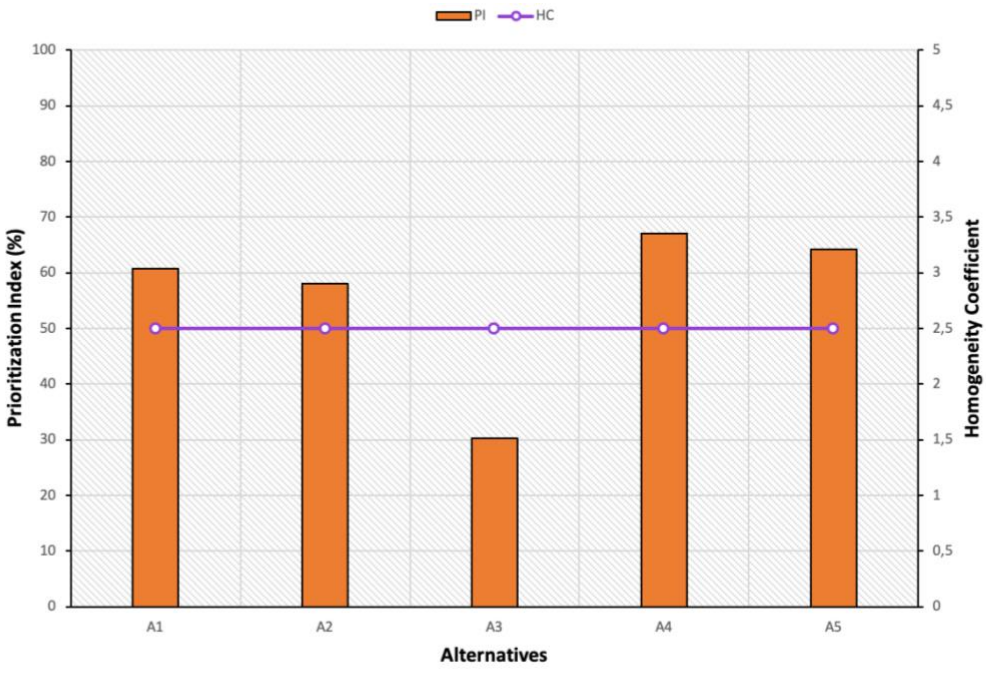

Figure 4-22: Sensitivity Analysis 1: equal HC

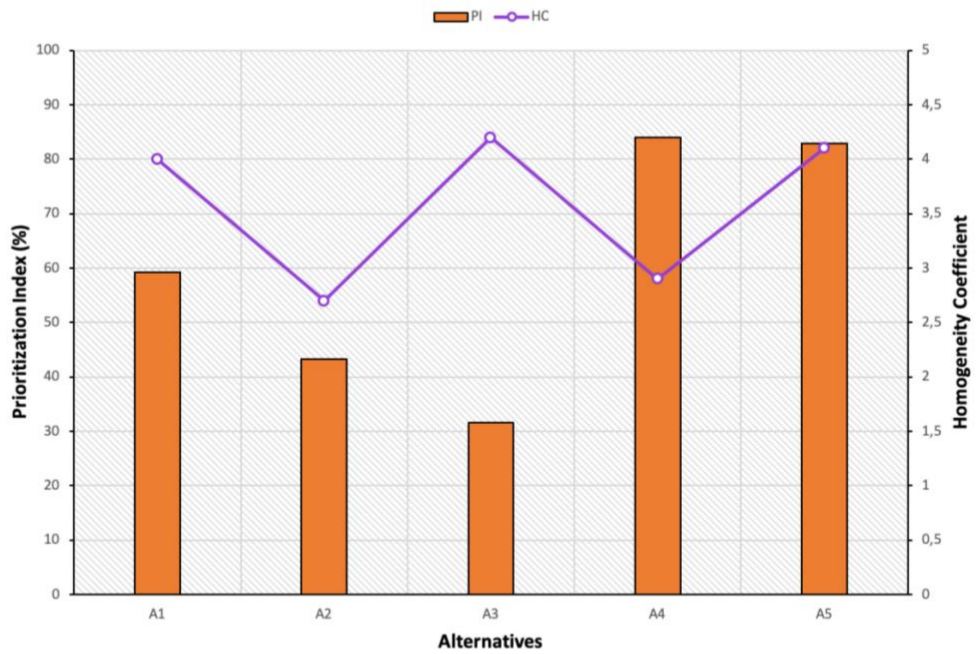

Figure 4-23: Sensitivity Analysis 2: Reversed HC

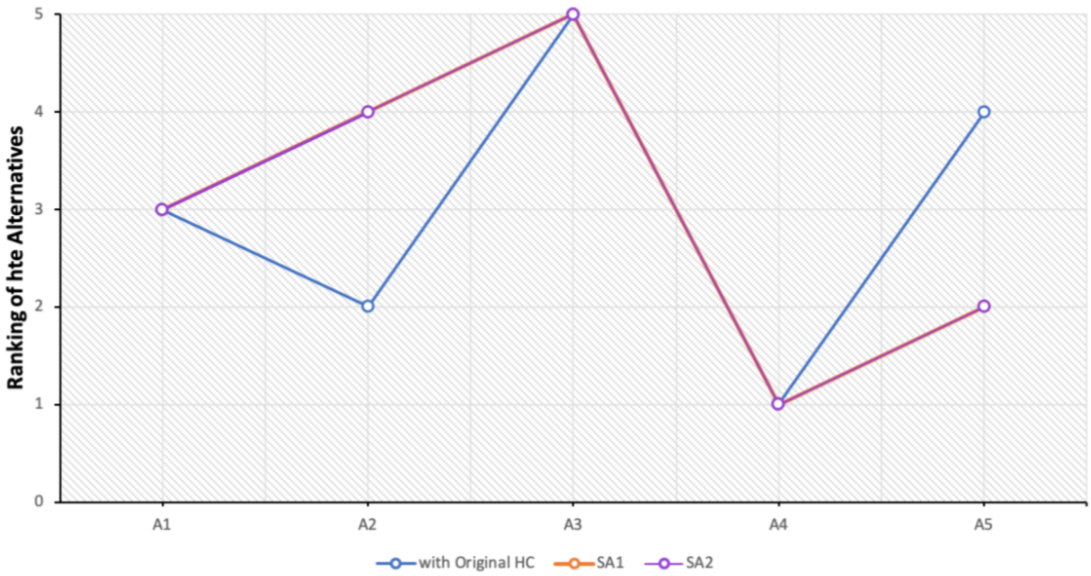

Figure 4-24: Comparison of Alternatives Ranking

From the first analysis (fig. 4-22), the overall index is lower, as the homogeneity coefficient average is also lower. However, despite the change in the coefficients, the pattern of the indexes is similar to the original one, with the only change of position between alternatives 2 and 5. The same results are obtained reversing the order of the HC (SA2) (fig. 4-23). Thus, both rankings from the sensitivity analysis are the same (fig. 4-24). So, it demonstrates that the influence of the coefficients is only on the second and fifth alternative. The further conclusion will be exposed on the final chapter of this thesis.

The next two figures compare the changes in the prioritization indexes and the final ranking (fig. 4-25 & 4-26) when the sensitivity analyses are done on the requirement weights. Similar behaviour to the previous analyses is denoted, smaller indexes, and changes on the final ranking. The individual results graph of each analysis is not of interest since their HC is not changed; however, those figures will be illustrated in appendix C.

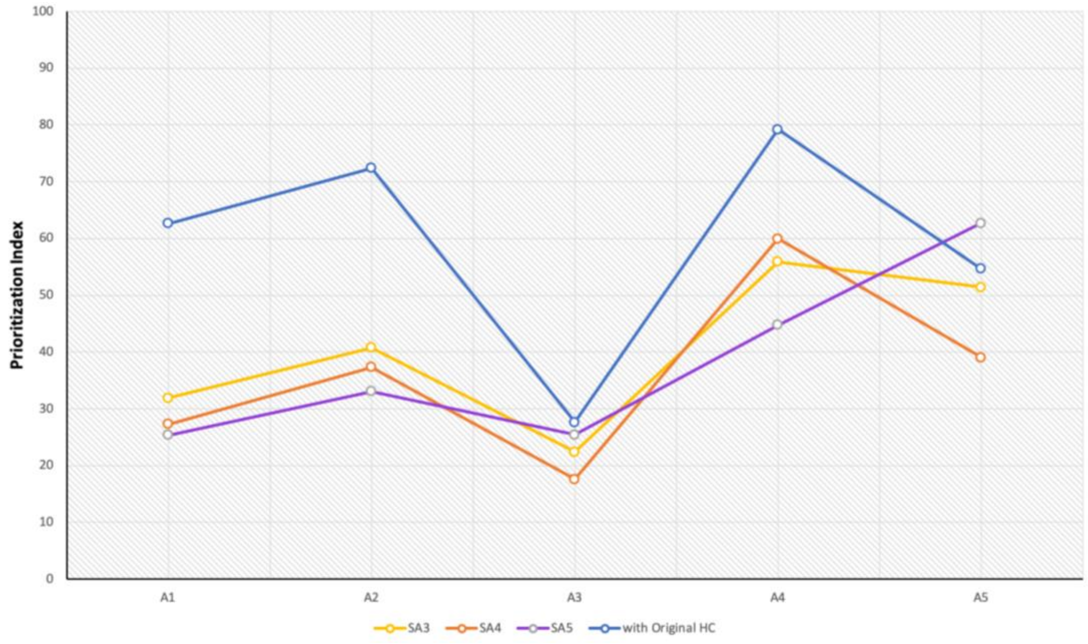

Figure 4-25: Comparison of the prioritization index

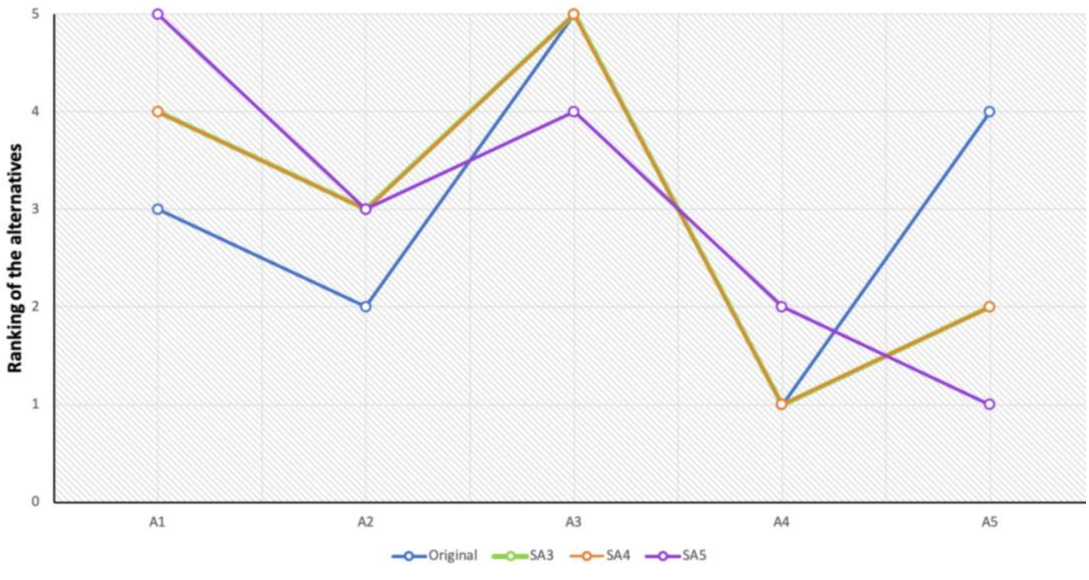

Figure 4-26: Comparison of the Alternatives Ranking

4.7.Reading of results

The results of the study show that the fourth alternative is the best suited to be the first implemented, and the rest follows with similar values except for A3. After the sensitivity analyses, this priority is confirmed. This alternative is the one located in *Comte d'Urgell – Montaner,* from the *L'Antigua Esquerra de l'Eixample* district. Only in the last analysis (SA5), where the economic requirement has a more considerable influence, the alternatives fall to the second position, and alternative 5 (*Badajoz-Llacuna*), the one already implemented, takes the first place.

There are two explanations for this switch; first, contrary to the rest of the alternatives, in *Badajoz-Llacuna,* instead of reducing loading and unloading spots, they are increased; secondly, it has one of the highest homogenizing coefficients which diminishes the adverse effects of the unitary cost substantially. Then, it is logical that when the economic requirement is considered the decisive factor, the alternative five becomes the first.

Nevertheless, there is another revealing lecture from all sensitivity analyses carried out regarding alternative 5. It went from an original fourth place in the ranking to the second or first position once changing the weights in the coefficients, and the requirements. Meaning that from an economic and environmental perspective, it is very convenient, which suggests it was a good idea for a pilot study to be one of the first Superblocks implemented.

However, since the social requirement is the principal driving force, the most important result is the first obtained; hence, the fourth alternative should be implemented first. It has the worse current situation (highest homogeneity coefficient), and scores highly in all features evaluated (fig. 19). It could be that implementing a Superblock in one of the highest density areas, with massive traffic congestion and pollution levels, responds with the best results.

A second obvious reading from the outcomes is that alternative 3 (Parc Joan Miró) is almost always ranked the last. Again, only when the economic requirement is the most significant, the alternative gains one position. The reasons are the same that for alternative

5, it has a low coefficient, reducing the unitary cost negative impact. So, from a decision-maker perspective seems reasonable to be the last Superblock implemented. It is not a revelation since it has one of the lowest numbers of inhabitants, and the Joan Miró park implies the most prominent public space per person.

5. Conclusions

In summary, it is paramount to change the city's street perception as just connections from one destination to another. The capacity to move freely should not prevail, but rather coexist with the ability to bear healthy social interactions. Cities need to recover the public space to re-establish the sophisticated and compacted diversity of uses that bring the streets alive, from a social and economic position.

Cities charm comes from their street image, engaging crowded streets are pleasant and appealing; on the contrary, sluggish deserted streets are felt unsafe, degrading the city looks. Personalities like Jane Jacobs or Cerdà himself spoke of an important distinction between cities and towns: "… cities are, by definition, **full of strangers**." (Jacobs, 1961). The idiosyncrasy of great city district is its ability of strangers to interact and feel invulnerable among the streets.

A **high-density population** district like Eixample in Barcelona is the maximum expression of stranger's agglomeration. Nowadays, these large densities of inhabitants are poorly managed, with low public and green space per person and high pollution levels. However, they present the best conditions to execute **tactical urbanism** measures to enhance the neighbourhoods' quality of life. They assure the goal of vibrant and sustainable public space. But, why streets pacification in a context of high density is optimal?

First, the compactness and intricacy of these districts prevent decay and isolation of proper urban planning. Imagine creating of a playground in a neighbourhood with no kids; the park would rotten and inappropriately be used. Then, the generation of new public space in an area with a significant flux of pedestrian seems obvious. When appropriate tactics provide adequate goods and services, their inhabitants respond, filling the streets with joy.

Second, when the streets are filled with civilians, gather balcony spectators, increasing the number of eyes upon the street. This concept is crucial for lowering crime enticement. Empty streets cry out for criminal activities, the more people watching the streets, the more secure it becomes. Then, it is clear that filling the streets is easier in compact cities.

Apart from social reform, the sustainability goal also aims to environmental problems associated with **climate change**. Reducing car dependency by enhancing public and active means of transport cuts down the number of **premature mortalities** related to pollution exposure. **Ecosystemic urbanism** focused on balanced and proportionated use of the public space is the path to reach the sustainability goal.

In the case of Barcelona, this ecosystemic urbanism translates in the name of the **Superblock model**. It is an old concept, regarding the unification of nine blocks into a new urban cell. Inside the cell, the inhabitants are put back on top of the **hierarchy dominance** of the space. Car privileges are diminished, reducing both speed and access to the cell's interior to encourage greener mechanisms of mobility. The **superblock model** is the perfect candidate for the re-urbanization of Barcelona if the right policies are adapted to invigorate local businesses and increase the variety of uses. As mentioned, there is no point in creating new spaces if no one will use them. Moreover, the model contributes to reducing health issues related to pollution and a sedentary lifestyle, becoming a landmark for the sustainability of future cities.

Nevertheless, from an economic perspective, it is inconceivable to implement such a network of Superblocks on the entire city in the short term. **Multi-Criteria Decision-Making methodologies** are an excellent tool to give a critical opinion for the selection of the right place to initiate the application. Specifically, **MIVES** methodology yields a ranking of the alternatives (each particular superblock) evaluating the contribution based on sustainability preferences. Unlike others, only focused on monetary terms, the **MIVES** framework considers economic, social, and environmental aspects, rationalising those subjective aspects through the generation of an index value.

The methodology has seen to deliver accurate and coherent results through the implementation of three fundamental phases. First, a preliminary **homogenization process** to make comparable all alternatives considered. This step is essential in the case of Barcelona's Superblock since each alternative's initial conditions are different. It is a preliminary process before any model is implemented.

The second phase defines the **requirement tree** and its **value functions**. It is the body of the MIVES methodology, where the variables and their evaluation expression are defined. It is vital to make sure each important aspect is considered while ensuring that they are not taken into account twice in different indicators.

Finally, the third phase consists of the **assignation of weights**. This is crucial to introduce the preferences of the decision-maker. However, when the tree requirement is somehow substantially large, the **Analytic Hierarchy Process (AHP)** helps the consistency in the assignation of weights.

Then, the MIVES methodology has been applied in five superblocks located in different areas of Barcelona, in particular, four from the *Eixample* district, and one in *Sant Martí*. The first superblock is in the neighbourhood of *La Dreta de l'Eixample* around *Girona Street*. The second and third ones in *La Nova Esquerra de l'Eixample*, between *Entença – Viladomat* and *Parc Joan Miró,* respectively. The fourth one is situated in *l'Antiga Esquerra de l'Eixample* neighbourhood, in *Comte d'Urgell – Montaner,* and the last alternative in *El Parc i la Llacuna del Poblenou*, between *Badajoz – Llacuna*.

The selection of the four first alternatives, from the Eixample district, is because the Superblocks in each alternative are on the phase before prioritizing the action's execution, putting the alternatives selected in the ideal position to prioritize which one should be first executed.

The fifth superblock in *Sant Marti* district works as a reference to see if the results obtained are coherent and accurate. The alternative was one of the first superblocks implemented, which served as a pilot test to see the improvements from this new urban plan.

After applying MIVES methodology, the results show that alternative *Comte d’Urgell – Montaner* must be prioritized first. From the **environmental requirement** standpoint, in both indicators evaluated, it has the most significant **congestion improvement** from all alternatives. It may not have the highest value in the **social requirement** indicators but maintains a certain elevated mark in all five indicators considered, which makes an overall good mark. Finally, the evaluation of the **economic requirement** shows the worse adverse effect on **local commerce**, as the concentration of commerce is the highest of all alternatives, and the reduction of loading and unloading spots is more perceived. On the contrary, it has the cheapest unitary cost, as most of the priority works are done in other alternatives. Thus, the economic requirement is balanced out.

To sum up, the alternative *Comte d’Urgell – Montaner* has the best grades in the social and environmental requirements, and since these requirements represent 85 percent of the index value, it is clear that it provides the best sustainable benefits and it should be first implemented.

The next in line are alternative *Entença – Viladomat*, and *Aragó – GV de les Corts Catalanes*. Despite that both alternatives are located in different neighbourhoods, they present similar value in all social, environmental, and economic indicators. They only differ in the Bike Mobility, where *Entença – Viladomat* alternative has a reduction of bicing stations.

The least benefit from the execution of the Superblock model is the alternative *Parc Joan Miró*. This alternative's initial characteristics implied that the superblock would probably not contribute to a great sustainable gain. It does not have the highest density population amongst the alternative, and it is the only alternative with a public park, an enormous public space that reduces the possible benefits from the superblock implementation. After the application of MIVES, this initial suggestion is demonstrated, and the alternative is regarded as the least sustainable.

A final note on MIVES is that the methodology provides accurate and coherent results. The most densified areas, with less public space per inhabitant, are ranked at the top. Any possible action in these alternatives represent a tremendous impact, on the objectives of this thesis, to recover the public space in a context of a high-density population. The possible differences, of the alternatives ranked at the top, in implementation of the superblocks are difficult to notice without the MIVES performance.

The accuracy of the methodology provides a reasonable prioritization list, where it makes sense that the least preferable alternative (Parc Joan Miró) is the one with the biggest public park inside the superblock. Thus, MIVES methodology is proven to give excellent and robustness results, with a great potential to be used in other fields of decision-making problems.

Appendix A

Pairwise Comparison Matrix and their eigenvalue and eigenvector used to obtain the weigths on the requirement tree.

DCl vs PCL

1	5
1/5	1

Max. Eigenvalue	Eigenvector
2	(1 , 0.2)

mPRS vs DoU

1	1/7
7	1

Max. Eigenvalue	Eigenvector
2	(0.14, 1)

Figure A-1: Indicators matrix, and their respective eigenvalue and eigenvector

Economy Criteria vs Invesment Criteria

1	9
1/9	1

Max. Eigenvalue	Eigenvector
2	(1 , 0.11)

Functional (i) vs Structural (j) vs Tactical (k)

1	1/3	1/8
3	1	1/7
8	7	1

Max. Eigenvalue	Eigenvector
3,1	(0.09, 0.54, 1)

Figure A-2: Criteria matrix, and their respective eigenvalue and eigenvector

Environmental (i) vs Economical (j) vs Social (k)		
1	2	1/6
1/2	1	1/7
6	7	1

Max. Eigenvalue	Eigenvector
3,03	(0.2, 0.12, 1)

Figure A-3: Requirement matrix, and their eigenvalue and eigenvector

Appendix B

Value functions and relative weights used in the all sensitivity analyses.

	Environmental Requirement		Social Requirement				Economical Requirement	
Alternative	DCl	PCl	PSG	BiM	mPSR	DoU	EIC	UC
Parc Joan Miró	0,07	0,14	0,01	0,70	0,99	0,36	0,30	0,69
Entença - Viladomat	0,20	0,35	0,67	0,00	0,96	0,36	0,02	0,55
Comte d'Urgell - Montaner	0,60	1,00	0,67	0,89	0,99	0,03	0,00	0,98
Aragó - GV les Corts Catalanes	0,12	0,14	0,86	0,73	0,69	0,22	0,02	0,06
Badajoz - Llacuna	0,01	0,06	0,59	0,99	1,00	0,65	1,00	0,50
Relative Indicator weights	0,83	0,17	1,00	0,13	0,88	1,00	1,00	1,00
Relative Criteria weights	1		0,61	0,3313		0,06	0,90	0,10
Relative Requirement weights	0,15		0,76				0,09	

Figure B-1: SA1

Alternative	Environmental Requirement		Social Requirement				Economical Requirement	
	DCl	PCl	PSG	BiM	mPSR	DoU	EIC	UC
Parc Joan Miró	0,08	0,08	0,02	0,77	0,99	0,50	0,30	0,77
Entença - Viladomat	0,08	0,06	0,42	0,00	0,96	0,14	0,02	0,50
Comte d'Urgell - Montaner	0,78	0,64	0,99	0,93	1,00	0,11	0,00	0,98
Aragó - GV les Corts Catalanes	0,06	0,03	0,78	0,75	0,87	0,07	0,02	0,03
Badajoz - Llacuna	0,01	0,04	0,97	1,00	1,00	0,91	1,00	0,64
Relative Indicator weights	0,83	0,17	1,00	0,13	0,88	1,00	1,00	1,00
Relative Criteria weights	1		0,61	0,3313		0,06	0,90	0,10
Relative Requirement weights	0,15		0,76				0,09	

Figure B-2: SA2

Alternative	Environmental Requirement		Social Requirement				Economical Requirement	
	DCl	PCl	PSG	BiM	mPSR	DoU	EIC	UC
Parc Joan Miró	0,02	0,02	0,01	0,71	0,94	0,24	0,30	0,66
Entença - Viladomat	0,27	0,21	0,93	0,00	0,93	0,93	0,02	0,68
Comte d'Urgell - Montaner	0,73	0,58	0,91	0,95	0,98	0,15	0,00	0,98
Aragó - GV les Corts Catalanes	0,14	0,07	0,98	0,81	0,45	0,53	0,02	0,29
Badajoz - Llacuna	0,00	0,01	0,39	0,99	0,98	0,78	1,00	0,49
Relative Indicator weights	0,83	0,17	1,00	0,13	0,88	1,00	1,00	1,00
Relative Criteria weights	1		0,61	0,3313		0,06	0,90	0,10
Relative Requirement weights	0,33		0,33				0,33	

Figure B-3: SA3

Alternative	Environmental Requirement DCl	PCl	Social Requirement PSG	BiM	mPSR	DoU	Economical Requirement ElC	UC
Parc Joan Miró	0,02	0,02	0,01	0,71	0,94	0,24	0,30	0,66
Entença - Viladomat	0,27	0,21	0,93	0,00	0,93	0,93	0,02	0,68
Comte d'Urgell - Montaner	0,73	0,58	0,91	0,95	0,98	0,15	0,00	0,98
Aragó - GV les Corts Catalanes	0,14	0,07	0,98	0,81	0,45	0,53	0,02	0,29
Badajoz - Llacuna	0,00	0,01	0,39	0,99	0,98	0,78	1,00	0,49
Relative Indicator weights	0,83	0,17	1,00	0,13	0,88	1,00	1,00	1,00
Relative Criteria weights	1		0,61	0,3313		0,06	0,90	0,10
Relative Requirement weights	0,5		0,25				0,25	

Figure B-4: SA4

Alternative	Environmental Requirement DCl	PCl	Social Requirement PSG	BiM	mPSR	DoU	Economical Requirement ElC	UC
Parc Joan Miró	0,02	0,02	0,01	0,71	0,94	0,24	0,30	0,66
Entença - Viladomat	0,27	0,21	0,93	0,00	0,93	0,93	0,02	0,68
Comte d'Urgell - Montaner	0,73	0,58	0,91	0,95	0,98	0,15	0,00	0,98
Aragó - GV les Corts Catalanes	0,14	0,07	0,98	0,81	0,45	0,53	0,02	0,29
Badajoz - Llacuna	0,00	0,01	0,39	0,99	0,98	0,78	1,00	0,49
Relative Indicator weights	0,83	0,17	1,00	0,13	0,88	1,00	1,00	1,00
Relative Criteria weights	1		0,61	0,3313		0,06	0,90	0,10
Relative Requirement	0,25		0,25				0,5	

Figure B-5: SA5

Appendix C

The next figures show the individual graphs of the prioritization index of the sensitivity analyses 3, 4, and 5.

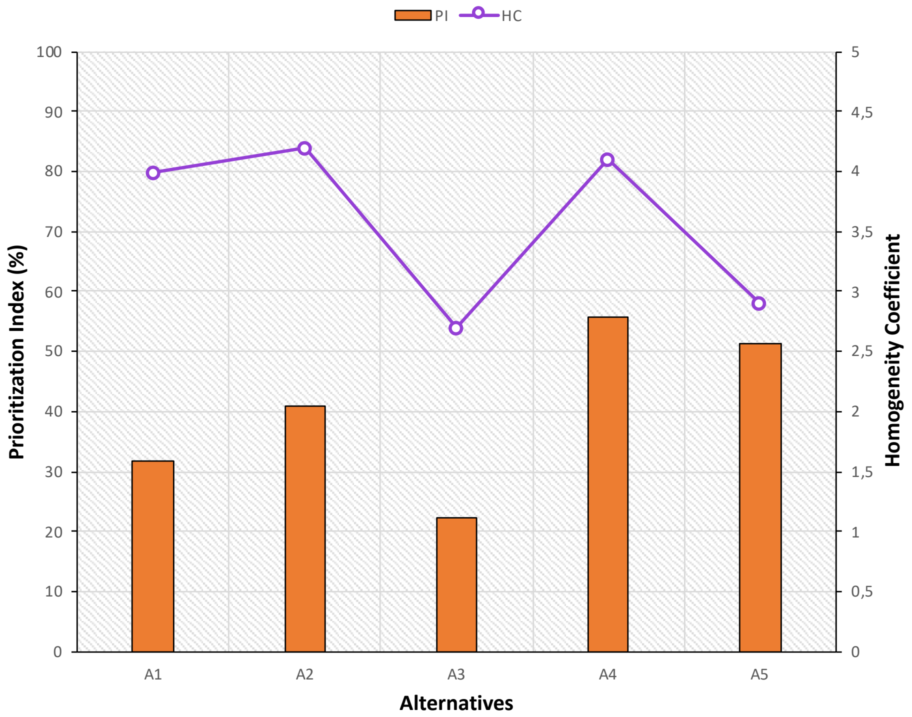

Figure C-1: SA3

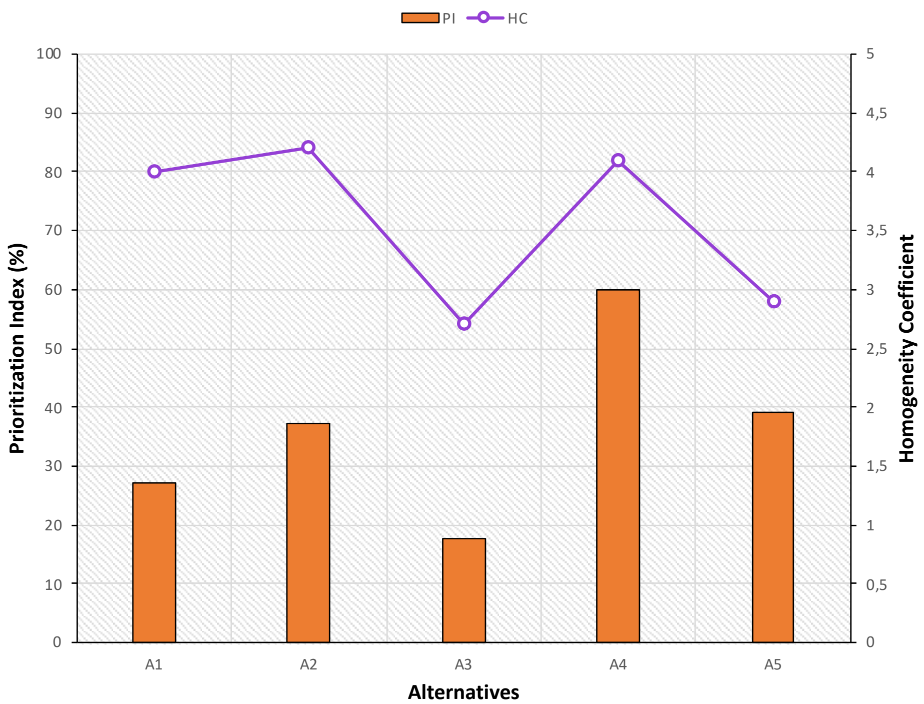

Figure C-2: SA4

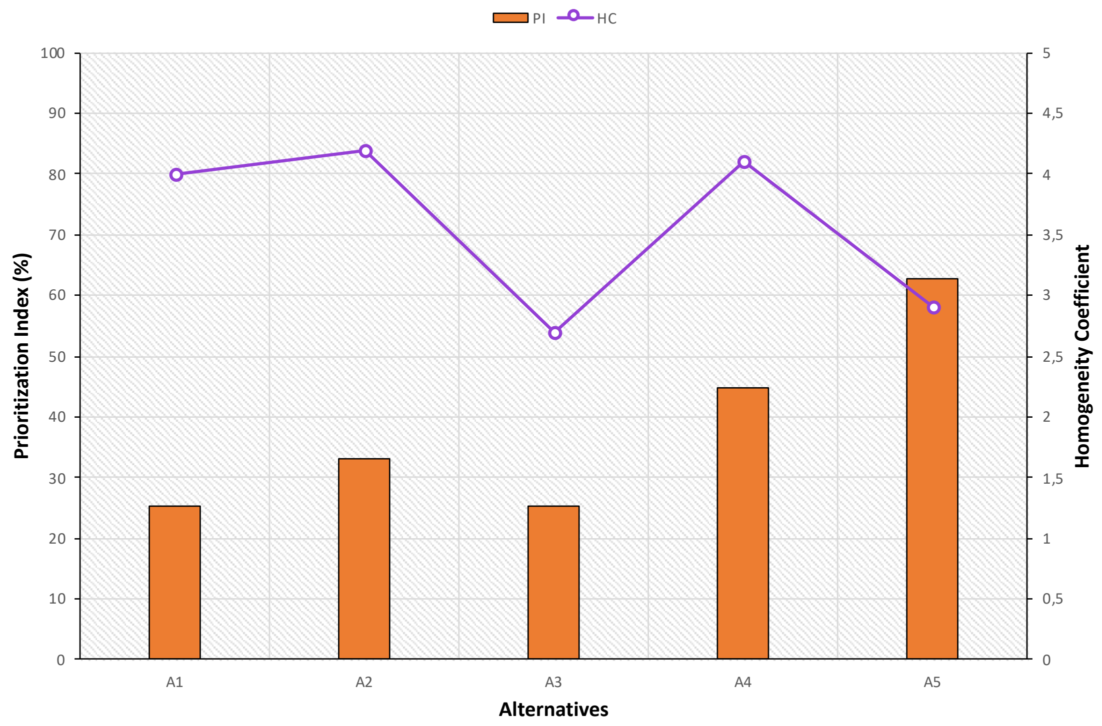

Figure C-2: SA5

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