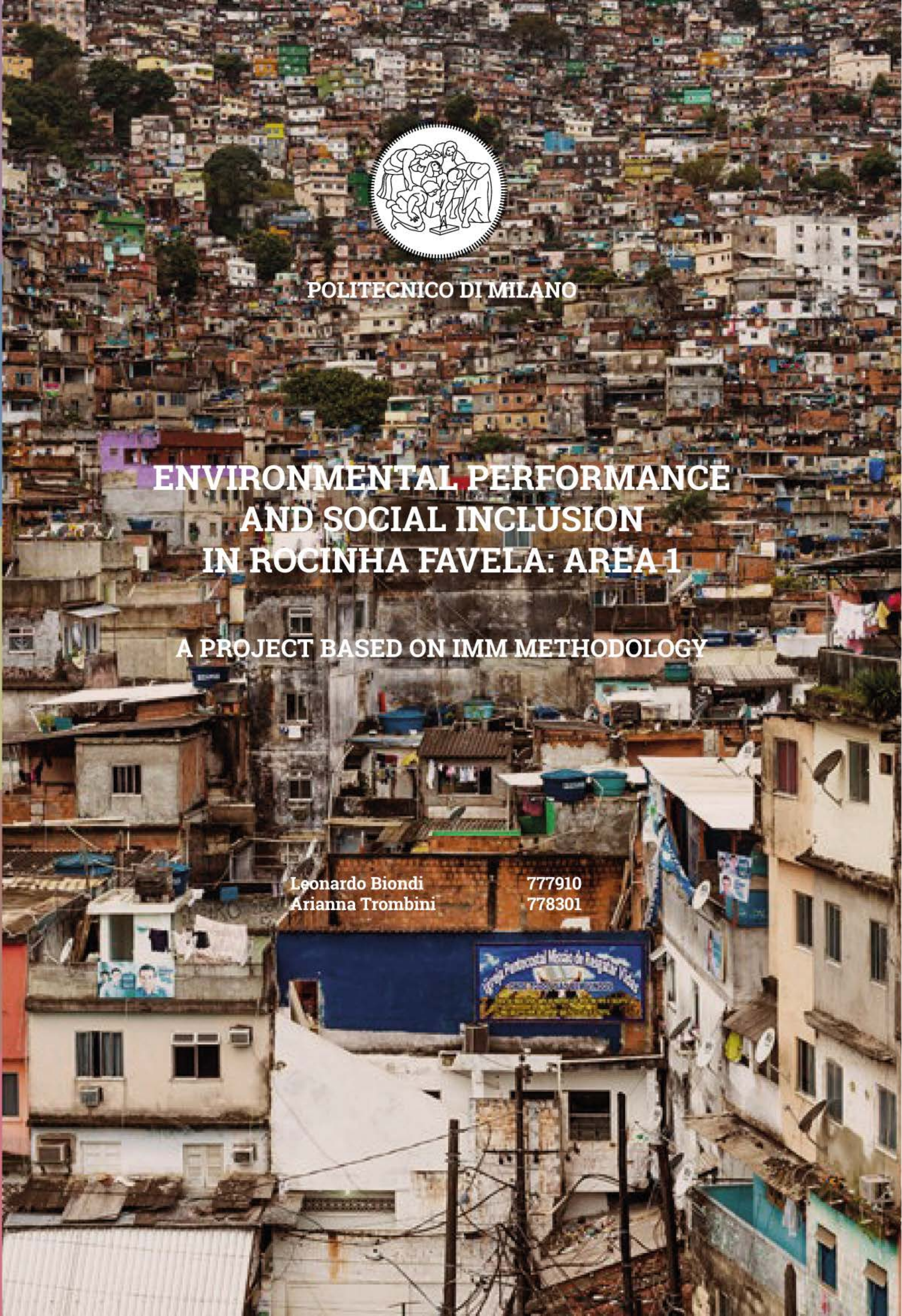

POLITECNICO DI MILANO

ENVIRONMENTAL PERFORMANCE AND SOCIAL INCLUSION IN ROCINHA FAVELA: AREA 1

A PROJECT BASED ON IMM METHODOLOGY

Leonardo Biondi 777910
Arianna Trombini 778301

POLITECNICO DI MILANO
Scuola di Architettura, Urbanistica e Ingegneria delle costruzioni
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Authors:	Leonardo Biondi	777910
	Arianna Trombini	778301
Supervisor:	Prof. Arch. Massimo Tadi	
Co-supervisor:	Prof. Ing. Gabriele Masera	

ABSTRACT

A small patch of land containing the population of a city, Rocinha is the biggest favela of Rio de Janeiro. This singular urban environment has found, over time, its own equilibrium, removed from any planning of the greater city, and indeed, generally ignored by the powers that be until very recently. While the balance found by Rocinha's inhabitants is indubitably functional in its own way, it is, at the same time, unquestionably dysfunctional in many aspects, especially the overall lack of infrastructures, an overwhelming urban density, widespread sanitary issue and low level of education. This thesis is weaved into the larger "PolimiparaRocinha" project, started on October 1st, 2016, and winner of the Politecnico di Milano "Polisocial" award. The "PolimiparaRocinha" project has been developed in collaboration with the Universidade Federal do Rio de Janeiro, and the help of various associations operating inside the favela, chief among them "Il sorriso dei miei bimbi".

In order to analyse the unique urban landscape of Rocinha and assess the benefits of the interventions proposed hereafter, this thesis employs the Integrated Modification Methodology. The multifaceted urban analyses required by IMM have been carried out since 2016 by multiple teams, bringing together the multidisciplinary skills necessary to see their completion. In particular, this thesis positions itself within the second phase of IMM, and aims to solve five primary issues of Rocinha, through so-called "Pilot Projects": Mobility, through the development of a slow mobility network; Energy, with the installation of PV panels and the implementation of a smart energy grid on selected areas; Water, by expanding the insufficient drainage and sewerage network, as well as constructing a new water purification system; Food, which aims to improve the health of the populace via educational programs; and Waste, providing the inhabitants with a sustainable models of waste disposal, such as a biogas plant, while enhancing the existing ones.

In this thesis, these projects have been developed inside one of the Intervention Areas selected by the urban analysis, and the results obtained therein will serve to determine the benefits that a widespread diffusion, from the local scale to the intermediate scale, could be brought to Rocinha. The Intervention Area discussed in this thesis (Area 1) cuts through the upper left side of the favela, bridging the more active lower part, containing the a number of important buildings, to the mostly residential upper zone; improving the connection between the two halves is one of the main goals of the project. Furthermore, Area 1 is not only the sole Intervention Area in which all pilot projects can be implemented, but also where one can witness all the urban environments of Rocinha, making it a smaller-scale example of the benefits the urban intervention can bring to Rocinha. The architectural design will focus on the refurbishment of one of the existing buildings, currently a gas depot, into a residential building, with some social functions and shops on the ground floor, increasing the attraction force and urban quality of the lower part of Area 1.

SINOSSI

Un piccolo lembo di terra contente gli abitanti di una città, Rocinha è la più grande favela di Rio de Janeiro. Questo particolarissimo contesto urbano ha raggiunto, nel tempo, un proprio equilibrio, indipendente dalla pianificazione della vicina metropoli; al punto che, fino a poco tempo fa, è stata ignorata dalle autorità. Sebbene questo equilibrio raggiunto dagli abitanti di Rocinha sia indubbiamente a suo modo funzionante, è, allo stesso tempo, incontestabilmente disfunzionale in diversi aspetti, specialmente la complessiva mancanza d'infrastrutture, l'opprimente densità urbana, le diffuse emergenze sanitarie ed il basso livello d'istruzione. Questa tesi s'inserisce nel più grande progetto "PolimiparaRocinha", partito il primo Ottobre 2016, vincitore del premio "Polisocial" del Politecnico di Milano. "PolimiparaRocinha" è stato portato avanti con la collaborazione dell'Universidade Federal do Rio de Janeiro, nonché l'aiuto di varie associazioni operanti nella favela, prima fra tutte "Il sorriso dei miei bimbi".

Per analizzare il singolare ambiente urbano di Rocinha e determinare i benefici derivanti dagli interventi proposti, questa tesi impiega l'Integrated Modification Methodology. Le poliedriche analisi urbanistiche richieste dall'IMM sono state eseguite dal 2016 da vari gruppi, raggruppando le abilità multidisciplinari necessarie a portarle a termine. In particolare, questa tesi si posiziona nella seconda fase dell'IMM ed ha l'obiettivo di risolvere cinque delle principali problematiche di Rocinha, attraverso i cosiddetti "Progetti Pilota": Mobilità, attraverso lo sviluppo di un sistema di viabilità dolce; Energia, con l'istallazione di pannelli fotovoltaici e l'implementazione di una smart grid in aree selezionate; Acqua, espandendo le inadeguate reti di drenaggio e fognarie e costruendo un nuovo impianto per la potabilizzazione dell'acqua; Cibo, che ha l'obiettivo di migliorare la salute della popolazione attraverso programmi educativi; e Rifiuti, fornendo agli abitanti modelli per lo smaltimento sostenibile, come un impianto a biogas, e migliorando quelli esistenti.

In questa tesi, i progetti sono stati sviluppati all'interno una delle Aree d'Intervento selezionate dall'analisi urbanistica ed i risultati così ottenuti serviranno a determinare i benefici che un'adozione diffusa, dalla scala locale a quella intermedia, potrà portare a Rocinha. L'Area d'Intervento discussa in questa tesi (Area 1) si sviluppa lungo la parte alta sinistra della favela, connettendo la più attiva parte bassa, in cui sorgono importanti edifici, con la zona alta, prevalentemente residenziale; il miglioramento della connessione fra le due parti è uno dei punti fondamentali del progetto. Inoltre, l'Area 1 non è solo l'unica Area d'Intervento in cui tutti i progetti pilota possono essere realizzati, ma anche dove convivono tutti gli ambienti urbani di Rocinha; tanto che essa funge da esempio in piccolo dei benefici che gli interventi possono portare a Rocinha. Il progetto architettonico si concentra sul recupero di uno degli edifici esistenti, ad oggi un deposito per bombole di gas, in un edificio residenziale, con alcune funzioni sociali e terziarie al piano terra, aumentando la forza d'attrazione e la qualità urbana della parte bassa dell'Area 1.

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Figure 1.1 Rio de Janeiro bay with the Cristo Redentor in the foreground. Source: dentroriodejaneiro.it

1 TERRITORIAL FRAMEWORK

Brazil is one of the richest countries on Earth, in culture, history, nature and resources; and the city of Rio de Janeiro is its window to the rest of the world. Rocinha, and favelas in general, are the dark shadow cast by the shining lights of Rio, places mostly unknown not just to the world at large, but by the Brazilian themselves, who have, and continue to, ignore these urban realities or think of them as just a problem to be solved.

While no urban intervention and architectural design can exist in a vacuum, an urban environment so far removed from what the First World countries consider "normal" requires an even deeper knowledge of the historical, geographical, economical and social conditions that saw its birth and growth.

This chapter aims to collect and display all the necessary knowledge that helped shape the project, from expanses of Brazil, down to the alleys of Rocinha. It provides the reader with a comprehensive, if abridged, picture to better understand the who, the where, the when, the what and the whys of this project.

1. TERRITORIAL FRAMEWORK

1.1 Geography and morphology.

1.1.1 Brasil

Figure 1.1.1 Geolocation of Brazil, the city and Rocinha.

The Federative Republic of Brazil (Repúlica Federativa do Brasil) is the fifth-largest country in the world (8,515,767 km^2), occupying half the landmass of South America. It borders with every South American country but Chile and Ecuador. Brazil stretches roughly 4,350 km and encompasses a wide range of tropical and subtropical landscapes and contains most of the Amazon River basin, which has both the world's largest river system and most-extensive virgin rainforest.

As of 2018, Brazil is estimated to have 208,495,000 inhabitants, making it the fifth most-populous country on Earth and accounting for one-third of Latin America's population. Most of the inhabitants are concentrated along the eastern seaboard, although the capital, Brasília, is located far inland. While Brazil is one of the

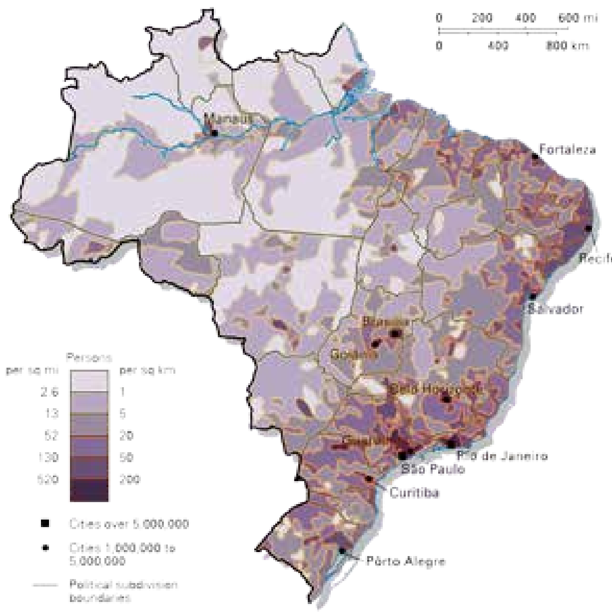


Figure 1.1.2 Map of population density in Brazil.
Source: Encyclopedia Britannica

world's major economies, the country struggles with extreme social inequalities, environmental degradation, intermittent financial crises and a sometimes deadlocked political system.

Unique among the Americas, Brazil did not fragment following independence from Portugal. Thanks to that, Portuguese is the universally accepted language among Brazil's native Indians.

The Brazilian government has grouped the country's states into five geographical and statistical units named Major Regions (Grandes Regiões): The tropical North (Norte), comprising over two-fifths of Brazil, including the largest portion of the Amazon rainforest and the Guiana and Brazilian highlands, which accounts for little of the nation's economy and population.

The Northeast (Nordeste), both the hottest and driest region, comprises nearly one-fifth of the Brazilian territory and more than one-fourth of the population. It contains the oldest European settlements, dating ack to the 16th century and accounts for one-fifth of the nation agricultural production, though general unemployment rate remains high.

The Southeast (Sudeste) covers only one-tenth of Brazil's land area but contains two-fifths of the population and the greatest concentration of industrial and agricultural production in the nation. The region includes not only Rio de Janeiro, the nation's capital from 1763 to 1960, but also São Paulo, Brazil's economic and demographic heartland, and the Minas Gerais state, rich in mineral wealth.

The South (Sul) stretches below the Tropic of Capricorn and it's the smallest of Brazil's regions, though occupying roughly an area as large as the isle of Britain. It has a diversified economy, including a strong manufacturing sector.

Figure 1.1.3 View of Amazon river in North region. Source: Wikipedia

Figure 1.1.4 Natural park "Lencois maranhenses" in the Northest. Source: Wikipedia

Figure 1.1.5 Sao Paolo skyline. Source: Wikipedia

Figure 1.1.6 Mato Grosso do Sul. Source: Wikipedia

The South has about one-seventh of the nation's population, including many people of European ancestry, mainly Italians and Germans. It has an important tourist trade, partly due to the presence of the Iguaçu Falls, near the Argentine border.

The Central-West (Centro-Oeste) contains the Federal District, in which Brasília is located. The region covers roughly one-fourth of Brazil, including forested valleys, semiarid highlands and vast wetlands.

Figure 1.1.7 Brasilia skyline. Source: Wikipedia

Brazil's physical features can be grouped into five main divisions: the Guiana Highlands, which contains the nation's highest point (Neblina Peak, 3,014 metres); the Amazon lowlands, characterized by gently undulating hills (terra firme) composed of layers of ancient (2.5 million years) alluvial soil; the Pantanal, the largest freshwater wetlands in the world (140,000 km^2); the Brazilian Highlands, covering more than half of the country, rich of mineral resources, and the Coastal Lowlands, which are comparatively small, but have widely varied features, containing many deep harbours, such as Guanabara Bay, where Rio de Janeiro lays.

1.1.2 Rio de Janeiro

The city of Rio de Janeiro is located on a strip of Brazilian coast facing the Atlantic Ocean, close to the Tropic of Capricorn, in an area where the shoreline is oriented east–west. Its geographical coordinates are: latitude 22°54'25" S longitude 43°11'17" W.

Rio de Janeiro has had to grow between the sea and a steep mountain range, consequently the cityscape has adapted to its surroundings, unlike other cases where the metropolitan area has changed the landscape.

Figure 1.1.8 Rio de Janeiro landscape, the coexistance between the city and the mountains. Source: Wikipedia

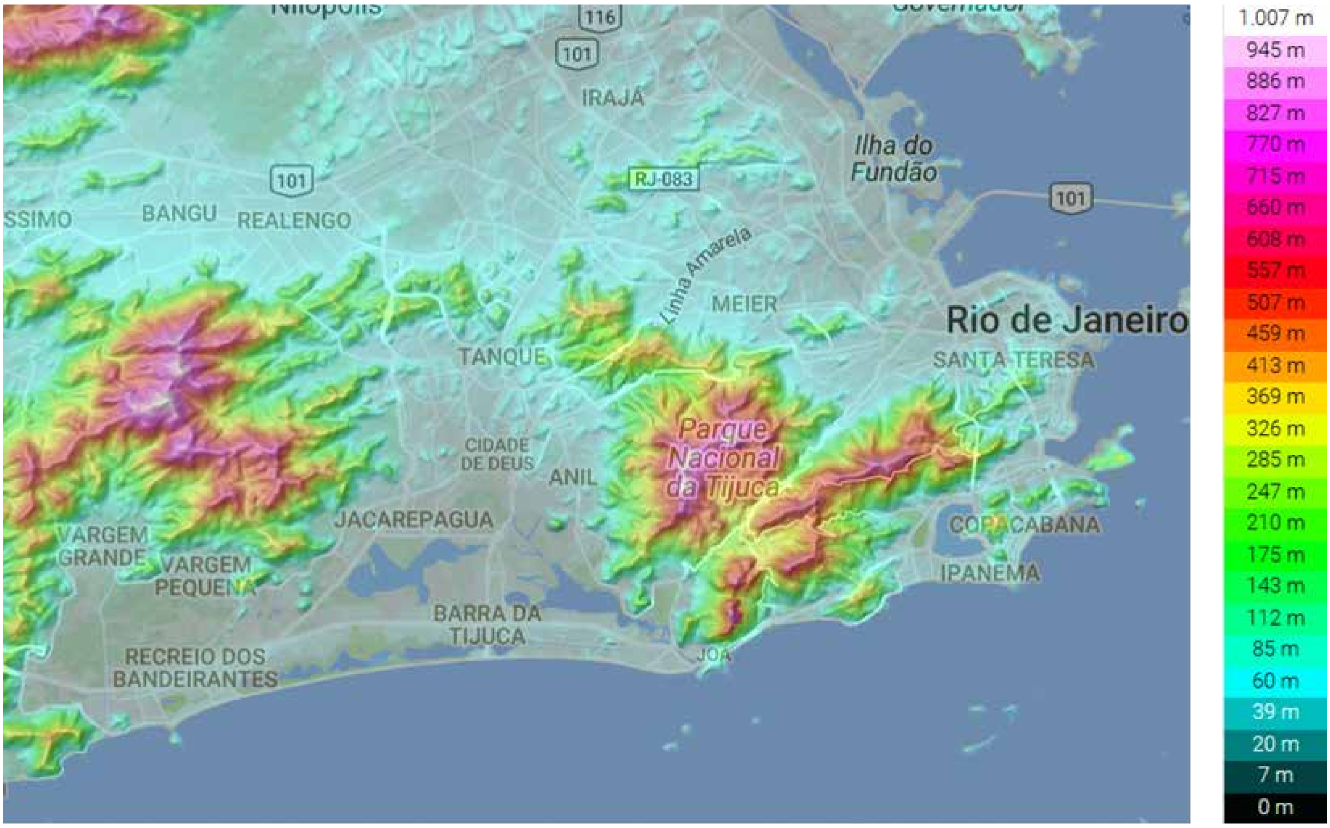


Figure 1.1.9 City morphology.

From topographic point of view, the city of Rio starts at sea level and reach maximum height at about 1,000 m with the Pico da Tijuca.

Due to their proximity to the sea, all the mountains (or “morros”) have been shaped by the wind, resulting in rounded profiles or, as Brazilians say, a “sugarloaf” profile; this phenomenon makes it very unlikely to find jagged rock walls. This peculiar feature is exemplified by the aptly-called “Pão de Açúcar”, a lone 396-m peak surrounded by the sea, famous around the world.

The other most recognizable mountain in Rio de Janeiro is Corcovado, whose fame is due to the renowned statue of Christ the Redeemer, built at its summit.

Figure 1.1.10 Pao de Açucar mountain in Rio.
Source: Wikipedia

Figure 1.1.11 View of Cristo Redentor in Rio.
Source: Wikipedia

Another notable geological feature is Pedra da Gavea, one of the highest monolithic mountains in the world that ends directly in the ocean, with an elevation of 844 m. Said mountain is located inside of Parque Nacional da Tijuca, that it is claimed to be the world's largest urban forest, covering some 32 km².

As previously mentioned, the city of Rio de Janeiro had to grow between strong natural features, among them, the altitude and imperviousness of the terrain seem also to inform the local standard of living: at the base, where the altitude is closer to sea level, the rich and medium class neighbourhoods are located, conversely, as the terrain becomes steeper and rougher, there the slums are found, extremely poor districts called "favelas".

Due to the circumstances of their inception, growth and socio-economic characteristics, favelas can be see as small cities inside the city, the two urban zones somewhat independent from each other. Thus, favelas contain not only houses, but also business activities and leisure places, so much so that several of their inhabitants have never felt the need to go out and see the outside world or even the city of Rio de Janeiro.

Figure 1.1.12 Pedra da Gavea mountain in Rio. Source: Wikipedia

Figure 1.1.13 Urban connection bethween the city and the favela. Source: Wikipedia

Figure 1.1.14 Morphology of Rio: the city, the mountains and the sea in background. Courtesy of Daniele Ronchi

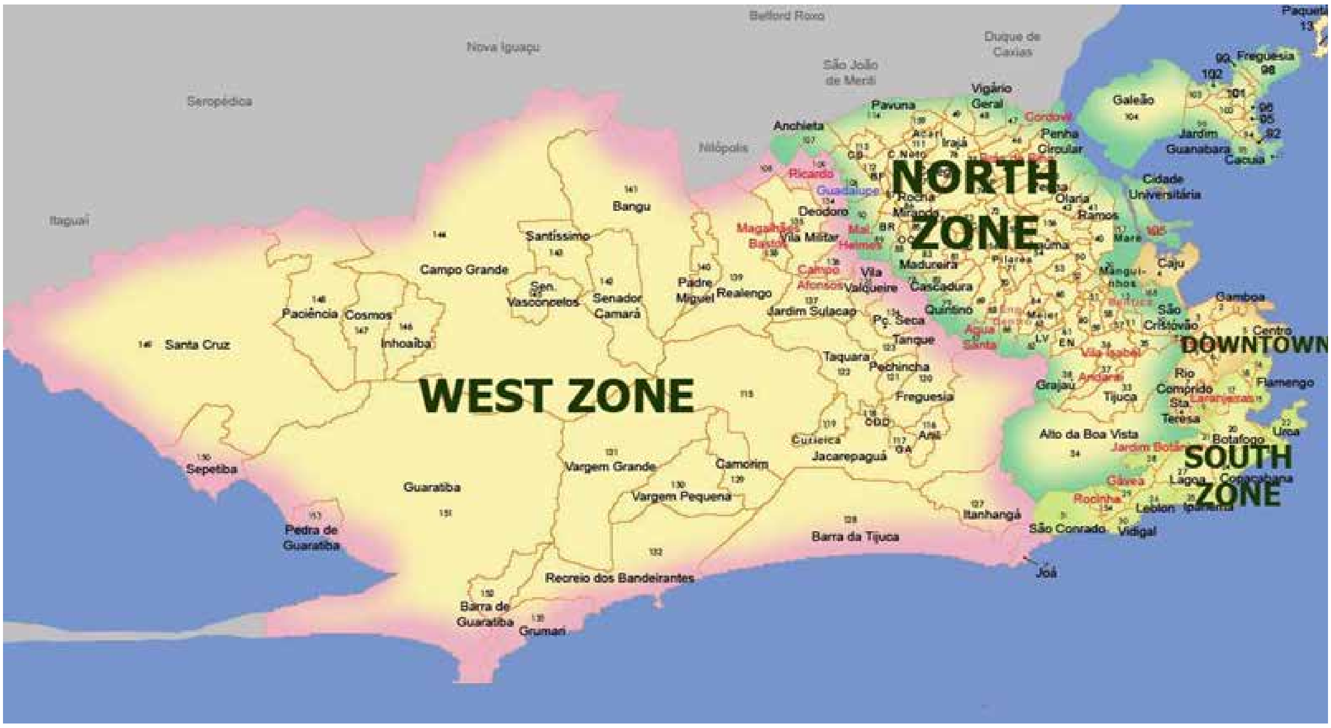


Figure 1.1.15 The city of Rio with its zones and its neighbourhoods.

The metropolitan area of Rio de Janeiro occupies an area of 1182.3 km² and it can be divided in four main zones: the Centre (Centro), the South Zone (Zona Sul), the North Zone (Zona Norte) and the West Zone (Zona Oeste). Each zone can be subdivided in other neighbourhoods, based on their peculiarities.

The Centre, or Downtown (Cidade), roughly corresponds to the old city limits, though few colonial-era buildings remain, owing to a series of remodelling and modernizing efforts, such as the reconstruction of the port in 1907. The urban landscape of the centre reflects these historical remodelling phases, with buildings from different eras juxtaposed to one another. The Municipal Theatre, built at the start of the 20th century, is almost a replica of the Paris Opera House. The Ministry of Education (1936) was conceived by the architect Le Corbusier, while the Bank of Brazil's headquarters is an example of International Style. The icon of these contrasts can be considered Praça 15 de Novembro, a colonial-era waterfront substantially renovated in 1997.

Figure 1.1.16 Dodwntown neighbourhood, picture taken by Leonardo Biondi.

Figure 1.1.17 View of Rio from Barra da Tijuca, picture taken by Arianna Trombini.

The South Zone is the core or Rio's metropolitan area, and the city's political heart, containing Laranjeiras Palace, the Rio residence of Brazil's president, Guanabara Palace, the State Governor's residence, and Catete Palace, the former president's residence, often called Brazil's White House.

To the south, facing the ocean, are Rio's most famous beaches (Copacabana, Leblon and Ipanema), while to the east is Flamengo beach and the eponymous district, facing Botafogo Bay, whose eastern shore is dominated by the Sugar Loaf Mountain. Inland, to the west, in the Cosme Velho neighbourhood, lays the beginning of the funicular railroad to Mount Corcovado. The Zone also contains the famous Lagoa (lagoon), as well as the Jardim Botânico (Botanical Garden).

The North Zone is a heavily populated industrial centre, its development hampered by the mountainous ridge that runs east-west, most of it incorporated in the Tijuca National Park. To the north, one can find the Maracanã district, home to Rio's famed stadium, and further north, the historical district of São Cristóvão, containing the Quinta da Boa Vista park, which hold the National Museum and Rio's renowned zoo, the former Imperial Palace.

To the east, a small island houses the Federal University of Rio de Janeiro, while Governador Island is the site of Galeão-Antonio Carlos Jobim International Airport.

The West Zone, now accessible thanks to new roads and tunnels made at the end of the 20th century, is the site of much of the city's more recent growth.

The purpose of our thesis is to develop sustainable urban solutions for challenging cityscapes, such as Rocinha, that is said to be Rio de Janeiro's largest favela, if not the biggest in Brazil or even South America.

Figure 1.1.18 View of Ipanema beach in Rio, picture taken by Leonardo Biondi.

Figure 1.1.19 View of Rio from Pão de Açúcar, picture taken by Arianna Trombini..

Figure 1.1.20 View of Rio from Barra da Tijuca, picture taken by Arianna Trombini.

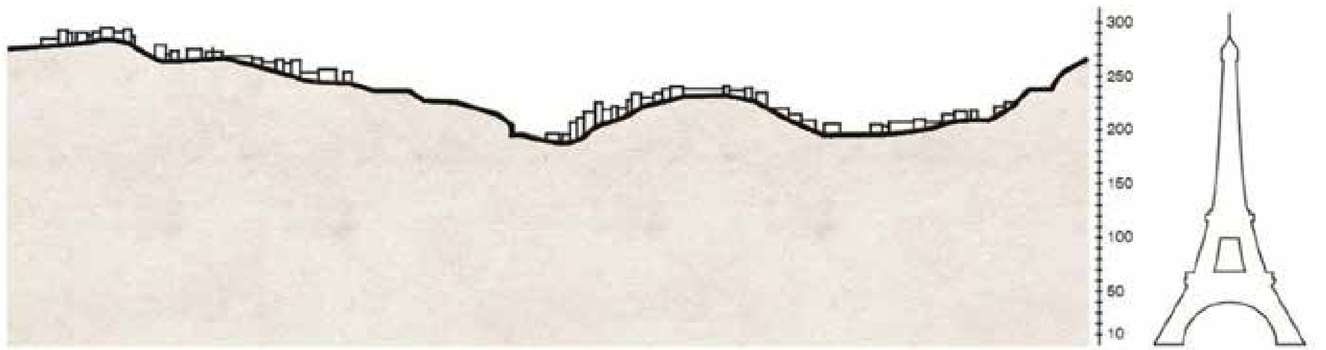
Figure 1.1.21 View of Rocinha, picture taken by Arianna Trombini.

1.1.3 Rocinha

The favela of Rocinha, whose name means "little farm", is found in the South Zone of Rio de Janeiro. Its boundaries are well-defined: walled on north by the same mountain range that contains the Pedra da Gávea and on south by the Morro dois Irmãos; on its Western and Eastern sides, the favela is constricted by the neighbourhoods of Gávea and São Conrado.

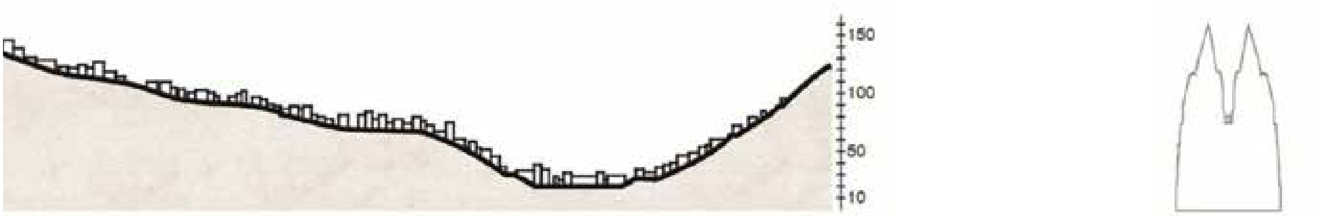
The entirety of Rocinha lays on a sloping stretch of land. This peculiar position worsens many of Rocinha's social, economic, geomorphological and services problems. The slope starts at sea level, where the highway and the tunnel that connects the neighbourhoods of Leblon and Gávea to São Conrado are located; to the North, it reaches about 150 m, while to the East, the side facing Gávea, it touches its highest point at around 300 m.

The tropical forest of the Tijuca national park can hardly resist the attacks of new buildings that continue to expand on all fronts, to the point that it has become impossible to see the whole favela from a single point.



ROCINHA
Maximum height: 300 m

EIFFEL TOWER
Height: 300 m



ROCINHA
Medium height: 150 m

COLOGNE CATHEDRAL
Spire height: 157 m

Figure 1.1.22 Comparisons on high levels between Rocinha and famous buildings.

Figure 1.1.23 View of the 3D model of Rocinha, courtesy of Hakon Rensaa.

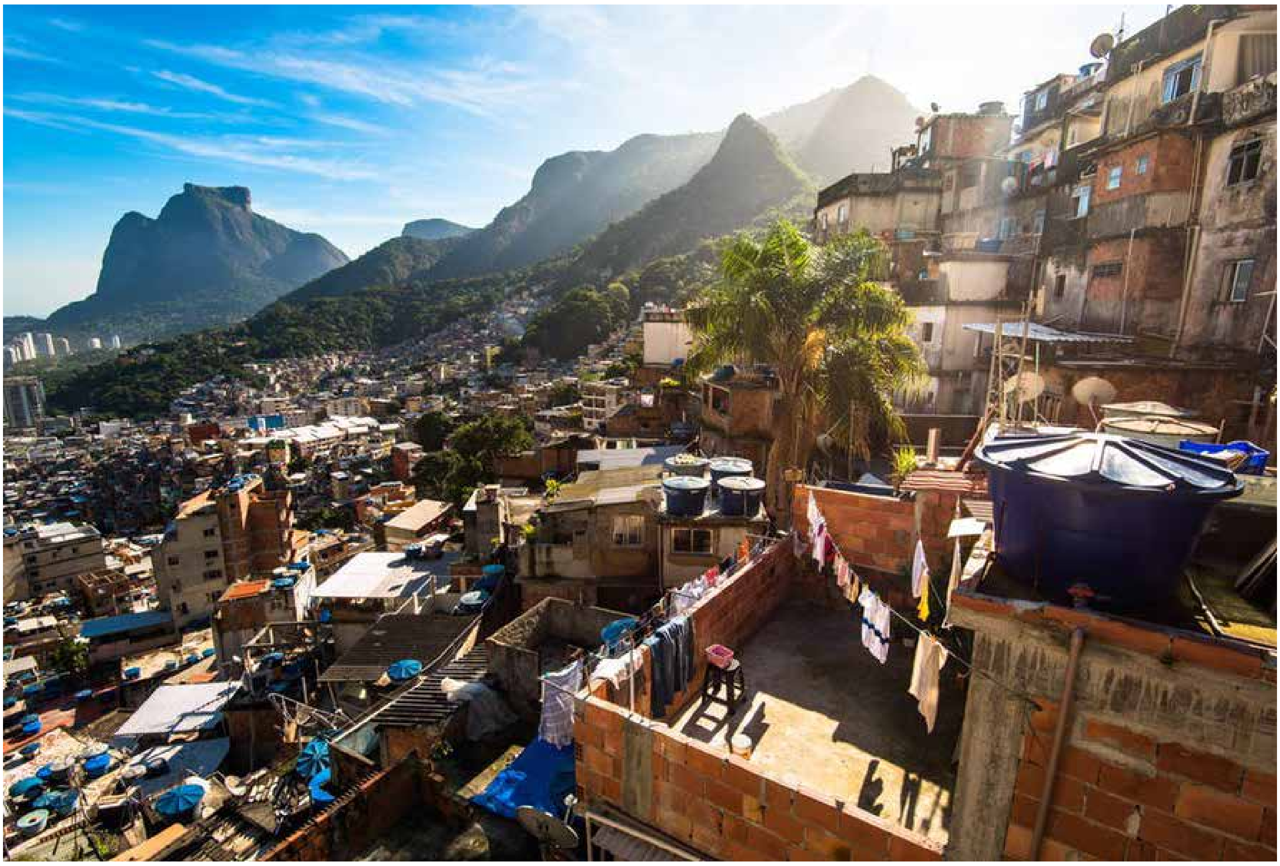


Figure 1.1.24 A view of the favela of Rocinha.

Figure 1.1.25 A view of the favela Rocinha, picture taken by Arianna Trombini.

The favela occupies a surface area of 1.44 km^2. The official census assert that 70,000 people live inside Rocinha, however unofficial, but more accurate, estimates put its population over 200,000 individuals, which means that Rocinha has a population density between 48,611 to 138,888 pop./km^2; for comparison, the world's most densely populated city (Dhaka, capital of Bangladesh) has 42,659 pop./km^2. For a better understanding of these data, we prepared the following visual comparisons.

Tot surface: 286 Km^2
Inhabitants: 192.672

Tot surface: 183 Km^2
Inhabitants: 184.826

Tot surface: 468 Km^2
Inhabitants: 85.458

Figure 1.1.26 Comparisons on density data between Rocinha and known cases.

Rocinha is connected to the city centre thanks to AutoEstrada Lagoa-Barra and the metro line 4, which stops at the São Conrado-Rocinha station, both are located to the southern edge of the favela, just next the neighbourhood of São Conrado.

The favela of Rocinha can be considered as an aggregation of sub-Barrios, in addition to neighbourhoods. The official districts that the favela has been divided into, with no regard to the aforementioned Barrios, are instead tailored to meet different parameters (Demographic census, IBGE choices) or related to the presence of primary services (water, sewage ecc.). Therefore, while the state of Rio de Janeiro split the favela in 8 sectors for the planning of its PAC intervention, historically, the inhabitants of

Figure 1.1.27 A view of the favela of Rocinha, picture taken by Arianna Trombini.

the favela consider themselves to belong to one of the 25 Sub-Bairros. The following map lists all the 25 neighbourhoods of Rocinha, they are: Largo do Boiadero, Bairro Barcelos, Campo da Esperança, Cidade Nova, Rua 4, Rua 3, Rua 2, Portão Vermelho, Morro da Roupa Suja, Macega, Terreirão, Capado, Faz Depressa, Rua 1, Setor 199, Vila Vermelha, Vila Cruzado, Vila Laboriaux, Vila Verde, Curva do "S", Cachopa, Cachopinha, Pastor Aimir, Dioneia, Vila União.

Figure 1.1.28 Distribution map of Rocinha's neighbourhoods.

1.2 Climate analysis

1.2.1 Rio de Janeiro climate data

According to the Köppen climate classification, Rio de Janeiro possesses a tropical savannah climate (Aw) with influential tropical monsoon climate (Am). The city has a relatively cold season from May to October and a hot and damp season from December to March, characterized also by long periods of heavy rain. The months of November and December are intermediaries, with seasons between the warm and cold one. Heavy rainfall is expected all year round.

1.2.1.1 Temperature and humidity

In Rio de Janeiro the average annual temperature is 23.2 °C (73.7 °F). The highest temperatures are concentrated between the months of December and March. In these period, the maximum average temperature is above 29 °C (84.5 °F) and the minimum average temperature around 22 °C (71.3 °F). Meanwhile, the period from June to September registers the lowest temperatures, with a maximum average temperature around 25 °C (77 °F) and a minimum average temperature around 17 °C (62.6 °F). January is the warmest month of the year, with an average temperature of 26.1 °C (79 °F). While July is the coldest month, with an average temperature of 20.6 °C (69.1 °F).

Several factors influence the temperature and the development of different micro-climates in the city of Rio de Janeiro. There are natural factors within the city, such as the proximity to the ocean, altitude, general and secondary atmospheric circulation, type of vegetation and land use, as well as anthropogenic factors such as the development of heat islands.

However, the most important factors that influence the temperature are the winds and sea breezes. In winter, from June to September, cold winds and morning sea breezes bring mild temperatures. On the other hand, in summer, from December to March, warm fronts (the Intertropical Convergence Zone in the form of winds from the Amazon Forest), the strongest sea-borne winds (often from an extra-tropical cyclone) and summer evapotranspiration bring weather reverses or storms.

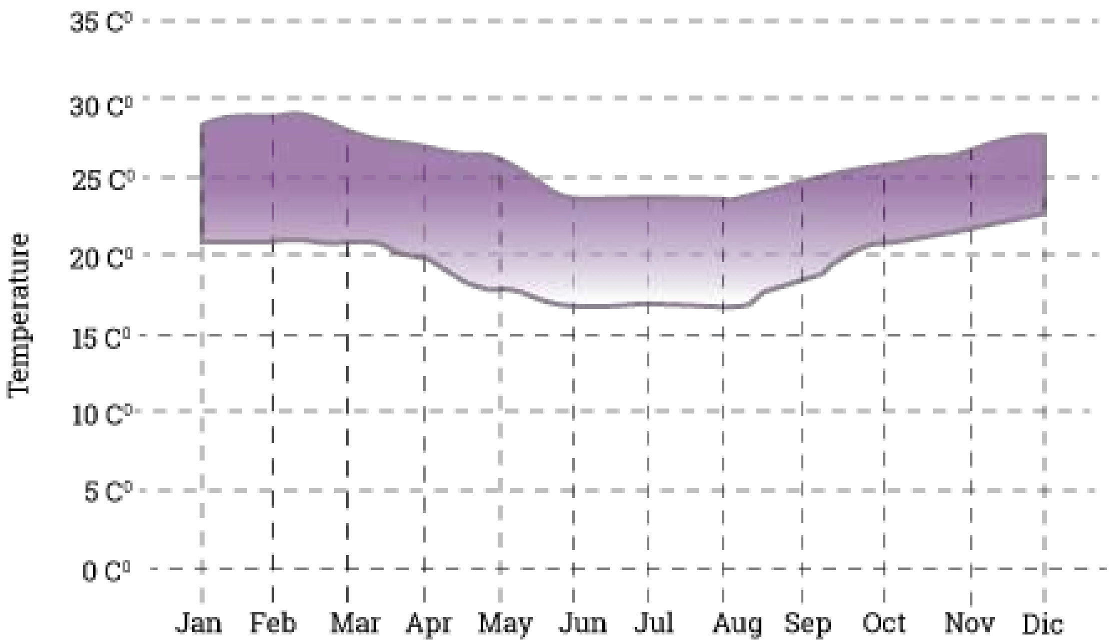


Figure 1.2.1 Average max and min temperatures in Rio de Janeiro, Brazil, source https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rio-de-Janeiro,Brazil.

During all the year the city is subjected to a high relative humidity value of the air, reaching an annual average around 80%, undergoing little variation over the months. In fact, the only significant, if slight, variation happens during the winter, from June to September, due to the lowering of the temperatures.

The high relative humidity in Rio de Janeiro depends from two factors. First, the geographic position and the tropical latitude, secondly the proximity to the Atlantic Ocean. Moreover, warm sea currents wash the city, thereby favouring the humid climate.

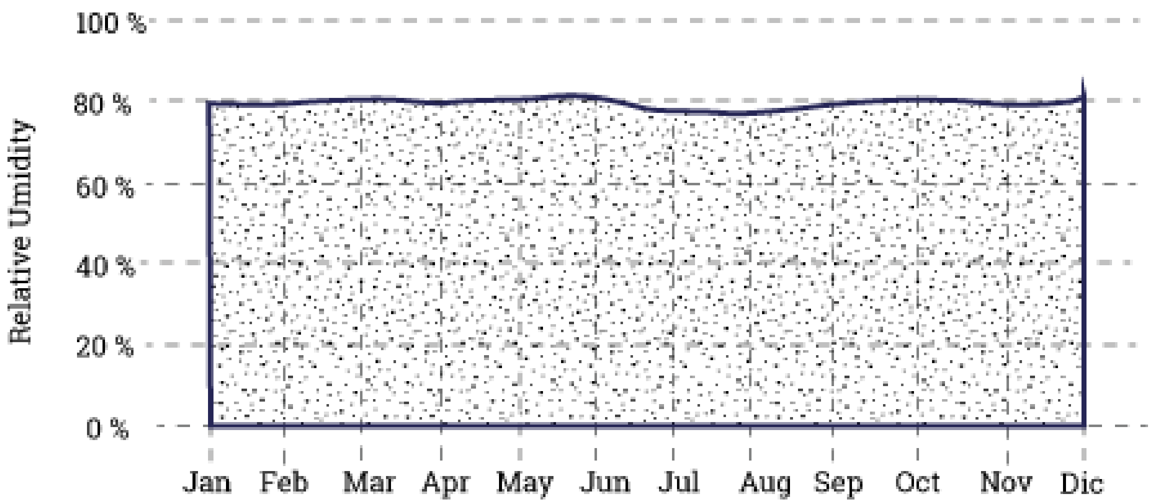


Figure 1.2.2 Average relative humidity in Rio de Janeiro, Brazil, source https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rio-de-Janeiro,Brazil.

1.2.1.2 Precipitations

The average annual precipitation is 1,069 mm (42.1 in) and the annual amount of rainy days is 131. Obviously, the concentration of rain occurs during the hottest months, due to the tropical savannah climate. For this reason, between November and March there are accumulations values over 100.00 mm, while from April to August, there is a decrease, with accumulations values around 41.00 mm monthly. In particular, April is the rainiest month and December is the driest.

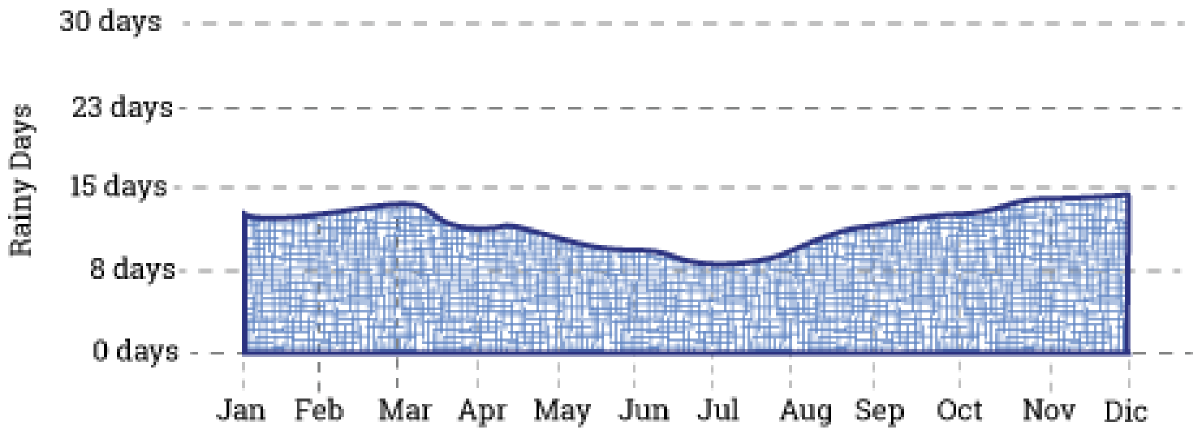


Figure 1.2.3 Average rainy days in Rio de Janeiro, Brazil, source https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rio-de-Janeiro,Brazil.

Consequently, droughts are very rare, but can happen from time to time, due to the strong tropical climate. The last drought period, the worst in decades, hit Rio de Janeiro and all the South-East of Brazil between 2014-2015. Within the city of Rio de Janeiro there are some areas that register more rainfall, such as the mountainous areas, since they constitute a physical barrier to the humid wind that comes from the Atlantic. The strong storms and this abrupt climate change between summer and winter often cause catastrophic floods and landslides, mostly during the hottest months.

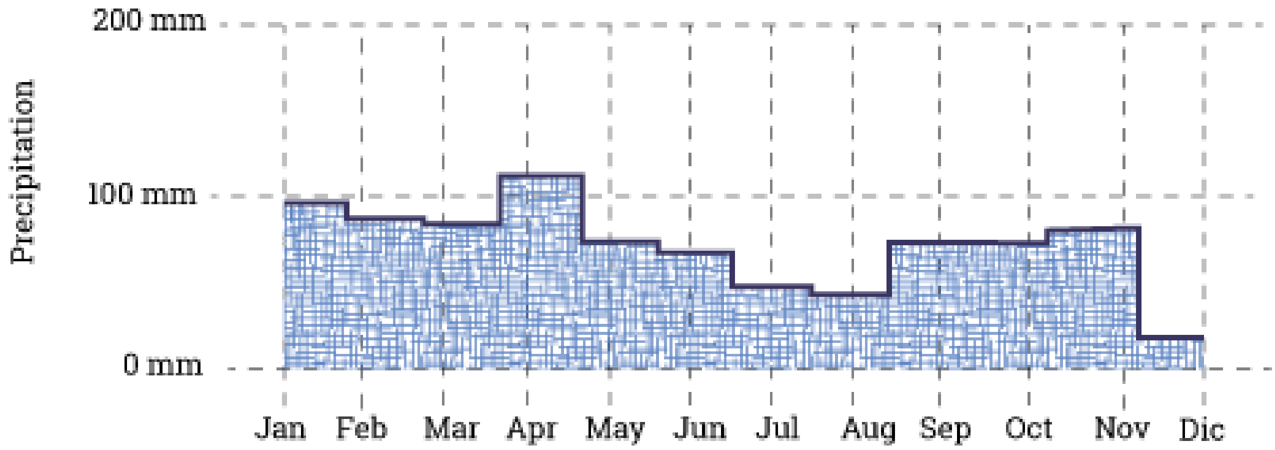


Figure 1.2.4 Average precipitation in Rio de Janeiro, Brazil, source https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rio-de-Janeiro,Brazil.

1.2.1.3 Atmospheric pressure

The average configuration of the atmospheric pressure doesn't change substantially because the city is in a tropical area. However, the atmospheric pressure goes through variations throughout the day, the so-called barometric tide, presenting two peaks of maximum pressure and two peaks of minimum pressure due to the temperature variation. Based on the influence of the predominant activity of a more intense hot or cold air mass, the most extreme values of atmospheric pressure can be found between August and September.

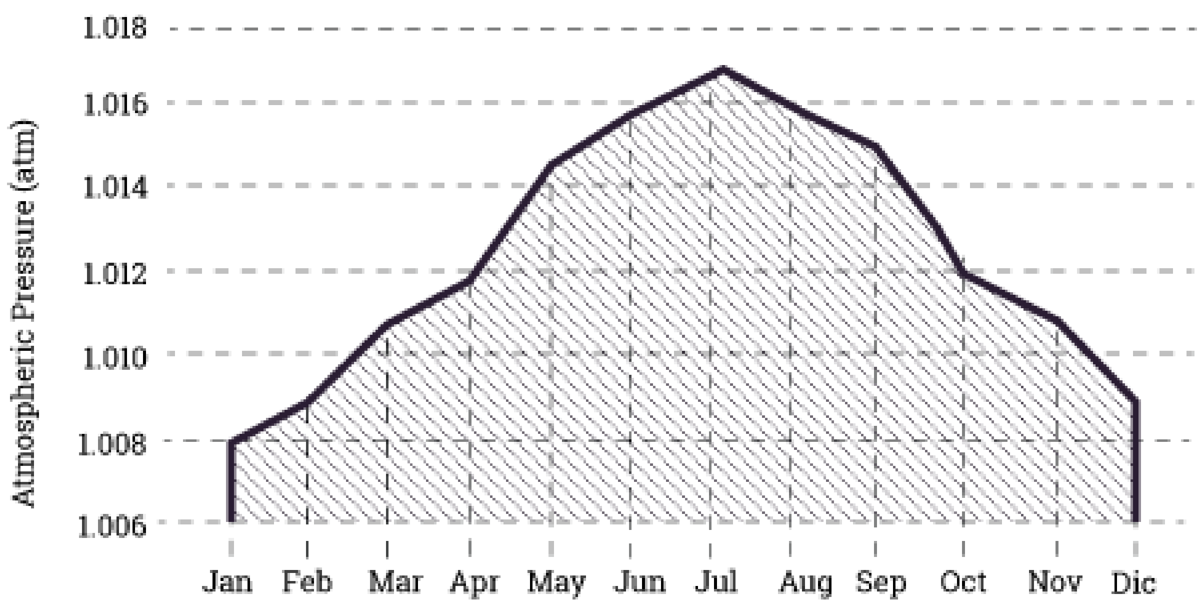


Figure 1.2.5 Average atmospheric pressure in Rio de Janeiro, Brazil, source https://it.weatherspark.com/y/30583/Condizioni-meteorologiche-medie-a-Santos-Dumont-Brasile-tutto-l'anno.

1.2.1.4 Wind

The wind velocity is mostly regular throughout the year, though, on average, the wind is stronger in November and weaker in May. The wind prevalent direction is the South, its speed almost twice than that coming from the other directions. In the city proper, dominant winds are southerly during the afternoon and night (sea breeze) and northerly at late night and in the morning (land breeze).

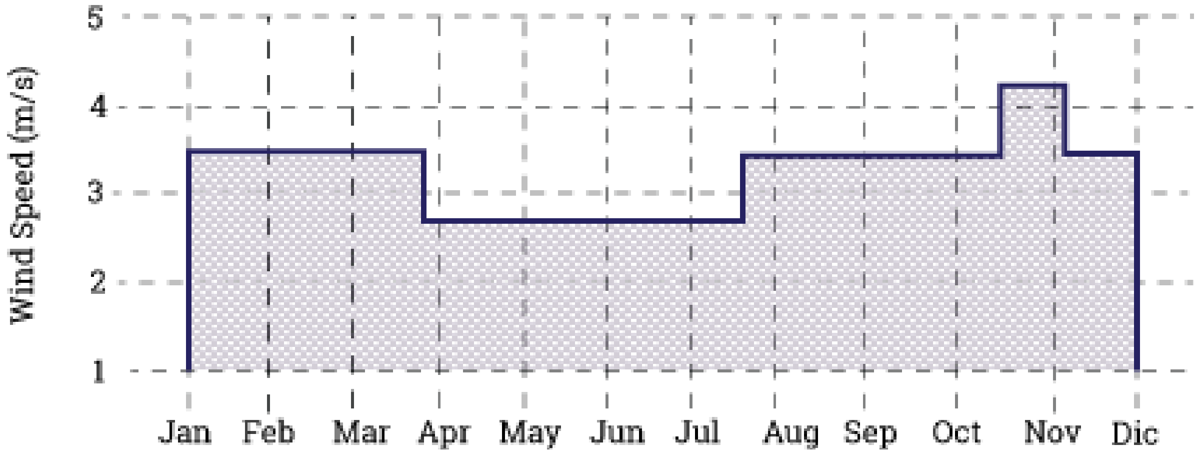


Figure 1.2.6 Average wind speed in Rio de Janeiro, Brazil, source https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rio-de-Janeiro,Brazil.

In spring and summer, when the land surface heating is more intense, the temperature gradient between continent and ocean intensifies the sea breeze circulation and increases the frequency of winds blowing from the south quadrants, compared to the annual pattern. In autumn and winter, winds coming from the southerly direction are less frequent, while the northerly ones increase.

1.2.1.5 Solar radiation

The city of Rio de Janeiro is subjected to high sunshine values throughout the year. In fact, during the summer, between December and March, there are, on average, 7 hours of sun a day, while during the winter, 6 a day.

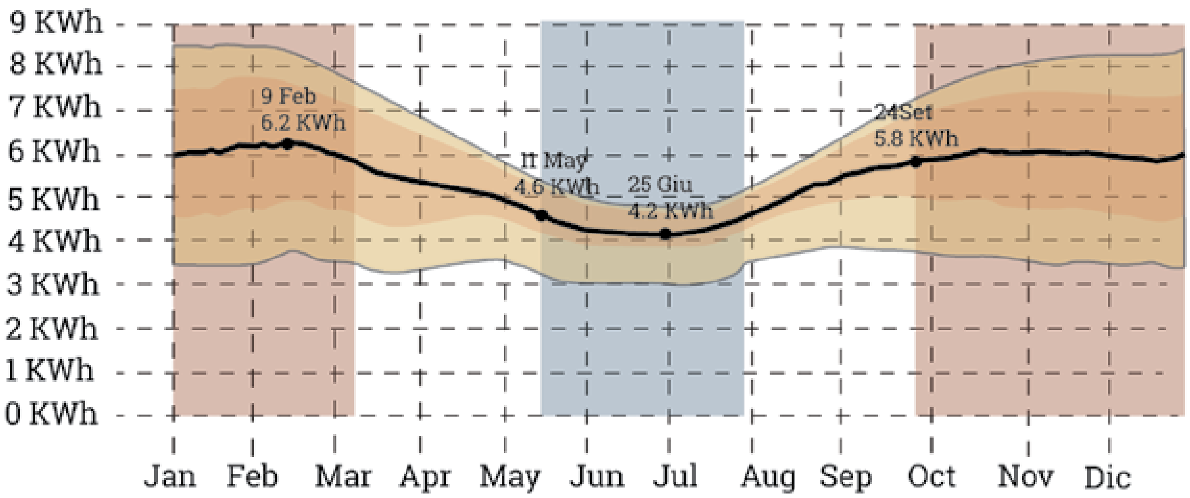


Figure 1.2.7 Average solar energy in Rio de Janeiro, Brazil, source https://it.weatherspark.com/y/30583/Condizioni-meteorologiche-medie-a-Santos-Dumont-Brasile-tutto-l'anno.

Figure 1.2.8 Shadow map at summer solstice (10 am/6 pm).

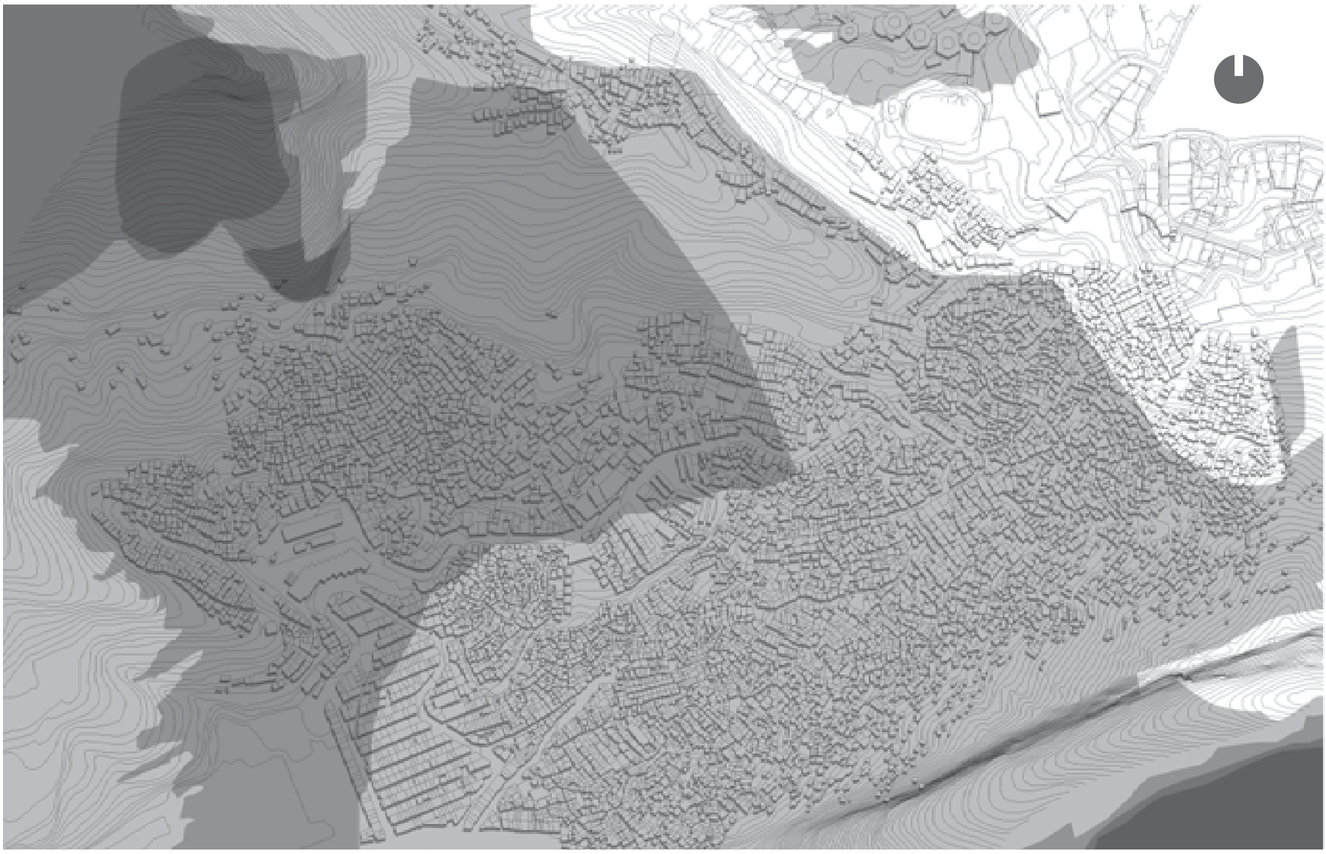


Figure 1.2.9 Shadow map at winter solstice (10 am/6 pm).

Furthermore, February is the sunniest month while September has the lowest amount of sunshine. Rio de Janeiro has one of the highest solar incidences in the world, due to its location. In fact, it receives a solar radiation of 1.7 MW/m2 per annum, with an average of direct normal radiance of 5.18 kWh/m2 per day. These high values are due to the solar altitude angle that is very close to 90°. In particular, the day with the highest solar energy of the year is the 8th February, with an average of 6.2 kWh/m2, on the other hand, the day with the lowest solar energy of the year is the 25th June, with an average of 4.2 kWh/m2.

1.2.2 Rocinha microclimate

In Rio de Janeiro there are some different micro-climates, one of which is situated in Rocinha. Some factors influence this micro-climate,such as the proximity to the Tijuca forest and to the Atlantic Ocean, the high land use and the heat islands.

In summer, winds and sea breezes blow during all day lowering the temperatures perceived but lifting the night-time temperatures. However, the temperature is on average close to that of the city, in fact, during these periods there are maximum average temperatures above 29 °C (84.5 °F) and minimum average temperatures around 22 °C (71.3 °F).

On the other hand, during winter, the temperatures are lower than those in the surrounding neighbourhoods, due to the proximity to the Tijuca forest. In this period, the minimum temperatures can reach 14° C (57.2 °F).

The average annual precipitation in Rocinha varies between 800 mm to 1,200 mm. Winter corresponds with the dry season, with the lowest amount of rainfall, meanwhile, the possibility of torrential rains is highest during summer.

1.3 Historical Scenario

Fig.1.3.1 António Manuel da Fonseca, “Vasco da Gama”, oil on canvas, 1838, Greenwich Hospital Collection.

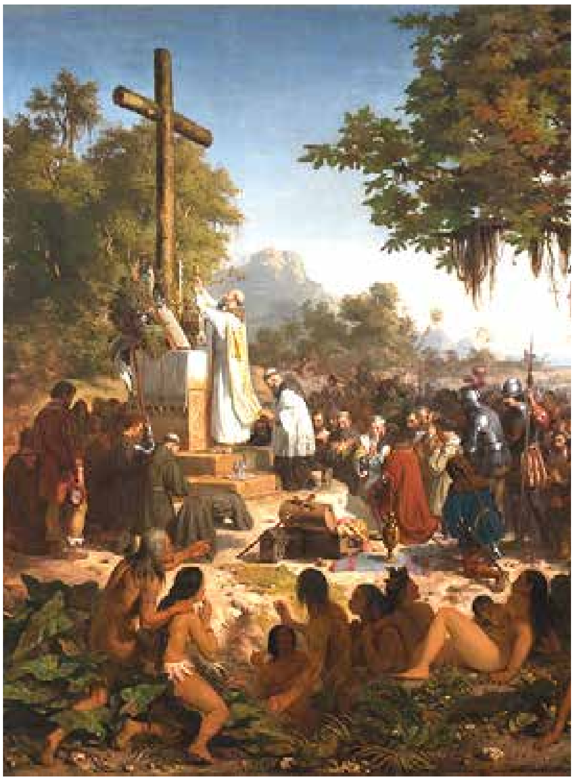


Fig.1.3.2 Victor Meirelles, “First mass in Brasil”, oil on canvas, 1860, Museu Nacional de Belas Artes.

1.3.1 Brasil

1.3.1.1 Prehistory

The region that became the Federative Republic of Brazil has been settled at least since 9000 BC, as attested by archaeological sites near the Amazonian towns of Santarém and Monte Alegre, in the Amazon lowlands, by mixed communities of farmers, fishers, hunters and gatherers. Tupian-speaking Indians inhabited the coastal areas and were the first group encountered by Portuguese explorer.

1.3.1.2 Early period

In 1498, the Portuguese navigator Vasco da Gama discovered an all-water route to the East Indies via Cape of Good Hope. Hoping to capitalize on the discovery to expand Portugal’s colonial holdings in Asia, the king dispatched an armada to India under Pedro Álvares Cabral.

In avoiding the Gulf of Guinea in Africa, Cabral bore so far West that on April 22, 1500, he sighted the mainland of South America. The newly-discovered land, called Vera Cruz, was swiftly claimed by the Portuguese crown. It was soon renamed Brazil, due to the copious amount of brazilwood found there.

The first systematic colonization effort was made in 1533, as the colony was divided into 15 hereditary captaincies along the coast headed by a donatário , though very few were ultimately successful. Among them, the captaincy of Pernambuco was converted into a great sugar-producing region, the first example of a profitable agrarian export from the New World to Europe.

To strengthen his authority in Brazil, King John unified the donatários under a governor-general, Tom de Sousa, who landed in Brazil in 1549 and founded Salvador (Bahia), capital of Brazil for 214 years.

The Jesuits converted many Indians to Christianity and settled them in aldeias (villages). This caused frictions between the Portuguese colonists, who resented the missionaries’ control over the valuable supply of slave labour. Both parties appealed to the crown and, in 1574, a royal decree granted the Jesuits full control over the Indians in the aldeias, while at the same time permitting the colonists to enslave Indians in “legitimate warfare”. This also contributed to an increase in the numbers of slaves imported from Africa, due to labour shortage.

Fig.1.3.3 J. Dower, W. M. Higgins, "Brazil", 1832, W. & R. Chambers, London in David Rumsey Historical Map Collection.

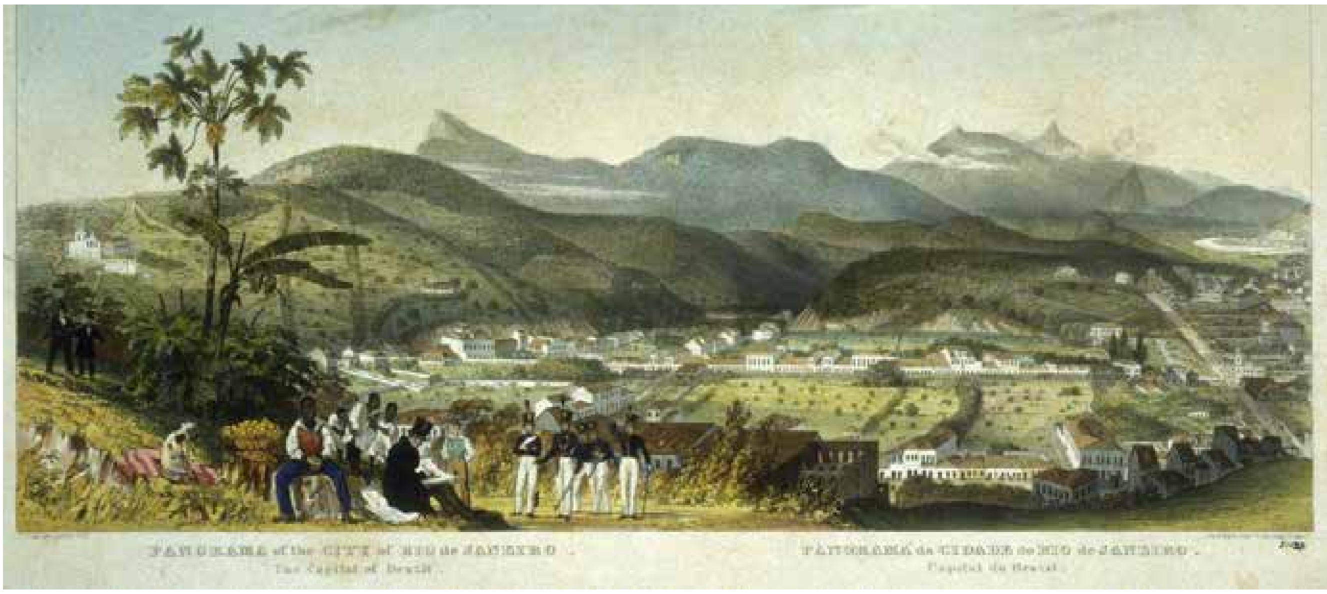


Fig.1.3.4 Louis Haghe, "Panorama of the City of Rio de Janeiro. The Capital of Brazil", Lithograph With Hand Coloring, 1837.

In 1555, the French, to establish their own colony, took possession of the harbour of Rio de Janeiro, but were quickly blockaded and made to surrender by governor-general Mem de Sá, who subsequently (1567) founded the eponymous city to ward of future attacks at the bay.

Between the 16th and the 18th century, the sugar industry was the principal source of Brazilian wealth, with vast plantations owned by a small number of families and worked by slaves. Coffee became a major export in the 18th century.

In 1695, prospectors first discovered large deposits of gold in what is now the state of Minas Gerais, triggering a gold rush in the hitherto unbroken wilderness, large swats of the population abandoning the coast. As the Southeast grew richer, the Portuguese government transferred the capital from Salvador to Rio de Janeiro in 1763.

Fig.1.3.5 Henri Grevedon, A lithography of Emperor Dom Pedro I at age 32 , 1830, Museu Imperial.

At the end of the 18th century, King Joseph's prime minister, the Marquis de Pombal, introduced a number of reforms into Brazil. He abolished the donatátio system, granted legal rights to the Indians and, in 1759, he expelled the Jesuits from Brazil and Portugal.

After Napoleon's invasion on Portugal in 1807, prince regent Dom João fled to Brazil, arriving at Rio de Janeiro on March 7, 1808, making it the only colony to serve as the seat of government for its mother country. The prince's decree of December 16, 1815 designated the Portuguese dominions as the United Kingdom of Portugal, Brazil and the Algarves, making Brazil coequal to Portugal.

Forced to return to Portugal due to revolts, King John VI appointed his son Dom Pedro as regent of Brazil on April 22, 1821. Against the will of the Cortes (parliament), on June 3, 1822 the regent convoked a constituent assembly, and, on September 7, he proclaimed the independence of Brazil and was crowned emperor on December 1. Portugal acknowledged the new nation in 1825.

1.3.1.3 The Brazilian Empire

Pedro I popularity dropped after losing a costly war with Argentina (1825-28), losing the Cisplatine province (Uruguay) and making unpopular policies, finally abdicating in favour of his five-year-old son on April 7, 1831.

The regency proved to be the most agitated period in Brazilian history, with outright civil war breaking out in some provinces. Pedro II was swiftly crowned on July 23, 1840, though he was but 14.

The new emperor's reign lasted nearly half a century and was a varied and fruitful epoch. Brazil helped overthrow the Argentine dictator Juan Manuel de Rosas in 1852 and invaded Uruguay, embroidered in civil war, in 1864, triggering the War of the Triple Alliance (1864-70) when Paraguayan dictator Francisco Solano López declared war on Brazil, Argentina and Uruguay. The war was lost by Paraguay.

The war highlighted the empire's major social and economic problems, especially the slave-based plantation agriculture system. Antislavery agitation began in the 1860s, with the practice finally abolished completely by the princess regent on May 13, 1888.

Tensions between the more conservative neo-feudal elites and the more progressive urban residents, who believed a republic better suited Brazil's emerging capitalist system, resulted in the latter forming a civil-military conspiracy that carried out a coup on November 15, 1889, causing the abdication of Pedro II and the end of the empire.

1.3.1.4 The republic to 1960

Manuel Deodoro da Fonseca, leader of the coup, became provisional president and promulgated a new constitution on February 24, 1891, establishing a federal republic.

From 1894 on, starting with Prudente de Morais, Brazil was led by the so-called "coffee presidents", who, while ensuring peace and financial reforms, ruled with little democracy, with only the landowning minority being allowed to vote. Coffee dominated the economy, accounting for more than half of export by the turn of the 20th century.

Due to its friendly relationship with United States and the United Kingdom, Brazil was

Fig.1.3.6 "Brasão de Grandes Armas do Império do Brasil", source: heraldesign.

Diario Popular

PROPRIEDADE DE LISBOA, CAMPOS & COMP.

REDACTOR RESPONSAVEL AMERICO DE CAMPOS — GERENTE JOSÉ MARIA LISBOA

ANNO VI

VIVA A REPUBLICA!

15 de Novembro de 1889

PROCLAMAÇÃO

Fig.1.3.7 First page of the Diário Popular of November 16, 1889, announcing the proclamation of the Republic, National Archives of Brazil.

Fig.1.3.8 Governo do Brasil, Foto oficial de Getúlio Vargas, 1930, Galeria de Presidentes.

sympathetic to the Allied cause, declaring war on Germany on October 26, 1917 and held a seat in the League of Nations.

After a fraudulent election in 1922, a handful of disgruntled officers staged an unsuccessful coup in Rio de Janeiro in July. The revolt nonetheless initiated an eight-year period of unrest, led by groups of junior officers, known as tenentes ("lieutenant").

Getúlio Vargas, the losing candidate in the 1930 presidential election, led a revolt that placed him in power. He remained a central figure in Brazilian politics for the next 24 years, holding office as chief executive between 1930-45 and 1951-54.

Agitations following the Great Depression led to many uprisings, which did nothing but reinforce Vargas hold on power, culminating in the Estado Nôvo ("New State"), which gave him practically absolute powers.

Brazil was again on the Allies' side during Word War II, and declared was against Germany and Italy on August 22, 1942, even sending an expeditionary force to Italy in July 1944.

As the war ended, on October 29, 1945 some military officer staged a coup that forced President Vargas to resign, though he won the general elections of 1950, but unable to dominate again the political forces of the country. Brazil's economic difficulties of the time led to the creation of the national petroleum corporation Petrobrás in 1953. Vargas faced rising antipathy during his last term, in an administration where corruption was rampart. On August 24, 1954 a group of army officers demanded his resignation and the former dictator committed suicide.

Fig.1.3.9 Marcel Gautherot, "Brasilia", photo, 1958-1960, source: Archdaily.

Fig.1.3.10 Marcel Gautherot, "Brasilia", photo, 1958-1960, source: Archdaily.

The presidential elections of October 1955 were won by Juscelino Kubitschek de Oliveira, who after an attempted coup and a countercoup on November 11, 1955, formally took office on January 31, 1956. Kubitschek most known accomplishment is the planning, initially constructing and dedicating (April 21, 1960) Brasília, the new federal capital.

1.3.1.5 Brazil since 1960

The presidential elections of 1960 were marked with uncertainty, resulting in a president and vice-president from opposing parties, Jânio Quadros and João Goulart. A period of political upheaval followed, with Quadros resigning on August 25, 1961 and, after a brief parliamentary interlude, Goulart assuming presidency after a plebiscite on January 6, 1963, but then fleeing into exile on April 2, 1964 after a rebellion started on March 31.

The rebellion leaders seized powers and the presidency was awarded to Castelo Branco on April 11, 1964, though opposition remained from both military and civilian sides.

The regime created an artificial, two-party system composed by the National Renewal Alliance (Aliança Renovadora Nacional; ARENA) and the Brazilian Democratic Movement (Movimento Democrático Brasileiro; MDB), with the former quickly dominating the political scene till 1978.

Over the years, the regime progressively loosened restraints on the democratic process, until 1982, when direct elections for state governors were held for the first time since 1965, and the opposition won most of the larger states. By then, Brazil boasted the 10th largest gross national product, though the country did not escape the economic crises shaking Latin America in the 1980s.

In January 1985, Tancredo de Almeida Neves became the first president elected democratically since 1964, though dying before assuming office and succeeded by his vice-president and José Sarney. While democracy had been restored, the old-regime elites still inhibit reform of the political system in the early 1990s.

It wasn't until January 1st, 2003 that the first transition between a democratically elected president to a democratically elected successor happened, when Luiz Inácio Lula da Silva won the elections of October 27th, 2002 over José Serra, the government-backed candidate.

Lula held the executive office for two consecutive terms (the limit imposed by the constitution), until 2009, whereupon he endorsed his former chief of staff, Dilma Rousseff, as the candidate for the 2010 election, which she won.

At the start of 2011, Brazil started to suffer the impact of the 2008 financial crisis, as the Roussef administration faced accusation of corruption.

In recent years, Brazil has hosted both the 2014 Football World Cup and the 2016 Olympic Games, gaining both international recognition and discontent among its citizens for the expenditures associated with these events.

Fig.1.3.11 Ricardo Stucker, Luiz Inácio Lula da Silva, Presidente do Brasil, 2003, source: Agência Brasil - Secretaria de Imprensa e Divulgação.

1.3.2 Favelas: an informal urban layout

The megacities urbanization, has caused the development of spontaneous and self-built settlements populated by poor people, concentrated in the suburbs, the poorest areas of the cities. The public authorities were unable to control the phenomenon to the point that entire neighbourhoods were lacking adequate infrastructure and public equipment, contributing to social segregation.

The name “Favela” comes from a Rio de Janeiro neighbourhood called “Morro da Favela”, that was occupied by the soldiers returned from the war of Canudos (1895 - 1896), in the Bahia state, because the government neither paid their wages or gave them land to settle in. This area became the first irregular urban agglomeration of Rio de Janeiro.

While some traces the origin of the favela in the Brazilian communities formed by impoverished former slaves in the late 19th century, the present chaotic urban texture started to develop from the ‘40s and ‘70s, following the great wave of migration from the countryside to the cities.

Poor and confronted with the exorbitant costs for scarce land and hosing, those rural migrants had little choice but to become squatters. From 1950 to 1980, the number of people living in favelas in Rio de Janeiro alone increased from about 170,000 to over 600,000, and by the early 21st century, it was estimated that there were as any as 1,000 favelas in Rio alone. A 2010 census reveals that at least 6 percent of Brazil’s population lives in favelas.

Those urban areas were for the longest time thought as “temporary” living spaces, that would eventually be removed. For this reason, social policies avoided to provide the necessary services. It was only in 1992 that the Plan Director of Rio de Janeiro decided to organize and integrate the favelas in the city, officially recognizing them as part of the city. Over the years the Brazilian government has taken a number of different approaches in dealing with favelas, from programs to eradicate the favelas to efforts to provide or improve infrastructure and permanent housing.

The “favelization” process is still ongoing and continues to increase the problem of population density and safety. The lack of infrastructure gives rise to improvised and jerry-rigged plumbing

Figure 1.3.12 Image of Sao Paulo’s Paraisopòlis (“Paradaise City”) and the adjacent favela, source: “Rugby project in ‘Paradise City’ favela offers youngsters Olympic dream”, CNN.

and electrical wiring. Often water must be ported over great distances, and rudimentary methods of waste disposal pose health hazards. As a result of the crowding, unsanitary conditions, poor nutrition, and pollution, disease is rampant in the poorer favelas, and infant mortality rates are high. Therefore, it is important to intervene on the urbanization for reducing disparities, but also to enhance the associative and public space, for decreasing the problem of population density and improving the living conditions.

The organic development of the favelas is a self-organized process that, in the absence of any alternatives, becomes a practical, if insufficient, solution from an economic and social point of view, from which some lessons can be learned regarding urban planning as an ideology and the space as an expression of individual power.

1.3.3 Rio de Janeiro

The Portuguese explorers arrived at Guanabara bay, where now Rio de Janeiro lays, on January 1st, 1502. The first settlement was built on the "Morro do Castelo", which now corresponds to the centre of the city. The expansion grew only in North and South direction, because the internal mountains formed a natural barrier. The city of Rio de Janeiro began to transform radically its urban shape from the 19th century onward. From 1850, international capitals were invested in the utilities sector (transportation, sewage system, gas, etc.).

In first years of the 20th century Rio de Janeiro had undergone big transformations. The mayor Pereira Passos started a transformation led by an urban renewal program, "Reforma Passos". This reform involved the extension of the main streets of the city centre: with the construction of the "Avenida Beira Mar", as a link from Downtown to Botafogo, as well as the "Avenida Atlantica" along the neighbourhood of Copacabana.

The increase in the population density within the southern area demanded a transformation of the urban shape. The most important measures were the

Figure 1.3.13 Ratão Diniz, photo of sawerage problem in a Favela in Rio de Janeiro.

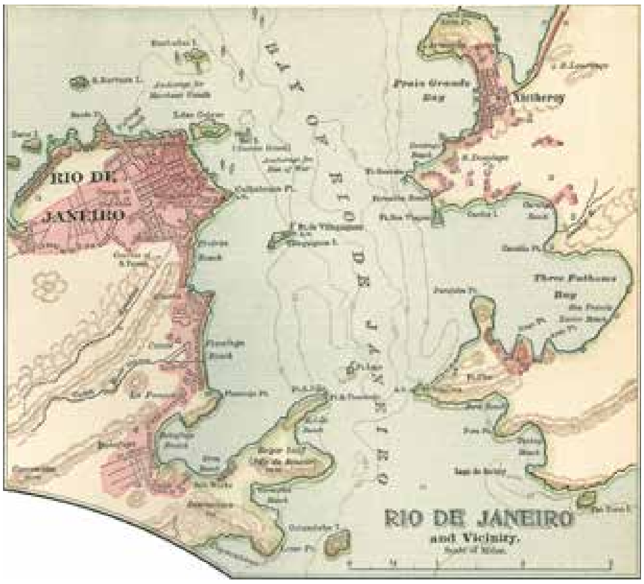


Fig.1.3.14 Map of Rio de Janeiro, 10th edition of Encyclopedia Britannica, 1900.

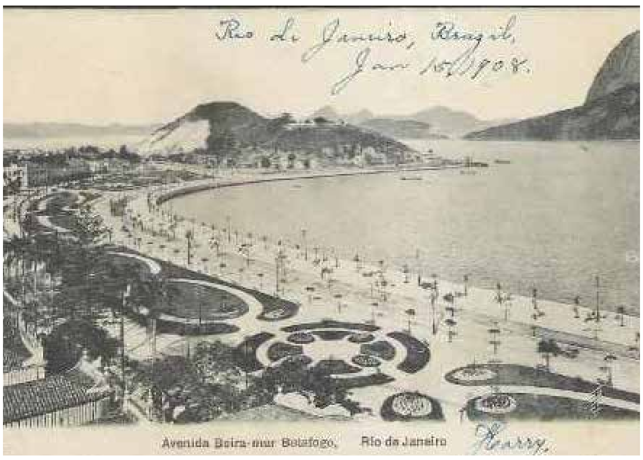


Fig.1.3.15 Print of Avenida Beira mar, 1908.

Figure 1.3.16 Copacabana Beach in Rio de Janeiro, photo, 1890, source: HistoryPorn.

Figure 1.3.17 Copacabana Beach in Rio de Janeiro, photo, 2015, courtesy of Joyce Guimaraes.

extension of Copacabana Beach, the construction of the Rio-Niteroi Bridge, the continuation of the Perimetral Avenue, the construction of the oceanic interceptor of the South zone as well as the first metro lines. The process of income concentration led to two significant effects on the evolution of the city: a drastic process of removing the slums from the south area and the expansion of São Conrado and Barra da Tijuca. The current structure of Rio de Janeiro is the expression of an evolution process that is at the same time both linear and discontinuous.

1.3.4 Rocinha

The land upon which Rocinha sprawls today, was inhabited by different people throughout history. First by the Tupi people, one of the most important indigenous populations of Brazil, who occupied the areas along the Atlantic coast. Then, by the Portuguese colonizers, which took possession through force and the extermination of the local inhabitants. And, lastly, by the African slaves, brought in Brazil and forced to work in the local farms and plantations, founded by the European conquerors.

A farm was built in the area between São Conrado e Gávea in the XVIII century, called Quebra Canghala, that started producing coffee and sugar canes, along with other small crops by the middle of XIX century. This farm bordered the lands of José Magalhães Seixas and São José da Alagoinha da Gávea, Portuguese figures linked to the slavery abolition movement, who encouraged the construction of the Quilombo of Leblon at the foot of Morro Dois Irmãos. (In Brazil, a quilombo is a community of African slaves escaped from the plantations). When, on May 13th, 1888, Isabel, Princess Imperial of Brazil, promulgated the "Lei Áurea", which formally decreed the abolishment of slavery in the country, said community was given recognition, and subsequently expanded to the forest where Rocinha now lays.

While Estrada da Gávea already existed, the first contacts between the ex-slaves' descendants and the city of Rio de Janeiro became possible only with the advent of the tram in the middle of XIX century.

The Company Castro Guidão, founded by the Portuguese brothers Braulio Norberto and Adriano at the beginning of XX century, rose to prominence in the Brazilian business and expanded its activities in the textile and agricultural fields. In the 1920s, the Company owned some farms in Rio the Janeiro and was able to acquire Quebra Cangalha farm as well, which was subsequently divided in lots and sold. It was then that the streets 1,2,3 and 4, existing today, were laid down. Around this period, Rocinha was given its name, meaning "little farm". The name came from the abundant production of vegetables that characterized this area, sold in the market placed at Largo das Três Vendas, now Santos Dumont Square, in the neighbourhood of Gávea.

The market, known throughout all Rio de Janeiro, played a very important role in the plantation of different kinds of fruit and vegetables in the adjacent land. In the 1930s the Company went bankrupt and the site was declared without owner, consequently, people began to occupy the now-free lots. Hence, Rocinha urban growth became irregular and characterized by self-built settlements, typical of a favela.

An Italian community, escaped from Europe and from the Second World War, contributed to the Rocinha urbanization, with the construction of rua Via Àpia da Rocinha and its perpendicular streets with similar Italian names. This small patch was the only one characterized by a regular urban grid inside the favela.

Estrada da Gávea has always been a very important avenue.

Figure 1.3.18 " Terrenos para vender en prstacoes mensaes na Estrada da Gavea" ,The Company Castro Guidão's map, in which all the sold plots of land, source: Museu Sankofa Archive.

Figure 1.3.19 Circuito da Gávea, photo, 1933, source: Arquivo / O Globo, 1933.

During the colonial period, it was a muddy track that connected the neighbourhood of Gávea with the sea. In 1916, the road network was improved by Marshal Conrado Jacob de Niemeyer, who also built Niemeyer Avenue, an extension of Estrada da Gávea along the Atlantic coast, which connect the site with Leblon.

The street was paved in 1930 and equipped with electric lighting in 1937. Estrada da Gávea was a part of the official circuit Niemeyer-Gávea, a route of 11 km around Morro Dois Irmãos, in the Grand Prix of Rio de Janeiro, from 1st of October 1933 to January 1954.

On May 1st, 1938, the chapel and the school of Nossa Senhora da Boa Viagem were inaugurated in Estrada da Gávea. The church had a very important role for the community's consolidation, thanks the socially useful work offered to inhabitants. The Catholic Church founded the Leone XIII Foundation, which helped the Rio de Janeiro favelas with the creation of action centres. In Rocinha, the Foundation built the Social Action Centre of São José, in the rooms of the local church. Its work of control, supervision and education was very important inside the favela.

Rocinha followed the development of the neighbourhood of Ipanema, Leblon, Gávea, Jardim Botânico and Lagoa until 1950s. In the 1960s, the favelas removal policy from the Rio de Janeiro hills gained significant momentum, with the goal of freeing areas for new controlled urban expansions. All the while, a significant number of inhabitants were bounced around inside of the city. With the building development and the people migration from Rio de Janeiro state to the capital, the community expansion became exponential. Many farmers, who later became bricklayers, were called in the city for the construction of the tunnel Zuzu Angel and built their homes near the construction site, occupying areas around Rocinha. New settlements were raised, like Vila Laboriaux, Dionéia, Vila Cruzado and Vila Verde, thereby transforming Rocinha in Rio de Janeiro's biggest favela. The population increase introduced the first facilities, businesses and institutions inside the favela, which, despite numerous failings, resulted into a change in the material used in urban development. The wooden and zinc houses started to be replaced by ones made from concrete and bricks, built on three or four floors. New connections with the city were constructed.

Rocinha was, for the longest time, ignored by the Rio de Janeiro government. Consequently, some neighbourhood associations of residents were born to give an organization and to try to improve the social and hygienic conditions of the favela. In 1993, Rocinha was officially recognized as a neighbourhood of the city by the Prefecture of Rio de Janeiro, which started to collaborate

Figure 1.3.20 Rocinha landscape, left photo, 1958, Acervo pessoal da Família Castro Guidão; right photo, 2014, source: Alamy.

with the inhabitants. This cooperation brought good results. Plano Setorial da Rocinha promoted improvement in the health, hygienic, safety, cultural and social fields, through the construction of schools and leisure areas inside the favela. In 2005, the architect Luiz Carlos de Menezes Toledo, along with his team, won a competition for the urbanization of Rocinha, through the development of residential buildings.

The architect Oscar Niemeyer designed a pedestrian walkway on the highway, which connected Rocinha with the sport complex, built some years before. Other projects are promoted in the Plano de Desenvolvimento Sustentável (PDS), the last document inside the Programa de Aceleração do Crescimento na comunidade (PAC), which invests on inhabitants, considered the initiators of Rocinha's transformations.

Unfortunately, the poverty and the social degradation gave way to the birth of criminal organizations, which introduced criminal actions and violence inside the community. After a lot of conflicts against the criminal gangs, the state of Rio de Janeiro reclaimed the occupied territories of Rocinha, starting from November 2011, through the installation of a Pacifying Police Unit, a law enforcement and social services program. The 28a Unidade de Polícia Pacificadora (UPP) was installed in Rocinha on 20th September 2012, through a security operation with hundreds of police and military. The conflicts for the territories control between different criminal gangs restarted on September 2017, after some years of peace and tranquillity.

1.4 The contrast between city and favela

1.4.1 Introduction

For the social data and the social analysis of Rio de Janeiro, we have based our research on the IBGE census. In particular, we considered the 2010 IBGE census, being the last one performed. These data are very important for understand the demographic trend, the growth rate of the city and the aging rate of the population.

1.4.2 Demographic data

1.4.2.1 Rio de Janeiro

The Municipality of Rio de Janeiro has a population of 6,320,446, with an increment of 7,9% in the last ten years. A good portion of the population, which increased dramatically in the 20th century, live in an informal settlement. In fact, 20% of Rio's population, 1,393,314 people, live in favelas.

In Rio de Janeiro, there is an almost even split between men and women, with numbers leaning slightly more towards women; who accounts for 53.4% of the population (3,360,629 people), while men make up the remaining 46.6% (2,959,817 people).

The table on the side shows the data on population, households, number of inhabitants per household, occupied areas and population density for Rio de Janeiro. Since the city extends over a surface of 1,200.177 km^2, the resulting population density is relatively low, with 5,265.82 pop./ km^2.

The 2010 IBGE census studied the size of families through the number of people (muradores) per house, as the table shows. It is possible to notice that the most common number of family members is 2 to 4 people, which accounts for 69.4% of families. Furthermore, there is a significant number of singles, namely 17.5% of the total population. Conversely, there are few bigger family units with 6 or more members. From these data, it is possible to calculate the average size of families in Rio de Janeiro, which is 2,62 per house, with a total of 2,144,020 families in the city.

The population of Rio de Janeiro can be split into four age groups, as the table on the side shows: the children between 0 and 14 years old; the young people between 15 and 29 years old; the adult population between 30 and 64 years old and the elderly people from 65 years old and up.

The data show that children represent 20% of the total population, numbering 1,226,388 people. The young people are 1,523,960, meaning 24.1% of the total inhabitants of the city. However, the population of Rio de Janeiro is mainly comprised of adults between 30 and 64 years of age, accounting for 46% of the total population. The elderly from 65 years old and up are only 661,699, that represent 10.5% of the whole.

To perform a more in-depth analysis of the inhabitants is very important to consider and study the age pyramid. It is a significant social data that shows the tendency of the population aging and a graphic representation of the distribution of the population according to the age. The age pyramid of Rio de Janeiro is characterized by a rectangular shape, since there are less children and young people than adult. Furthermore, it is possible to notice a difference in the number of men and women above 30 years of age, which is particularly evident after the 65 years mark, where the women are twice than men.

During the last ten years, Rio de Janeiro has had a significant increase of population, as birth rate (0.015%) is almost twice the mortality rate (0.008%). Though the biggest contributing factor in the growth of the city is immigration, with the final population growth percentage being 0.74%, as the table on the side shows.

Community	Surface (km²)	Population (pop)	Density (Pop/km²)	Household	Pop/household (%)
Rio de Janeiro	1,200.18	6,320,446	5,265.82	2,408,891	2.62
Rocinha	1.44	69,161	48,028.47	23,347	2.96

Tab. 1.4.1 Demographic data divided between Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Family members	Household			
	Rio de Janeiro		Rocinha	
	Pop.	%	Pop.	%
Total	2,144,020	100	23,399	100
1 morador	375,616	17.5	4,073	17.4
2 moradores	564,889	26.3	5,869	25.1
3 moradores	530,687	24.8	6,185	26.4
4 moradores	392,544	18.3	4,068	17.4
5 moradores	167,617	7.8	1,817	7.8
6 moradores	64,331	3	752	3.2
7 moradores	25,429	1.2	334	1.4
8 moradores	11,679	0.5	137	0.6
9 moradores	5,236	0.2	72	0.3
10+ moradores	5,992	0.3	92	0.4

Tab. 1.4.2 Household data divided between Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Com-munity	Age group/sex									
	From to 14		From 15 to 29		From 30 to 65		More than 65		Total	
	M	W	M	W	M	W	M	W	M	W
Rio de Janeiro	622,532	603,856	756,036	767,924	1,334,772	1,573,627	246,477	415,222	3,128,562	3,191,884
Rocinha	8,552	8,540	11,033	10,838	13,719	14,200	821	1,458	34,125	35,036

Tab. 1.4.3. Age data divided between Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Com-munity	Age group/sex									
	From to 14		From 15 to 29		From 30 to 65		More than 65		Total	
	M	W	M	W	M	W	M	W	M	W
Rio de Janeiro	622,532	603,856	756,036	767,924	1,334,772	1,573,627	246,477	415,222	3,128,562	3,191,884
Rocinha	8,552	8,540	11,033	10,838	13,719	14,200	821	1,458	34,125	35,036

Tab. 1.4.4. Age data divided per sex between Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

1.4.2.2 Rocinha

The UPP Rocinha is formed by two communities: the Vila Parque da Cidade and the Rocinha itself. According to the 2010 IBGE census, Rocinha has a population of 69,161 people, but unofficial estimates present a population around 200,000 inhabitants, sometimes more. In this analisys, and for the subsequent ones, we will consider the official data only.

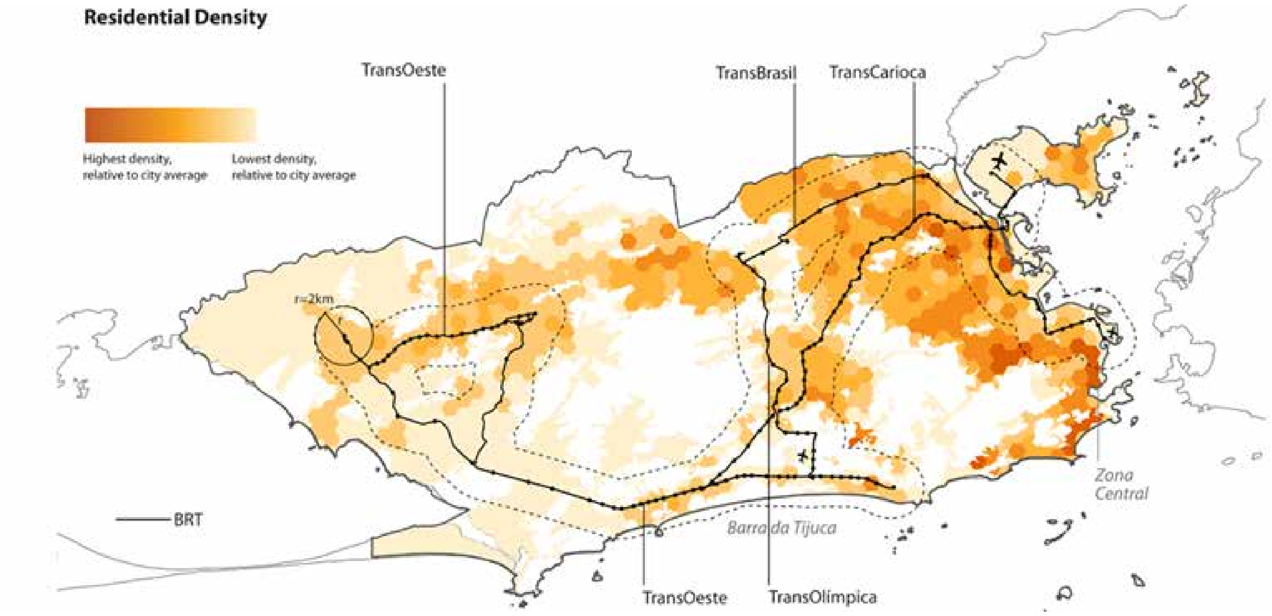
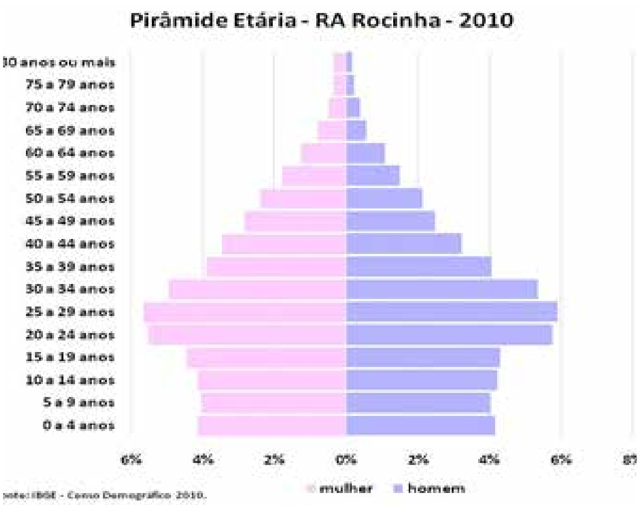


Figure 1.4.1 Residential density map in Rocinha linked to the network geography of the Rio Bus Rapid Transit system. source: LSE City.

As for Rio de Janeiro, also the population of Rocinha is split almost evenly between men and women; there are men 34,125, meaning 49.7% of the total population, and 35,036 women, accounting for 50.7% of the inhabitants. Rocinha has an area of 1.44 km^2, thus the population density is extremely high, sitting at 48,028.47 pop./km^2. If we were to consider the unofficial population the density would dramatically increases to 138,888.89 pop./km^2.The table shows the number of families and their size. As for Rio de Janeiro, also the most common family unit in the favela is made up of 2 to 4 people, that represents 68.9% of the total.



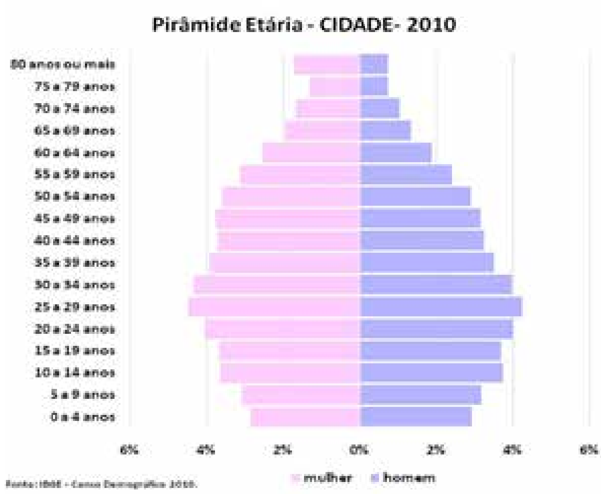


Figure 1.4.2 Age pyramids of the entire city of Rio de Janeiro and of Rocinha. Source: 2010 IBGE Census.

There are also a few bigger families, with 6 or more people. As done for the data from Rio de Janeiro, since the table shows the total number of families that live in Rocinha (23,347), it is possible to calculate the average size of families living in the favela. This results in the average number of "muradores" per house in favela being 2,96, slighly over the 2,62 registered for Rio de Janeiro.

Again, it is possible to divide the population of Rocinha in four age groups: the children between 0 and 14 years old; the young people between 15 and 29 years old; the adult population between 30 and 64 years old and the elderly people from 65 years old and up.

As shown by the table on the side, the majority of the inhabitants are younger people. In fact, the children represent about 25% of the total population, 17,092 people, while the young people are approximately 32% of the total, which means 21,871 people. So the total percentage of younger people is 57% compared to the 43.5% of Rio de Janeiro. The remaining population is mostly made up of adults, 27,919 people or 40% of the inhabitants, with the elderly filling the remaining 3%, a significant gap, compared to the 10,5% of Rio de Janeiro.

For this reason, the age pyramid of Rocinha is completed different from Rio's, formin a triangular shape, since ost of the population is concentrated among the youger generations, between 0 and 29 years of age. Moreover, the population decrease sharply the more it approaces older generations, reaching almost insignificant percentages (under 1%) after 65 years of age.

1.4.3 Economic data

1.4.3.1 Introduction

We have considered and analysed the socio-economic data about the jobs and the average income of the population of Rio de Janeiro and Rocinha. These data are very important to understand the economy of the territory and the real-life conditions of the population. For the economic analysis, in accordance with the 2010 IBGE census we consider all the inhabitants at least 10 years old. For the social data and the social analysis of Rio de Janeiro, we have based our research on the IBGE census. In particular, we considered the 2010 IBGE census, being the last one performed. These data are very important for understand the demographic trend, the growth rate of the city and the aging rate of the population.

Figure 1.4.3 Catadores working at "De Olho No Lixo" cooperative. Source: Correiro do Brasil.

1.4.3.2 Rio de Janeiro

The table on the side shows that 47.5% of the whole population of Rio de Janeiro is considered unemployed. However, it is important to analyse critically said number, as it contains all the population over 10 years of age, without having specific categories for students and retirees (over 65 years of age), respectively 15% and 10.5% of the total. In other words, the percentage drops to a more manageable 22% of unemployed inhabitants. The table also shows the most significant percentages of employment, namely employees (29.2%) and self-employed (10.2%).

Another important data is the monthly income per capita, since it shows significant information on the life conditions of the families in Rio de Janeiro and on the wealth and poverty rate of the inhabitants of the city.

In accordance with the 2010 IBGE census, the inhabitants were split into ten income brackets, based on minimum salary, that is R$ 510,00:

- Until 1/8 times of minimum salary (R$ 0 - R$ 63,75);
- From 1/8 to 1/4 times of minimum salary (R$ 63,75 - R$ 127,50);
- From 1/4 to 1/2 times of minimum salary (R$ 127,50 - R$ 255,00);
- From 1/2 to 1 times of minimum salary (R$ 255,00 - R$ 510,00);
- From 1 to 2 times of minimum salary (R$ 510,00 - R$ 1020,00);
- From 2 to 3 times of minimum salary (R$ 1020,00 - R$ 1530,00);
- From 3 to 5 times of minimum salary (R$ 1530,00 - R$ 2550,00);
- From 5 to 10 times of minimum salary (R$ 2550,00 - R$ 5100,00);
- More than 10 times of minimum salary (R$ 5100,00 and more);
- No minimum salary (R$ 0).

With the first two income brackets being considered under the poverty line. The table on the side shows that most of the population of Rio de Janeiro falls within the income brackets from 1/2 to 2 times of minimum salary (33.9%), while a small percentage is considered to be below the poverty line.

1.4.3.3 Rocinha

The data regarding the community UPP Rocinha paints a different picture for the favela when compared to Rio de Janeiro. The total unemployment rate is significantly smaller (40.5%, compared to Rio de Janeiro’s 47.5%), even more so when students (26%) and retirees (3%) are subtracted, which brings the unemployment rate down to 11.5%, half that of Rio the Janeiro. In Rocinha, almost half of the workforce (42.3%) possesses a formal contract (employees), a significant higher percentage than that observed for the municipality of Rio de Janeiro, sitting just below 30%.

Another glaring difference comes from the analysis of the monthly income per capita, as most of Rocinha inhabitants fall within the income brackets from 1/2 to 2 times of minimum salary (51.7%), significantly more than the 33,9% of Rio de Janeiro.

Slightly more than 48% of the economically active population of Rocinha works in the city of Rio de Janeiro. Factoring in the unemployment rate (40.7%), it could be said that of the total number of people employed in Rocinha, 81.9% commute in Rio.

Again, only 3% of Rocinha’s population is recorded as living below the poverty line.

Employment	Population with 10 or more years of age			
	Rio de Janeiro		Rocinha	
	Pop.	%	Pop.	%
Total	5,559,923	100	58,121	100
Employee	1,625,490	29.2	24,586	42.3
Armed forces	59,746	0.1	114	0.2
Public officials	143,718	2.6	98	0.2
Employees without contract	423,888	7.6	5,131	8.8
Self-employed	566,342	10.2	4,077	7.0
Employed	68,545	1.2	69	0.1
Unpaid	32,604	0.6	265	0.5
Unemployed	2,639,591	47.5	23,782	40.9

Tab. 1.4.5. Employment rate between Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Employment	Population with 10 or more years of age			
	Rio de Janeiro		Rocinha	
	Abs.	%	Abs.	%
Total	5,559,923	100	58.121	100
Until 1/8 times of minimum salary	38,257	0.7	250	0.4
From 1/8 to 1/4 times of minimum salary	53,399	1	573	1
From 1/4 to 1/2 times of minimum salary	74,443	1.3	905	1.6
From 1/2 to 1times of minimum salary	723,071	13	11,468	19.7
From 1 to 2 times of minimum salary	1,163,682	20.9	18,575	32.0
From 2 to 3 times of minimum salary	486,076	8.7	3,997	6.9
From 3 to 5 times of minimum salary	470,814	8.5	1,880	3.2
From 5 to 10 times of minimum salary	445,156	8	475	0.8
More than 10 times of minimum salary	348,148	6.3	104	0.2
No minimum salary	1,756,877	31.6	19,294	34.2

Tab. 1.4.6. Employment distribution in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

1.4.4 Services and infrastructures

1.4.4.1 Introduction

Another important aspect taken into account by our analysis are the services and infrastructures of Rio de Janeiro and Rocinha both. In other words, the quantification of the provision of basic urban sanitation, of waste collection service and of electric energy service. These data are very important for understand the diffusion of basic urban services in the city and in the favela, but also to understand the real-life condition of the population within.

1.4.4.2 Rio de Janeiro

The analysis of basic urban sanitation is divided in two-parts, water supply and sewerage provision. The tables on the side show the provision of basic urban sanitation in the city, considering both water and sewerage.

The data report a well-connected system for the water supply and the sewerage both, with almost all households possessing an appropriate water supply (only 1.5% are reported insufficient) and an appropriate connection to the sewerage system or to a septic tank (94.9%).

It should be emphasized that all the data show only the provision of basic urban sanitation, but they don't show the quality of the service.

For the analysis on waste, aligning with the 2010 IBGE census, the houses have been divided in two categories: whether the service is an appropriate or an inappropriate one. An appropriate service indicates that the house benefit from a door-to-door collection service or workers that dispose of the waste in appropriate garbage collection tank. Conversely, an inappropriate service means that waste is disposed of on the street, in the sewage, in uncultivated land or burnt. The waste data show that most of households of Rio de Janeiro are covered by a collection service, with only 0,7% indicated as having an inappropriate waste collection service. It should be emphasized that all the data show the coverage of waste collection service, but they don't show the amount, the quality and the frequency of service.

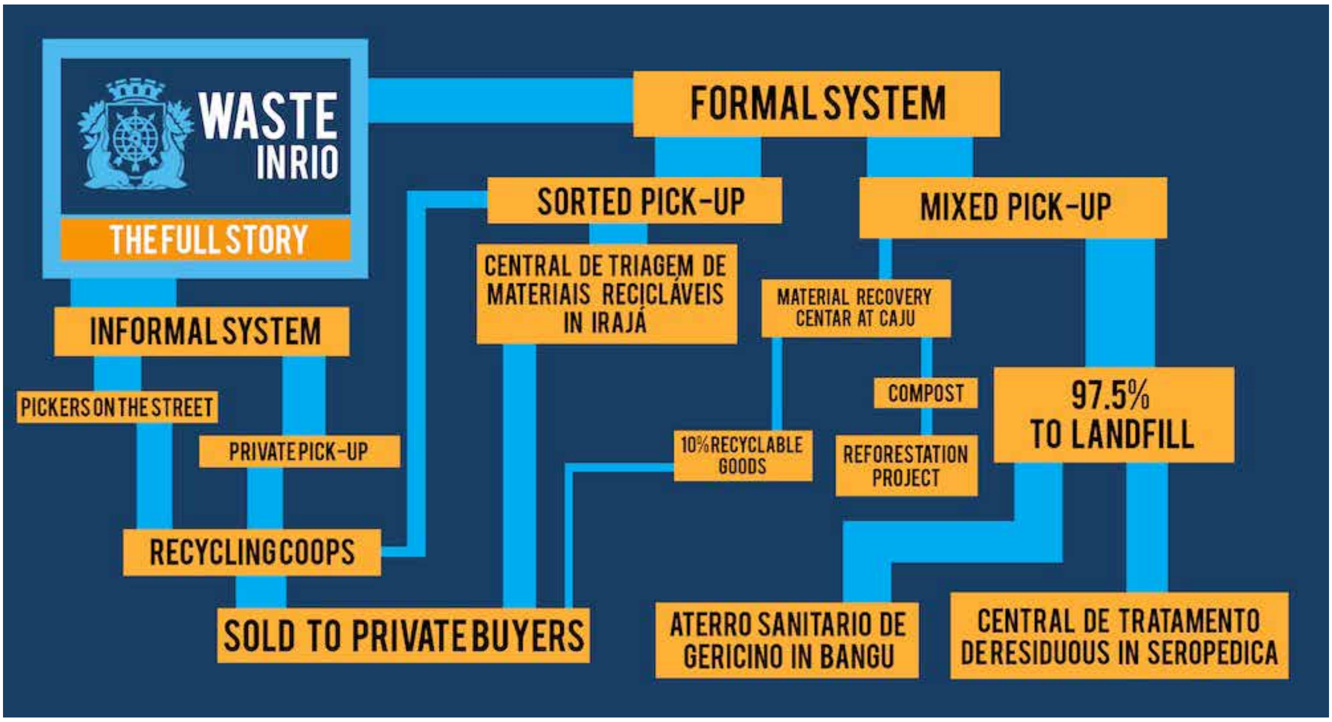


Figure 1.4.4 scheme of Rio's waste collecting system, source: http://www.rioonwatch.org.

The tables on the side show the houses provision of electric energy. All the inhabitants of Rio de Janeiro have access to electricity, either from the official public service or other sources, such as the Sun, wind and generators. Most of them relay on the former, with only 1.4% of the energy coming from other sources.

Furthermore, in accordance with the 2010 IBGE census, it's possible to quantify how many houses have an electric meter. While most of the households possess one, there exist a 6.0% of the houses without it, it's reasonable to assume that the latter either don't receive electricity from the official public source or have an illegal connection to the electricity grid.

Community	Water supply					
	Appropriate		Inappropriate		Total	
	Homes	%	Homes	%	Homes	%
Rio de Janeiro	2,372,758	98.5	36,133	1.5	2,408,891	100
Rocinha	23,040	98.7	307	1.3	23,347	100

Tab. 1.4.7. Water supply in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Community	Waste collection service					
	Appropriate		Inappropriate		Total	
	Homes	%	Homes	%	Homes	%
Rio de Janeiro	2,392,029	99,3	16,862	0.7	2,408,891	100
Rocinha	22,934	98,2	413	1.8	23,347	100

Tab. 1.4.8. Waste collection service in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Community	Sewerage					
	Connection to sewarage		Without connection to sewerage		Total	
	Appropriate	Inappropriate				
	Homes	%	Homes	%	Homes	%
Rio de Janeiro	2,392,029	99.3	16,862	0.7	2,408,891	100
Rocinha	22,934	98.2	413	1.8	23,347	100

Tab. 1.4.9. Sewerage system in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Community	Sewerage									
	Connection to sewarage				Without connection to sewerage		Without electric energy		Total	
	Appropriate		Inappropriate							
	Homes	%	Homes	%	Homes	%	Homes	%	Homes	%
Rio de Janeiro	2,228,224	92.6	1,444,534	6.0	33,724	1.4	0	0.0	2,408,891	100
Rocinha	20,924	89.6	2,062	8.8	349	1.5	12	0.1	23	100

Tab. 1.4.10. Electric energy distribution in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Figure 1.4.5 Most of the waste and sewage from the favela runs through open sewers like this one in Rocinha. Source : ROCINHA.ORG "O Portal da Rocinha Real".

Figure 1.4.6 The Vila Laboriaux primary source of potable water, Picture taken Arianna Trombini.

1.4.4.2 Rocinha

The 2010 IBGE census proves not to be a reliable source regarding the services and infrastructures built within Rocinha. The data affirm that the services provided should either be on par or even better than those of Rio, but the site inspection revealed an unquestionably worse, reality.

Since until recently most of the favelas are not considered proper neighbourhoods by the authorities, they have not been supplied with the appropriate services in relation to the population's needs. While transportation services are, at best, inadequate, the direst problems are linked to the water supply and disposal system, indeed the access to potable water is severily limited and a proper sewage system barely even exists.

The existing stormwater canals, themselves deficient, called "talvegues", often become the sewerage of the favela, where home disposal, garbage and organic waste, transported by the rainwater, accumulate together inside. This pressing problem derives either from the scarcity of drainage capacity, the open-air water storage, the enormous population density or the lack of proper disposal systems, likely a combination of all factors listed above.

Consequently, hygiene conditions are alarming by any standards even at best of times. A dramatic issue related to open air water storage, especially at tropical climate zones, is the proliferation of mosquitoes and other insects which multiply easily, laying their eggs in the stagnant water, and become a perfect driver for many diseases.

Despite the lack of public attention, most of the buildings are served by basic plumbing and electricity, mainly linked illegally to the grid, but practically accepted by the government. The water supply system is managed by Cedae, a company in charge of providing clean water to a main tank settled on the top of the favela, that serves other small tanks that are on the top of the roofs of the houses. Water quality is insufficient, to the point that each house tap is equipped with a specific filter to try and avoid bacterial infections and other problems, though the latter issue is hardly confined to Rocinha, as the city of Rio as a whole suffers from it.

1.4.5 Education

The last important data that we have considered are the cultural data both in Rio de Janeiro and in Rocinha. The education data of 2010 IBGE census refer to the literacy rate of boys and girls with five or more years of age. The data simply show the number of people with ability to read and write, rather than school attendance's numbers.

1.4.5.1 Rio de Janeiro

Aligning to the 2010 IBGE census, the inhabitants are divided in two age groups, from 8 to 9 years of age, and from 10 to 14 years of age. The tables on the side shows the absolute values and the percentages of the literate people for every age groups.

The data show that most of children between 8 and 9 years of age in Rio de Janeiro can read and write, while only 7.3% are illiterates. The situation improves further in the age bracket from 10 to 14 years of age, where the illiteracy rate is lowered to 2.0%.

1.4.5. Rocinha

The situation is slightly different in Rocinha, where the percentage of literate children between 8 and 9 years is lower than Rio de Janeiro, topping at 88.7%, while for the group from age 10 to 14 the tow cases are reportedly equivalent. Moreover, the number of girl and boy in both age groups are balanced. However, these percentages cannot simply be taken at face value. Further analysis of data taken from the PAC census (2008/2009), which promoted many thematic group debates on Education among the residents, shows that the illiteracy rate increases with age groups: while only 0.8% in the 15-19 years group, it slowly climbs to 4.8% in the 30-59 years group, topping at 21.8% for people over 60 years of age.

In other words, the education programs implemented in the last years were aimed only at children, while essentially ignoring the adult portion of the populace, which, in turn, points to the need of specific policies aimed at the latter. Moreover, the residents highlighted a lack of networking between kindergartens and preschools, decreasing the students' ability to apply at the right time; while higher-quality institutes that are present aren't always affordable to the general population.

Figure 1.4.7 A mother taking care of her child in the streets of Rocinha, picture taken by Arianna Trombini.

Figure 1.4.8 Music lesson at School "Sace Sabe Tudo" picture taken by Arianna Trombini.

The PAC census also reports that, while attendance is relatively high in the younger age bracket, not all young adults attend the education level appropriate for their age: in fact, while 79% of residents between 15 and 17 years of age attend school, only 39% are in high school.

Access to university-level education is scarce, with only two community pre-school courses present in the favela, both affiliated with institutes from the city of Rio; furthermore, the dropout rate is extremely high, as students are often forced not to attend by their circumstances.

Community	**Inhabitants from 8 to 9 years of age**					
	Literate		**Illiterate**		**Total**	
	Pop.	%	Pop.	%	Pop.	%
Rio de Janeiro	141,927	92.7	11,176	7.3	153,103	100
Rocinha	1,922	88.7	245	11.3	2,167	100

Tab. 1.4.11. Literacy level (8-9 years) in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Community	**Inhabitants from 8 to 9 years of age**					
	Literate		**Illiterate**		**Total**	
	Boy	Girl	Boy	Girl	Boy	Girl
Rocinha	945	977	138	107	1,083	1,084

Tab. 1.4.12. Boys and girls' literacy level (8-9 years) in Rocinha. Source: 2010 IBGE Census.

Community	**Inhabitants from 10 to 14 years of age**					
	Literate		**Illiterate**		**Total**	
	Pop.	%	Pop.	%	Pop.	%
Rio de Janeiro	654,974	98.0	13,367	2.0	668,341	100
Rocinha	5,592	96.5	200	3.5	5,792	100

Tab. 1.4.13. Literacy level (10-14 years) in Rio de Janeiro and Rocinha. Source: 2010 IBGE Census.

Community	**Inhabitants from 10 to 14 years of age**					
	Literate		**Illiterate**		**Total**	
	Boy	Girl	Boy	Girl	Boy	Girl
Rocinha	2,787	2,805	127	73	2,914	2,878

Tab. 1.4.14. Boys and girls' literacy level (10-14 years) in Rocinha. Source: 2010 IBGE Census.

1.5 Site inspection: the experience inside the biggest favela in south America.

1.5.1 Urban Characterization

Rocinha is located in the southern part of the Municipality of Rio de Janeiro, near the "bairros" (neighbourhoods) of São Conrado and Vidigal. The community lays between two mountains: the Morros Laboriaux and the Morro Dois Irmãos, within the sub-basin of São Conrado, itself part of the microbasin of Lagoas Oceânicas.

The bairro of Rocinha is split into 25 sub-bairros, named according to the local tradition of its residents, though other sectorization are used by different government institutions such as CEDAE 23 sectors (water and sewage networks), IBGE's 80 census tracts (2010), the 15 work zones (Zonas de Trabalho) defined by the Programa Saúde da Família (Family Health Program) and 8 areas of intervention defined by the Plano Diretor, themselves derived from the PAC (Programa de Aceleração do Crescimento) in 2008.

While most of Rocinha presents an extremely dense urban environment, there exist some internal variations. The more formal and consolidated buildings can be found along Estrada da Gavea, conversely, the urban density decreases at the edges of the favela, as the terrain becomes rocky and even steeper. The biggest exception to the informal urbanization of Rocinha is the Bairro Barcelos, near the base of the favela.

As the terrain morphology prevents Rocinha to expand significantly, the favela has become one of the most verticalized of Rio de Janeiro, with some buildings reaching 11 storeys high. As the population keeps growing, further verticalization is prevented only by the relatively low-quality materials available to the inhabitants, as the vast majority of Rocinha's houses are built with bricks, though even these buildings manage to reach 7-8 storeys at times.

1.5.2 The goal

The "PolimiparaRocinha" project aims to improve the environmental performance of an informal and hostile context such as the favela of Rocinha, located in Rio de Janeiro. Key factor of the designing process will be the importance of social inclusion, to design proper technical solutions approved and acknowledged by the local community. One of the main issues that the project needs to overcome is the lack of accurate information dealing with the morphology of the urban context and the local culture, which complicates the analysis phase and the formulation of realistic and correct solutions. The collaboration between three different groups of graduating students allowed for better understanding of the context of Rocinha, the biggest favela in South America.

Figure 1.5.1 View of Rocinha at sunset, picture taken by Arianna Trombini.

The principal aim of the stay in Rio de Janeiro was to try and clarify the typical morphological aspects of the favela, as to have the necessary tools to directly answer the main technological challenges that the implementation of the researched technical solutions may face in the future. With the support of the local Italian NGO, "Il Sorriso dei miei Bimbi", it was possible to plan multiple guided visits inside the favela to observe and study the local context and, specifically, the three intervention areas chosen before leaving Italy. Unfortunately, we achieved our purposes only partially due to the explosion of one of the fiercest drug trafficking wars Rocinha has ever seen, which forced us to a single day visit inside the favela, insufficient to understand the local context. Our stay was planned to last two weeks, which were useful to live the city of Rio de Janeiro and meet different actors directly or indirectly involved with Rocinha, to investigate the applicability of other case studies to our hostile context and to better understand the best practices to engage with the local population.

Figure 1.5.2 Our team with Barbara Olivi inside the NGO "il sorriso dei miei bimbi".

1.5.3 The entry into Rocinha

1.5.3.1 DE OLHO NO LIXO: the cooperative working with waste disposal

During our sole visit inside Rocinha we had the opportunity to access the structures belonging to the "De Olho No Lixo" cooperative, situated in the lowest part of the favela, near the main entrances. Their work to collect the favela's waste started with the help of the "Secretaria do Meio Ambiente" of Rio de Janeiro and with the organization of a cooperative formed by 30 "Catadores".

Figure 1.5.3 Meeting with Ricardo Miranda at "De Olho No Lixo".Picture taken by Arianna Trombini

The organized space of the cooperative allows to compact the recyclable garbage collected in the areas of the favela covered by the service with the help of a compacting machine and to resell the finished product to people interested in this kind of commerce, creating a microeconomy which improves Rocinha's waste management. Other educational activities, involving the reuse of recycled materials, are held inside the cooperative spaces, but the core of its activity remains the microeconomy generated by the waste management, which is the only business that grants an income to the "Catadores". Their experience in terms of waste management and the possibility to use the free spaces of the cooperative (which is not a common characteristic inside Rocinha), were evaluated as optimal assets to implement other useful projects to improve the quality of the entire system of the favela. We had the opportunity to speak with Ricardo, the main referent

Figure 1.5.4 Waste collection at "De Olho No Lixo". Picture taken by Arianna Trombini

of the “De Olho no Lixo” project, who showed interest in implementing different activities which could grant benefits for both the community (in terms of waste collection) and the cooperative (in terms possibility of higher income). This established collaboration could help the “PolimiparaRocinha” to design realistic solutions and could grant possible solutions in terms of applicability and local management, a key requirement which needs to be answered to ensure the continued duration and correct realization of the projects.

A small group of us payed a visit to Rocinha a second time another morning to meet at “De Olho no Lixo” a representative of the “Secretaria do Meio Ambiental”, highlighting the strong interest that our first meeting with Ricardo raised and promoting a possible collaboration of the project with the public administration.

1.5.3.2 Inside the bowels of Rocinha

Our visit inside Rocinha was characterized by a long walk through the main roads of the favela and some “becos”, which helped our group to highlight the main traits which distinguish the different typologies of streets and to analyse the entire mobility network in order to outline the opportunities and the weaknesses of a possible bike-sharing system which will be discussed further on.

We had the opportunity to walk through the intervention area n°2 while the area n°1 was considered too steep to cross for a first visit inside Rocinha, while area n°3 was situated in a deeper in the favela and judged too dangerous due to the raging drug trafficking war. This is one of the main reasons which induced us to change the focus of the intervention area n°3 and move to a safer place between Rua Nova and Largo do Boiadero. The walkthrough of the intervention area n°2 permitted us to visualize all the problems that needed to be tackled in a harsh and steep context such as Rocinha, especially regarding the water management issue. The typical “becos” of Rocinha show an extreme lack of sunlight and natural ventilation and the possibility to cross the neighbourhoods is ensured only by the presence of narrow concrete and highly steep stairs. It was also possible to observe the presence of different downpipes which released the water collected on the houses’ roofs in a not-well-defined sewage system.

1.5.3.2 Il sorriso dei miei Bimbi

The entire visit was possible thanks to the availability of Barbara and Julio, the local responsible of the ONG “Il Sorriso dei miei Bimbi” who work in Rocinha since 20 years, and Fernando Urucu, a historian born in Rocinha.

The guidance and the willingness of Fernando were useful in order to understand better the context of the favela and to safely walk through it because of his highly considered status of “leader” inside Rocinha. We had the opportunity to pay a visit to the “Garagem das lettras”, the literary coffee located in Rua Dioneia managed by Barbara and Julio, who are involved in the local children education with the help of another structure situated in the lower part of the favela, the “Escolinha Saci Sabe Tudo”, which offers afterschool activities for children.

Figure 1.5.5 Portrait of Barbara an Julio, picture, source: Facebook.

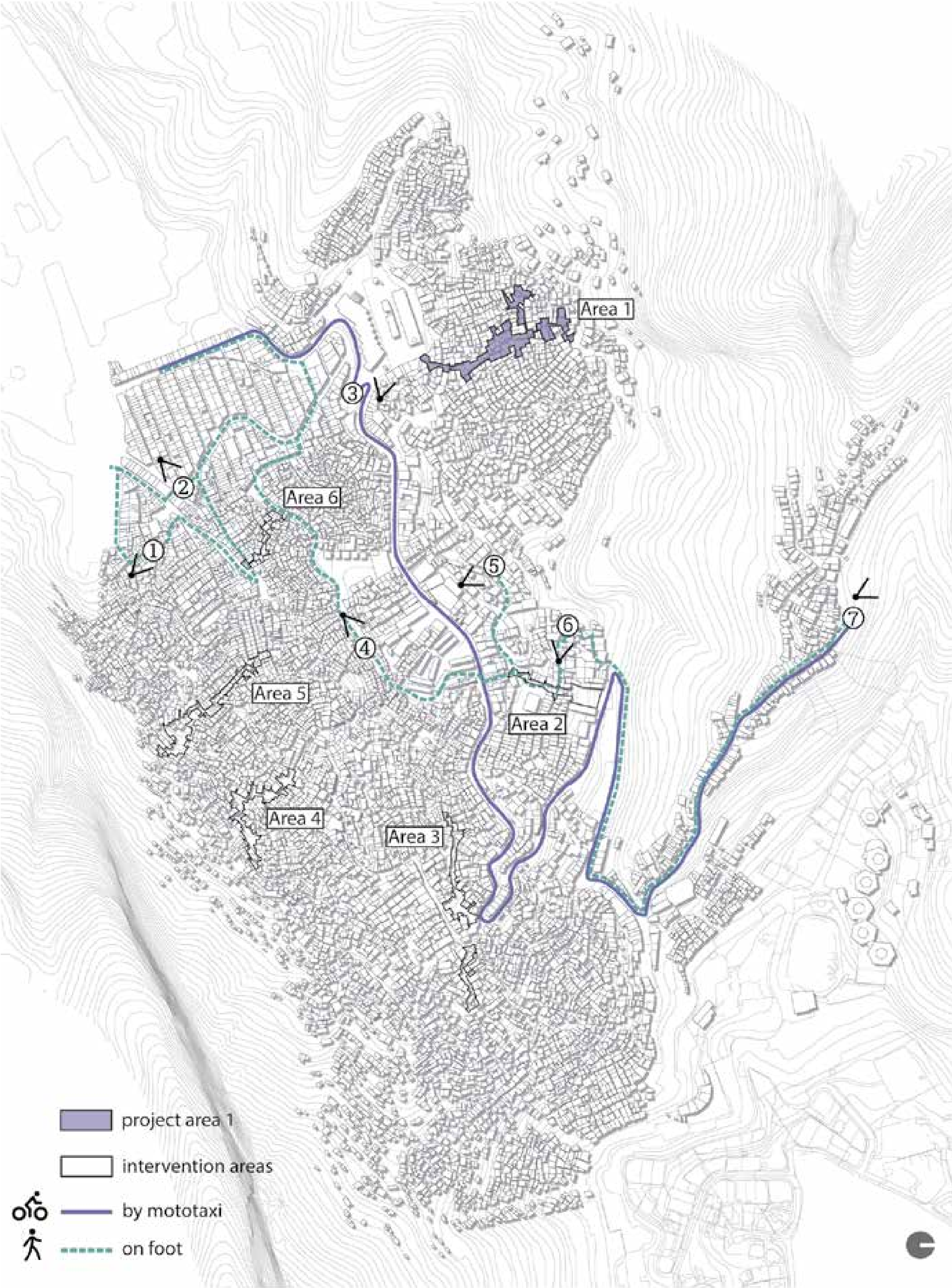


Figure 1.5.6 The itinerary followed inside Rocinha during our visit.

Figure 1.5.7 Pic 1: Largo do Boiadero, the biggest market area in Rocinha.

Figure 1.5.8 Pic 2: Children playing at School "Sace Sabe Tudo", pic. taken by Arianna Trombini.

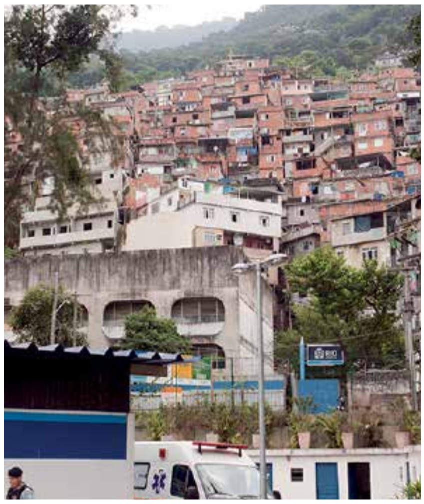


Figure 1.5.9 Pic 3. View of the intervention Area 1, picture, source: googlemaps.

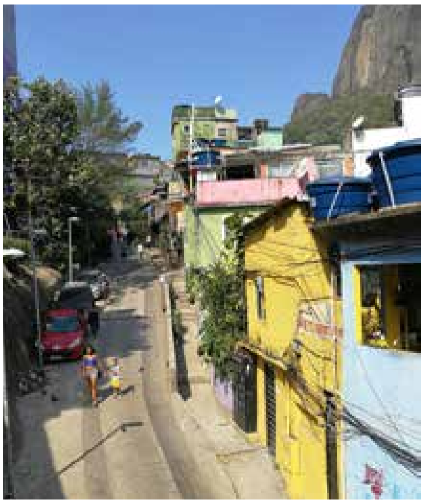


Figure 1.5.10 Pic. 4: View of Rua Nova, picture taken by Arianna Trombini.

Figure 1.5.11 Pic. 5: Our team ouside "Garagem das Letras".

Figure 1.5.12 Pic. 6: Inside "Il sorriso dei miei bimbini", picture taken by Arianna Trombini.

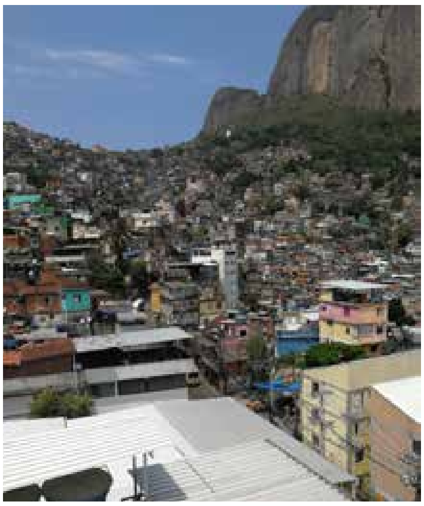


Figure 1.5.13 Pic. 7: View of Rocinha from "il sorriso dei miei bimbi", pic. taken by Arianna Trombini.

Figure 1.5.14 Pic 8: Beco in Rocinha. Picture taken by Arianna Trombini.

Figure 1.5.15 Pic 9: Vila Laboriaux, main source of potable water, pic. taken by Arianna Trombini.

1.5.4 Analysis of applicable case studies.

1.5.4.1 Introduction

The bursting violent events which occurred during our stay in Rio de Janeiro prevented us to further analyse the favela context, which could have been very useful for our work.

Despite these drawbacks, we had the opportunity to analyse different applied projects located in other favelas and outline the pros and the cons of each intervention, especially regarding the replicability of each solution in the harsh context of Rocinha looking from a technical perspective, a social perspective and a project management perspective.

1.5.4.2 VALE ENCANTADO: the biogas plant of a small community inside the Tijuca Forest

Located in Alto da Boa Vista, inside the large "Parque Nacional da Tijuca", the Vale Encantado favela is a small community of about 30 families which experimented a bio-digestor system to deal with the organic waste collection producing biogas and fertilizer as finished products to reuse. The first aim of the system is the disposal of the organic waste and the sewage.

The temporal continuity in terms of production is granted by the presence of a local restaurant which disposes its waste using a bio-digestor directly connected to the kitchen. We had the opportunity to speak with Tito Cals, an environmental engineer working for the UFRJ University who designed the double system present in Vale Encantado favela (one attached to the local restaurant and the other isolated in the forest) and presented us the technical aspects regarding his project.

The biogas produced using this system is just enough to sustain a single family for an hour and a half, and while the fertilizer could be resold outside the community, in Vale Encantado it is considered only as organic waste to be disposed of.

The bio-digestor shows a simple grade of replicability in other contexts for its low cost and for the availability of construction materials, and it has a good potential in creating possible micro-economic systems, but the management of a dangerous substance (such as the biogas produced) may represent a safety hazard that should be evaluated before the installation in other communities. The technical aspects about the bio-digestor system will be discussed further on.

Figure 1.5.16 Meeting with Tito Cals and the Biogas system at Vale Encantado, picture taken by Arianna Trombini.

Figure 1.5.17 Meeting with Tito Cals and the Biogas system at Vale Encantado, picture taken by Arianna Trombini.

1.5.4.3 FAVELA CANTAGALO: the local aquaponic system and the VIVA RIO commitment.

Favela Cantagalo is another informal urban settlement located on a high hill between Copacabana beach and the Lagoa with a steep topography comparable to Rocinha. On the top of the settlement, a 50-year-old long abandoned hotel now houses the "VivaRio" complex, an ensemble of spaces used for educational purposes and laboratorial activities recently instituted by the "VivaRio" social enterprise.

This enterprise works through innovative projects in areas impacted with social problems, such as poverty or criminality, and directly collaborates with the public administration (it is directly involved in the "De Olho no Lixo" project as well). Accompanied by Edu, a technical educator and person in charge of numerous activities inside the "VivaRio" complex, we had the opportunity to examine the basic structure of an aquaponic system used for educational purposes during the FIFA World Cup in 2014 and soon after abandoned.

Figure 1.5.18 Meeting with Edu and Baltazar at Cantagalo. View of the aquaponic container, picture taken by Arianna Trombini.

Due to the lack of time and people engaged in its management, the aquaponic structure laid in a state of abandonment, but it is clear the level of replicability of this system can be considered good for Rocinha for its intrinsic potential of being a strong educational tool for children about the topic of food, with the use of the "De Olho no Lixo" spaces and personnel. Further technical analysis regarding the functioning of the aquaponic system will be discussed.

Looking at the aspects regarding the applicability of social projects in harsh contexts, it is noticeable the distance of the "VivaRio" complex from the community which hosts the entire structure: the differences between the futuristic and high-tech laboratories seen inside the big structure located on top of the hill and the rest of the favela Cantagalo were highlighted by the lack of residents in the restored open spaces of the 50-year-old hotel.

1.5.5 "Leaderanças" and community engagment.

1.5.5.1 Introduction

During our stay in Rio de Janeiro we contacted different actors involved in activities inside Rocinha who clearly explained the correct modes of engagement with the residents, by letting them take part to the intervention process, and more importantly to the management process. The community acceptance is the key of every intervention project inside the favelas.

1.5.5.2 The FAVELA VERDE experience

One of the most interesting meeting we had in Rio de Janeiro revealed the complicated engagement process that "Favela Verde", an NGO involved in educational activities related to the respect of the environment, had to accomplish to be well received in the local community of Vila Laboriaux neighbourhood. The most important aspect to consider is that the hardest part of the process is to "enter the communities". A key step for the acceptance of "Favela Verde" was organizing a meeting with 20 different leaders of the Rocinha community, to explain exhaustively the proposal, followed by almost a year and a half of participatory process made

Figure 1.5.19 Our team at Garagem das letras with Barbara Olivi.

possible with the use of surveys made with and for the local inhabitants. Participatory processes were mandatory, but the key factor in proposing a project inside a favela context was to involve the local leaders, the people who have power and influence on the other residents and represent large groups of locals and their ideas. Drug dealers and leaders are not always the same, but the presence of criminal organizations inside the social context of Rocinha is relevant in terms of acceptance and community engagement. Another important factor which determines the success or the failure of a project proposal over time is the direct involvement of the population in the management of the activities: the long-lasting programs implemented in Rocinha are managed by the residents with the collaboration of external partners (e.g. universities). When we were in Rio de Janeiro, "Favela Verde" was going through a transitional phase with the exit of international volunteers and the entry of local inhabitants.

This explanation showed us the different approaches followed by "Favela Verde" and "VivaRio" in entering the communities, with the second example considered riskier, because of the direct intervention of a social enterprise with the help of the public administration, which is not considered trustworthy by the favela residents. Further analysis referred to the community engagement of the project will be considered in other sections of this work.

1.6 Intervention area analysis: Area 1

1.6.1 Introduction

The analyses and interventions described in the following chapters will focus on a specific section of Rocinha, from here thereafter designated "Area 1". This area is among six that were identified by the IMM analysis and local surveys as those with most potential.

On a side note, from 2016 onward, Rocinha has been added to the Google Maps and Google Earth databases, using 360° cameras mounted on backpacks to survey and map the favela's activities even inside its narrow bowels. This tool has been extremely useful in all the following analyses.

1.6.2 Localization and topography

Aea 1 extends in the North-West corner of the favela, from the circuit formed by Estrada da Gávea and Villa Verde, near the bottom of Rocinha, to the tail end Rua Dionéia, the narrow road climbing Morro do Cochrane. The southernmost part of Area 1 borders on Caminho de Boiadero, along which Rocinha's market traditionally stretches, while in the upper part the houses are progressively replaced by trees, until only the latter remain. There's a significant difference in height between Villa Verde (129.85 m) and Rua Dionéia (257.55 m at its endpoint), over a relatively short distance (around 200 m), which makes Area 1 one of the steepest in the favela, with a slope rate averaging 70%. Small green patches are sprinkled throughout the area.

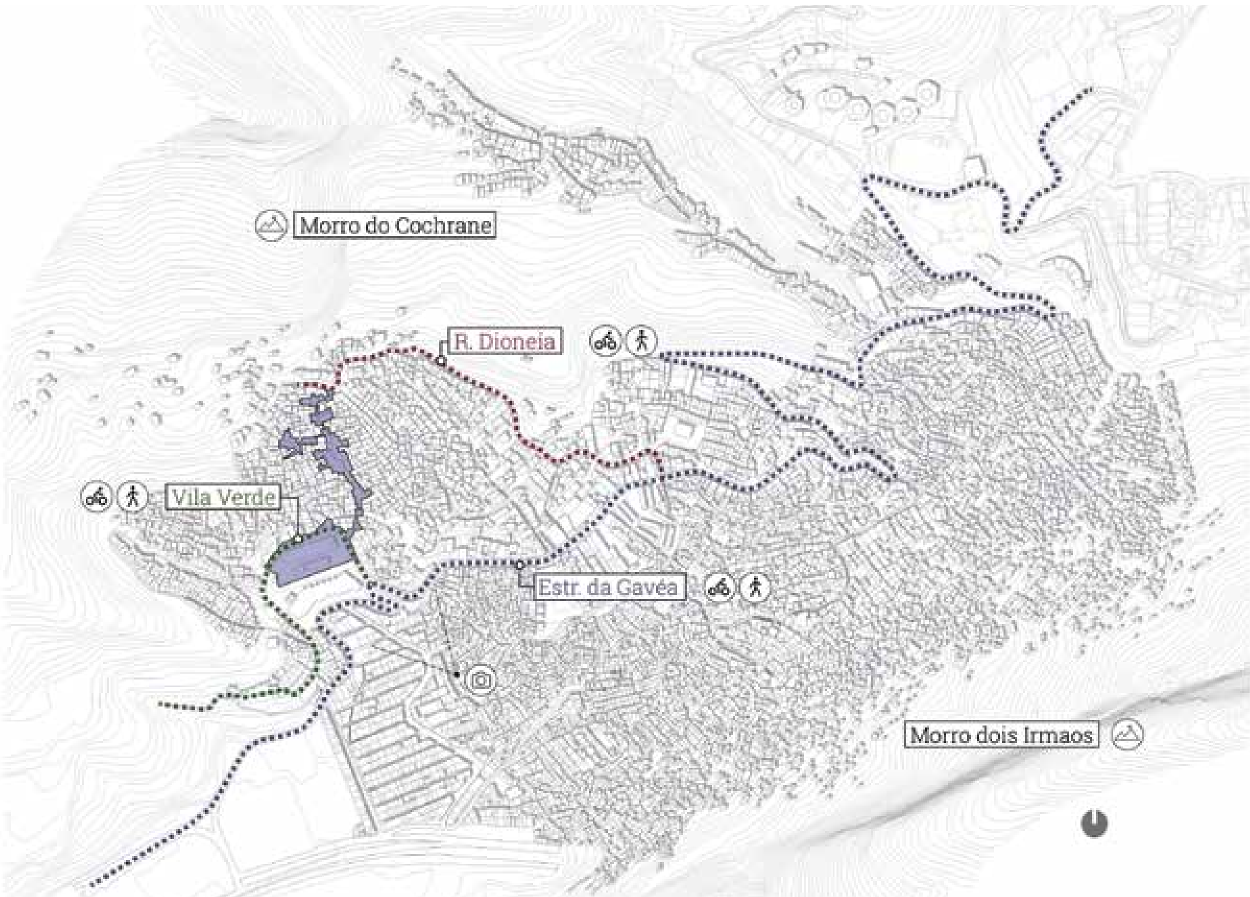


Figure 1.6.1 Localization of intervention Area 1.

1.6.3 Urban morphology

Most of Area 1 presents a densely built urban environment (dense occupation), interrupted only by the major roads mentioned above, as is the case in most of Rocinha, with only the bottom of the area possessing some open spaces. This discontinuity in the otherwise choked urban fabric has been created two massive buildings housing functions important not only to Area, but to the favela as a whole: the Emergency Care Unit of Rocinha (UPA: Unidade de Pronto Atendimento) and the school "CIEP Doutor Bento Rubião"; by the end of 2018, a third building has been added between these two: a two-storey gas depot owned by "Waldemar Agua e Gas".

The majority of the buildings in Area 1 are multi-storey, most being between three and four storeys high, though many have a single floor and a few tops at eight. The height distribution is not even throughout the area: most of the buildings around Villa Verde are between five and six storeys (consolidated occupation), while those along Rua Dionéia sit around two, with few exceptions; for the most part, the height of the buildings decreases as they climb higher towards the mountain. Households are, mainly, built with bricks and mortar over a reinforced concrete structure.

1.6.4 Accessibility and functions

As Estrada da Gávea is Rocinha's main transportation artery, shops and activities are concentrated at the bottom of Area 1, around Villa Verde, where mixed-use buildings are prevalent, along with the three major functions described above. On the flip side, the dense urban landscape that forms the majority of Area 1 is almost exclusively residential, as urban density and slope rate make access a difficult proposition; the households bordering Rua Dionéia are only marginally more accessible by vehicles, and only by making a large circuit around Rocinha. Thus, most of the inhabitants of Area 1 are forced to come down to Villa Verde or Caminho de Boiadero to find their necessities.

The urban environment comprising the greater part of Intervention Area 1 is almost exclusively residential, since extremely high urban density and slope rate make access a difficult proposition; the households bordering Rua Dionéia are only marginally more accessible by vehicles, and even then, only by making a large circuit around Rocinha. Therefore, most of the inhabitants of Area 1 are forced to take the more direct but less accessible route and come down to Villa Verde.

Figure 1.6.2 View of intervention Area 1 from Estrada da Gavea.

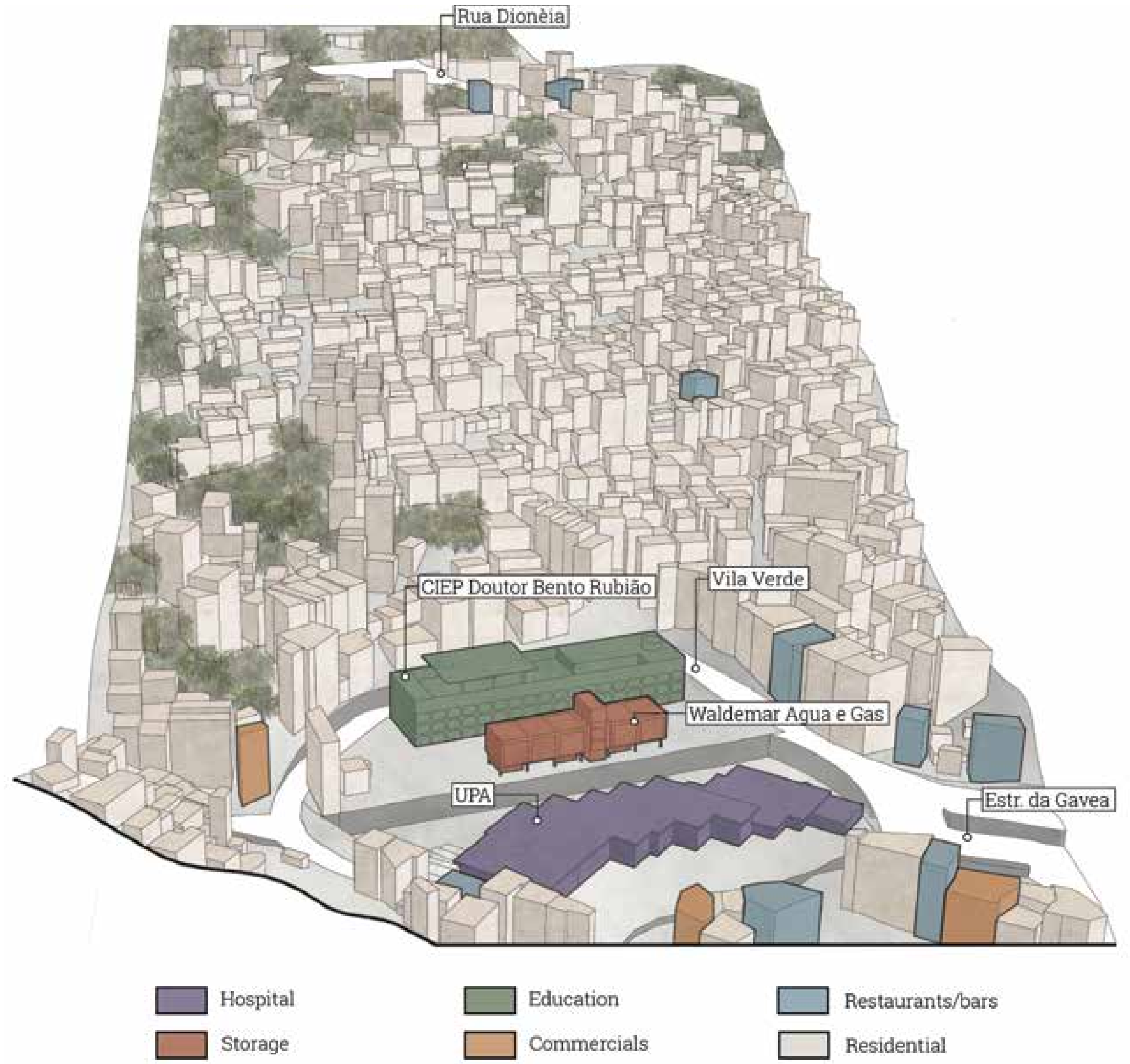


Figure 1.6.3 Map of Intervention area 1's main functions and connections.

1.6.5 Streets and roads

Area 1 is bordered by two of the few roads snaking though Rocinha: Villa Verde on the bottom and Rua Dionéia at the top, the former is directly connected to Estrada da Gávea, and thus to the existing road network of Rocinha, such as it is. Similarly, while the latter connects to the Gávea as well, it does so only after a wide circuit, comparatively far from the intervention area.

These roads are usually paved, though worn by use, especially Estrada da Gávea, almost every day choked by all kinds of vehicles, be they public or private; on the other hand, Rua Dionéia is not only narrower, but also quite steep, to the point that it is inaccessible to most public transportation services, but the nigh-ubiquitous mototaxi.

This leaves most of the area accessible only by foot though a series of very narrow alleys (Becos) typical of Rocinha and favelas with similar landscape. These Becos, often so steep they become staircases, form an intricate streets' network through the bowels of the favela not dissimilar to a medieval town, with houses stacked one on top of the others, to occupy as much of the little available space as possible, oftentimes blocking the skies.

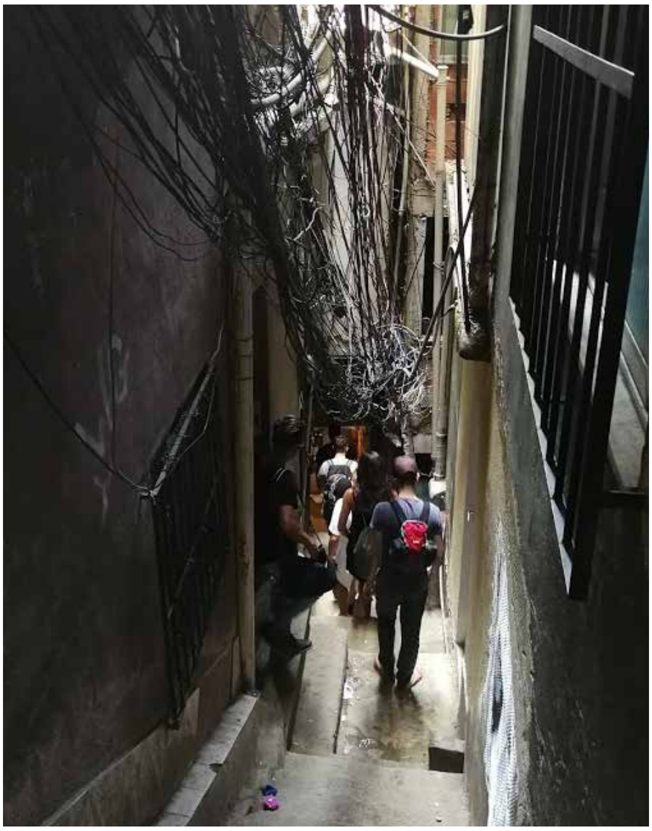


Figure 1.6.4 The “becos” of Rocinha. Picture taken by Arianna Trombini.

Figure 1.6.5 Staircases leading into households. Picture taken by Arianna Trombini.

Figure 1.6.6 Rua Maria do Carmo, one of the highest point of the favela. Picture taken by Arianna Trombini.

Figure 1.6.7 Via Ápia, in the lowest part of Rocinha. Picture taken by Arianna Trombini.

1.6.6 Conclusion

The image of Rocinha, and thus Area 1, as a medieval urban landscape transported in the present is an apt comparison, and one easy to visualize. Both are informal, dense urbanization with only the most important, and massive, buildings, being given enough space: like the cathedrals of the past, the school and the UPP muscle their way into the favela due to their size and utility.

While of course Rocinha possesses modern services (internet, electricity, water, etc.), they are often built illegally by the population and often faulty. Like a medieval town, the favela suffers from uncountable overpopulation and sanitation issues, the latter in particular linked to the lack of education about proper waste disposal. At the same time, many Brazilian and foreign designers see only the problems of this urban environment, and, like a medieval borough, seeks to dismantle and replace it with a “proper” urban environment, failing to acknowledge how such drastic interventions have, in the past, improved the urban quality at the expense of its inhabitants, often displaced to make way for “better” buildings.

The project presented in the following chapters aims to improve the living conditions of Area 1, and Rocinha, with pinpoint interventions that answer individual problems without disturbing the existing urban and social setup, magnifying Area 1’s potential while slowly abating its issues and giving its inhabitants the means to improve further.

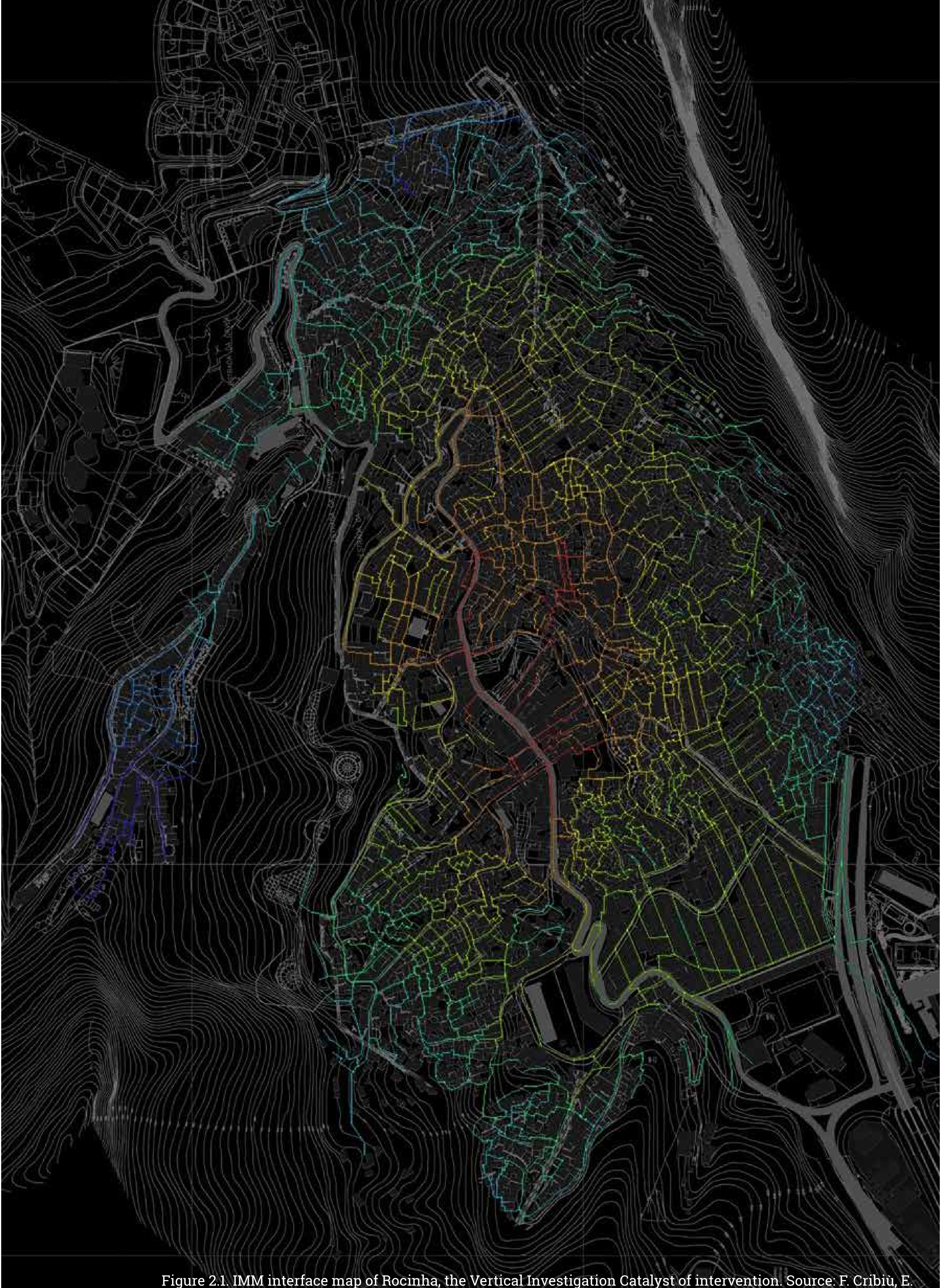


Figure 2.1. IMM interface map of Rocinha, the Vertical Investigation Catalyst of intervention. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016

2 IMM METHODOLOGY

IMM is the acronym of Integrated Modification Methodology, an innovative design methodology, developed by IMMdesignlab, based on a specific process with the main goal of improving the CAS' (complex adaptive systems) energy performance, through the modification of its constituents and the optimization of the architecture of their ligands. Its approach is fundamentally Holistic, Multi-Layer, Multi-scale.

This methodology considers the city as a dynamic CAS comprised of the superimposition of an enormous number of interrelated components, categorized in different Layers or "Subsystems", (Themselves CAS) which through their inner arrangement and the architecture of their ligands provide a certain physical and provisional arrangement of the CAS.

The IMM investigates the relationships between urban morphology and energy consumption by focusing mostly on the 'Subsystems' characterized by physical characters and arrangements. The main object of this design process is to address a more sustainable and better performing urban arrangement, aligned to the UN Sustainable Development Goals 2030.

2. IMM: Integrated Modification Methodology

2.1 Methodology and previous work done in Rocinha

The Integrated Modification Methodology is a multistage, iterative urban analysis tool, focused on sustainability, which allows the designers to conduct their investigation even without being physically present on site. IMM follows a Holistic approach, Multi-layer and Multi-scale. Ideally, assuming the designer possesses enough information about the site's characteristics they can identify the weakest point of the urban context and define a set of Design Ordering Principles (DOP), the latter will form the basis for the future retrofitting transformation.

IMM defines the urban context as a dynamic Complex Adaptive System (CAS) and investigates the relationship between urban morphology and energy consumption.

This objective is achieved by dividing the urban system into two main Layers or Subsystem:

- The Horizontal analysis, which focuses on four physical characteristics of the urban texture: Volume, Voids, Function and Transportation;
- The Vertical analysis, which represents the first level of superimposition and studies the relationships between the previous characteristics. This analysis results in six categories: Porosity, Proximity, Diversity, Interface, Accessibility and Effectiveness.

The overlapping of the vertical levels results in the second level of the superimposition that determinates four categories: Compactness, Complexity, Connectivity and Management.

All of the aforementioned categories are quantified by numerical indexes describing the state of the urban system. These numbers allow the designer to conduct an objective analysis. The design decisions will proceed by choosing two catalysts, which are the two weakest indexes, one from the horizontal analysis, the other from the vertical one. Finally, the second level of superimposition will be broken down into the DOPs, those will guide the design process.

Once the design is completed, the IMM analysis is applied again on the final product. Thus, allowing the designers to check the changes of the categories expressed again by the numerical indexes and evaluate the effectiveness of the intervention. This phase is called Retrofitting.

Thanks to the scientific approach provided by IMM and the cooperation of local contacts, chief among them the team at UFRJ, we were able to work on Rocinha from Italy after the site inspection described in the previous chapter.

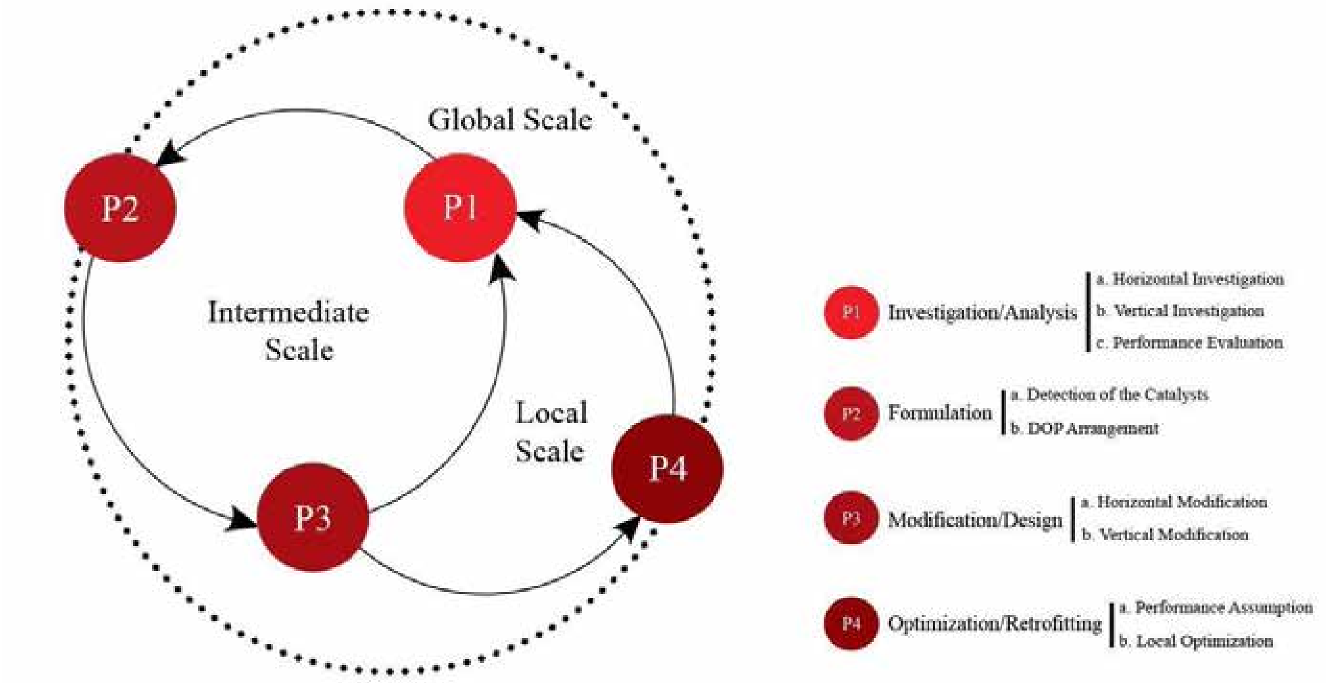


Figure 2.1.1 The iterative process of IMM. Source: IMMdesignlab

1	1a	Horizontal Investigation	Dismantling the system to investigate	Actual CAS Arragment	Investigation/observation and measurament
	1b	Vertical Investigation	The actual value of Key categories		
	1c	Actual performance of the system based on 12 indicators		Actual CAS performaces	
2	2a	Detection of the trasformation's Horizontal and Vertical Catalyst and reactants		Catalyst selection and Reactant ordering	Assumption and Interpreation formulation
	2b	Assumption of 12 IMM ordering principles		DOP Arrangement	
3	3a	Horizontal modification	The catalyst drives the local transformation,changing the structure of the layers	Catalyzers modification and chain reactor	Modification intervention and Design
	3b	Vertical modification	Local transformation acts globally, changing the entire system configuration		
4	4a	Performance of the new CAS based on 12 indicators		New CAS performance	Retrofitting
	4b	Local modification optimization is a process involving again the first level of superimposition for improving locally their performance. Local optimization works using selected tools/features: -Volume/Voids -Solar Game/Winter -Volume/Functions -Level of mixed use -Functions/Voids -Function distribution -Transports/Voids -Number of intersection -Transports/Functions -Service area control -Transport/ Volume -Catchment area control			

Tab. 2.1.1 Phasing in IMM. Source: IMMdesignlab

Some parts of the first information regarding Rocinha were obtained thanks to the work done using the same methodology by a team composed by former students who took part in the "PolimiparaRocinha" project a year before our commitment.

It is important to note that not only IMM is a still developing methodology, but in this instance it is also applied to the "extreme" urban conditions of Rocinha. Thus, the project has a greater challenge to overcome. The first step of the analysis is to define the scale: the global scale is the city of Rio de Janeiro, the middle scale is Rocinha favela (the focus of the previous work), the local scale are the intervention areas (the real focus of our analysis and project).

The analysis also considers the environmental conditions and the energy efficiency, including water treatment, sewage system and waste disposal strategies in a systemic approach. Following the IMM's principles, the aim is to improve the current urban landscape of the favela to a more sustainable environment, with a special focus to social inclusion.

The results of the analyses of the previous work has been illustrated in the paragraphs below and, because of its focus on the entire CAS of Rocinha, it represents the starting point of our research.

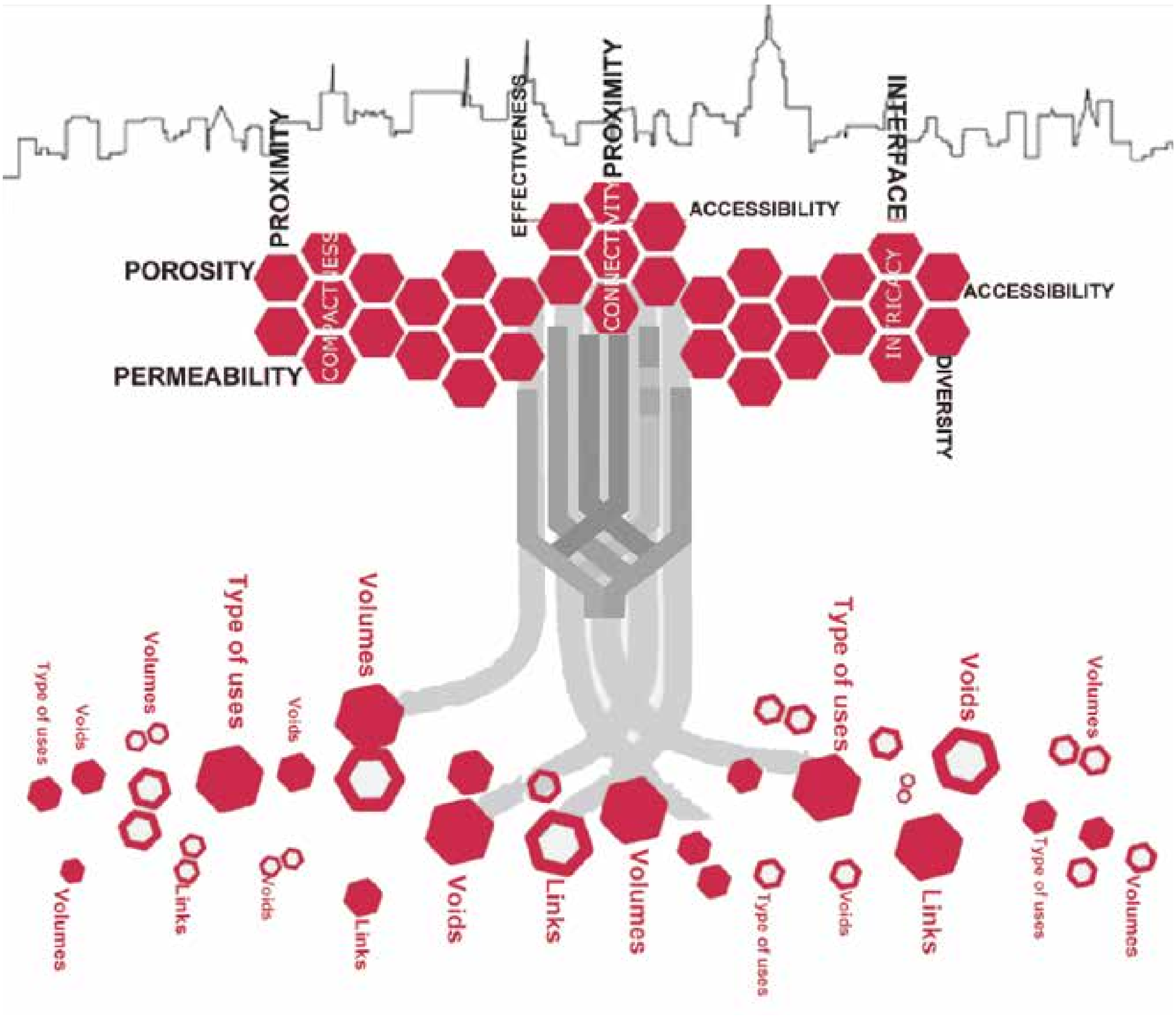


Figure 2.1.2 The elements which constitutes IMM methodology. Source: IMMdesignlab

2.2 Phase 1: Investigation/Analysis

The first phase investigates the physical configuration and characteristics of the CAS represented by the urban system of Rocinha. The main goals of the investigation phase are three:

- Knowledge of the physical arrangement of Rocinha;
- Appraisal of the role and value of the keys categories;
- Evaluation of the current energy performance of the favela.

2.2.1 Horizontal Investigation

2.2.1.1 Introduction

The Horizontal investigation starts by dismantling the physical components of the CAS into the four layers defined by IMM. Each subsystem is analysed separately in order to observe their individual characteristics, aiming to understand the urban configuration (Morphology), the socio-cultural space (Typology) and the incidence of human activity (Technology).

2.2.1.2 VOLUME and VOID

From the volume analysis the urban texture of Rocinha appears extremely dense. This situation, typical of the favelas, is due to both a disproportioned amount of people (approximately 200.000 inhabitants) concentrated in a limited space (1,5 km) and a nearly total absent urban planning.

The urban texture of Rocinha is in continuous expansion regulated only by agreements between families or flatmates.

The buildings sometimes have also a significant elevation, possessing in many times up to eight floors with some rare exceptions reaching eleven storeys. Due to the geographical configuration of the area surrounding Rocinha, the buildings are most densely packed near the centre of the favela and along Estrada da Gavea and, conversely, thin as they close to the mountain and the slope increases.

The direct consequence of such densely populated city is a near total lack of open spaces and the presence of narrow passages, akin to a medieval hamlet. Thus, it is difficult to move around the favela, with few exceptions: the lower part closer to the metro station, and the two main roads Estrada da Gavea and Rua Nova.

Thanks to the maps of Volume and Voids derived from IMM, it was possible to estimate the actual number of people living in Rocinha, by calculating the volumes of the buildings. The analysis shows that around 80% of the favela is built space, since there are 685.000 square meters built on 850.000 square meter total.

2.2.1.3 FUNCTION

The first investigation phase proceeded away from the site, by studying old municipality's maps and digital mapping tools. This process was useful to acquire preliminary data before visiting Rocinha. Most functions are concentrated around the voids area as they are the most accessible. Meaning the south-west part of the favela and Estrada da Gavea.

During the survey, it was possible to ascertain the presence of various functions even in the less accessible areas. Those are however extremely difficult to locate and map due to the dynamic expansion of the favela.

Thanks to the collaboration with the Brazilian team of UFRJ, who could provide more up-to-date information, it was possible to define the most important functions for the community till we could compiling a list of eleven key-functions: Health services; Educational services; Sport facilities; Food market; Shopping; Bar and restaurants; Police; Post office; Bank/atm; Waste collection; Parks.

2.2.1.4 TRANSPORTATION

Rocinha has three different types of public mobility: Buses; Mini buses; Moto-taxi. During the FIFA world cup of 2014, Rocinha was integrated to the metro system of Rio de Janeiro (stop of Sao Conrado). This went a long way to improve connectivity between the favela and the wider city of Rio.

While it was easy to map the buses' network by using the buses stop as reference points, it was more difficult to do the same with the moto-taxies, due to the informal nature of the service. To solve this problem, it was conducted a direct survey asking to the inhabitants of the favela the stops of the moto-taxies and their routes.

Usually, IMM investigation defines the catchment of the bus stops as a circle with a radius of 400 meters (approximately a five-minutes walking distance). However, it was not effective for the peculiar urban morphology of the site. To define more accurately the five-minute catchment area, it was used a software provided by www.walkalytics.com. The results of the analysis were irregularly shaped catchment areas that took into account the morphology of the site. A superimposition of catchment area determines a zone close to multiple public transportation services. In order to better represent the greater value of the metro station, it was attributed a catchment area of 1200 meters, approximately 15 minutes walking.

In line with previous analysis, the public transportation network is stronger in the areas with more Functions and Voids. Specifically, the neighbourhood closer to the metro station and Estrada da Gavea. A peculiar exception to this trend is Rua Nova, easy to traverse but with very little public transportation.

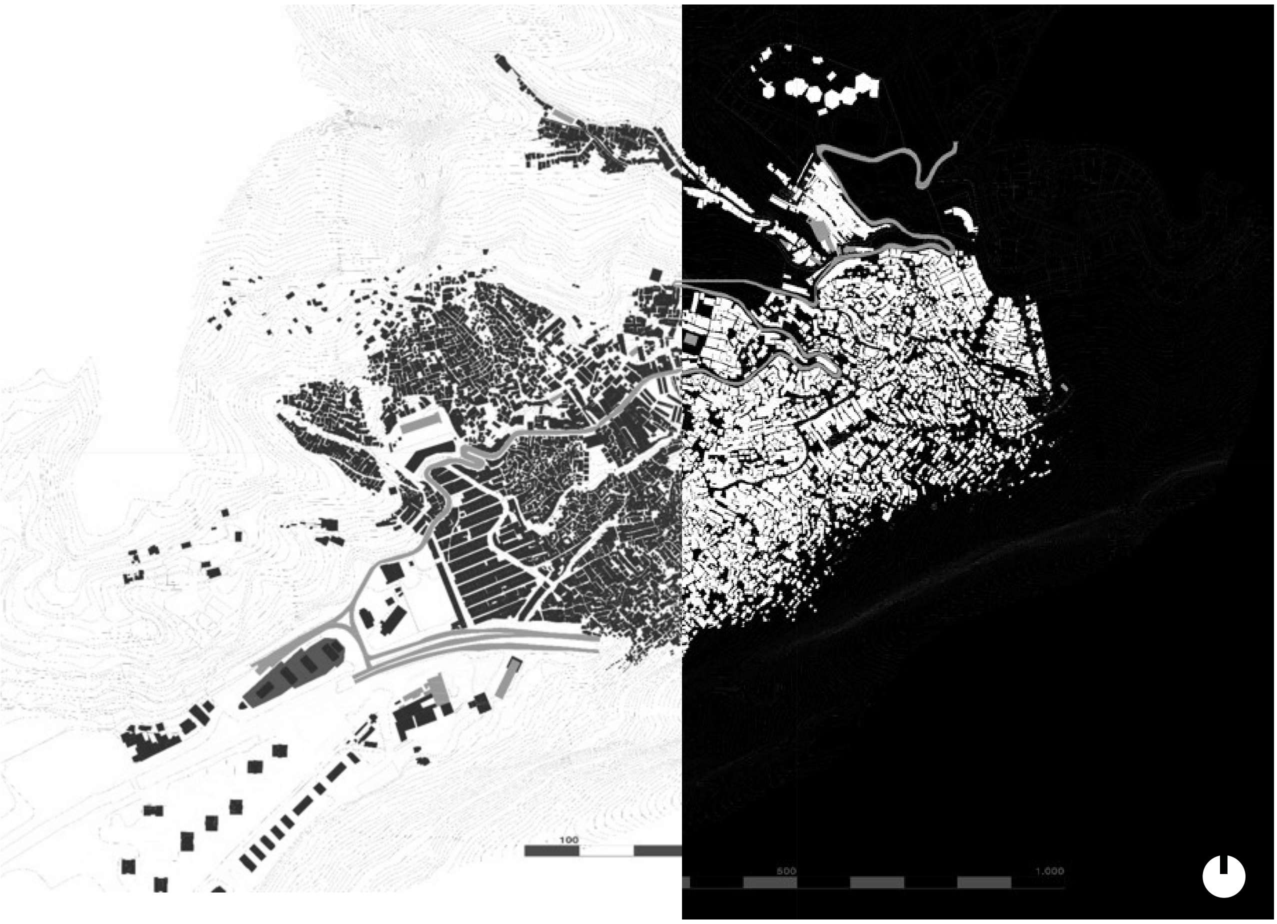


Figure 2.2.1 IMM Volume Voids map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

Figure 2.2.2 IMM Function map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

Figure 2.2.3 IMM Transportation map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

2.2.2 Vertical investigation: first level of superimposition

2.2.2.1 Introduction

The vertical investigation consists in the superimposition of two Horizontal layers. The superimposition is crucial to obtain results supporting the performances of the site. The investigation was conducted by paying attention to the peculiarities of the site and adapting the IMM when needed. The goal of the vertical analysis is to define some morphological, typological and technological features of the city, called "Key Categories". These features inform the designer of the current situation and performances of the urban context in order to achieve a sustainable urban design intervention.

The vertical investigation is researched about the comprehensive configuration of the CAS. Thus, it requires special attention when describing the correlation between the different subsystems (global configuration) in order to assign a proper role and specific characteristics to each of them. The main goal of the first level of superimposition is to understand how the system components (Volume, Voids, Functions and Transportations) are interrelated.

2.2.2.2 POROSITY

Porosity is the superimposition of Volume and Voids layers, it measures the void spaces in a material, and it is a fraction of the volume of Voids over the total volume.

"The Volume layer clearly defines the presence of this principle layer; the urban conveys the physical meaning of the city. Indeed, one can imagine the city as a solid porous volume, sponge like, with various sizes of holes linked by linear void layers; where by the integration of these two layers, urban Volume and Void, porosities".

An indicator associated with the porosity is Density. The built-up space volume ratio to the total area of the site, the ration between areas of the buildings to the intervention site area and the inhabitant's ratio to the volume and area are all considered as Density indicators in IMM. Porosity has an optimal span; hence, there are optimal limits for the maximum and the minimum Porosity. The optimal span is based upon the others Key categories and changes according to the context. Furthermore, the optimal span of every KCs is highly dependent on the vertical relation with other KCs.

The first step was to delimit the volume of the urban environment. To properly define this volume, it was borrowed the concepts of urban canopy layer from the definition of urban heat island. Through this concept, the boundary of the urban environment is the ridge-like pattern of the varying building heights. Having defined the boundaries of the building environment, the representation of the map of Porosity was made by overlapping the Volume and Voids maps.

2.2.2.3 PROXIMITY

Proximity is the superimposition of the Volume and Function layers. Proximity is the number of key functions within a predetermined walkable distance or the easiness of accessing an urban key function by walking. Thus, Proximity is highly related to the pedestrian fruition of spaces.

Key functions are: Education space, Administrative service, Entertainment facilities, and Commercial facilities and so on. Each case study has his own key functions, previously identified by the Horizontal analysis. Proximity is dependent on the number of different functions, whilst it is independent from the quantity of each singular type of function. The urban scale Proximity is applied to be in the range of districts and neighbourhoods.

As with the Transportation, the Walkalitycs online software was useful to better describe the five minutes walking distance in Rocinha peculiar urban morphology. The overlapping of multiple catchment areas shows a high level of Proximity and vice versa.

As the previous analysis indicated the Proximity index is higher in the southern part of the favela and along Estrada da Gavea. An interesting point to note is how the waste collection points are located only in the southern part of Rocinha.

2.2.2.4 DIVERSITY

Diversity is the superimposition of the Voids and Functions layers. Merriam-Webster defines Diversity as "the condition of having or being composed of differing elements." In IMM, Diversity refers to the link of the two elements from the horizontal investigation, showing their functions in a defined boundary. Diversity classifies the space between buildings into three categories: Necessary regular activities, Necessary occasional activities and Optional activities. The result of the correlation between Functions and the adjacent Voids shows the range of different function in each zone.

The first step is to divide the spaces according to the functions or reuse following the categories defined above. The Necessary regular activities are the ones the community needs in a constant and repetitive way, such as educational facilities. The Necessary occasional activities are the ones not frequently needed, for example, governmental facilities.

The Optional activities are the ones that are not necessary but exist mostly for leisure, like cafes and restaurants. The key functions selected during the horizontal analysis allow to define the job density, which represents the job potential in a space and to map the buildings housing a key-function which become points of interest. With the help of the Brazilian partners it was possible to divide the eleven key-categories between the three activities listed above:

- Necessary regular activities: educational services, health services, waste collection and food market;
- Necessary occasional activities: bank/atm, police, post offices, parks and shopping;
- Optional activities: bar, restaurants and sport facilities.

To define the catchment area of each activity it was used again the walkalitics software. Since diversity is maximised within open spaces surrounded by functions the southern part of the favela and Estrada da Gavea are the most attractive. Again, Rua Nova, despite having potential open spaces, is excluded due to have very little functions surrounding it.

2.2.2.5 ACCESSIBILITY

Accessibility is the superimposition of the Transportation and Function layer. Specifically, it is the number of jobs related to key functions reachable within twenty minutes using the public transportation network.

The aim of the analysis is to understand the relationship between key-functions and transportation nodes to highlight the less accessible areas in a city. Since the Transportation and the Function map show the major concentration of nodal points around the same areas (Estrada da Gavea and the southern part of Rocinha), this analysis just confirmed the close correlation between Transportation and Function.

2.2.2.6 INTERFACE

Interface is the superimposition of the Void and Transportation layers. It is mainly an indicator of the quality of movement provided by the street network and the efficiency of the urban morphology. Interface analyses and evaluates the Transportation links in the network or simply the urban flow. It is assessed by calculating the mean depth for each individual link. To develop the interface map it was used the software "UCL Depthmap", developed by the University College of London which processes a 2d file calculating the number of intersections within a street grid.

The results are shown in a "heat scale" with warmer colours representing a better interface zone. Contrary to previous results, it is possible to spot a great interface zone at the centre of the favela representing the great number of intersection of its street network.

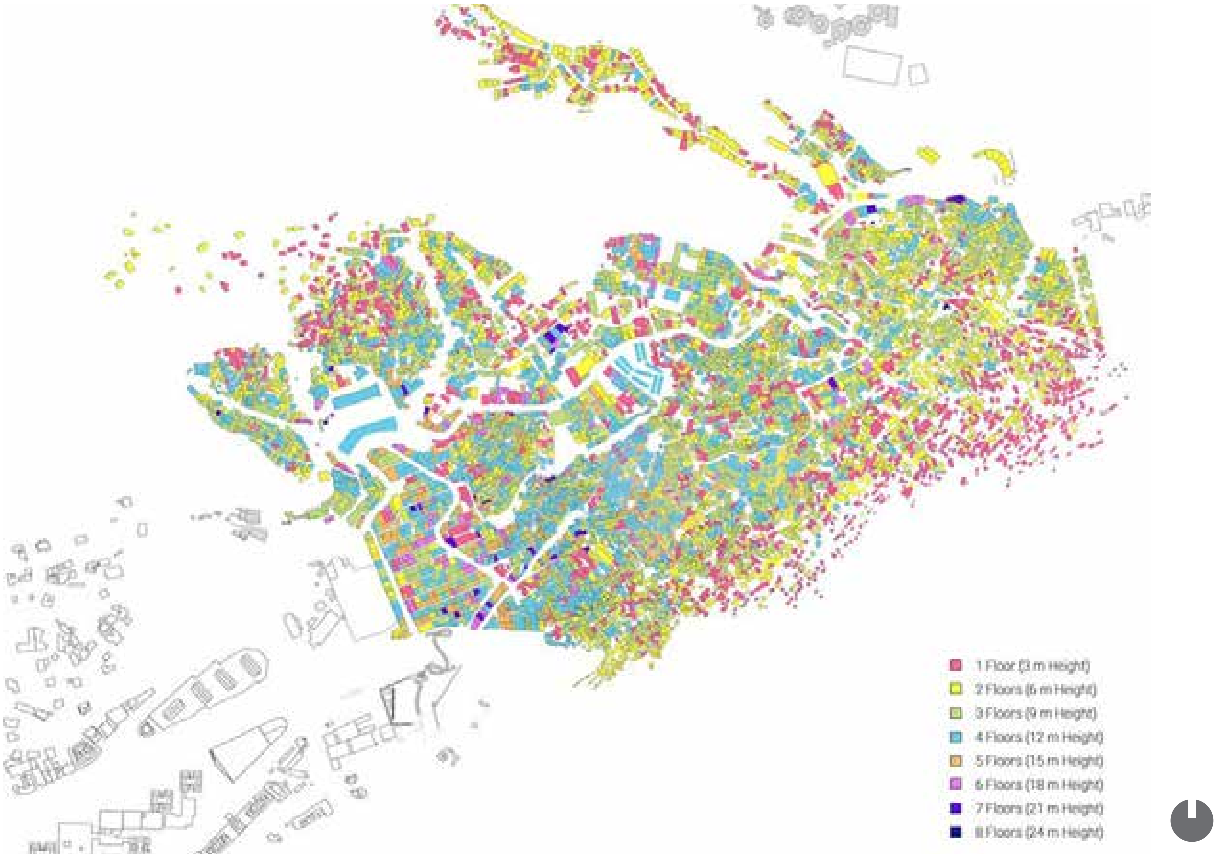


Figure 2.2.4 IMM Porosity map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

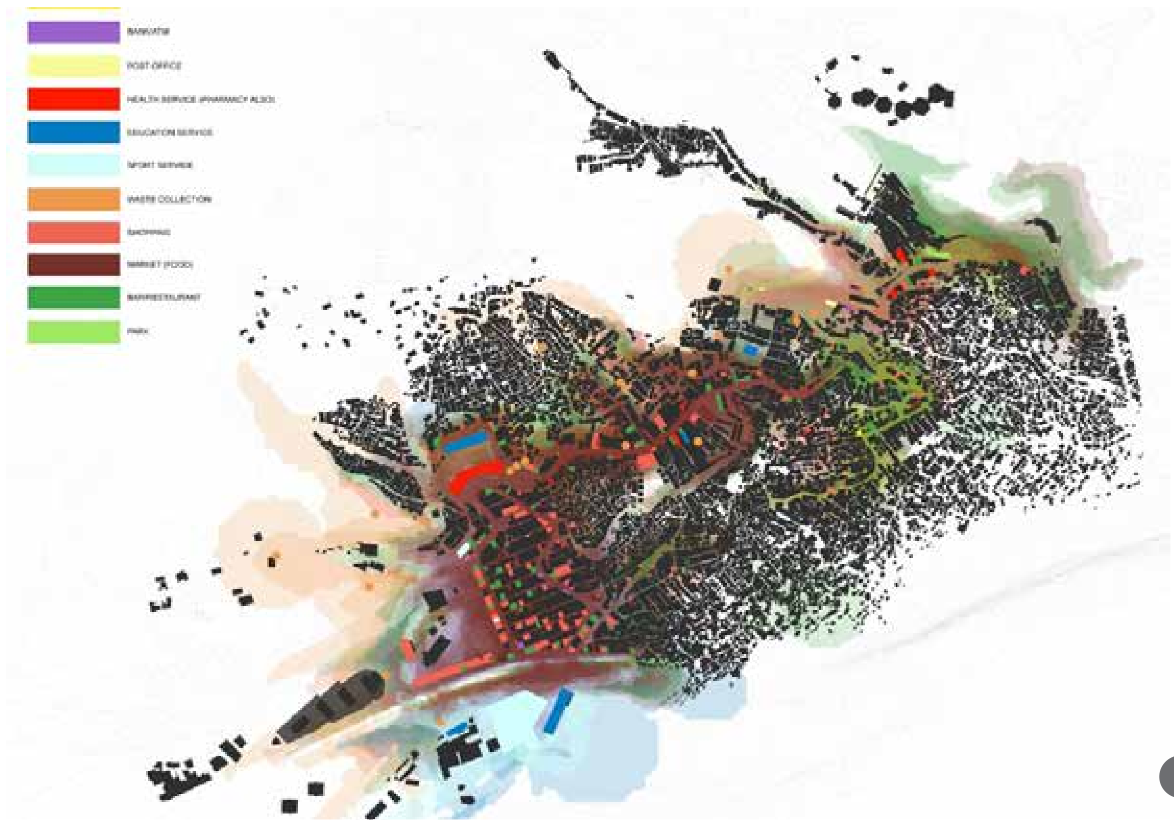


Figure 2.2.5 IMM Proximity map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

Figure 2.2.6 IMM Diversity map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: “Environmental performances and social inclusion”, 2016.

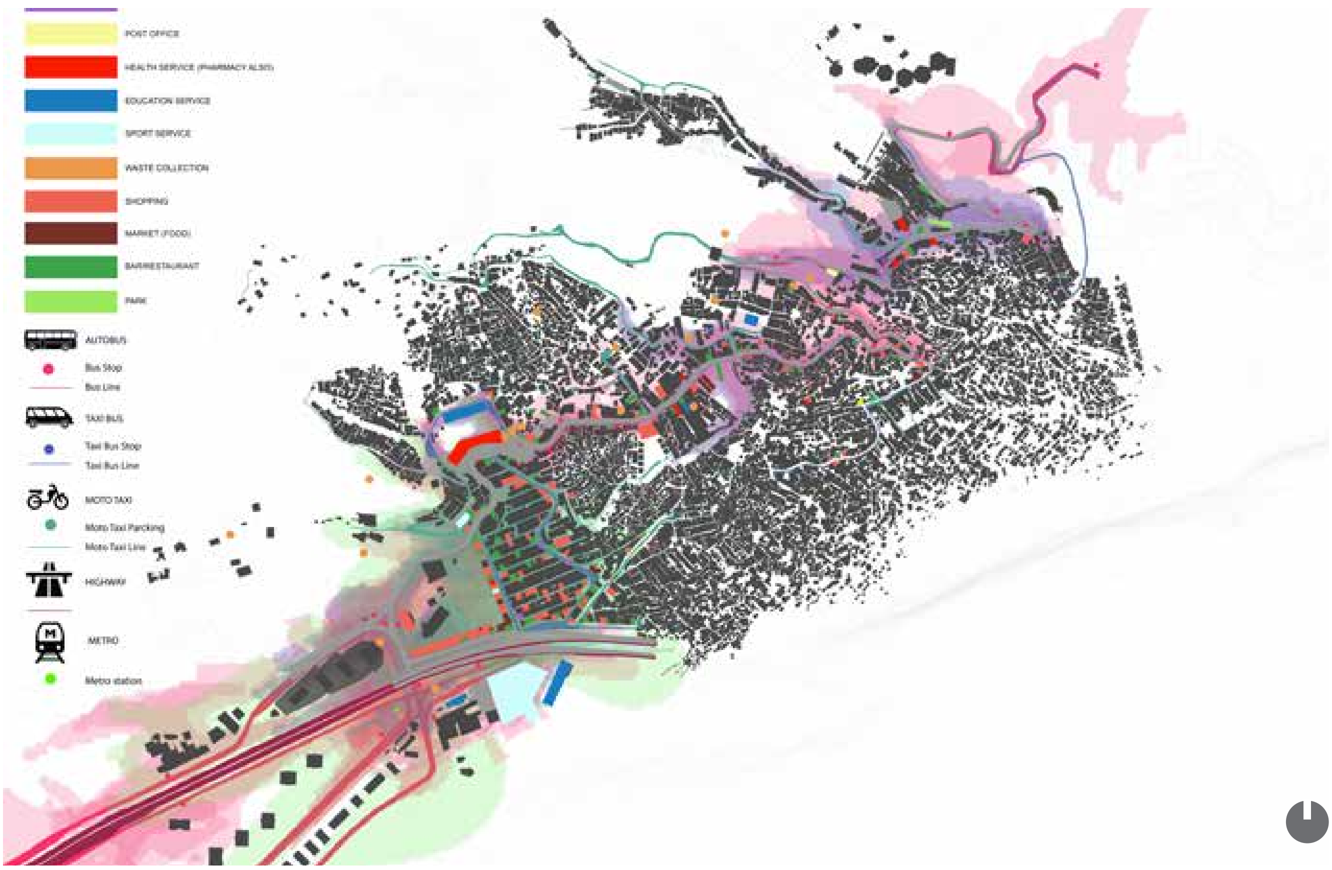


Figure 2.2.7 IMM Accessibility map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: “Environmental performances and social inclusion”, 2016.

2.2.2.7 EFFECTIVENESS

The Effectiveness map comes from the superimposition of Transportation and Volume layers. It defines the capability of an urban environment of producing a desired result, in terms of Transportation, to cover built volumes around it. At the same time, it also defines the potential development on an intermediate scale. An extant Transportation network in an unbuilt area represents potential. Effectiveness is represented by how many Transportation nodes can be reached in a built area.

In Rocinha the potential gradient was considered to be zero since it is unfeasible to plan for any future urban development, at the same time, those surfaces hosting built volumes that have good transportation homogeneity have been highlighted. To better represent the results of the analysis, it was necessary to chose an appropriate drawing scale; the scale chosen for the representation was a square grid with sides of 25 x 25 meters each. Because the horizontal analysis identified four kind of public transportation, it became necessary to develop a separate map for each of them.

The buses and mini buses maps defines very similar catchment areas, since both systems have stops mainly along Estrada da Gavea. A similar situation occurs for the moto-taxies and subway maps, with their catchment areas concentrated around the lowest part of the favela, though for different reasons. For the subway because there is only one metro station, for the moto-taxies because, while you have multiple choice of destinations, their starting point is always at the "entrance" of the favela. These results are in line with those highlighted by the previous analyses.

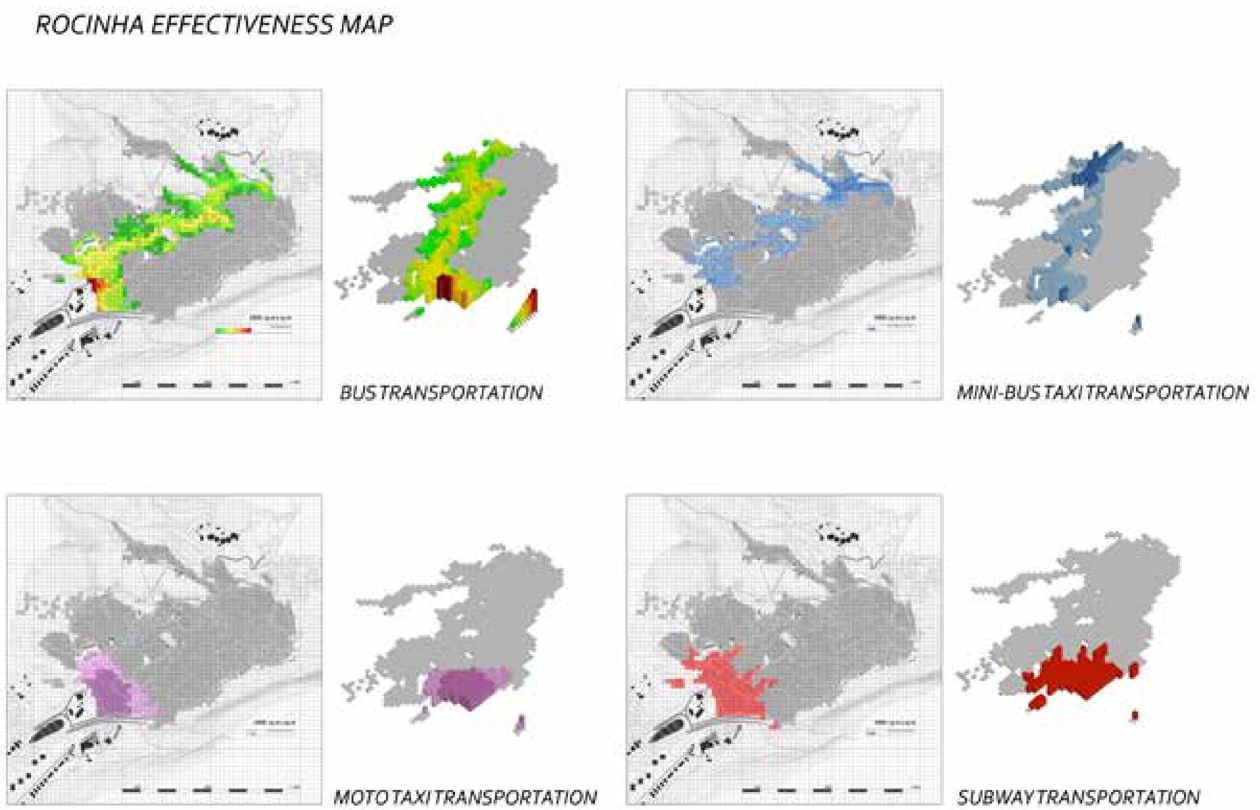


Figure 2.2.8 Effectivness map of Rocinha. Source: F. Cribiù, E. Ravagli, R. Martinelli: "Environmental performances and social inclusion", 2016.

2.3 Phase 2: Formulation

The next phase of the IMM process is called “Formulation Phase” and consists of:

- Choosing the Catalysts, one from the horizontal and one from the vertical investigation;
- Defining the DOPs (Design Ordering Principles).

The main goals of the formulation phase are three:

- The hypothesis of the Catalysts, based on the knowledge obtained in the previous phases, as to explain the CAS configuration, its behaviour and performance;
- Understand the role of the Catalysts in each Sub-system and Key categories;
- Preliminary control of the local consequences of the design choices.

2.3.1 Horizontal investigation catalyst: Volume/Voids

The catalyst chosen from the Horizontal investigation was Volume (and its complementary Voids), since the urban density of Rocinha is its most problematic aspect and influences all the other parameters. The negative influence of the uncontrolled urban development is especially evident on a social level. It is not only cause of health and safety hazards, but also it severely restricts social inclusion.

The public transportation network and the layout of the function also reflect the urban landscape disposition exacerbating even more the existing situation. An example is Estrada da Gavea, which is constantly overcrowded by people and vehicles. This situation is especially evident in the effectiveness analysis where, as previously stated, the potential is zero. High volume density causes a confused and irregular urban texture bereft of rules, and a lack of quality urban voids. This lack of qualitative open spaces becomes an especially important point, as they are a crucial interaction place within the favela community. This is demonstrated by the fact that the few voids that exist are a hub of social interaction.

In conclusion, the dense urban texture is an unfavourable environment for:

- The growth of a capillary and useful Voids network;
- The development of a homogenous and widespread Transportation system;
- A more efficient distribution of Functions.

2.3.2 Vertical investigation catalyst: Interface

While the weakest categories were Interface and Proximity, it was decided to give more importance to the relationship between Voids and Transportation, because the presence of functions comes after the accessibility, the safety and the infrastructures. The choice of the Interface KC reflects how much more beneficial the Voids could become if well connected. Moreover, due to the difficulty of verifying the data about Function, all the Vertical analysis connected to it (like Proximity) will be as accurate as those for the Interface, based instead on objective data related to mobility network and its nodes.

2.3.3 Conclusion

The analysis conducted by the first team of students gave us fundamental instruments to fully understand the characteristics of the complex system of Rocinha through an accurate Investigation phase which highlighted all the main strengths and weaknesses of the context summarized by the detection of the transformation’s Horizontal and Vertical Catalysts. Once the transformation’s Catalysts were obtained, our work gained the principal requests that needed to be satisfied and a precise direction in terms of elaborating a proper solution that met the needs.

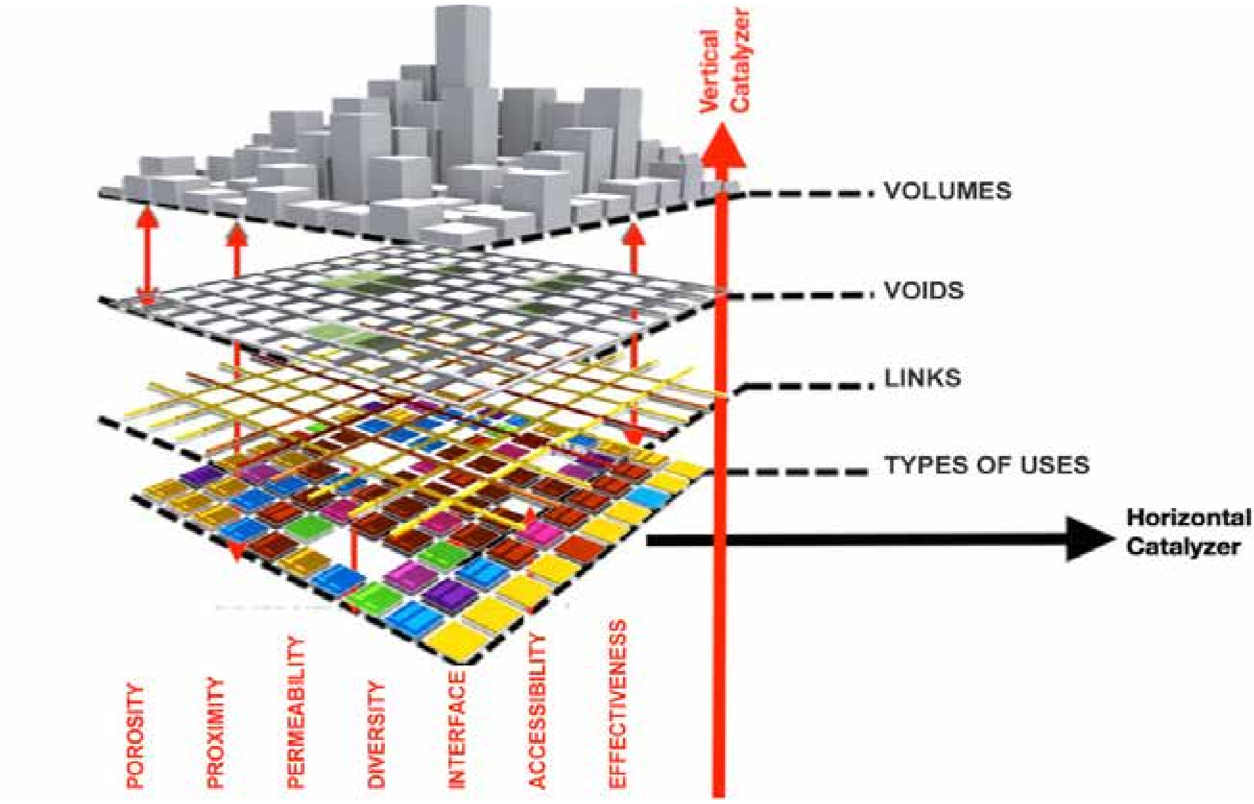


Figure 2.3.1 IMM dismantling of the Complex Adaptive System. Source: IMMdesignlab

The IMM methodology imposed us to go back to the Investigation phase in order to evaluate the single intervention areas, choose the right DOPs in terms of importance and propose more accurate and local solutions, so that the Retrofitting phase can be done assuming that all the design choices made in the local scale will be applied in the intermediate scale of the entire favela.

2.4 IMM Urban Analysis: Area 1

In order to obtain the relevant data to plan the intervention into the site identified as “Area 1”, it was necessary to conduct again an urban analysis using the Integrated Modification Methodology focused on said area. The analysis followed the same steps detailed for the CAS Rocinha.

Listed below are the results obtained through the IMM analysis.

2.4.1 Horizontal Investigation

2.4.1.1 Volume and Void

The analysis of the volumes and voids within Area 1, highlight two important discontinuities in the dense urban environment of Rocinha, located in the lower half and the upper limit of the area, respectively.

Three parameters have been identified as triggers of these less-densely built sites: the terrain geomorphology, the roads and the existence of three expansive buildings, housing functions vital to the community: the school “CIEP Doutor Bento Rubião”, a gas depot owned by “Waldemar Agua e Gas” and the Emergency Care Unit of Rocinha (UPA: Unidade de Pronto Atendimento).

These three parameters are not equal: while the extremely steep terrain on which the favela is built is the greatest limit to its urban expansion, as well as the main cause of Rocinha’s hydrogeological issues, roads and important functions have a positive impact on the area’s urban environment.

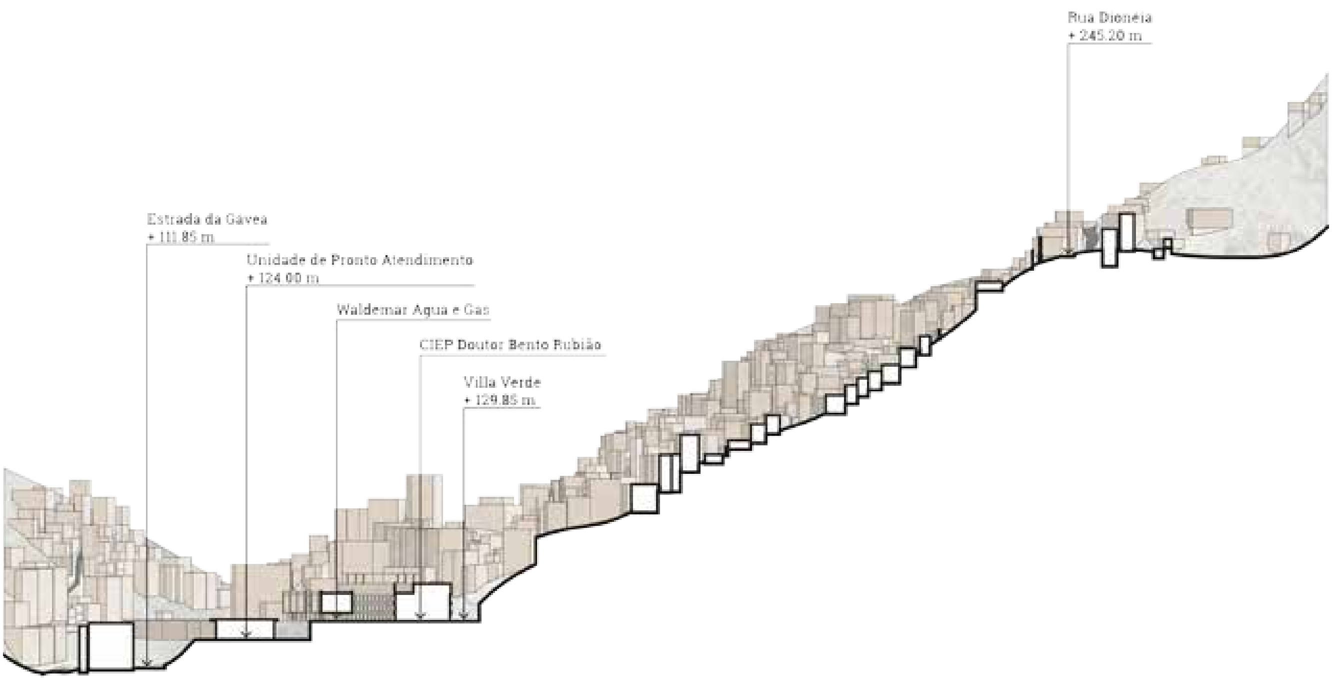


Figure 2.4.1 Section of Intervention Area 1.

Figure 2.4.2 IMM Volume-voids map of Intervention Area 1.

2.4.1.2 Transportation

In the lower half of Area 1, there are two major roads: Villa Verde, circling the school and the gas depot, and Estrada da Gávea, Rocinha major transportation artery. Consequently, all means of public transport are concentrated in said area. There are three stops along Estrada da Gávea: one bus stop and one taxi bus stop at the corner with Caminho do Boiadeiro and another bus stop further along the main road, just after the hairpin turn. The only public transport that operates outside these boundaries are moto taxis, which are able to partially spread into the secondary alleys of the area and bring passengers to the very top of Area 1, driving along Rua Dionéia.

The analysis of the transportation networks highlights for the first time the segregation between the upper and lower parts of the area, and the subsequent necessity to build a better connection between Villa Verde and Rua Dionéia.

Figure 2.4.3 Mototaxi along Rua Dioneia, picture taken by Arianna Trombini.

Figure 2.4.4 Public trasportation in Rocinha, picture, October 2010, source: http://lifeinrocinha.blogspot.com.

Figure 2.4.5 IMM Transportation map of Intervention Area 1.

2.4.1.3 Function

As noted in the Volume/Void analysis, Area 1 contains two major functions in its lower half, both servicing not only their vicinity, but Rocinha as a whole, namely CIEP Doutor Bento Rubião and the UPA. Combined, the personnel employed within these two buildings represents over half of the area's total workforce. Likewise, the remaining functions are concentrated in the lowermost half of Area 1, along the main roads, split between food-serving business (bars or restaurants) and shops of various kind, the latter almost three times more numerous than the former. By choice, the Waldemar gas depot has not been included in the functions, as the risk it represents to its surroundings far outweighs the few jobs it provides. Lastly, there's a waste collection point along Estrada da Gávea, near the right corner of the UPA.

Again, the analysis of the functions reinforces the sharp contrast between the upper and lower halves of Area 1, as no function of note can be found along Rua Dionéia.

Figure 2.4.6 Functions along Estrada da Gavea, picture taken by Arianna Trombini.

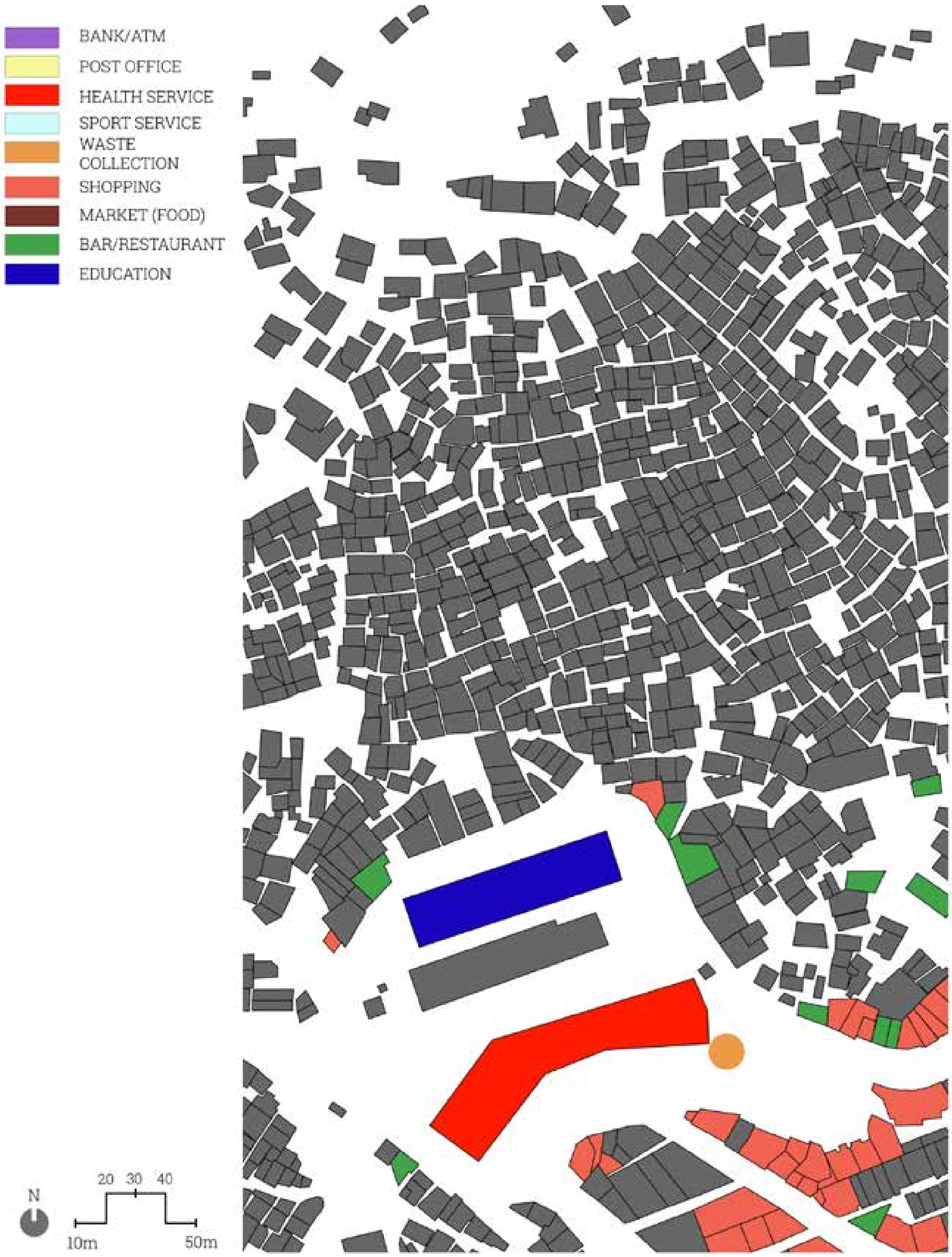


Figure 2.4.7 IMM Function map of intervention area n°1.

2.4.2 Vertical Investigation

2.4.2.2 Accessibility [Transportation – Function]

The accessibility analysis further reinforces the observations made separately for the horizontal layers it derives from. The results clearly underscore the intrinsic, two-way connection between the number and quality of functions and the presence of public transports: the lower half of Area possesses abundance of both, while the upper half, reached only by moto taxis, has none.

Figure 2.4.8 Shops and public transportation along Rua da Gavea, source: www.straitstimes.com.

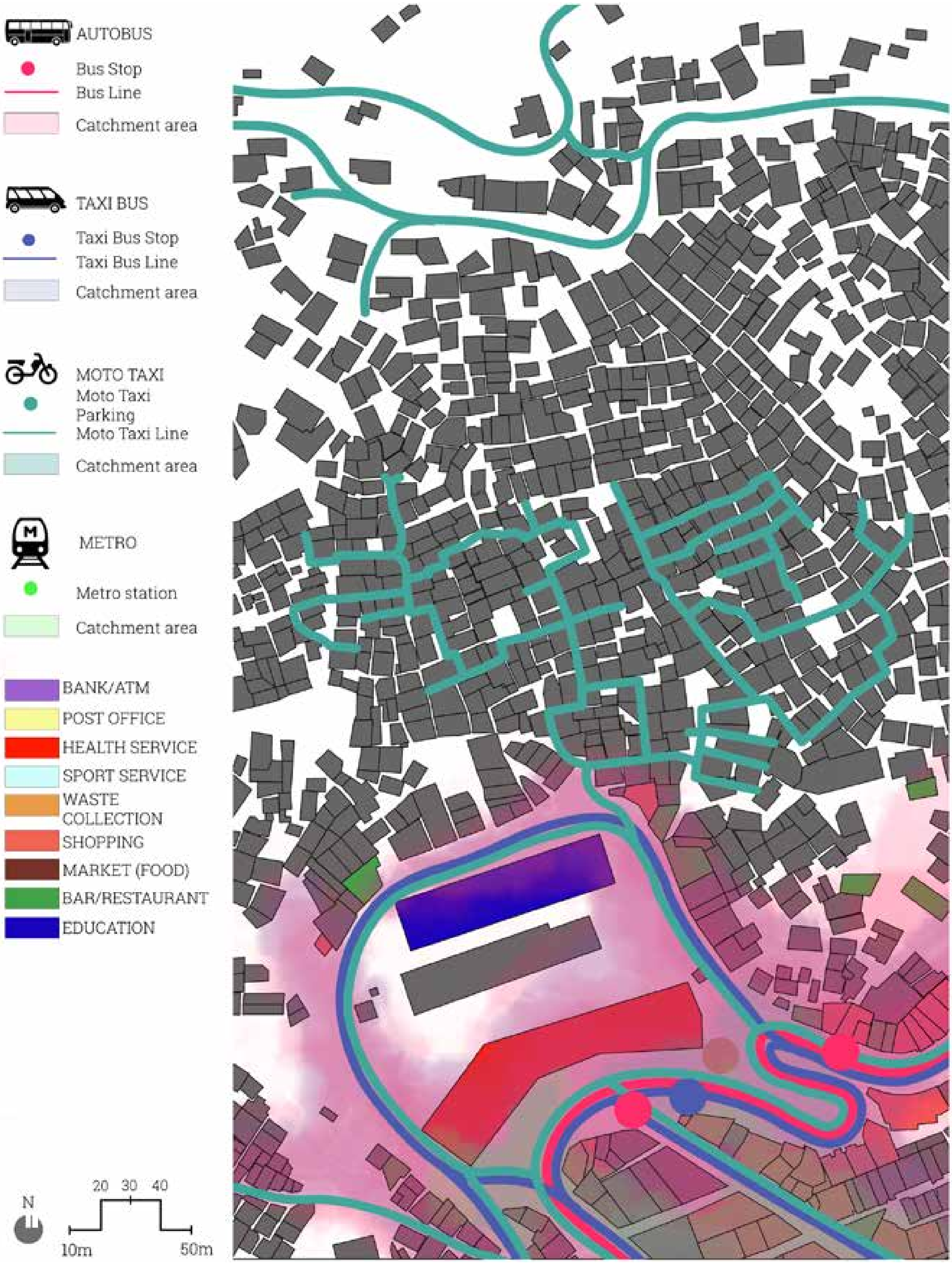


Figure 2.4.9 IMM Accessibility map of Intervention Area 1.

2.4.2.3 Diversity [Void – Function]

As previously stated, while the lower part of Area 1 has a good mix of functions, with catchment areas frequently overlapping. There are only three Necessary Regular Activities, namely the school, the UPA and the waste collection point, though the first two are particularly large, eleven Occasional Activities (restaurants and bars), and, finally, thirty-two Necessary Occasional Activities. As always, the upper half is devoid of any notable functions.

Figure 2.4.10 Enviroment at the starting point of the favela, on top of Rocinha, picture taken by Arianna Trombini.

Figure 2.4.11 Enviroment in the lower part of the favela, picture taken by Arianna Trombini.

Figure 2.4.12 IMM Diversity map of Intervention Area 1.

2.4.2.6 Interface [Void – Transportation]

The Interface analysis is merely a zoomed portion of the investigation conducted for the entire favela, as concentrating the software "ULC Depthmap" on a portion of a much larger urban environment will result in an altered output not properly simulating the real fluxes. Again, the "warmer" portion of the map is the lower half, though Rua Dionéia importance could increase if directly linked to Villa Verde.

Figure 2.4.13 View of Rua da Gavea, source: https://www.dailymail.co.uk.

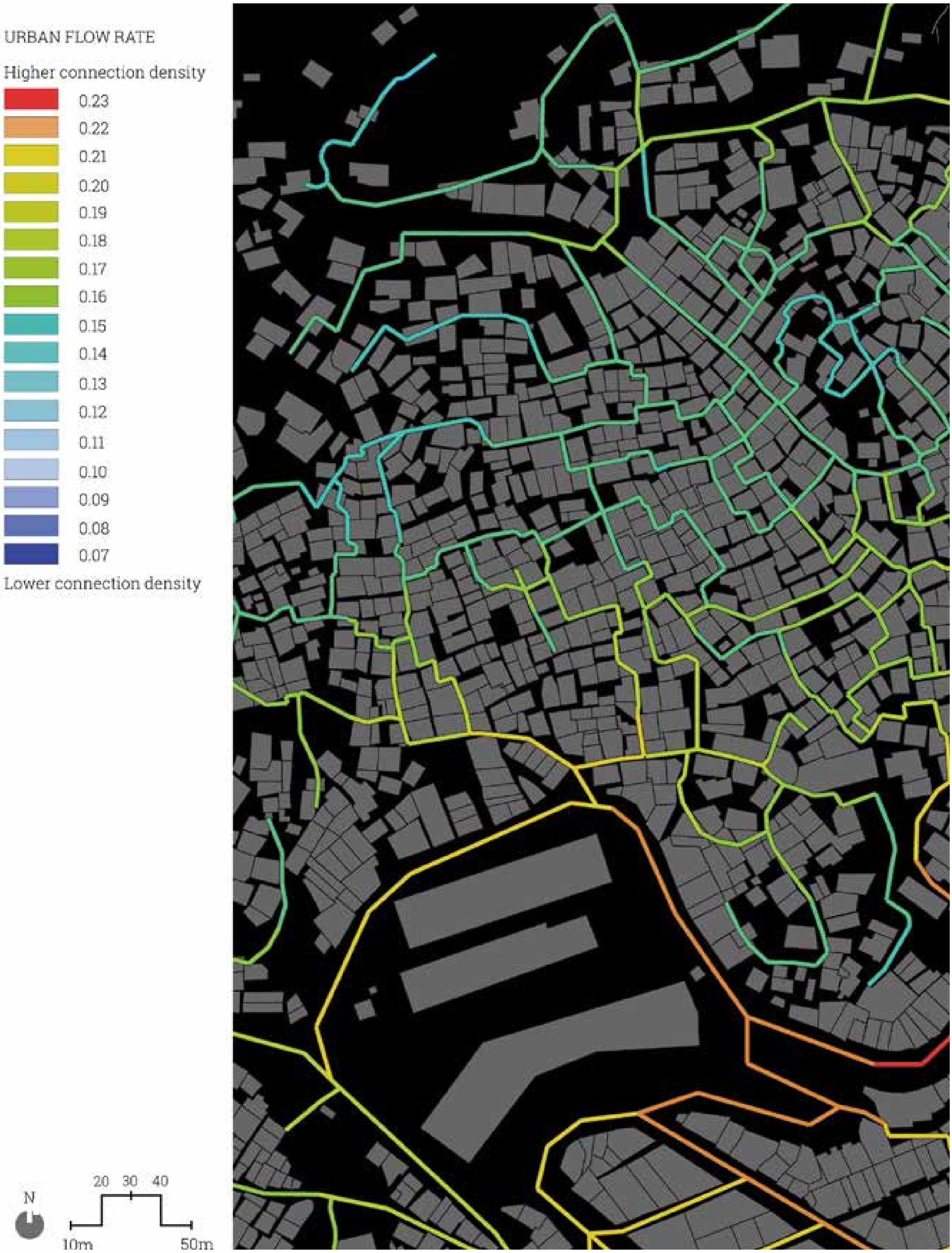


Figure 2.4.14 IMM Interface map of Intervention Area 1.

2.4.2.5 Effectiveness [Transportation – Volume]

As described in the Transportation analysis, there are only three bus and taxi bus stops, all located in the lower half of Area 1, thus the Effectiveness factor is maximized around Caminho do Boiadeiro, where two stops are located and the building density is very high, and spreads downward from there. Interestingly, there's a small patch were the factor is zero between the school and the gas depot, which may suggest the optimal spot for another bus/taxi bus stop.

Figure 2.4.15 View of the lower part of Rocinha, source: http://lifeinrocinha.blogspot.com

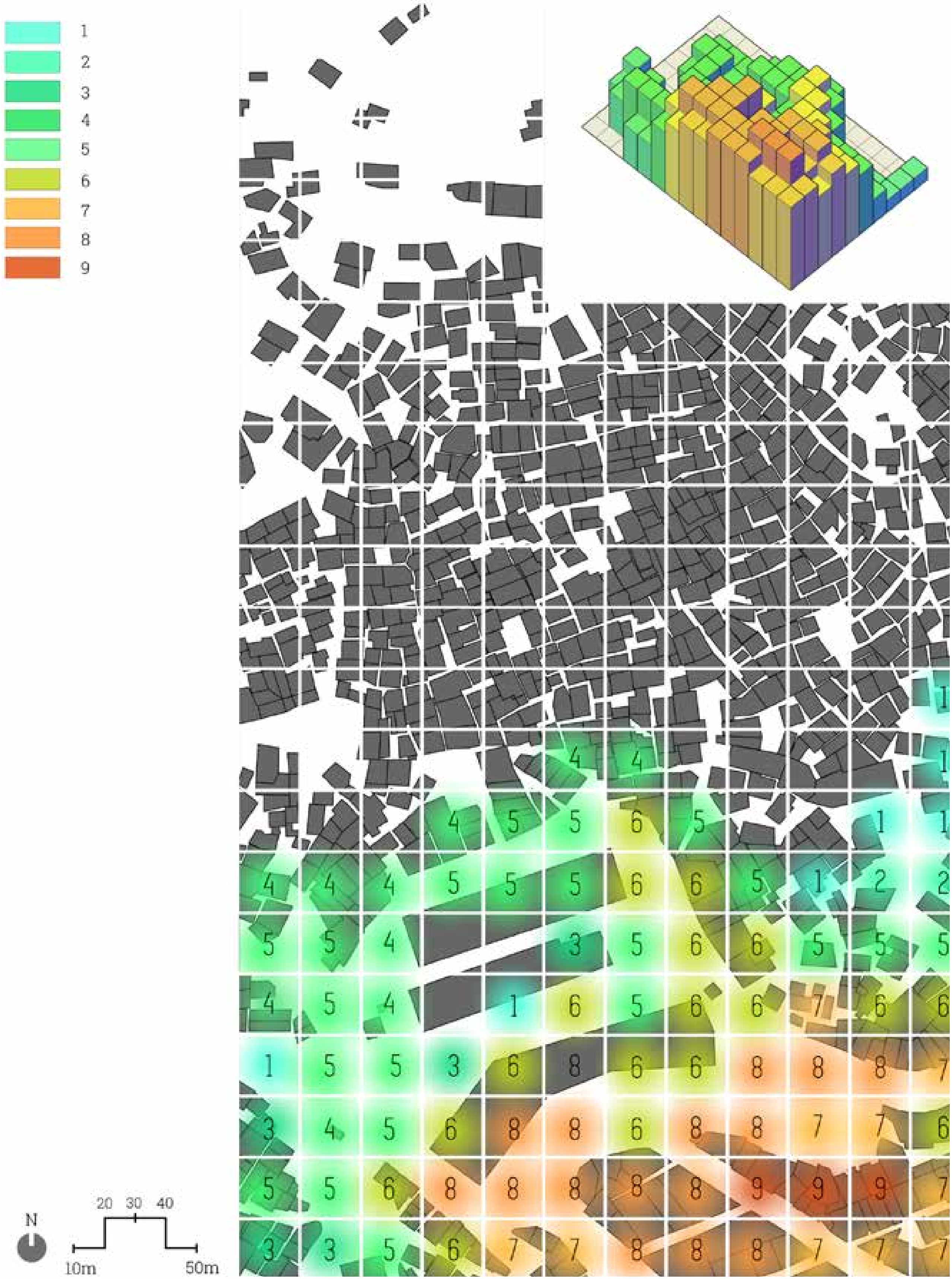


Figure 2.4.16 IMM Effectivness map of Intervention Area 1

2.4.2.4 Porosity [Volume – Voids]

Unlike most of Rocinha, Area 1 presents two important discontinuities in its urban frame: the fraying of the urban environment at the upper end and the opening made by the three major buildings in the lower half. To properly assess the Distribution Factor, it was decided to ignore the isolated houses in the northmost part, as even with a diameter of 10 metres, some would result as a "neighbourhood" made of a single building. Conversely, while the same phenomenon happened in the lower half when using smaller diameters, it was deemed acceptable, due to the size and importance of the buildings. After various iteration, a diameter of 6.00 metres was chosen, which results in 9 neighbourhoods and a Distribution Factor of 92%.

Below is the graph of Porosity's six parameters:

- Volume:

$$P_s = \frac{V_v}{V_t}$$

with:

V_v Volume of voids [m³]: $V_v = V_t - V_b$;

V_b Volume of buildings [m³]

V_t Total Volume [m³]: $V_t = A_t \cdot x_h$;

A_t =Total surface of Area 1 [m²];

x_h =Mean height of the buildings of Area 1 [m].

- Surfaces:

$$SURF = \frac{S_v}{A_t + S_v}$$

with:

S_v =Free Vertical Surfaces [m²].The sum of all free façades of the buildings of Area 1.

- COV(%) Coverage:

$$COV(\%) = \frac{A_b}{A_t}$$

with:

A_b=Total building area [m2].

- FAR(%) Gross Floor Area Ratio:

$$FAR(\%) = \frac{1}{5}\frac{\sum S_{ground} \cdot N_{floors}}{A_t}$$

with:

S_{ground} =Area of buildings with N_{floors} [m²]

N_{floors} = Number of floors.

- Distribution Factor:

$$BDF(\%) = 1 - \frac{N_{groups}(d) - 1}{100}$$

with:

$N_{groups}(d)$=Number of neighbourhoods individuated as previously described.

- NB(%) Number of Buildings:

$$NB(\%) = \frac{\frac{N_{build}}{A_t[he]}}{150}$$

with:

150 Represents extreme soil coverage (> 75%).

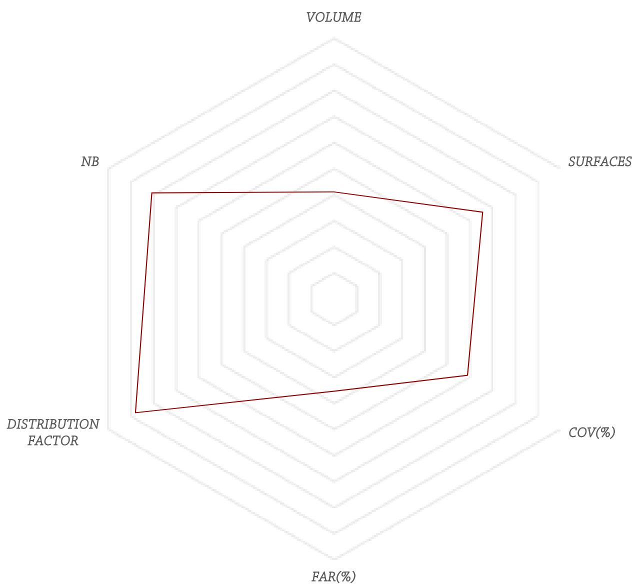


Figure 2.4.17 Porosity spectrum diagram

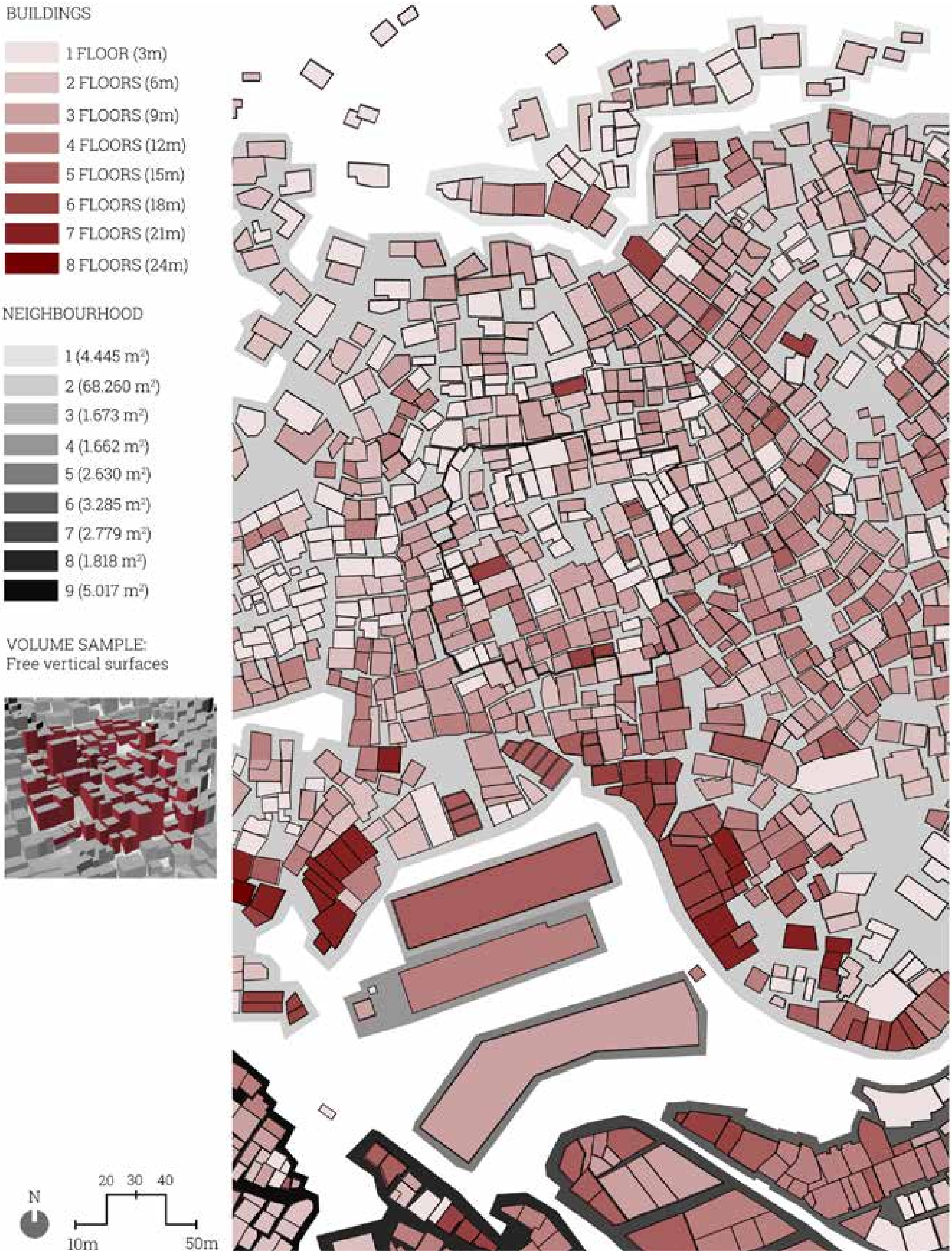


Figure 2.4.18 IMM Porosity map of Intervention Area 1

2.4.2.5 Proximity [Volume – Function]

Since all functions of Area 1 are located in its lower half, all the areas drawn by the Walkalitycs software are concentrated there, each function's zone overlapping with multiple others due to their concentration. Of the three categories of function, Necessary Occasional Activities are, by far, the most prevalent, while there are only three Necessary Regular Activities, and Optional Activities place somewhere in the middle. Again, the upper part is essentially empty.

The parameters represent, clockwise:

- L_{Sw}=Window Shop Surface [m2]. Calculated as the length of all shops' façade facing a street multiplied by flat-rate height of 4.00 metres;
- L_{St}=Total Lateral Surface [m2]. Calculated as the length of all buildings' façade facing a street multiplied by flat-rate height of 4.00 metres;
- L_{nm}=Non-Motorized Links Length [m]. The total length of streets not accessible by any vehicles in the area;
- L_t =Total Street Length [m];
- A_f=Functional Area [m2]. The total area occupied by all functions;
- A_t=Total Built Area [m2];
- S_p=Paved Street Surface [m2]:

$$S_p = (L_t - L_{nm}) \cdot 1.5\ m$$

- S_t=Total Street Surface [m2]:

$$S_t = \left(L_{nm} + S_p\right) \cdot 1.5\ m$$

- N_j= Number of Jobs. The total number of jobs offered by the area's functions;
- N_t= Total Occupied Population;
- S_{sw} = Sidewalk Surface [m2].

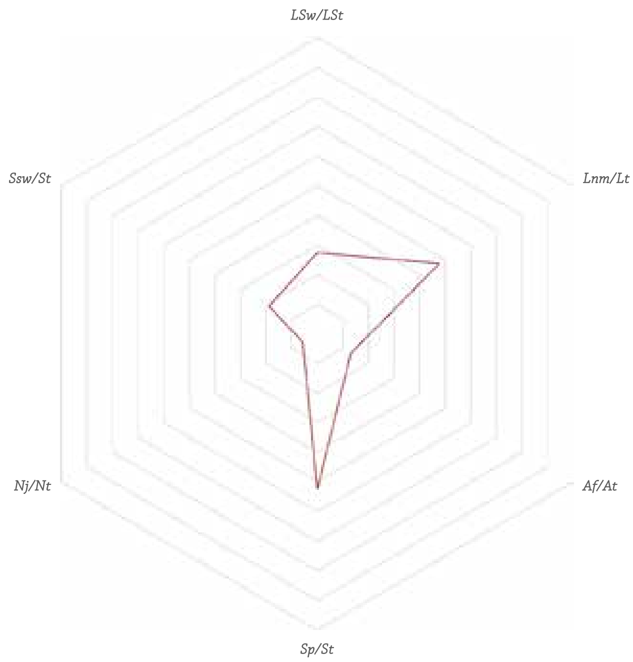


Figure 2.4.19 Proximity spectrum diagram

Figure 2.4.20 IMM Proximity map of Intervention Area 1

2.4.2.6 Permeability [Volume/Void – Transportation]

During this second phase of urban analysis in Rocinha, it has been decided to introduce another layer to the vertical investigation, as to better understand the urban environment of the sub-systems that make up the CAS Rocinha. This layer is called Permeability.

The Cambridge Dictionary of English defines Permeability as "the ability of a substance to allow gases or liquids to go through it". While Permeability is linked to Porosity, it is also related to the shape of the pores. In an urban analysis, Permeability becomes the ability of the urban form to permit or restrict the movement of people, vehicles and material and immaterial flows. Permeability refers either to how much of a two-dimensional plan area is "permeated" with accessible space or the extent to which an urban texture allows pedestrian movement .

Within the context of IMM analysis, Permeability is considered a compactness attribute, a level of organization, emerging by self-organized and synchronized states between the basic elements of the urban system structured as Volumes, Voids, Links, and Type of uses. For the purpose of this investigation, the urban structure is simplified as a bidimensional porous medium where buildings represent solid elements while open spaces (eg streets, squares) becomes pores.

Six spatial assets of the built environment have been identified, with the relationships between them explaining urban permeability:

- <u>Street Area</u> : represents which parts of the voids are open and continuous, making them accessible and affected by different urban flows. It is spatially complementary to the pores, represented by courts and urban cavities, in the construction of the void layer.

$$SA = \frac{A_s}{A_v}$$

with:

A_s= Street area [m^2]: A_s= S_t

A_v = Void area [m^2]: A_v= A_t- A_b

- <u>Average Link Length</u> : represents the distance between intersections, in other words the easiness of changing routes and finding an alternative path within walking distance.

$$L_l = \frac{L_t}{N_{streets} \cdot L_{max}}$$

with:

$N_{streets}$ = Number of streets;

L_{max} = Maximum street length rounded to the nearest 50 m [m].

- <u>Topography:</u> takes into account the natural slopes of the terrain, since projecting the urban environment on an XY plane shrinks the distances and hides height differences. Inclination means the introduction of ascent and descent in the urban flows, both of which affect the easiness of movement.

$$Topography = \frac{\sum \phi}{17°}$$

with:

Φ = Average slope: $\phi = \cos^{-1}(\frac{Projected\ Link\ Lenght}{3D\ Link\ Lenght})$

17°= angle of the most inclined street in the world (38%).

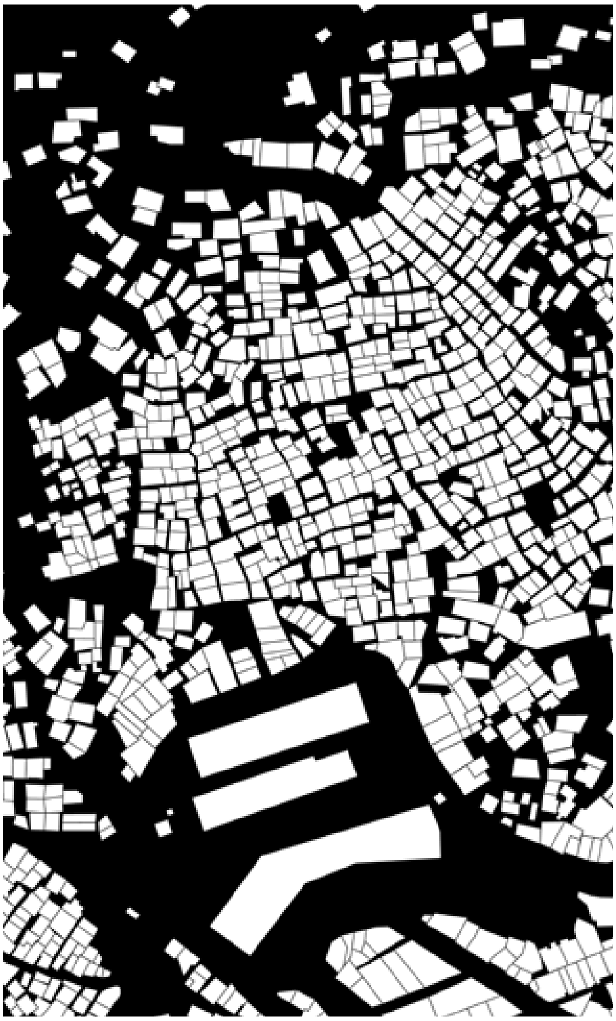


Figure 2.4.21 IMM Voids map

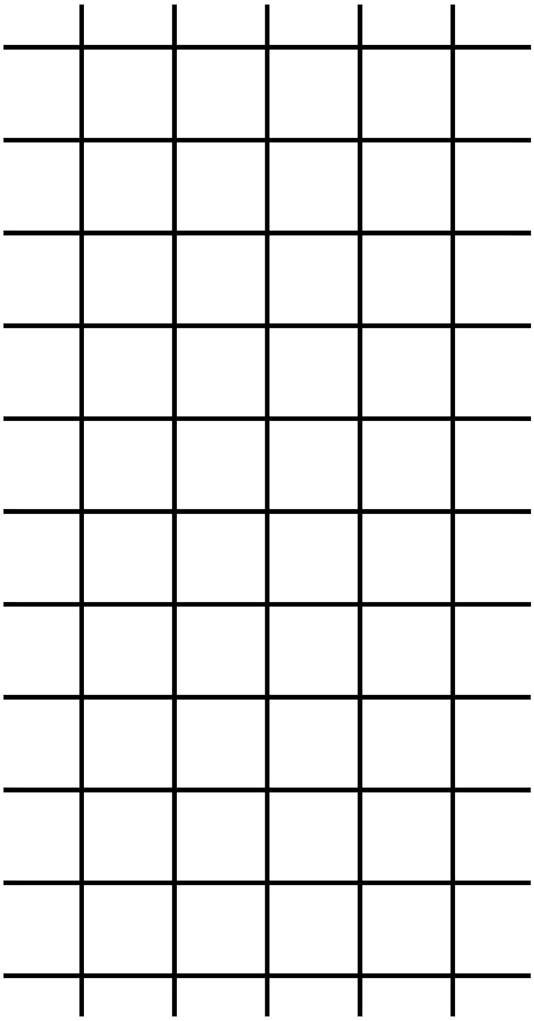


Figure 2.4.22 IMM Permeability Average Link Length illustration

Figure 2.4.23 IMM Permeability Topography illustration

- Directness: represents how much an area encourages flow, or how easily it can be crossed. It measures how direct is the path between two points, comparing the distance as the crow flies to the shortest possible path following the street network.

$$Directness = \sum \frac{L_d}{L_{sp}}$$

with:

L_d= Linear path, the distance measured as the crow flies [m].

L_{sp}= Shortest path, the shortest possible path following the street network [m].

- Tortuosity : serves as the counterpart of the Directness, measuring the ease of a flow through a porous medium. In this investigation, the tortuosity has been computed using the TauFactor plug-in for Matlab.

$$\tau_\gamma = \tau_x + \tau_y$$

with:

τx = Tortuosity measured by TauFactor on the x-axis;

τy = Tortuosity measured by TauFactor on the y-axis.

Figure 2.4.24 IMM Permeability Tortuosity τ_x map

Figure 2.4.25 IMM Permeability Tortuosity τ_y map

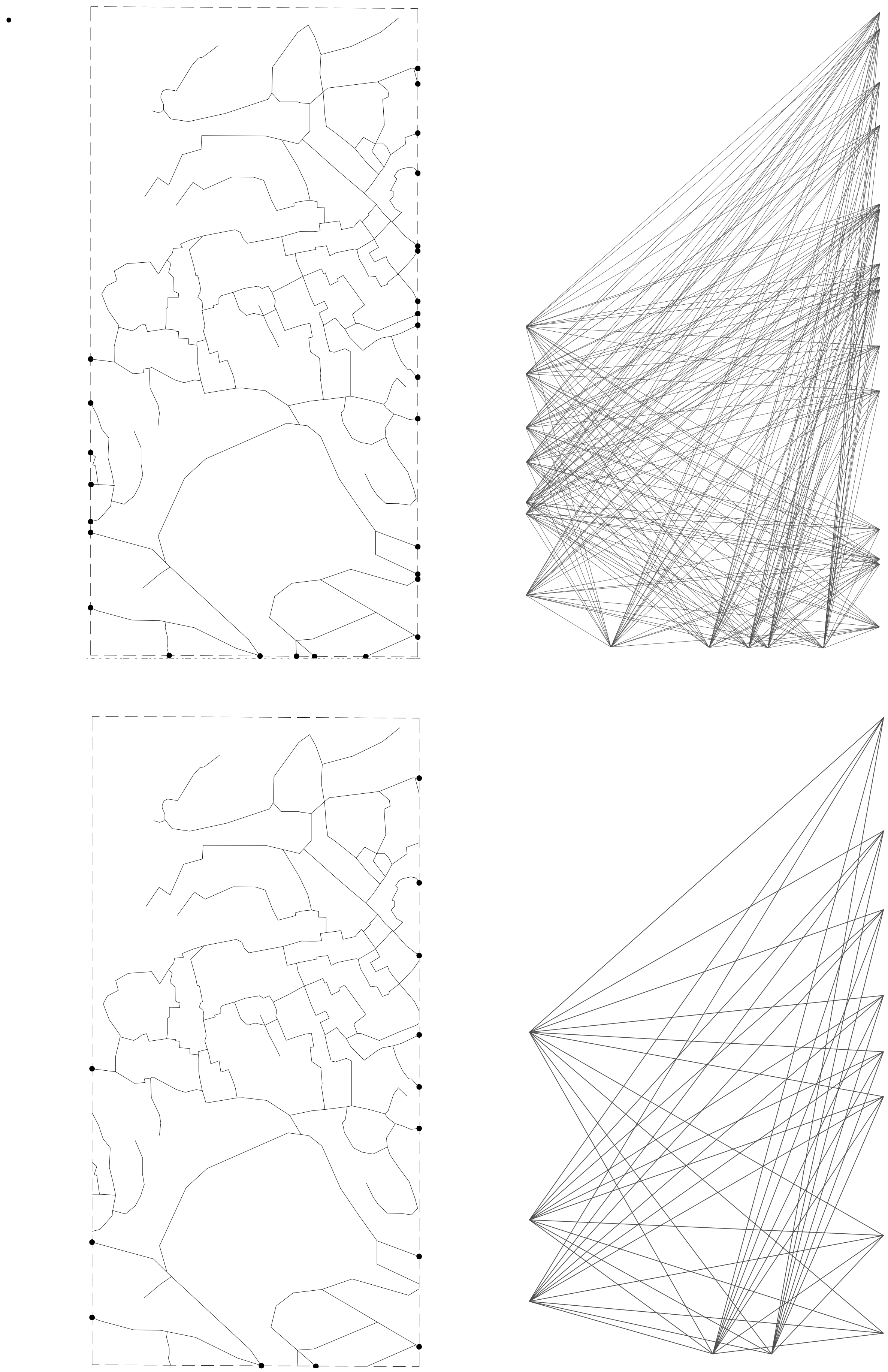


Figure 2.4.26 IMM Permeability Directness data processing

- Constrictivity : is expressed by a parameter named β, introduced by Petersen for a single pore with periodic constrictions. The value of β has been calculated using the method proposed by Münch and Holzer with the free software ImageJ/Fiji.

$$\beta = \left(\frac{r_{min}}{r_{\max}}\right)^2$$

with:

r_{min} [m] = the radius of the constricted area;

r_{max} [m] = the radius of the bulge.

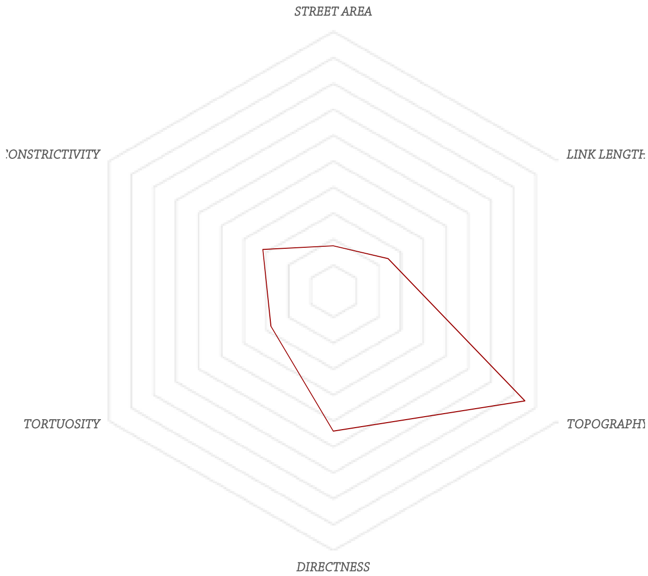


Figure 2.4.27 Permeability spectrum diagram

2.4.3 Results' analysis

2.4.3.1 Final results of Vertical Investigation

Proximity

		Ratio
L_{Sw} [m²]	**L_{St} [m²]**	**L_{Sw}/ L_{St}**
5,613.72	19,700.68	28.50%
L_{nm} [m]	**L_t [m]**	**L_{nm}/ L_t**
6,533.22	8,207.96	79.60%
A_f [m²]	**A_t [m²]**	**A_f/ A_t**
10,654.27	54,861.76	19.42%
S_p [m²]	**S_t [m²]**	**S_p/ S_t**
2,512.11	12,311.94	20.40%
N_j	**N_t**	**N_j/ N_t**
1,609	9,928	16.21%
S_{sw} [m²]	**S_t [m²]**	**S_{sw}/ S_t**
1,279.14	12,311.94	10.39%

Tab 2.4.1 Proximity ratio results

Porosity

A_t [m²]	x_h [m]	V_t [m³]	V_b [m³]	V_v [m³]	Ps
97,295.90	9.14	889,556.70	498,444.60	391,112.10	44.00%

Tab 2.4.2 Porosity final volum results

A_t [m²]	S_v [m²]	SURF
97,295.90	381,256.18	79.70%

Tab 2.4.3 Porosity surface results

At [m2]	Ab [m2]	COV
97,295.90	54,57.70	56.00%

Tab 2.4.4 Porosity coverage results

N_{floors}	S_{ground} [m²]	FAR
1	8,550.90	34,20%
2	11,160.10	
3	16,033.70	
4	11,563.90	
5	3,368.90	
6	2,935.50	
7	774.40	
8	130.20	

Tab 2.4.5 Porosity Gross Floor Area Ratio results

N_{groups}(d)	BDF
14	87.00%

Tab 2.4.6 Porosity results

At [ha]	Nbuild	NB
9.70	1145	78.50%

Tab 2.4.7 Porosity Number of Buildings results

Topography

Φ	Topography
12.63°	74.30%

Tab 2.4.8 Topography Average slope results

τ_x	τ_y	τ_y
2.20	2.89	39.30%

Tab 2.4.9 Topography TauFactor results

r_{min} [m]	r_{max} [m]	β
2.91	8.31	12.30%

Tab 2.4.10 Topography radius of the constricted area results

Permeability

A_s [m²]	A_t [m²]	A_b [m²]	A_v [m²]	SA
12311.90	97,295.90	54,57.70	42,778.20	28.80%

Tab 2.4.11 Permeability Street Area results

L_t [m]	$N_{streets}$	L_{max} [m]	L_l
8,207.96	530	209.25	7.70%

Tab 2.4.12 Permeability Link Length results

Path	L_d [m]	L_{sp} [m]	Directness
1-2	420.97	425.36	57.50%
1-3	112.92	629.84	
1-4	437.38	500.17	
1-5	180.22	678.40	
1-6	445.08	532.06	
1-8	249.76	634.86	
1-9	298.39	605.94	
1-10	316.08	593.56	
1-11	375.76	707.06	
2-3	428.37	667.35	
2-4	93.45	249.32	
2-5	446.51	715.91	
2-6	118.67	281.23	
2-8	422.29	672.38	
2-9	327.47	643.45	
2-10	306.17	630.99	
2-11	252.89	744.57	
3-4	420.10	586.93	
3-5	67.30	148.96	
3-6	421.40	493.51	
3-8	142.06	171.81	
3-9	216.42	255.24	
3-10	240.22	301.64	
3-11	314.64	439.94	
4-5	424.00	618.68	
4-6	25.22	170.07	
4-8	383.32	520.48	
4-9	275.40	527.38	
4-10	249.67	466.74	
4-11	180.45	344.10	
5-6	421.28	525.26	
5-8	84.60	99.83	
5-9	183.88	266.13	
5-10	211.38	312.54	
5-11	293.21	471.69	
6-8	96.01	427.06	

Tab 2.4.13 Permeability Directness results

Path	L_d [m]	L_{sp} [m]	Directness
6-10	238.44	373.32	57.50%
6-11	164.56	250.69	
8-9	116.36	167.94	
8-10	145.39	214.34	
8-11	229.99	373.50	
9-10	29.03	75.34	
9-11	113.63	344.95	
10-11	84.60	319.76	

Figure 2.4.14 Permeability Directness results

2.4.3.2 Conclusion

As noted several times throughout the analysis of both intervention Area 1 and Rocinha as a whole, the parameter that influences the most the urban environment of the favela is building density, to the point that most of the issues highlighted both in the previous and the subsequent analyses can be, at least in part, linked to it. In other words, hardly any significant improvement in intervention Area 1, and Rocinha besides, can be achieved unless the project acts onto this disproportionate urban density.

The magnitude of the issue is especially underscored by the data resulting from the Porosity investigation. While a 56% value of soil coverage may appear acceptable if taken at face value, it fails to properly capture the reality of Area 1, where relatively ample open spaces (in the lower half and the upper edges) are next to extremely built upon areas. In this instance, the Distribution Factor and the Number of Buildings (87% and 78.5%, respectively) more accurately describe how impenetrable Area 1's urban environment truly is.

The Permeability investigation offers further insight into the issue, especially with the very low value of Constrictivity (12.3%) and Tortuosity (39.3%), though again the latter would be much lower in the densest neighbourhoods of the area. The 57.5% value for Directness strengthens the previous statements, as it means that, on average, it takes half-again as much time to go from one point of the map to another, when compared to the linear route. Permeability also underscores how the issue of urban density is compounded to almost unsustainable levels (as the following chapter will explain), by Rocinha's morphology. Topography reaches a value of 74.3%, which descends from the extreme values of the terrain's slope (an average of 70% in Area 1, one of the worst in this regard).

Therefore, as mentioned, all the results of the IMM investigations are linked to the issue of urban density. Functions naturally concentrates in the few open and more accessible areas, leaving the rest of the neighbourhoods almost exclusively residential, which leads to the low values of Proximity across the board, excluding the ratio between non-motorized and total street length, sitting at 79.6%, itself a representation of the almost inexistent possibility of moving inside Area 1 by car outside the main roads.

Having established the most effective way of intervening in Area 1, the main goal of the urban project will be the construction of a better connection between Estrada da Gávea and Rua Dionéia, widening the existing streets by relocating some of the buildings in the vicinity, achieving the double goal of reducing urban density, while connecting the more vibrant lower part of the area, and the favela, with the upper edges, providing a way for new functions and interactions between the inhabitants.

2.5 Phase 3: Assumption

2.5.1 Introduction

The Assumption phase is carried out through the designing of the prototype projects, themselves representing the physical manifestation of the interrelationships between the DOPs. This small-scale projects were engineered, sized and adapted to the actual morphological context of the different intervention areas studied. Their aim is to meet the needs individuated by the IMM Investigation Phase and by the detection of the correct Catalysts and concretely increase the performance level of the CAS evaluated in previous sections.

The prototype projects are strictly related to the DOPs, whose importance is determined by the Catalysts assumed after the investigation phase. Starting from the evaluation of the DOPs, this chapter introduces the different prototype projects that need to be adapted in the actual context of the different intervention areas, their importance and the managerial perspective.

The engineering and the sizing of the projects (all aspects which are dependent of the actual context in which they are located and the design choices) are both topics which will be discussed and analysed further.

2.5.2 Design ordering principles

The DOPs were selected based on the principles suggested by IMM and ordered by importance related to the Catalysts:

1. Create a connected open space system to activate urban metabolism;
2. Implement a water manage system;
3. Prevent the negative impact of waste;
4. Balance the ground use;
5. Promote cycling and reinforce public transportation;
6. Foster the local energy production;
7. Convert the city in a food producer;
8. Foster mixed use spaces;
9. Promote walkability;
10. Change from multi-modality to inter-modality concept;
11. Balance the public transportation potential;
12. Make biodiversity an important part of urban life.

The DOPs have been split between four categories: Morphology, Typology, Management and Technology.

The circular diagram shown beside illustrates the interrelationships that exist between the DOPs, divided in their classification of morphology, typology, management and technology and their application in the case study of Rocinha:

The most important DOP, connected open spaces, is positioned at the centre. Said DOP is directly related to the Interface map (which is the vertical investigation catalyst) and it is connected to the other DOPs by numerous interrelationships. By creating open spaces, the existing connections will surely be enhanced, as one of the main problems of Rocinha is the lack of connections, as shown in the Interface map. This will also allow to balance the public transportation thanks to the presence of wider streets.

Fostering connections also means the promotion of walkability. If the new spaces being created are organised and assigned a function, it is possible to balance the ground use of the land, especially by creating green equipped areas, since at present most of the terrain is covered by concrete. As a consequence of this, the existence of biodiversity is fostered, while the drainage level of the soil increases.

Fostering the presence of mixed used spaces is implicitly related to the creation of connected open spaces by the functions organization. Within mixed used spaces, it is also important to include the implementation of vegetable gardens and green equipped areas to generate biodiversity with the aim to transform the complex system into a food producer.

The implementation of water management, the second DOP in order of importance, is also crucial to Rocinha's sustainable development. The water collected can be used for irrigation to promote the cultivation and biodiversity. The large amount of water flowing in the existing channels' network, helped by the impermeable terrain, the high slopes' rate of certain areas and clogged by the waste sometimes dumped into them, especially during heavy rainfalls, needs to be managed with the properly designed network and the installation of sewage and drainage elements such as detention basins and downpipes. The lack of potable water is another main critical issue currently present in the community of Rocinha: the installation of a proper depuration system is mandatory.

Waste is another of the biggest issues of Rocinha. Not only the population is not educated to recycle, but they lack the most basic infrastructure as well, with most of the sewerage network existing as open channels. The inhabitants often leave waste in the street without worrying about the very real and direct impacts on their own health.

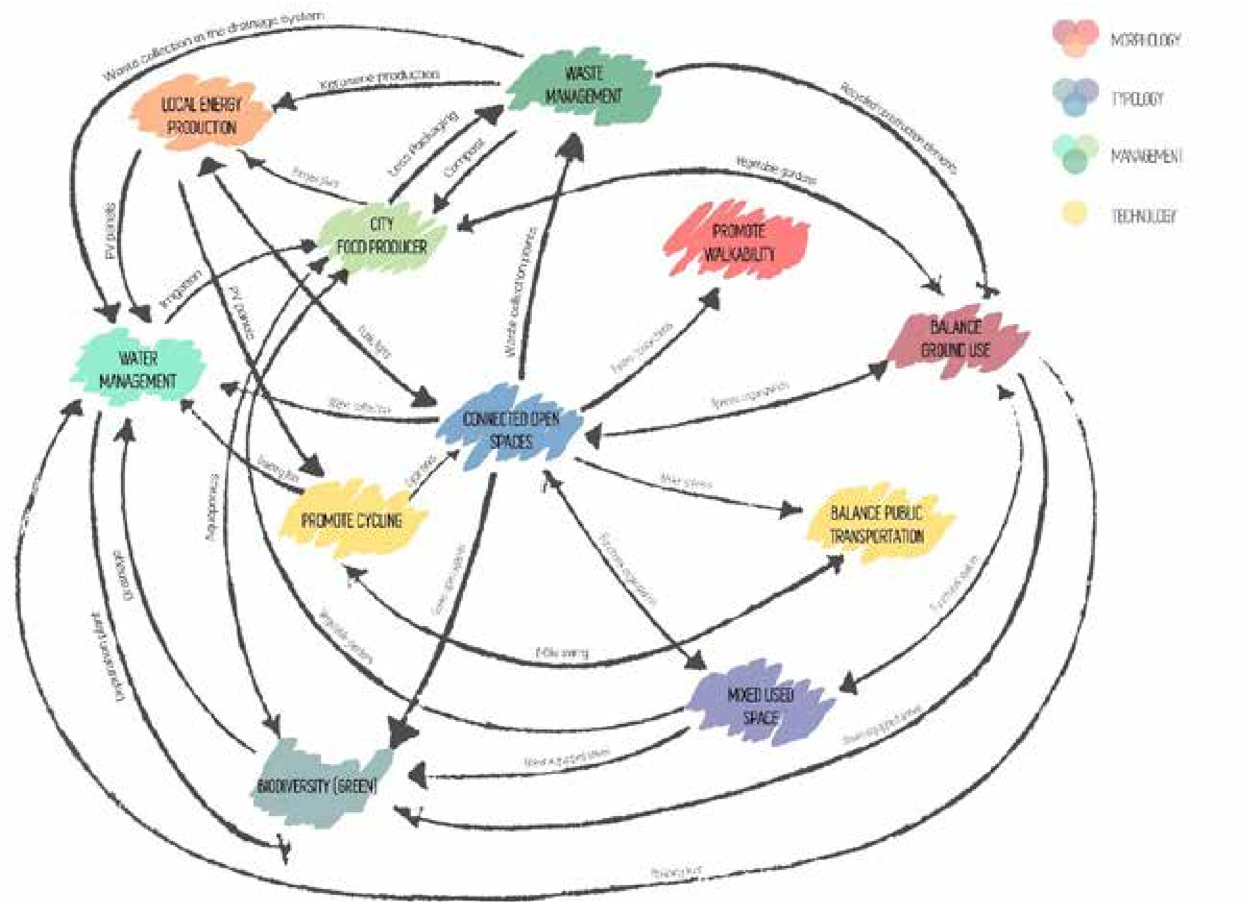


Figure 2.5.1 DOPs' and pilot projects' diagram

The creation of construction elements from recycled materials and prototype projects such as the biogas plant and the kerosene production through an innovative machine, will help the reduction of the overall amount of waste that needs to be disposed of. Another implementation in the system could be the production of biofertilizer through the biogas plant, which, in turn, could be used to propel the food production.

The promotion of the cyclability inside Rocinha plays a very important role in the improvement the performance of the complex adaptive system because of its direct influence on the IMM Interface Indicators and shows a great number of possible interrelationships with the other DOPs.

The implementation of cycle lanes connects the cyclability to the central DOP, connecting open spaces and balancing the public transportation system thanks to the installation of an E-bike sharing network. The provision of a draining floor to make the cycle lanes permits to improve the drainage level of the complex system, creating an interrelationship with the water management DOP.

The last DOP that needs to be studied in deep is the local energy production. The installation of a PV plant on top of the free roofs of Rocinha could be fundamental to manage properly the E-bike sharing system and all the appliances used for the other prototype projects. In the end, managing the public lights with renewable self-produced energy can improve the general level of safety inside Rocinha, permitting a good connection of the open spaces in terms of nocturnal visibility and indirectly promoting the walkability.

	DOP Design Ordering Principles	Key categories	Determinants
Morphology	1) Balance the ground use	Prorosity	Compactness
	2)Implement permeability to facilitate urban flow and adopt a locally based strategy forsotering the permeability.	Permeability	
Typology	3) Balance the distribution of functions and developing a multifunctional urban spaces 4) Make biodiversity an important part of urbn life	Diversity	Intricacy
	5) Create connected open spaces system, activate urban metabolysm	Interface	
Technology	6) Promote Walkability, cycling and reinforce their integration with public transportation	Proximity	Connectivity
	7) Balancing the public transporattion potential	Effectivness	
	8) Change from multimodality to inter-modality concept	Accassibility	
Menagment	9) Fostering the local energy production: Buildings as components of Community Energy System. (Smart Grid) 10) Convert the city in a food producer 11) Prevent the negative impact of waste 12) Implement water managment	Governance	

Tab. 2.5.1 DOP (Design Ordering Principles). Source: IMMdesignlab

2.5.3 From DOPs to prototypes

Having defined the objectives of our intervention through the DOPs, we selected 14 specific prototype projects that can be applied to Rocinha. These prototypes, when placed within the intervention areas, will not only improve the quality of life on a local level, but, as the prototypes multiply across the favela, also on a global level. Listed below are the prototype projects and to which DOPs they respond:

Number	Pilot project	DOP
1.	PV panels;	6
2.	E-Bike sharing;	5; 9; 10
3.	Public lights;	1; 8; 10
4.	Biogas plant;	3; 6
5.	Compost production;	3; 7
6.	Kerosene production;	3; 6
7.	Depuration plant;	2; 3
8.	Detention basin;	2
9.	Sewage system;	2; 3
10.	Drainage system;	2
11.	Downpipes;	2

Tab 2.5.2 DOPs' List of the Pilot Projects

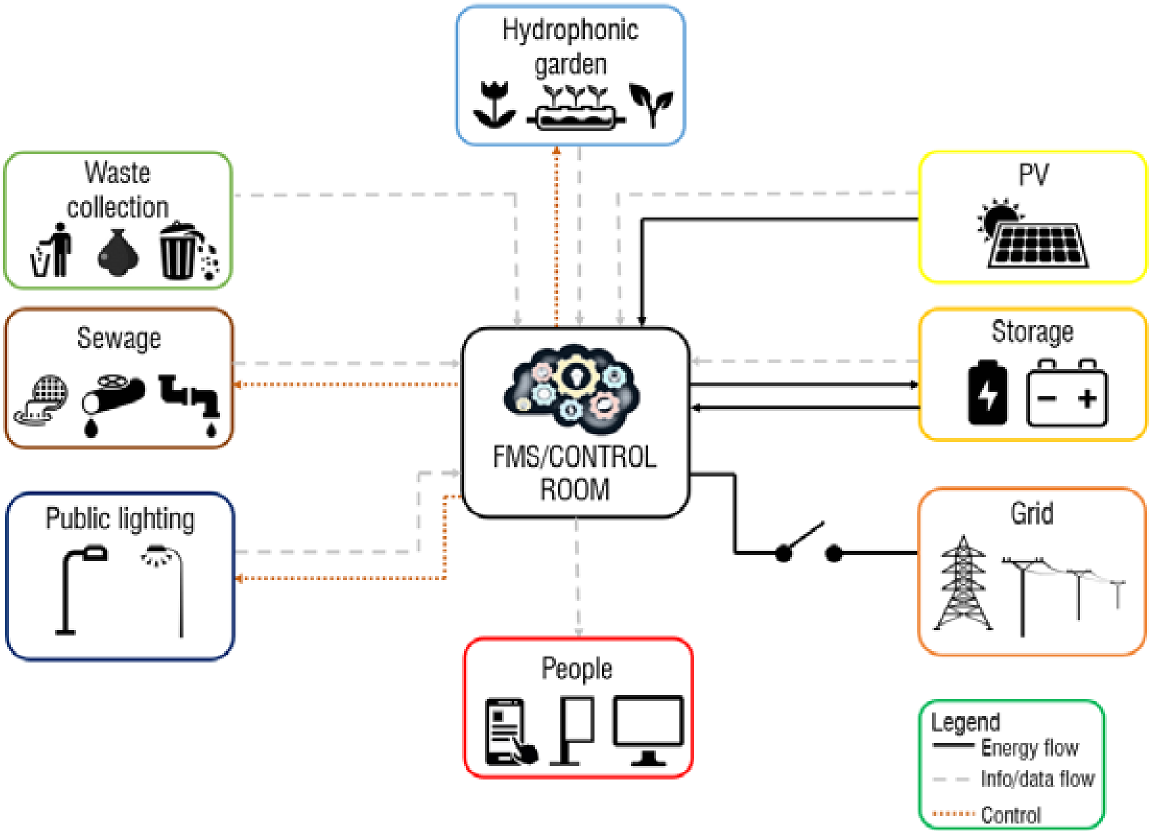


Figure 2.5.2 The data management of all the designed interventions. Source: "PolimiparaRocinha" team

Since all of the prototype projects satisfy specific requests of different topic, but at the same time they work as a combined force with mutual dependencies, it is necessary to split them in 5 different field of intervention: Mobility, Energy, Water, Food and Waste.

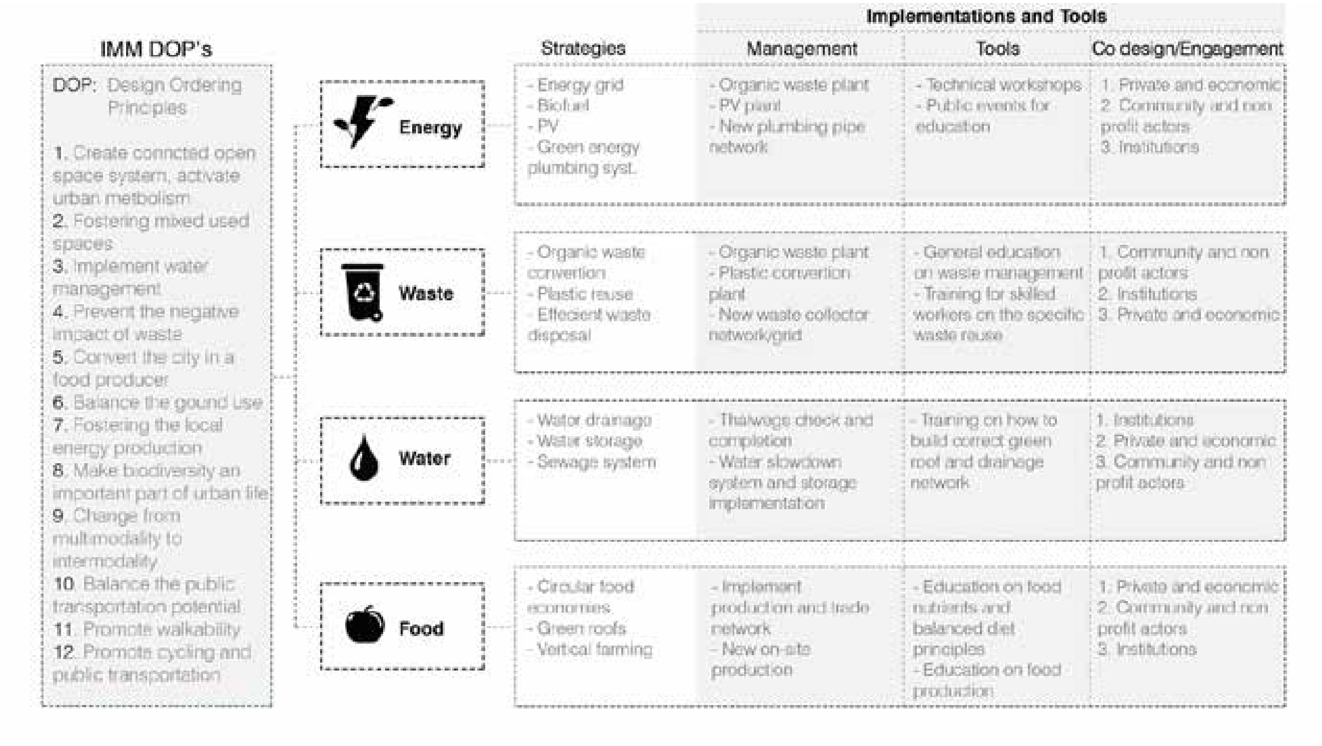


Figure 2.5.3 Design Ordering Principals.

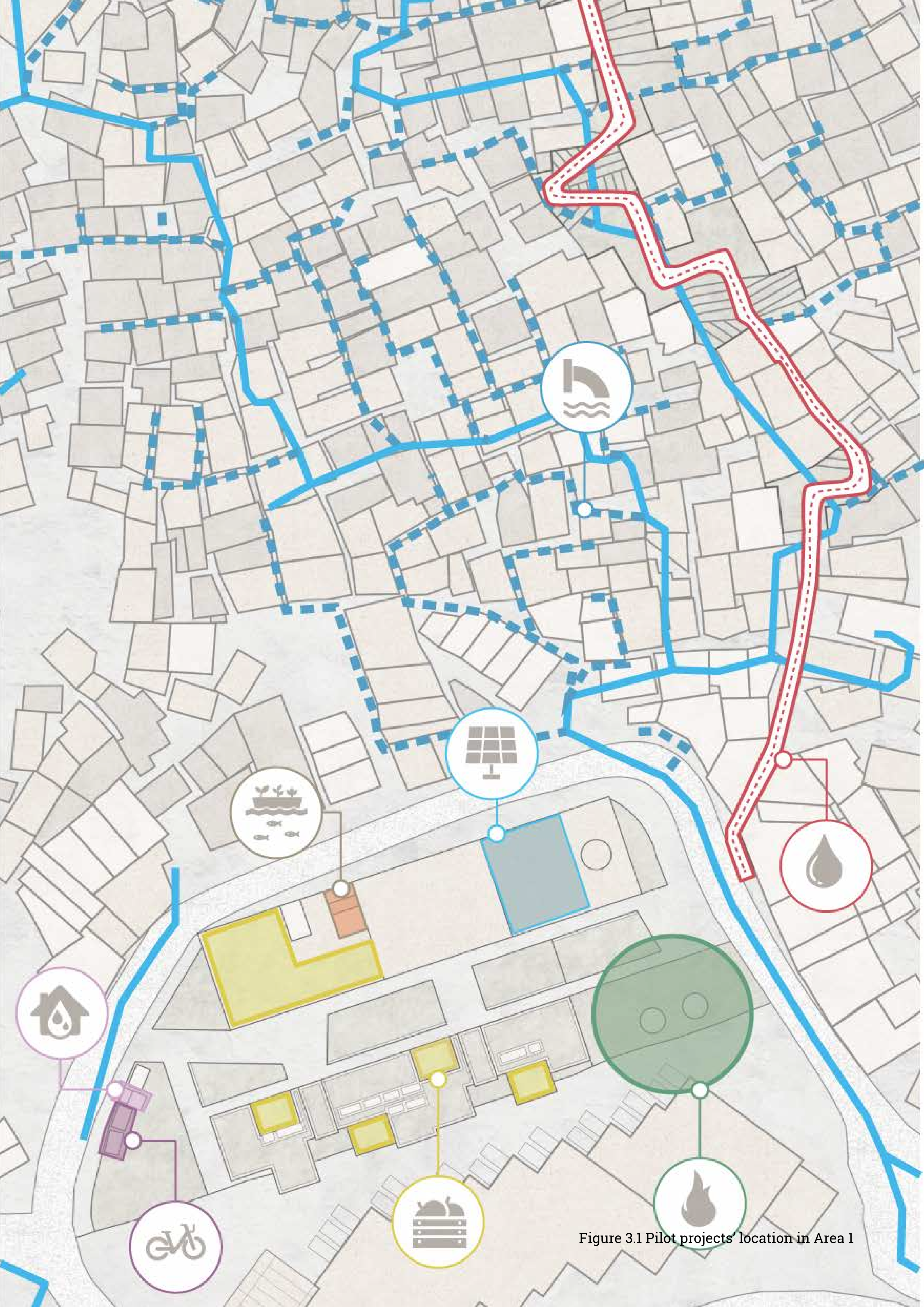


Figure 3.1 Pilot projects' location in Area 1

3 PILOT PROJECTS

The informal urban environment that is a favela gives rise to a closely-knitted and fiercely independent community. Therefore, the people of Rocinha are very resistant, almost impervious, to change, especially when brought from the "outside".

At the same time, however, many basic human necessities are barely met in Rocinha, and demand improvements that oftentimes only state-level actors can provide.

Pilot projects are this intervention's answer to this duality of needs: small, easy-to-implement interventions, some made and managed by the community, placed at strategic junctures inside the project areas, that provide the population with immediate and tangible benefits, fostering the inhabitants themselves to spread them across Rocinha.

The following chapter will analyse the pilot projects developed by the PolimiparaRocinha team, both at the favela's level and intervention area 1's level. Detailing the design and construction processes, the needs met by each and the benefits brought to the community.

3. Pilot Projects

Figure 3.2 Pilot projects fields of intervention

3.1 Mobility

Figure 3.1.1 Courtesy of www.area-arch.it

3.1.1 Introduction

Besides the basic problems that are present in the favelas of Rio de Janeiro and a general sense of isolation felt by the inhabitants, a more concrete feeling of "spatial segregation" is present due to the lack of efficient connections and transport systems between the formal and the informal city. In the last years multiple projects have been proposed to foster the interconnections between the formal city of Rio de Janeiro and the informal settlements spread throughout the metropolitan region, but all of them failed in their main goal of engaging the inhabitants of the favelas due to political and economic reasons.

In this chapter a short presentation of the main established programs and the reasons of their eventual failure is presented in order to come out with a better proposal for the favela of Rocinha based on the mistakes made in the past as well as a research conducted in 2013 by the Lincoln Institute of Land Policy focused on the transportation system in the informal settlements of Rio, a current program presented by the Municipality itself which grants future investments in the mobility system, collection and analysis of data taken from the 2010 national census and, most importantly, the harsh context and morphology of Rocinha taken as a constraint to wrestle with.

3.1.2 Documentation phase

3.1.2.1 The "Favela-Bairro" and "Morar Carioca" programs

The Favela-Bairro program, the brainchild of architect and city Secretary of Urbanism Luiz Paulo Conde and approved by the city government in 1994, was coordinated by the newly established Municipal Housing Secretariat (Secretária Municipal de Habitação). The government agency was assisted by COMLURB, the municipal trash-collection company, and the state water company CEDAE. The program's charter planned for infrastructure upgrades, social services, real estate regularization, and a crèche in every urbanized favela, to deal with the problem of the lack of affordable houses.

The entire program had an investment of about R$1.2 billion reaching about 168 communities in 16 years all around Rio de Janeiro. Although there was a significant increase in water and sewer access in communities, this program was largely administrated with a top down process, without properly engaging the inhabitants of the favelas and leading many of the main issues that forced people to live in informal settlements in the first place to remain unsolved.

In the words of Janice Perlman in the work "Favela: Four Decades of Living on the Edge in Rio de Janeiro": "Favela-Bairro was a bold leap forward but not the best. There are no best practices, only practices that are better than others at a particular time and place. Once an innovative idea reaches implementation and then becomes routinized, its internal contradictions present new challenges to be addressed."

With the imminent 2014 Football World Cup and the Olympic Games hosted in Rio in 2016, in 2010 the administration of Rio de Janeiro presented the Morar Carioca program, a R$9 billion plan which tried to address the critical issues of the favelas with strategies based on the direct participation of the communities and the fostering of educational and social services in order to connect physically and socially the informal settlements with the formal city. Accessibility was the keyword of the entire program, which had an international resonance thanks to the fact that Brazil was under the spotlight in that period.

A technical analysis was made, economic resources were raised, an international design competition was hosted and few international celebrations were given, but Morar Carioca program never became what was envisioned and planned to be due to political reasons, though it had a strong starting point with a significant number of actors involved in the process:

RIO PREFEITURA	SECRETARIA MUNICIPAL DE HABITAÇÃO (SMH)
RIO PREFEITURA	SECRETARIA MUNICIPAL DE MEIO AMBIENTE (SMAC)
ibase. Instituto Brasileiro de Análises Sociais e Econômicas	ONG CONTRACTUALIZED BY SMH TO PERFORM A "SOCIAL DIAGNOSIS" WITH THE PARTECIPATION OF THE COMMUNITIES
alta PLANNING + DESIGN	40 DESIGNING TEAM CALLED TO RETHINK FAVELAS' SYSTEMS PROVIDING SERVICES AND INFRASTRUCTURES
iab INSTITUTO DE ARQUITETOS DO BRASIL	IT HOSTED A DESIGN COMPETITION IN 2010 IN WHICH OVER 80 ARCHITECTUR FIRMS PRESENTED SAMPLE DESIGNS

Figure 3.1.2 Actors of the Morar Carioca program. Source: Morar Carioca, 2010

Technically speaking, the Municipality of Rio de Janeiro, with the economic support of Bloomberg Philanthropies, instructed Embarq Brasil to draw up a manual of projects and best practices for the implementation and the use of bicycles inside the favelas with the help of Alta Planning + Design, an American designing team specialized in theory and application of bike-oriented systems.

The manual shows a strategic vision based not only on technical solutions and guidelines for the implementation of the use of the bicycle in the favelas, but also on the political aspects of the program and systems to educate and engage the communities to avoid a top down process.

Figure 3.1.3 Process of the Morar Carioca program. Source: Morar Carioca, 2010

Four Keywords drive the entire program:

- **Safety**: there is a huge concern about safety inside the informal settlements because of the poor quality of the infrastructures and the excessive use of motorcycles and cars in the typical narrow streets of the favelas which discourage the bicycle usage;
- **Human scale**: although the large amount of money invested in the program, each project deals with the human scale of the inhabitants of the favela. An example of a bad project can be seen with the construction of a cableway system in Complexo do Alemão in 2011, trying to emulate the Medellin experience. This kind of project was completely out of scale and was implemented with a top down process, while the inhabitants of Complexo do Alemão had different needs and did not want a cableway to be built in their community. Today, the system is closed for economic reasons;
- **Community engagement**: what the cableway experience teaches us is to invest properly in the community engagement sooner than after the final approval of the projects, to work together with who is to become the beneficiary of the investment and to improve the programs with their help;
- **Integration**: the main goal of any program based on solutions for informal settlement is to foster the integration with the formal city to prevent the isolation phenomenon and help the inhabitants of the favelas feeling to be part of the city of Rio de Janeiro.

The programs presented in the manual try to answer the third aspect, because it is important to think about traditional and innovative solutions to boost the use of bicycles inside the communities, otherwise the system is likely to be rejected altogether. Three different aspects are taken in account:

- **Education**: a good example could be the "Ganha uma bicicleta" program, recycling discarded pieces and using them to make "new" bicycles. If someone needs a bicycle he could learn how to assemble it and at the end win it;
- **Incentive**: all the programs which link the use of a bicycle with a proper job, for example delivering mails in the community;
- **Equality**: all the actions strictly connected with bike sharing systems and bike repair shops.

Regarding the technical guidelines, the manual tries to solve the most common issues for cyclists present in a typical environment of a favela.

Figure 3.1.4 Minimum dimensions for a cycle path. Source: Morar Carioca, 2010

Narrow Streets

- It is only possible to get off the bycicle and continue walking;
- Flooding problems: it is imperative to design correctly the slopes towards the centre of the streets;
- Use of light coloured outdoor flooring in order to absorb less heat and reduce the urban heat island effect.

Figure 3.1.5 Narrow streets in Rocinha. Picture taken by Arianna Trombini

Slopes

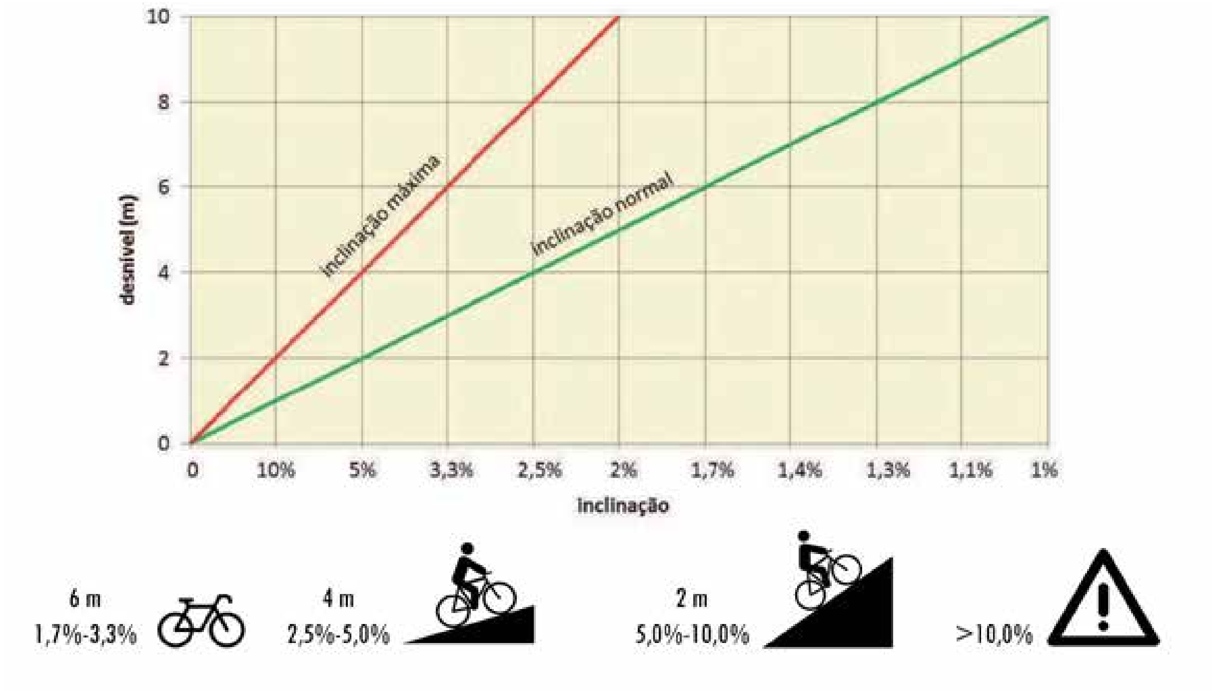


Figure 3.1.6 Slopes' classification. Source: Morar Carioca, 2010

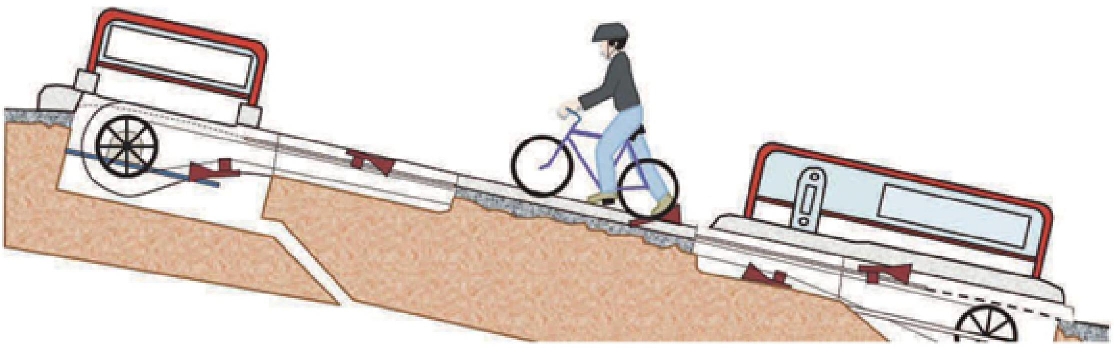


Figure 3.1.7 Bicycle travellator. Source: Morar Carioca, 2010

- Ideal solution for slope value between 10% and 20%. If installed beside roads, the system has to be signaled and with a minimum width of 1.00 m;
- It can be installed in non-traditional streets;
- The travellator system required streets with a minimum radius of curvature of 25.00 m.

Figure 3.1.8 Bicycle travellator detail. Source: www.boredpanda.com

Stairs

- The U-shaped concrete canal needs a minimum distance of 20 cm from the sidewall to allow the passage of bicycles;
- It's better to use a U-shaped canal than an L-shaped one. The L-shaped canal forces the cyclist to push his bicycle obliqually;
- The metallic canal can be used for both concrete and metallic stairs;
- It's important to have a surface that creates friction to allow a comfortable uphill and downhill pushing the bicycle.

Figure 3.1.9 Bicycle concrete canal in Monza railway station. Source: www.ilcittadinolomb.it

3.1.2.2 "Transportation in the favelas of Rio de Janeiro", Lincoln Institute of Land Policy, 2013

Written and brought about by by Jacob Koch, Luis Antonio Lindau and Carlos David Nassi for the Lincoln Institute of Land Policy in 2013, "This paper presents findings on transportation patterns in the slums of Rio de Janeiro, based upon a survey of 2,000 residents in three favelas of diverse typology and geographic location.

"The study aims to fill a gap in the academic literature on transportation in informal or slum areas." The research project was motivated by the lack of data available on the issues of transportation in the favelas, while the Morar Carioca program was strongly focused on investments in mobility with the objective of creating an "Integrated city".

Because of the gaps in the academic literature on said topic, the methodological approach used by the researchers was not standard. Firstly, this study's aim was to focus on selected case study locations with specific characteristics rather than look at the poor urban landscape more generally. The general approach used for the research took in account a wide spectrum of key questions on transportation to highlight different possible patterns.

The first phase consisted in designing a research survey which could compare results taken from the favelas and the metropolitan region of Rio de Janeiro which could answer two main issues: the travels within the favela and the travels outside the favela in the

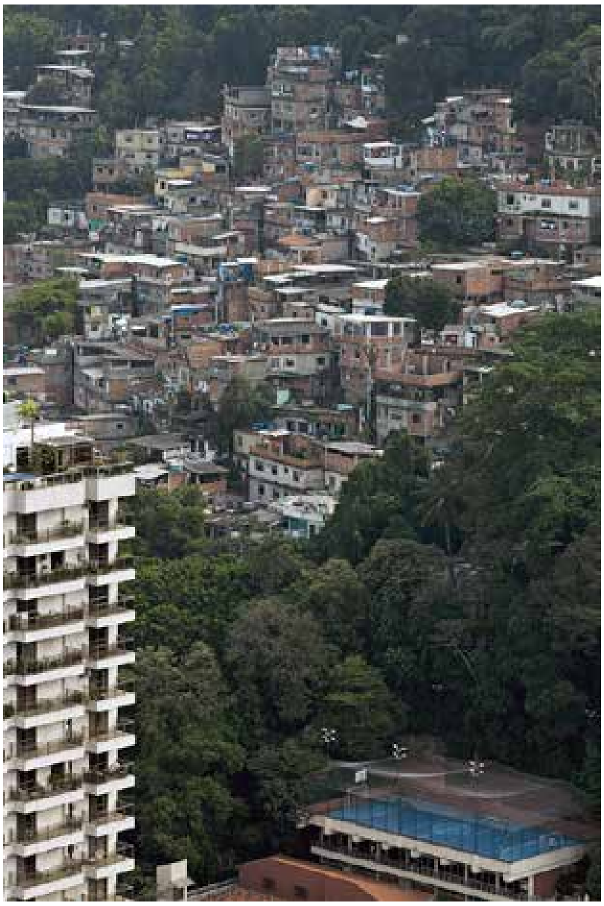


Figure 3.1.10 The Babilonia Chapeu Mangueira favela. Source: www.area-arch.it

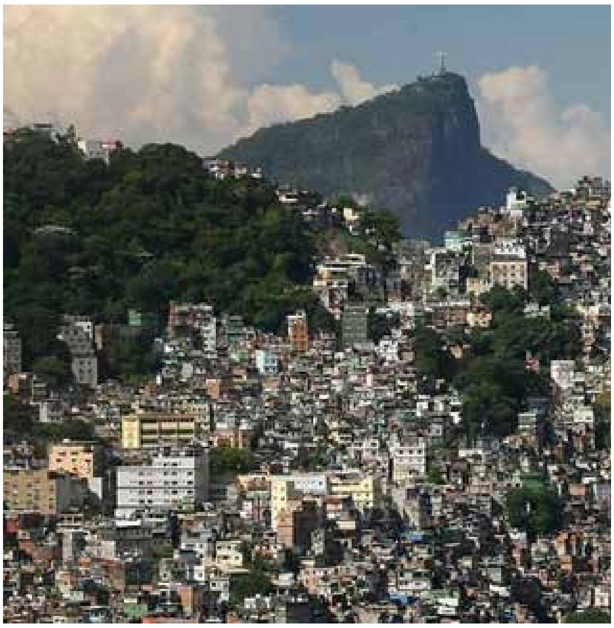


Figure 3.1.11 The Complexo da Penha favela. Source: www.oglobo.globo.com

formal city, to understand people's habits on a daily basis.

The second phase consisted in the sample selection, which was particularly difficult because of the uniqueness of each settlement in terms of history, age, geography and topography. In the end three samples were chosen based on the city's favela classification system, grouping all the settlements in three categories: isolated favela on a hillside; isolated favela in a flat area; "complexo" of favelas. The researchers chose Babilonia - Chapeu Mangueira favela from the first category; Batam favela from the second; Complexo da Penha as a "complexo" of favelas. For our purposes the first and the third samples are more interesting because they have a similar morphology when compared to Rocinha.

Then, the entire sample had been sized and it reached a total amount of 2,000 units, divided per gender and age. To reach and interview the entire sample it was very important to establish contacts in each of the communities selected through the local Residents' Associations. Once the researchers were introduced inside the communities, a pilot survey was tested in field conditions to make adjustment before beginning the data collections: for example, some filter questions were introduced.

In the end, over the course of five weeks, data taken from over 2,000 interviews were collected and analysed. Over 4,000 unique trips were captured and analysed to present different findings on vehicular ownership, modal split, mobility index, non-motorized transport, trip times and motives and hourly distribution of travel.

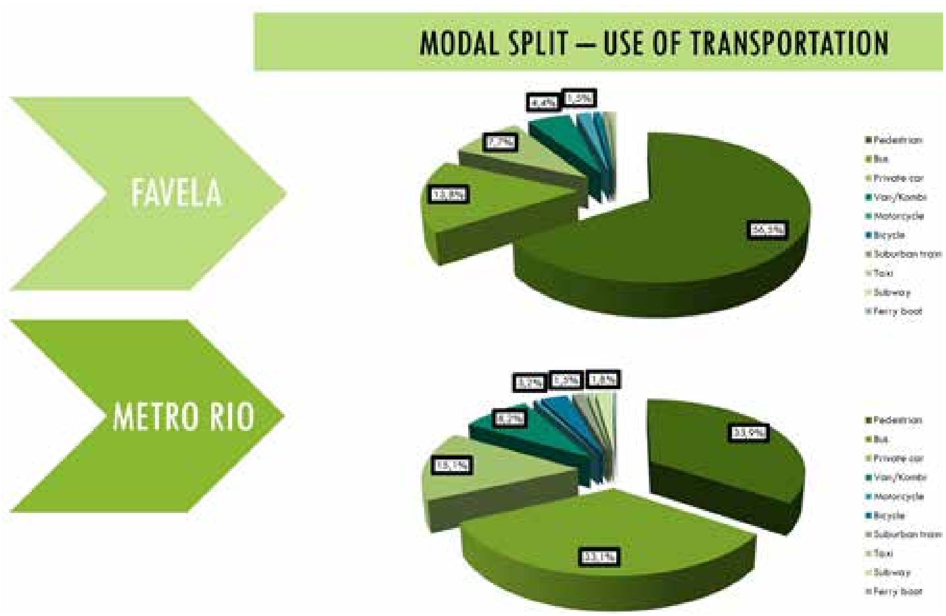


Figure 3.1.12 Modal split and use of transportation. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

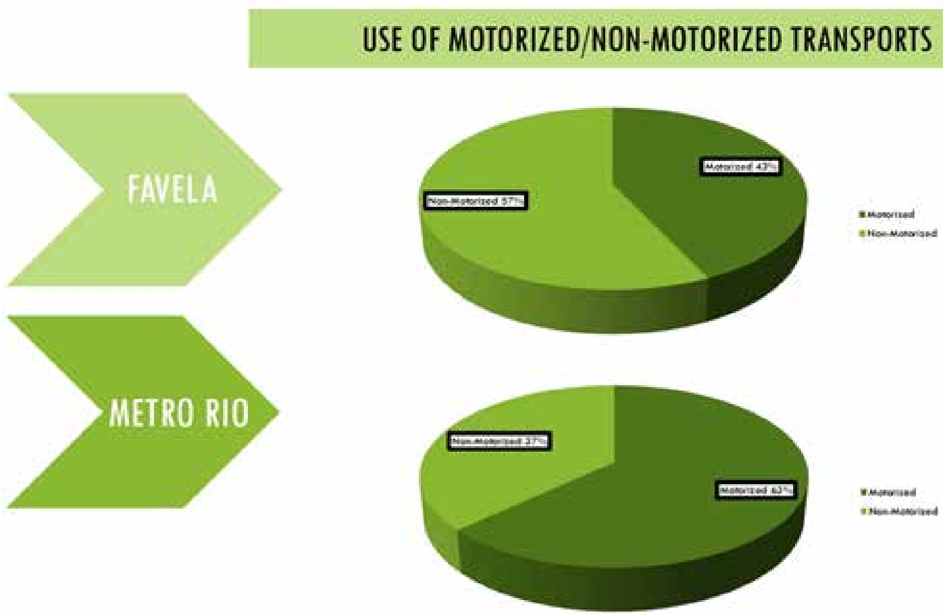


Figure 3.1.13 Use of motorized/non motorized transports. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

The primary difference lays in the number of trips made on foot, as inside the favelas it is the most common way to travel, while in the formal city buses are common such as the use of private car. Moving outside the favela introduces different modalities with over 5% of modal share.

It is no surprise that the vast majority of trips within the favelas are non-motorized (almost 91% considering only the trips made by foot), while moving outside make the inhabitants to consider more options, most of them motorized. Introducing the Mobility Index as the number of daily trips per person (which will be useful for further analysis), it has been found that the non-motorized trips present a higher value than the motorized ones.

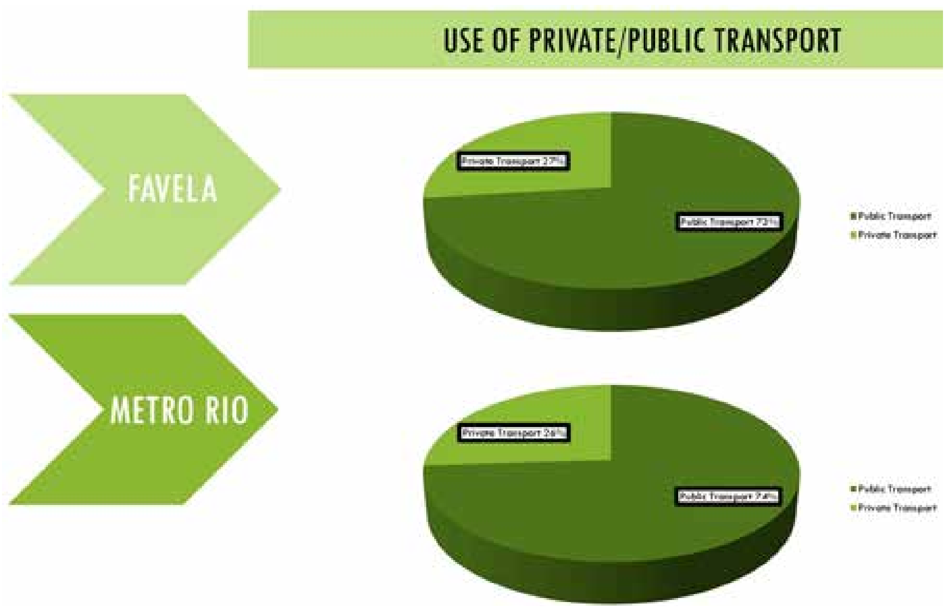


Figure 3.1.14 Use of private/public transport. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

Not many parameters taken as indicator in this survey show such remarkable similitude between the favela and metropolitan environment as the ratio of usage of public transports instead of the private ones. Though the reasons may be different: while inside the favelas the average time of a single trip is quite low (almost 15 minutes per trip), in Metro Rio the distances are more relevant and there is more general accessibility to the public transport system.

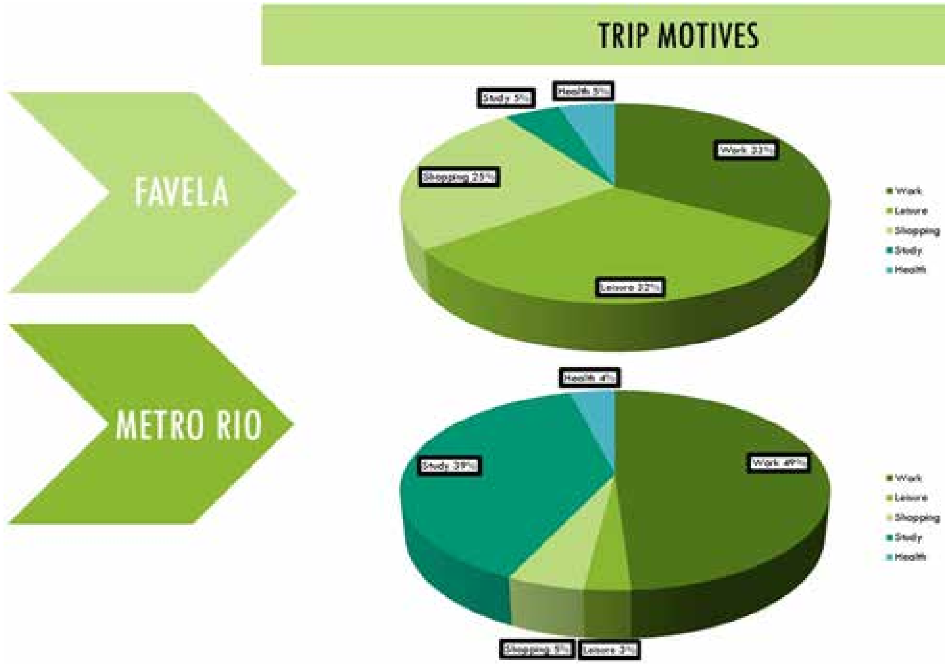


Figure 3.1.15 Trip Motives. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

These results will be discussed in detail in a further section of this chapter. It can be anticipated the fact that outside the favela the most important reason to make a trip is work, while inside the informal communities they are shopping and leisure (most of said trips are made on foot).

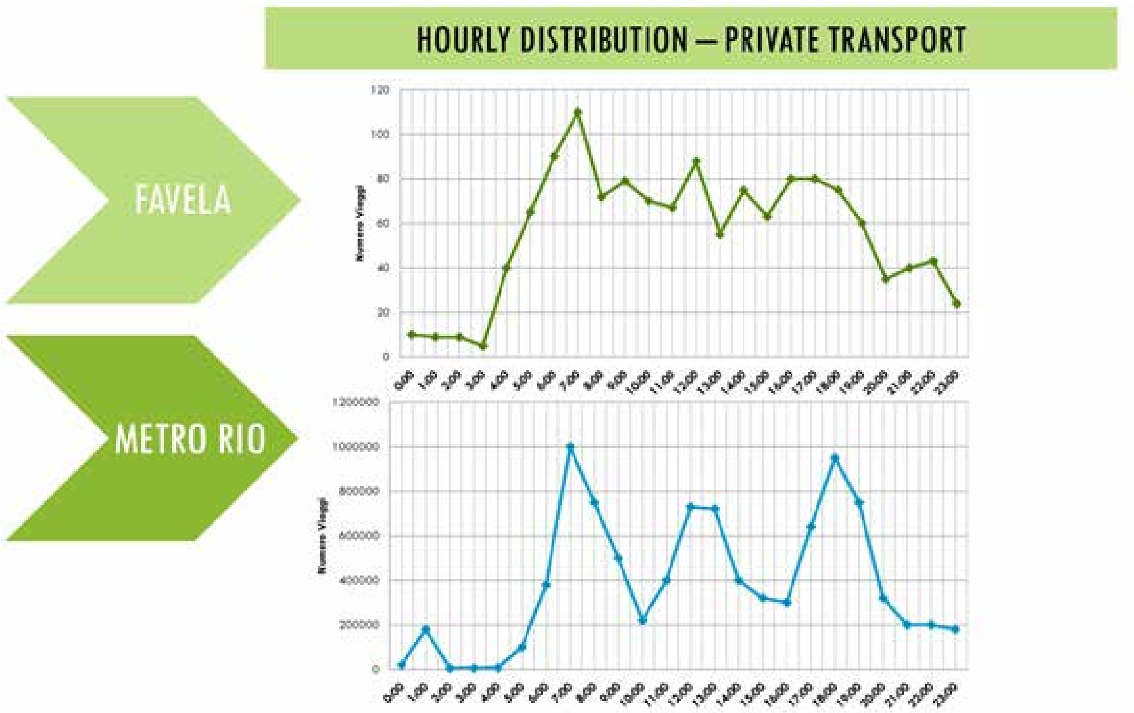


Figure 3.1.16 Hourly distribution of private transports. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

Use of individual transports peaks at the end of the typical workday, with the highest peaks around 6:00 pm and 9:00 pm. There are dips in individual transport use at lunchtime and at the beginning of the afternoon commute or rush-hour.

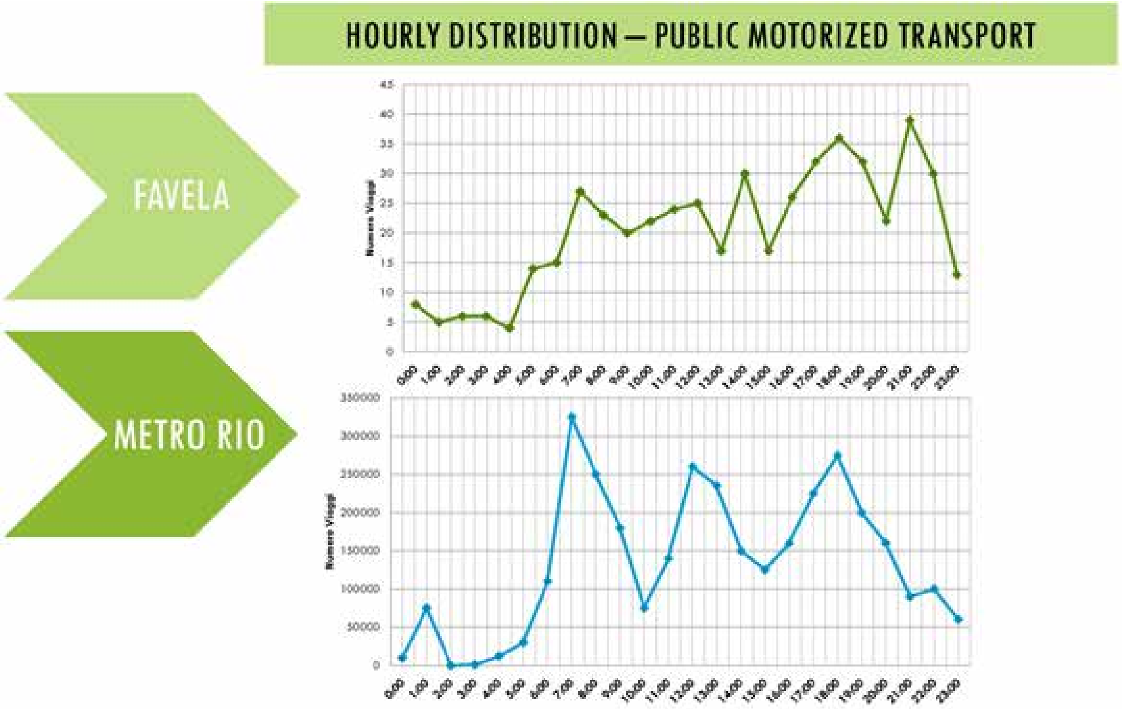


Figure 3.1.17 Hourly distribution of public transports. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

Public transport use mirrors the rhythms of the workday, with the highest peak during the commute between 6:00 and 7:00 am and peaks at lunchtime and the afternoon rush-hour.

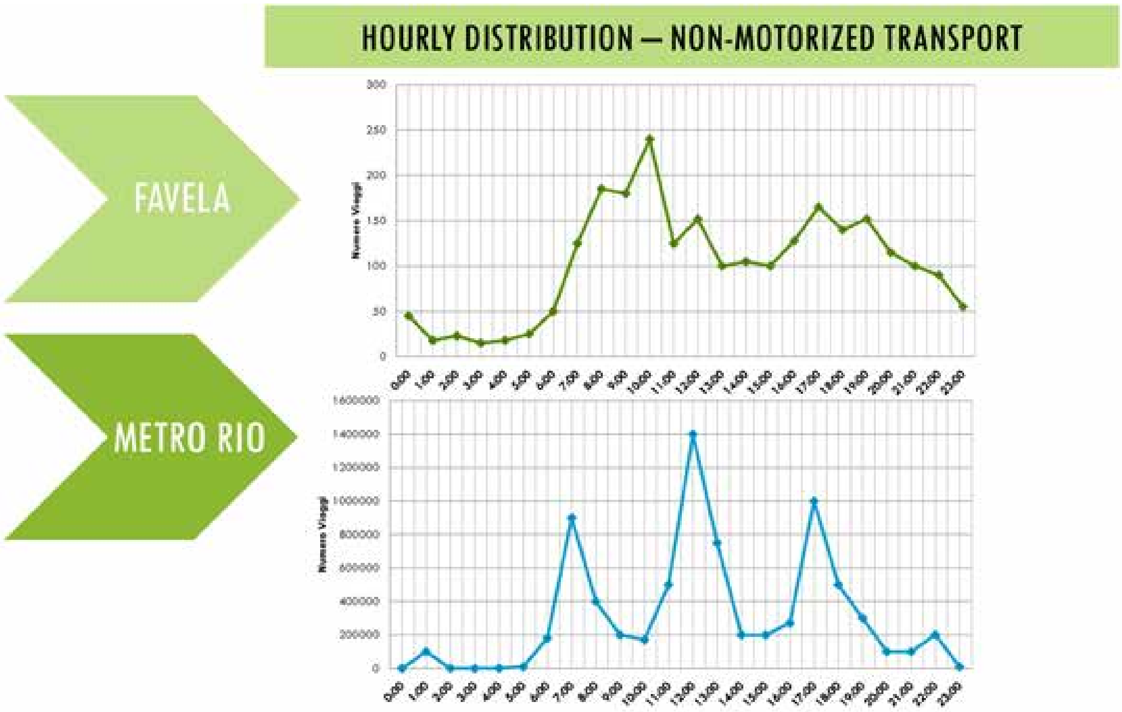


Figure 3.1.18 Hourly distribution of non-motorized transports. Source: Transportation in the favelas of Rio de Janeiro, Lincoln Institute of Land Policy, 2013

Non-motorized transport use rises throughout the morning hours, plateaus briefly at 8:00 am, and reaches a peak around 9:30 am. There is a brief early lunchtime peak and then peak levels from 4:30 pm to 7:30 pm.

At the end, numerous results regarding the statistical habits of transportation inside the favelas had been found, dividing the sample by gender, age and community of origin. In general, the most important results of this paper for our purposes are:

- Favelas' residents are used to walk more than using other transportation methods and in general they use more non-motorized transportation systems;
- Higher mobility indexes in the Metro city of Rio for motorized transportation systems, the opposite result for non-motorized systems;
- Access time for the public transportation system is higher in favela, but lower for the use of private transport.

The paper concludes its analysis suggesting possible future studies to upgrade the information on the favela environment and to improve the general accessibility of the communities towards the formal city:

- Interventions focused on supporting the non-motorized systems;
- Great potential on implementing bicycle systems inside the favelas;
- For safety reasons, ensure speed limits for motorized vehicle;
- Focus on the parking situation inside the informal city.

The first two guidelines stated at the end of the paper are more relevant for our purposes, as the main goal is to design a bicycle system inside the community of Rocinha.

The documentation phase brought us positive results in terms of potentiality of the implementation of a bicycle system inside the favelas. It makes sense for us to investigate further, analysing the possible pros and cons of the possibility to enhance the use of bicycles inside the community of Rocinha.

3.1.3 Analysis phase

The next phase consists in linking all the fundamental aspects studied in the previous section to the real case scenario of Rocinha, the biggest favela of Rio de Janeiro, and adapting the possible solutions to the context in order to enhance the system performances in terms of mobility and accessibility, knowing that there is a concrete possibility of raising the necessary funds thanks to the program Rio Conecta proposed by the municipality of the city of Rio de Janeiro.

3.1.3.1 The "Rio Conecta" program

The Rio conecta program is a recent initiative proposed by the local administration in order to answer two important questions:

- How to improve streets for the pedestrians in the city of Rio de Janeiro?
- How to enhance the accessibility in the city?

According to the Municipality, 75% of the daily trips are made on the sidewalks of the entire city, but not all of them are appropriate for great flows of people. Investments on the local infrastructures are fundamental to enhance the general accessibility to the mobility system, especially for the weakest part of the population.

With this program the Municipality of Rio de Janeiro is willing to invest about R$675 million to foster micro and interconnections and improve the safety level of the entire mobility system with projects applied on a small and a big scale. Different levels of investments are applied based on the importance of the connection places to upgrade: Rocinha is considered one of the most important interconnections at a large scale, with a total budget of R$250/m2 for interventions referred to:

- Enlargement and improvement of the sidewalks;
- Implementation of bicycle systems;
- Projects of new squares;

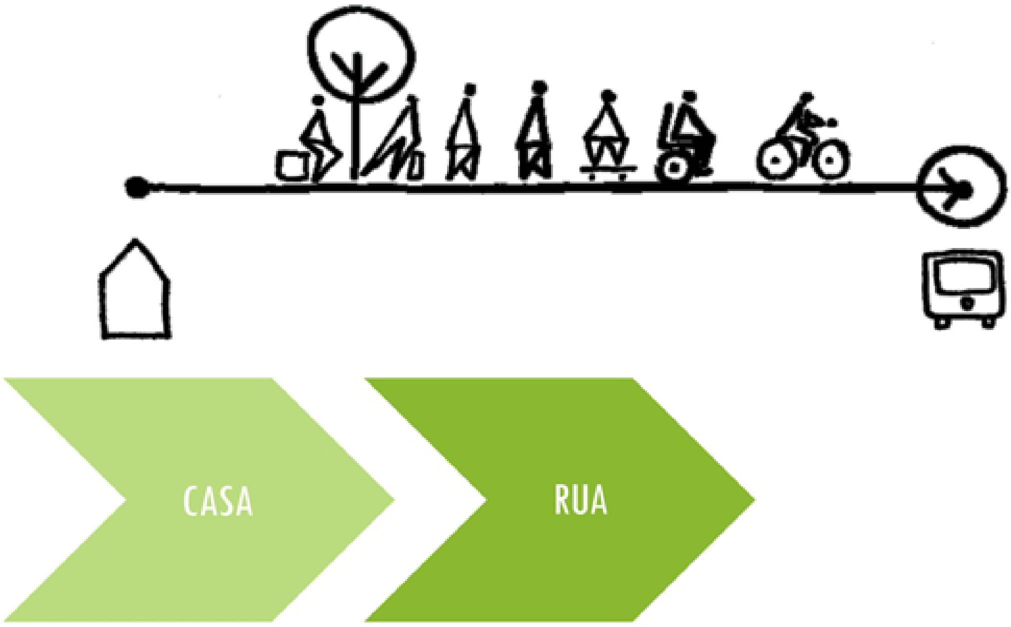


Figure 3.1.19 Connections inside the favela. Source: Rio Conecta

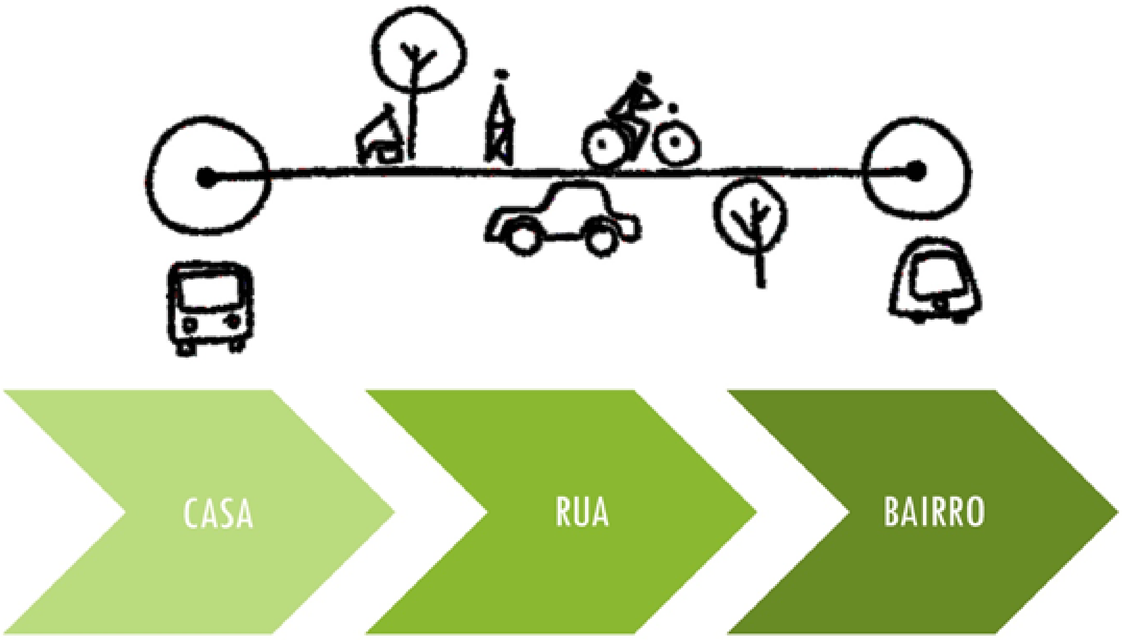


Figure 3.1.20 Connections inside the favela. Source: Rio Conecta

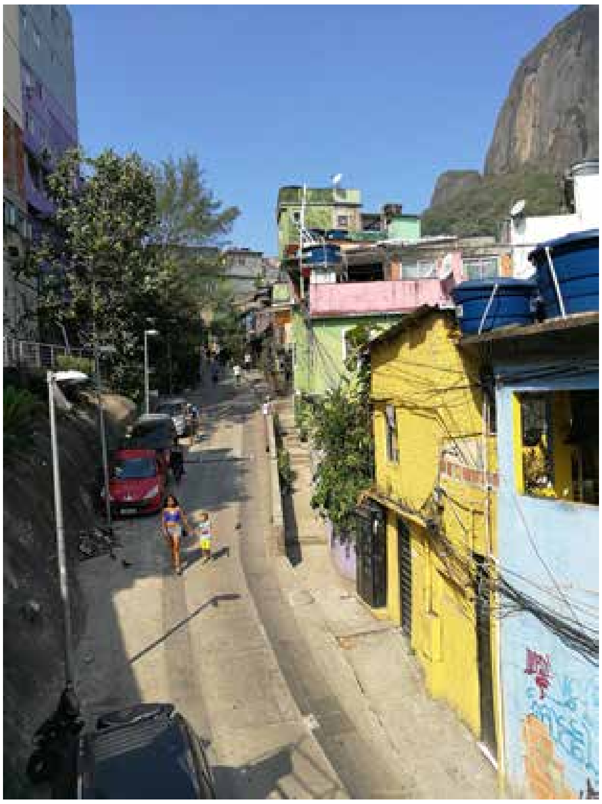


Figure 3.1.21 Rua Nova in Rocinha. Picture taken by Arianna Trombini

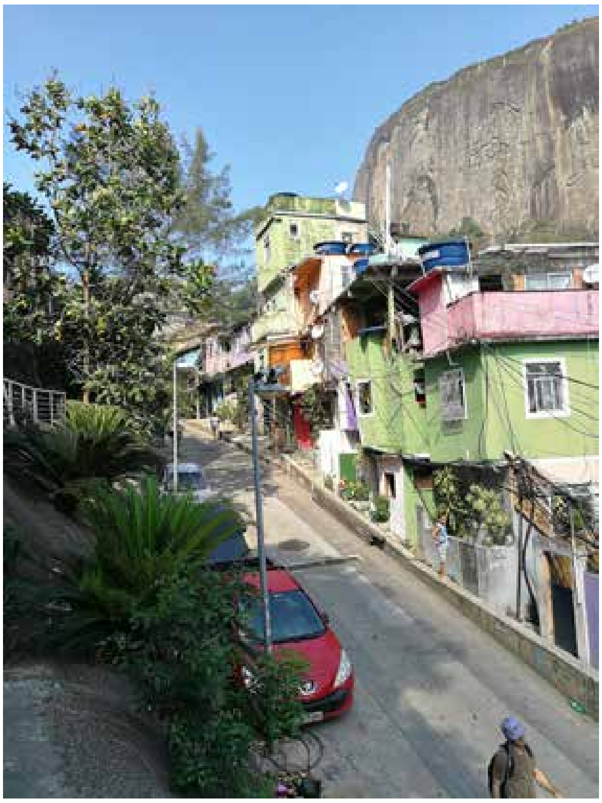


Figure 3.1.22 Rua Nova in Rocinha. Picture taken by Arianna Trombini

- Upgrading of the areas around the stations;
- Creation of bicycle racks and bike repair shops.

Those general strategies are useful to connect the subsystems “Ruas” and “Bairros” to the “Cidade”, improving the general level of accessibility for a larger number of people living in informal communities.

The main focus of this program is to work from within the communities that inhabits the favelas spread throughout the entirety of the region of Rio de Janeiro in order to connect the different microsystems of each “Bairro” to the regional macrosystem (which currently is considered good enough to serve the entire city), as the weak spot of the mobility network of the city is the general level of accessibility, the link between the micro and the macro, especially in the fringes.

Enhancing the quantity and the quality of the microconnections could reduce the time of the average access trip to the main mobility system for a larger number of people, granting a more efficient link between the scattered favelas and the formal city.

Bicycles are considered a transport system with good potential for implementation to enhance the level of accessibility to the wider mobility network of the city with relatively low costs. In the next sections the analysis will be focused on the favela of Rocinha and its morphology, since it is paramount to examine the real case scenario and the concrete chances of the implementation of a bike-oriented transportation system.

As for the former, the next step is to evaluate and quantify the benefits in terms of accessibility to the main city transportation network based on the total number of persons engaged to calculate the effective size of the cycle/pedestrian network in terms of number of bicycles to consider at the end.

Rocinha will be analysed in 2 different steps:

- The analysis of the topography of the favela, understanding the slope values of the different areas and the general level of usability of a bike also in terms of width of the streets;
- Context analysis, based on the presence of environmental opportunities to take advantage of and constraints to consider.

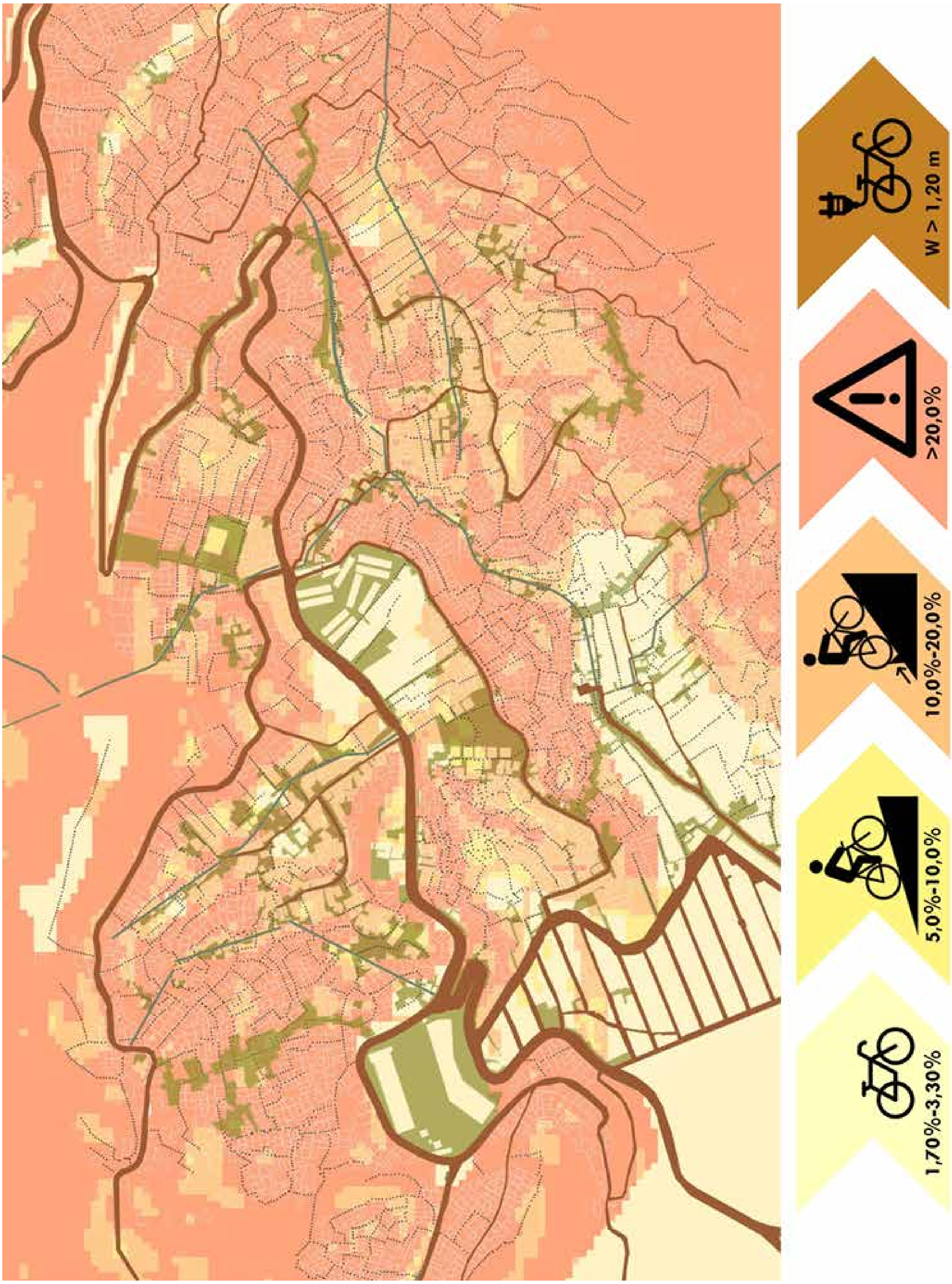
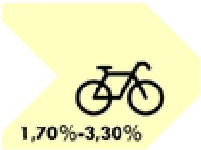


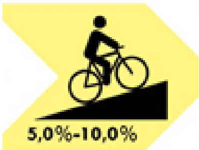
Figure 3.1.23 Terrain slope rate of Rocinha

3.1.3.2 Topography analysis

Working with a GIS file it was possible to highlight the main streets, the "becos" (narrow streets used by the inhabitants to move through different neighbourhoods) and the different slope levels in Rocinha. In the graphic representation previously shown it is possible to evaluate the level of physical implementation of a bike-oriented system with normal bicycles and e-bicycles, which are useful to overcome the slope constraint:



The neighbourhoods located in the lowest part of the favela (Bairro do Barcelos, Largo do Boiadero) are generally flat. Caminho do Boiadero and Rua do Canal are the most important streets with good possibilities of bike implementation. There is another flat area situated in the highest part of neighbourhood Rua Nova, but it is not linked with the rest of the highlighted zones.



There are few small areas with a slope value between 5% and 10% and they are not connected with each other: those are results not useful for the purposes of the general analysis.

The vast majority of the principal streets of Rocinha have a slope value between 10% and 20%. They could be passed through with the use of bicycles with the help of the steel sliding shoe system presented in the Embarq manual.

Apart from using the Estrada da Gávea, the most important road in Rocinha, and some secondary "Ruas", it is theoretically impossible to reach every corner of Rocinha because of its general high slope level. Some neighbourhoods have no possibility to be reached using a normal bicycle.

E-Bicycles could be useful to ignore high values of slope level, but from the analysis of the second parameter chosen (width of the streets) it stands out that the most of the "becos" present in Rocinha have a value lower than the minimum allowed.

Looking at the topography of the favela, it is possible to highlight some preferential routes which could be useful to connect different and distant areas. Those routes need to be verified with the second analysis based on the local context, but it could be seen a pattern that links four of the six zones selected for the "PolimiparaRocinha" project and, most importantly, a possible vertical connection between the lower and the higher part linked to the entrance of the "Parque Nacional da Tijuca" located in the neighbourhood Vila Laboriaux.

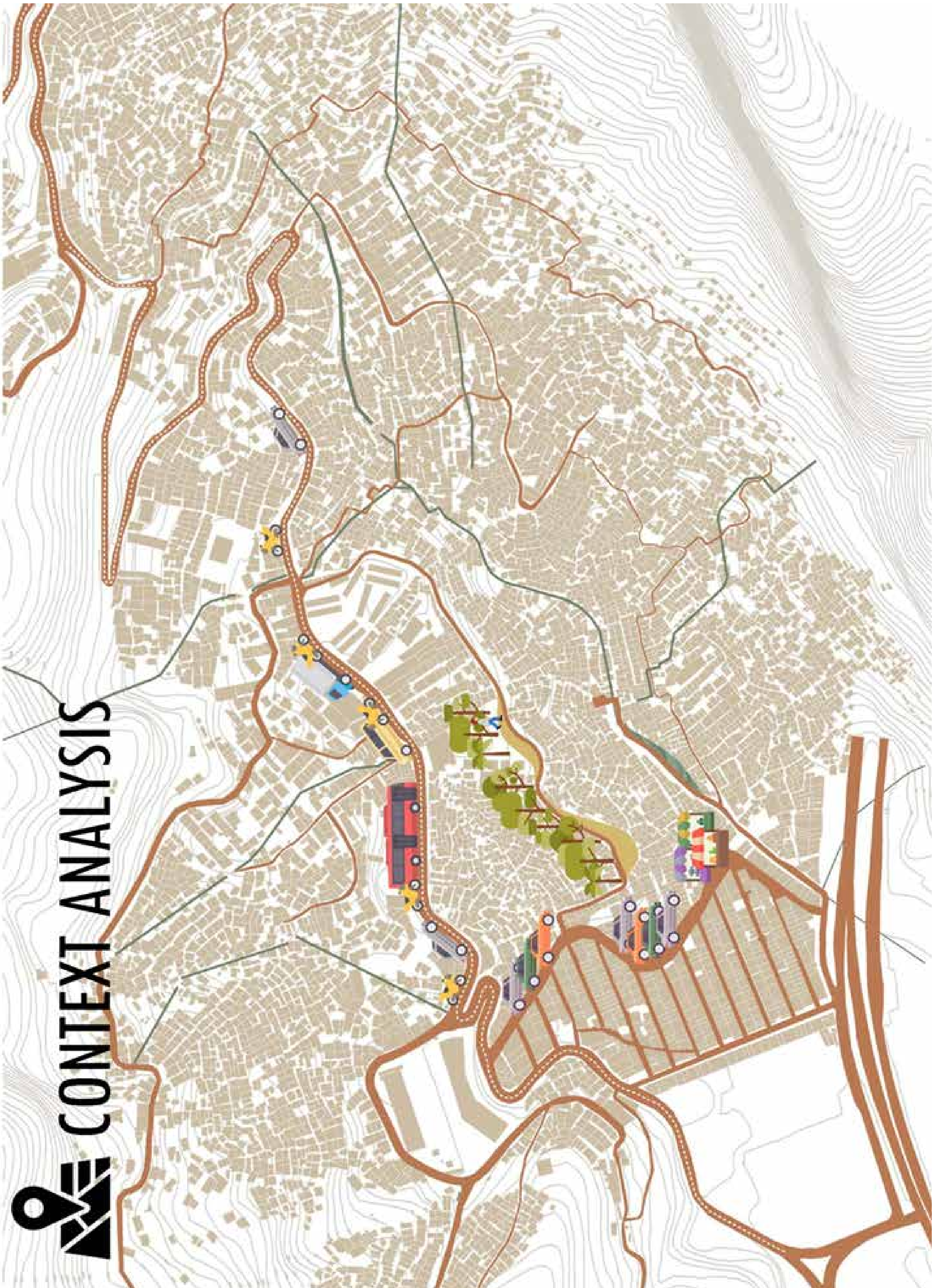


Figure 3.1.24 Rocinha's road network

3.1.3.3 Context analysis

It is important to understand the current situation of Rocinha not only in terms of morphology and intern mobility system, but also in terms of habits of the inhabitants and present critical issues which could affect the life of the community drastically changing its consuetude. The analysis is based on the information collected during our stay in Rio de Janeiro, directly noticing while walking inside the favela or asking persons who belong to the community and live in Rocinha. The analysis is more focused on the lower part of the favela because of the presence of most of the connection points between the community and the rest of the city and critical issues referred to them.

Figure 3.1.25 Estrada da Gávea. Source: Google Maps

Figure 3.1.26 Rua Nova. Source: Google Maps

Figure 3.1.27 Caminho do Boiadero. Source: Google Maps

Estrada da Gávea

Estrada da Gávea is the main road inside of Rocinha, used daily by COMLURB's trucks for garbage collection, buses lines 537, 538 and 539 and all the moto-taxis operating inside the favela. It is subject to intense traffic every day both upward and downward as well, with an insufficient overall width to design a cycle lane next to the great number of vehicles that usually pass through this road. Estrada da Gávea is a constraint which needs to be avoided for safety reasons as well.

Rua Nova

The old Rua 4 was renewed and enlarged during 2010's PAC, which renovated a big chunk of Rocinha, granting open space and an alternative to Estrada da Gávea in terms of mobility inside the favela. It is one of the few spots in Rocinha with the presence of vegetation. Today it is principally used by pedestrians and it has a tolerable slope level, so it has some potential in terms of implementation of a bicycle-based-system.

Caminho do Boiadero

Caminho do Boiadero is an one-way road that passes next to the Bairro Barcelos neighbourhood. It is used by cars and has almost 20 parking lots on the side of the road, but on Sundays it hosts the weekly historical "Feira" which has its heart in Largo do Boiadero. It seems to be possible to renovate this street for mobility purposes.

Largo do Boiadero

The historical square of Rocinha which hosts daily a fair with typical goods from the Northeast of Brazil. The square is entirely occupied by stands which are open every day and take part every Sunday at the historical "Feira". While the "Feira" is an important part of the life of the community and needs to be preserved, during the other days of the week it could be possible to move the stands from the square to create an open space useful to aggregate people or concentrate other leisure activities linked to the bike-oriented system. The Largo do Boiadero is an opportunity to exploit.

Rua do Valão

Situated in the lower part of the Favela, Rua do Valão is considered one of the main level streets of Rocinha. It is directly linked to Largo do Boiadero and Caminho do Boiadero, creating a sort of track which has a good potential of being implemented with a bicycle system. There is an important critical issue to face: the presence of the canal which gives the name to the street. Those canals are normally used by the inhabitants as garbage collectors, with all that imply in terms of sanitation.

Most of the main streets of the favela have the potential to be used to create a bicycle system with proper local solutions which could improve the current situation. Excluding Estrada da Gávea, which is too risky for the safety of the inhabitants and cyclists, the two analyses paint a situation where it is possible to design a lower slow mobility track which links the vast majority of the flat "bairros" and also a vertical connection in Rua Nova in order to connect the Portão Vermelho neighborhood with the more vibrant lower part of Rocinha.

With the assistance of e-bicycles and the presence of less traffic in the highest section of Estrada da Gávea, it is reasonable to plan for a connection through Rua Maria do Carmo with Vila Laboriaux, a neighborhood situated on the slopes of the "Parque Nacional da Tijuca".

In the next section the focus will be moved on the real project, presenting all the local solutions with the adopted materials and the data which are analysed to evaluate the actual benefits of the implementation of a bicycle-based-system.

Figure 3.1.28 Largo do Boiadero. Source: Google Maps

Figure 3.1.29 Rua do Valão. Source: Google Maps

Figure 3.1.30 Vila Laboriaux. Picture taken by Arianna Trombini

3.1.4 Project phase

Here is presented a graphic scheme of the project which summarizes all the key aspects taken in account during this phase and some values which are the results of the data processing and the design of the local solutions presented in the following sections.

3.1.4.1 Draining pavement

For the implementation of a bicycle lane inside Rocinha it was decided to use a solution based solely on a special epoxy resin and river stones, sand or recycled glass to enhance the draining performance of the favela soil. For the purposes of this study and to deepen the subject up to the practical aspects, it was decided to refer to a specific product currently on the market which responds to the minimum technical requirements: it was decided to implement the Aquastone© solution. This solution combines a 100% permeability of the soil with a high value in terms of mechanical resistance (ideal also for roads and cyclable streets).

Figure 3.1.31 Aquastone© tiles' granulometry. Source: http://www.aquastone.info

The product takes the colour depending on the type of stone used, so there is a wide range of choice which permits to differentiate the routes and signal the presence of a bicycle lane. In terms of methodology it is important to differentiate the two main phases: the preparation and verification of the base and the preparation and application of the aggregate.

Preparation and verification of the base

1. The first phase consists in the excavation of a 30 cm deep groove, due to the presence of both the drainage and the sewerage systems. The soil at the bottom must be levelled and compacted mechanically. Finally, a geotextile membrane of about 200 g/m2 is laid down to avoid unwanted infiltrations into the rocky terrain of Rocinha and direct the drained water to the correct path.
2. The second phase consists in applying delimitation guides made of steel or concrete to avoid displacements and allow the base gravel to be confined under the pavement's own weight.

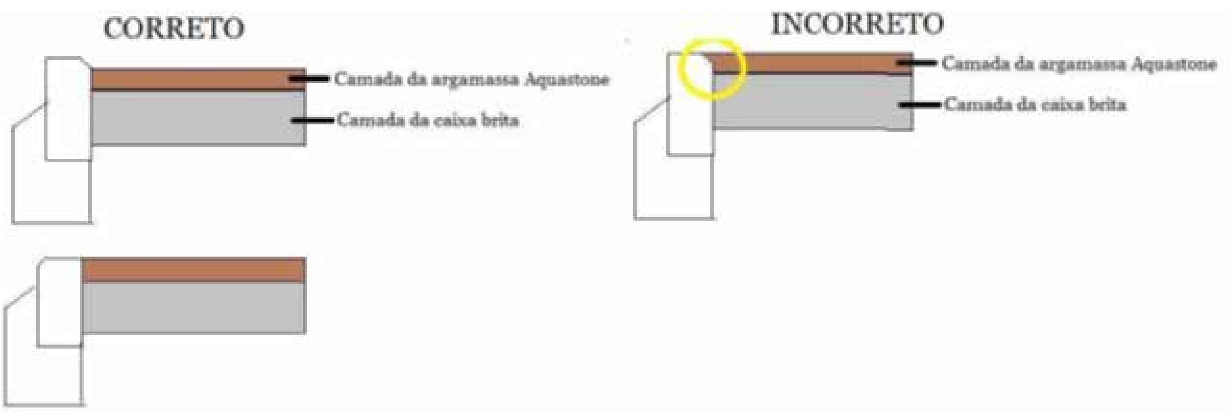


Figure 3.1.32 Correct application of delimitation guides. Source: http://www.aquastone.info

3. The third phase specifies the correct material stratification under the draining pavement.

Figure 3.1.33 Material stratification of the pavement. Source: http://www.aquastone.info

Two layers of gravel are needed, with distinct diameters:

- 5/10 cm of compacted gravel with a medium diameter between 2 and 32 mm (10 cm if cars pas over);
- 2 cm of compacted gravel with a medium diameter between 2 and 5 mm.

A vibrating machine is needed to compact the base.

Preparation and application of the aggregate

1. The first phase focuses on the application of the correct recipe of the aggregate starting from the choice of the most indicated raw materials. An expanse of verifications need to be made before the preparation of the aggregate:

- **Verification of the stones**: it is important to evaluate the general state of cleaning, impurity and the granulometry (between 1.5 and 10 mm). Suggestions include granites, silicas, quartz, glass, marble and limestones. The most important stipulation is to use stones of alluvial origin. Marine origin stones, pozzolans and porous stones need to be avoided, as salt could affect the polymerization and high porosity values result in a greater resin consumption.
- **Verification of the weather conditions**: the outside temperature needs to be between 10° and 40° with a normal level of air humidity and the absence of rain or snow weather;
- **Verification of the material quantity and weight**;
- **Verification of the base**: the base should have the right depth to contain the right thickness of draining pavement and irregularities which should not exceed a range of 2-3 mm.

2. The mixing phase is divided in two different but sequential processes:

- **Preparation of the binder**: the binder is composed of water and epoxy resin in a 2:1 proportion (for example, 4.5 kg of binder are needed for a 100 kg quantity of stones with a granulometry between 2 and 6 mm; at the end, 3 L of water and 1.5 kg of epoxy resin are the correct quantity to mix). The two components need to be mixed for 3 minutes with a mechanical mixer set at a 5000-rpm value. At the end the liquid should have a milky colour resulting from the emulsified air. The binder consumption can be estimated considering that 0.6 kg will be needed for 1 m2 of pavement of about 1 cm thickness.
- **Preparation of the aggregate**: using a vertical mixer, it is important to lay first the stones, then the binder previously prepared. The preparation in the mixer lasts 3 minutes; after the preparation the aggregate is ready to be applied in a short time (20 - 30 minutes).

3. The application phase consists in the transportation of the aggregate and in its application

on the previously prepared base. Normally, the transportation can be done using a mechanical loader; if the local context of the favela prevents the usage of mechanical transportation, it is possible to use a wheelbarrow. The process of transportation and application is continuous due to the fast maturation time of the aggregate. The product should be mechanically or manually (with a trowel, due to the narrow spaces) scattered and scraped. The surface should be left to mature for about 12-24 hours for pedestrian streets or for 3-5 days for roads. Expansion joints need to be made every 16-20 m2. The most important value to evaluate is the paving thickness, which is determined by its utilization:

- 2.5 - 3 cm for pedestrians, bicycles and light vehicles of less than 3.5 t;
- 4 - 5 cm for light vehicles;
- 5 - 6 cm for high traffic roads.

Alternative solution

Since the cycle/pedestrian network includes not only the main roads of the favela but also the narrow alleys of the case study areas, it is important to consider an alternative solution due to logistic problems: the steep and narrow streets of the intervention areas are inaccessible for the common means used to apply a liquid aggregate. It is fundamental to study an easier to install panel system. The panels chosen are made by pebbles, fibres, cement, additives and specific dyes and grant a 95% of permeability. For the purposes of this study and to deepen the subject up to the practical aspects, it was decided to refer to a specific product currently on the market which responds to the minimum technical requirements: it was decided to implement the Limestone© solution.

Figure 3.1.34 Limestone© tiles' colour selection. Source: http://www.aquastone.info

The dimension of a single tile for pedestrian/bicycles utilization is 50 x 50 x 5 cm. The application phase is akin to the Aquastone© solution for the preparation and verification of the base part, as the Limestone© product needs a minimum of 10 cm of compacted gravel with a medium diameter between 2 and 32 mm. After the compaction phase, the installation process is easy to manage since the tiles need only to be laid down on the gravel. After the installation, the joints need to be filled with dry sand and water. The use of a rubber hammer is indicated for the correctness of the tiles.

3.1.4.2 Demographic data processing and project of a cycle/pedestrian network

The goal of designing a slow mobility network in Rocinha came from the opportunity of the RIO CONECTA program, a project structured and financed by the Prefeitura of Rio de Janeiro, whose goal is to strengthen the entire city mobility system through the development of new connections. Said connections aim to improve the general level of Accessibility and the pedestrian Safety.

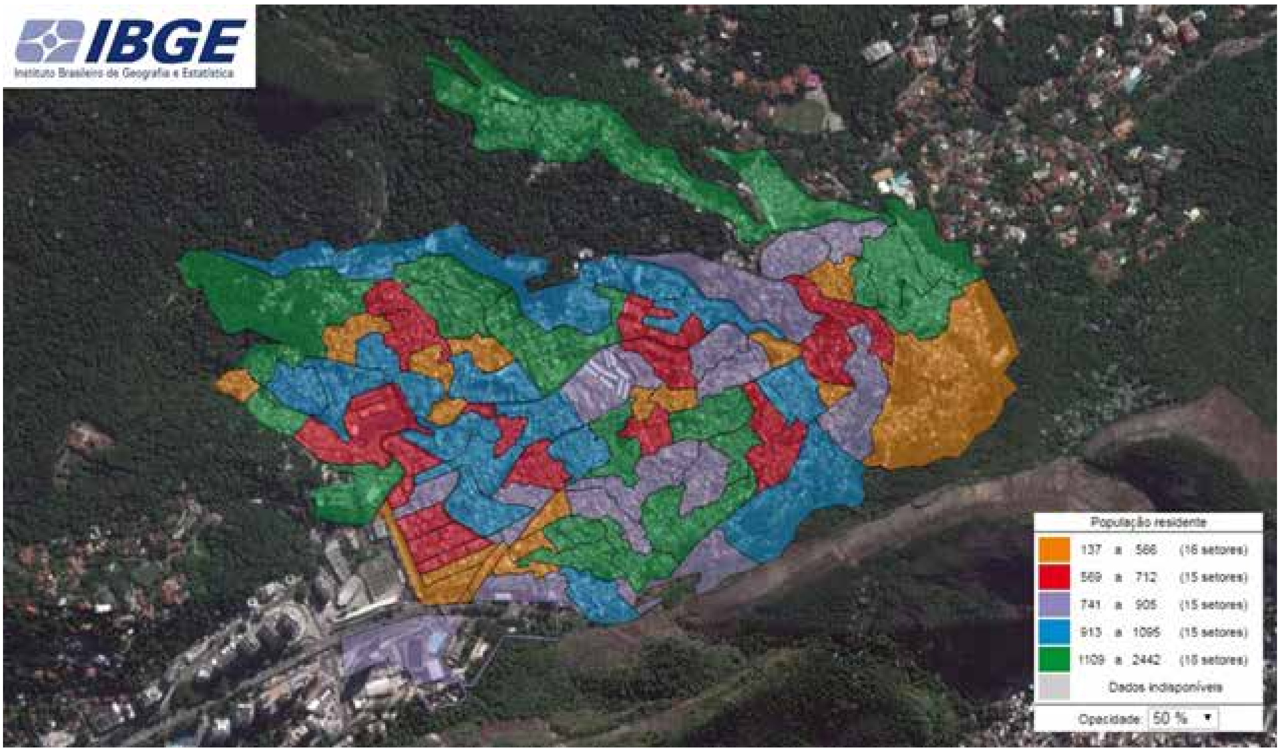


Figure 3.1.35 Population map of Rocinha. Source: IBGE 2010 census

First, it is necessary to investigate the actual potential level that a project of Cycle/pedestrian network will have inside Rocinha. This being the biggest favela of South America, it becomes complicated to implement projects improving the mobility of pedestrians, even more so due to its complicated morphology. Furthermore, to understand the internal divisions inside the community and the possible general level of engagement reached by this kind of mobility

Figure 3.1.36 The sectors of Rocinha according to the inhabitants.

system, it is very important to make a demographic study of the favela. The tool made available by the IBGE (Instituto Brasileiro de Geografia e Estatistica) was useful to collect data taken from the 2010 national census divided sector by sector.

The geoportal was useful to study different and geographically divided aspects of the population of Rocinha (age ranges, gender, literacy level, employment, ...). To avoid an excessive dispersion of the reference sample (according to the Census, Rocinha is divided in 79 different sectors), the official sectors were merged together, reducing them to the 21 neighbourhoods recognized by the locals. This kind of operation was possible only thanks to the website memoriarocinha.com.br, a web portal which collects historical documentations and photographs of Rocinha and includes a digital map showing all the names and the borders of said neighbourhoods.

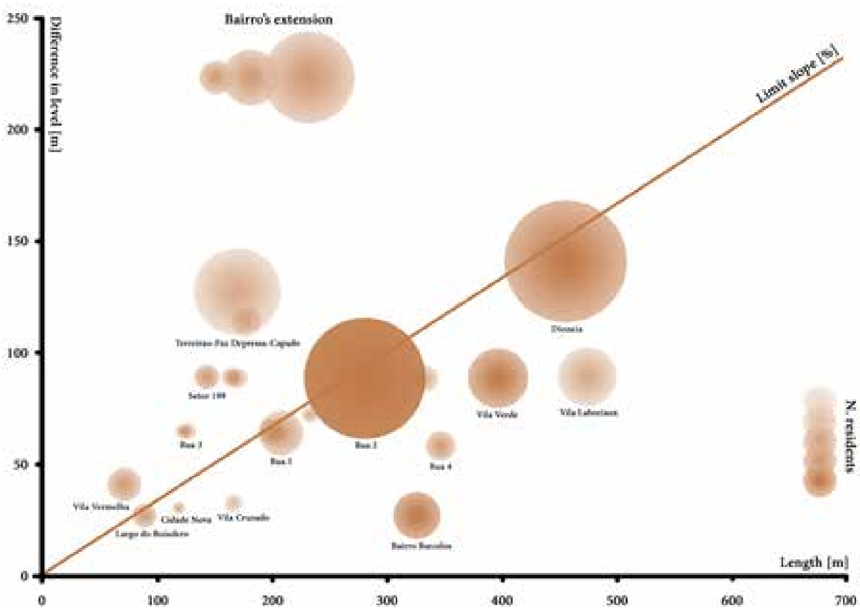


Figure 3.1.37 Sectors' slope classification

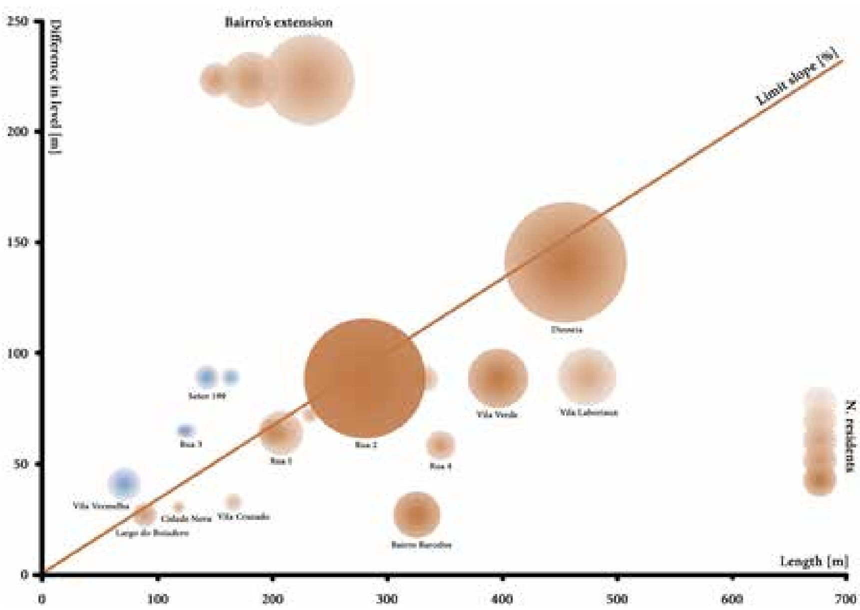


Figure 3.1.38 Sectors included in the intervention over the slope limit

Following the sampling of the residents in each neighbourhood, different analysis on the topography and the morphology were made, calculating the extension, the maximum difference in level and the medium slope of each area. Those data were useful to evaluate the Potential level expressed by the 21 neighbourhoods: crossing the samples regarding the people living in the favela who are potential users of the system and the physical characteristics is useful to understand the best places to include in the cycle/pedestrian network. Using a GIS model made it possible to highlight the streets of the favela with the highest potential to be included in the network and to exclude those areas which are not well connected to the actual mobility system inside Rocinha. Those neighbourhoods are: TERREIRAO-FAZ DEPRESSA-CAPADO, MORRO DA ROUPA SUJA and MACEGA, which are located in the south-eastern area of the favela, right at the bottom of the Morro Dois Irmãos. The graph below shows that the level of medium slope in these areas is high and that is because of their geographical position.

The graphs show which neighbourhoods of the 18 included in the design process have the most favourable condition for the implementation of the system: 13 have a sufficient level of morphological characteristics, while the remaining 5 areas (CACHOPA, CAMPO DA ESPERANÇA, RUA 3, VILA VERMELHA e SETOR 199), which are included in the cycle/ pedestrian network, have a high level of medium slope. It is impossible to expect that the bicycle will be used inside those neighbourhoods, so the implementation of bike racks and hypothetical bike sharing station will be done on the borders of the areas.

Starting from the beginning of this chapter, the general approach will present itself to be statistically correct; however, this kind of study is constrained by important limitations and force to approximate some data. The informal nature of the sample area (the entire favela of Rocinha) does not allow to have a correct estimation of the people living there: the 2010 national census counted more or less 70,000 residents inside the favela, but further studies and polls conducted by the Associations of the Residents and unofficial estimates made by other public authorities report a much higher number of inhabitants, with most reporting around 200,000 residents. The main aim of the entire project is to engineer different systems to give services to the people living inside the favela, so it is necessary to multiply the previously individuated sample 3 times, assuming that the distribution of the population taken by the IBGE geoportal remains the same. To collect more data on the resident population in Rocinha different platforms have been used: the public

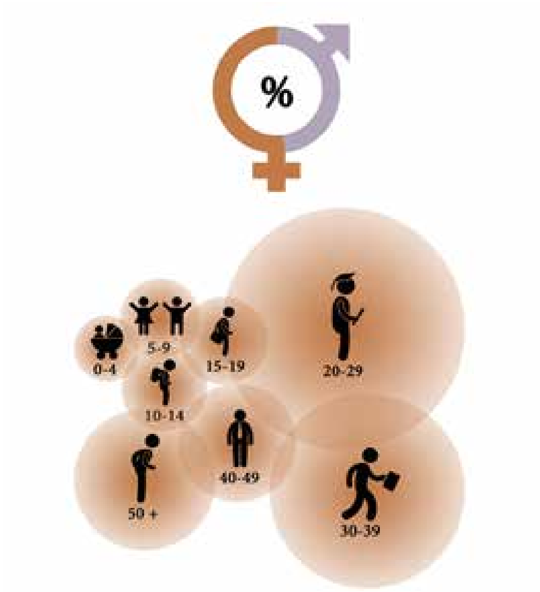


Figure 3.1.39 Rocinha’s demographics

Figure 3.1.40 Position of the three favelas analysed by the Lincoln University. Source: Google Maps

data given by IBGE and the web portal data.rio to study demographic trends; the 2013 paper published by the Lincoln University named "Transportation in the Favelas of Rio de Janeiro" to better understand the mobility habits of the sample considered.

Starting from the collection of demographic data it is possible to subdivide the population of Rocinha living in each one of the 18 neighbourhoods considered for the system in different categories based on gender and age ranges. It is possible to highlight a major presence of a relatively young part of the population (under 30 years) and exclude from the rest of the study the youngest part of the sample (0-4 years), since they can't be considered as possible users of the cycle/pedestrian system. The next phase consists in amplifying the sample. About 87% of the entire population is directly involved in the project, meaning 180,000 people subdivided in the different age ranges previously described.

It is important now to answer directly to different questions given by the designing process of a cycle/pedestrian network: knowing WHO is going to use the system and HOW MANY of them, the aim is to understand the mobility habits and trends: HOW the residents in the favela move; WHEN they make a trip considering a normal daily routine; WHY they move, so basically the motivations that push the residents to make a trip. Unfortunately, there are no official data or polls. The 2013 study published by Lincoln University is the only document which is possible to refer to. The study was conducted using a survey on a sample of 2,000 inhabitants of 3 different favelas of Rio de Janeiro chosen for their morphological differences and for the availability of the residents.

Because of its similarities with Rocinha (even if on a smaller scale), the example of Babilonia - Chapeu Mangueira is the most accurate to pursuit. For the results of this project, the major focus will be on all the results given by the sample coming from Babilonia - Chapeu Mangueira. One of the most important data to consider is the 25.3% of bicycle owners, a percentage composed by 60% of men and 40% of women and a subdivision in different age ranges as shown in the graph below:

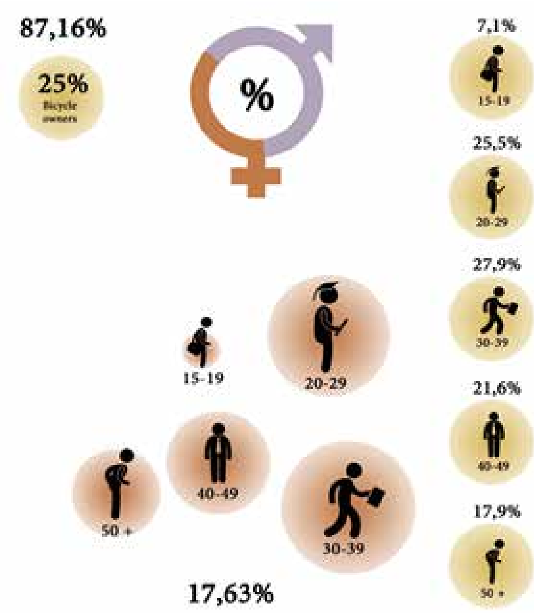


Figure 3.1.41 Babilonia-Chapeu Mangueira's occupancy

It is possible to evaluate the general level of potential possessed by the entire system for the section of the sample population composed by bicycle owners, the 17.63% of the total number of residents in Rocinha. To obtain that number it is necessary to apply the 25.3% value only to the sample population resident in the 13 areas previously highlighted for their sufficient morphological characteristics. At the end, to refine the sample, the data concerning the bicycle owners resident in the 5 impervious areas are excluded because it is easy to predict that in those neighbourhoods there will be a lower usage index.

Other interesting data that should be highlighted from the Lincoln University's paper are the graphs showing why the residents of the favelas move inside or outside their environment in which they live. The main reasons are shown below:

- Leisure
- Work
- Study
- Shopping

Each part of the population taken in account has its own habits. Through the analysis of these habits, it is possible to draw a table showing the single statistical trends. To make the analysis more realistic, work and study mobility habits are divided in inside and outside trips: that is because inside Rocinha it is possible to find only primary or first grade secondary schools, which guarantee education for children until the age of 14; for those who wish to continue their studies until 19, or to enrol in an university, the only way is to move outside the favela. Concerning the work motive, it is important to distinguish the inside workers from the outsiders, as the latter are statistically composed by a large number of people. The coefficient reported in the table will be useful afterwards in order to determine WHEN the residents make their trips within a daily routine. This kind of analysis is useful to understand better the general potential, the overlapping effects and the possible critical issues of the system.

Figure 3.1.42 Reasons for travel and age division

The following analysis transfer the data of the people who make up the sample to a general value which is more useful for dimensioning the system: the number of daily trips per person. This kind of statistics allows to better understand the number of daily trips inside an informal context and to design the correct number of stations, racks and bicycles which are parts of the bike sharing system that we want to implement inside Rocinha. Crossing all the data of the daily trips and the habits of the residents it is possible to represent with a good accuracy the daily routine of the cycle/pedestrian network usage, answering all the questions previously showed and understanding better the potential and the critical issues of the system. To transfer the data from the number of people involved to the number of daily trips, it is necessary to introduce the mobility index value, a special coefficient calculated differently for the inside and the outside trips that shows the average number of daily trips made by a single person. The mobility index value is divided between motorized and non-motorized trips: the Lincoln University's paper shows that inside favela settlements most of the trips are made on foot and that bicycles are used very rarely, because of the morphology of Rio de Janeiro and the lack of a cycle/pedestrian network which could boost bike usage. Considering the outside trips, the situation is overturned, with most of trips made using motorized vehicles, while the bicycle usage remains low.

Another limit which is necessary to consider is the lack of knowledge on how to ride a bicycle, as only 80% of favela residents can ride a bike. This value lowers and refines the reference sample of possible users of the cycle/pedestrian network of about 20%. Referring those data to Rocinha, it is possible to notice that on a potential 60,000 daily movements poll of bicycle owners only about 1,100 trips are made riding the bike, about 1.82% of the total. To better understand the potential advantages of designing a cycle/pedestrian network inside Rocinha, considering the refined sample of potential users, it is important to notice that over 297,000 non-motorized trips are made inside the favela daily; this number lowers to about 250,000 if the 80% value previously shown is considered. Currently, this project could involve about 20.40% of the total (24.25% if the lack of educational programs is taken in account). These results show that the implementation of educational programs based on boosting the bicycle usage could be useful to increase the potential poll of Rocinha and design a system for a larger number of people.

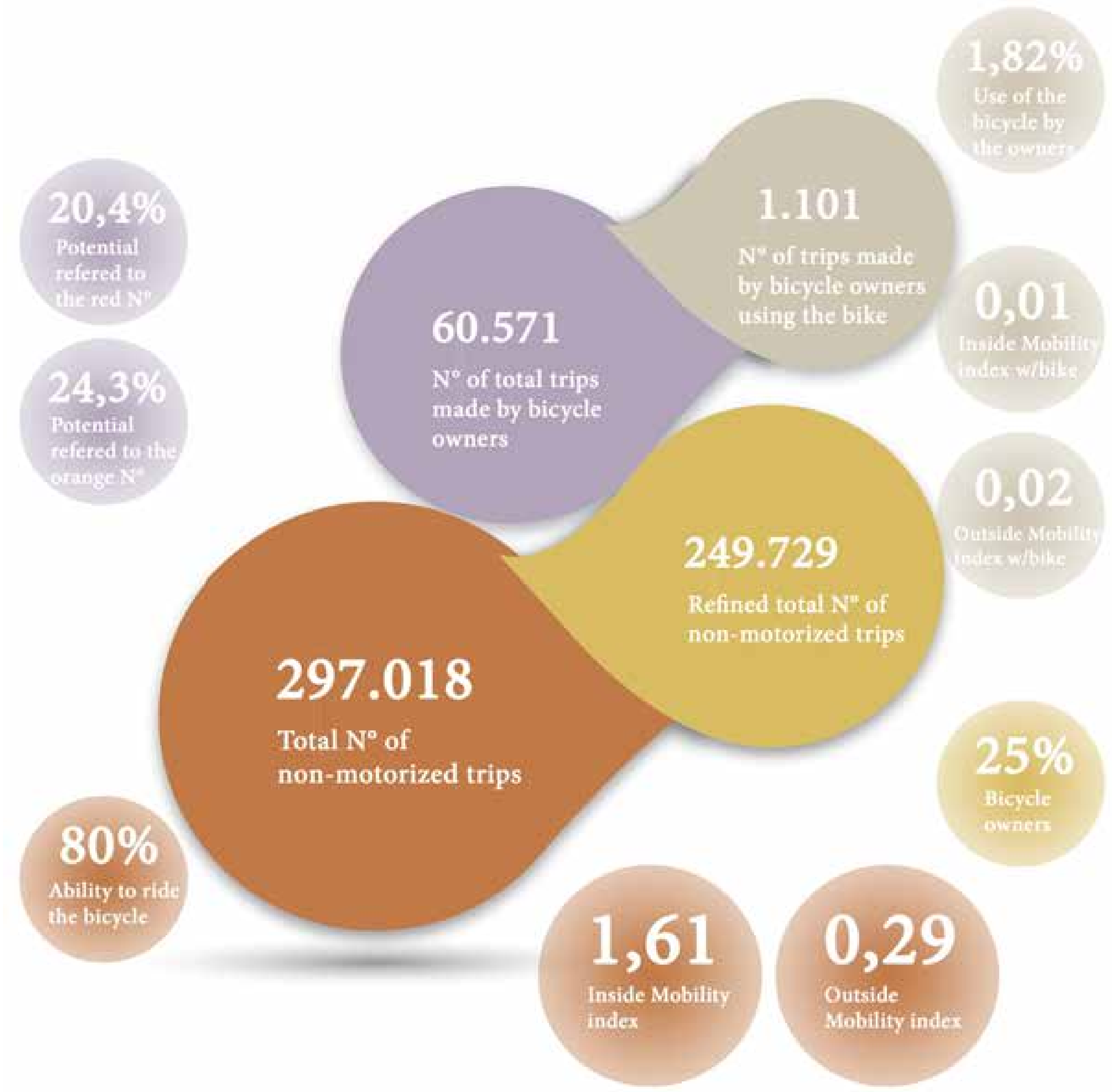


Figure 3.1.43 Analysis summary

The previous analysis leads to a first estimate of the bike sharing system dimension. Initially, a sampling of the Rocinha's entire territory is needed to locate the positions of the racks. Understanding the influence area of each station is not a simple task because of the morphology of Rocinha and its quite high average value of slope. To proceed it is necessary to analyse the coverage of the hypothetical network using circles with 100 m of radius, which is an easy distance to cover in a short time. This measure may be too strict for a normal urban context, but it is important to undersize the total influence of the system considering that the pedestrian mobility inside Rocinha is made complex by its morphology.

After the choice of the locations of the 12 hypothesized stations, the analysis proceeds with the calculation of the correct number of bicycles to implement inside Rocinha using the reference sample refined by: the application of different coefficients for each neighbourhood: the mobility index equals to 0.01 for the inside trips and equals to 0.02 for the outside trips (the actual trends); the different coefficients concerning the various habits of the Rocinha

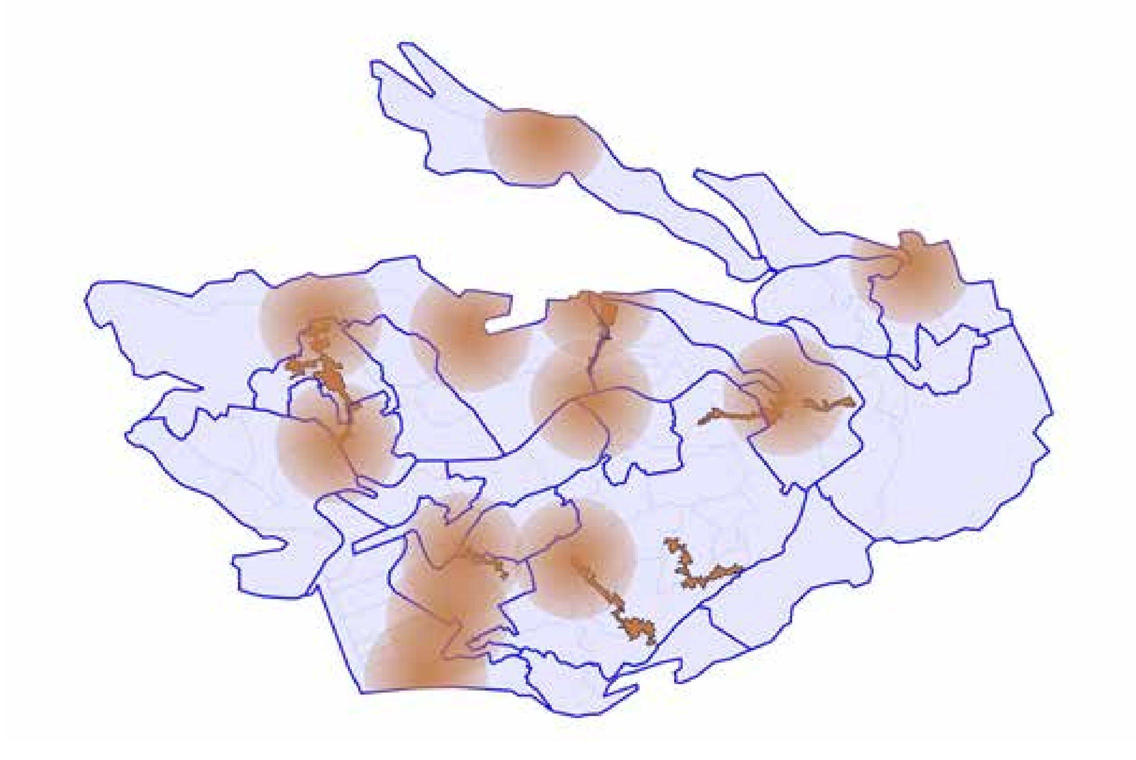


Figure 3.1.44 Slow mobility network coverage radius

population subdivisions. The 1,100 daily trips made by bicycle owners need to be subtracted from the total number, as they are more unlikely to be interested in the implementation of a bike sharing system, although the design of a cycle/pedestrian network could be generally appreciated.

In order to transfer the data from the number of daily trips to the effective number of bicycle to implement in the system, it is necessary to consult the guidelines written in the "Bike sharing planning guide", published by the ITPD (Institute for Transportation and Development Policy), an American institution which deals with the implementation inside the cities of slow mobility programs and systems. Together with the general guide, various case studies are presented and analysed, even the Bike Rio experience in the formal city of Rio de Janeiro, as to better understand how a bike sharing system should work. Unfortunately, most of the guidelines lose their effectiveness if used for a peculiar and complex system such as Rocinha or generally speaking a leaning favela of Rio de Janeiro. Analysing the Bike Rio case study, a coefficient was found and applied, representing the number of daily trips made by a single

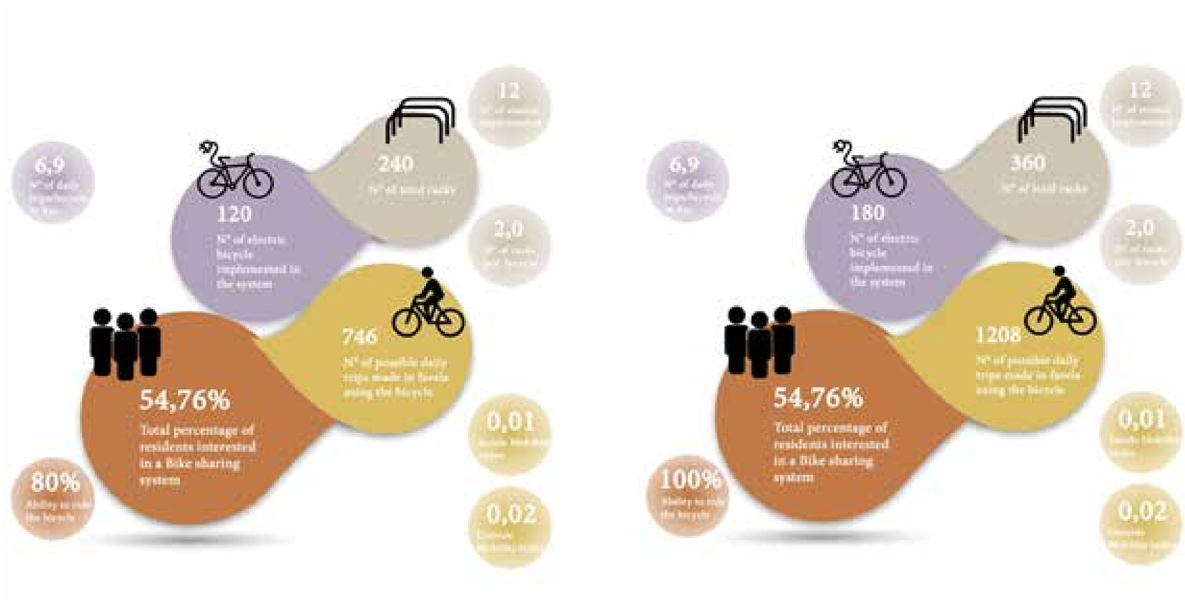


Figure 3.1.45 Slow mobility network implementation (current and 100% bike usage)

bicycle (6.9). In the end, it was possible to have a first estimate of 120 bicycle located in 12 stations, for a total amount of 240 parking spaces (a 2.0 per bike coefficient). This first dimensioning could be further refined with the hypothesis of a 100% poll (it means that everyone in Rocinha can ride the bicycle), which increases the total number of vehicles up to 180, for a total amount of 360 parking spaces. The second scenario overestimates the system because of an ideal but hypothetical condition of 100% of people knowing how to ride a bicycle, but it has a dimension that allows it to support a higher usage than expected. The general usage and tendency of using the bicycle could increase because of the implementation of educational programs in support of a cycle/pedestrian network which could be an incentive by itself. In the end it is possible to theorize a general increase of the bicycle mobility index during the years, so it is important to monitor the situation for possible future changes.

Once the questions of WHO, HOW MANY and WHY are answered, it is necessary to understand WHEN the supposed trips are made in order to realize the possible overlays between different kind of users and the risks for the people when there is contemporaneity with operations which could be dangerous for the general level of safety of the system (for example, it is necessary to know when the garbage collection happens, or even the provisioning of the businesses which are located for the vast majority in the lower part of the favela).

4 possible limit conditions are found:

- Schools in Rocinha have double time, in the morning and in the afternoon. The entrance is at 7:00 am, while the exit is at 1:00 pm and 5:00 pm;
- The garbage collection starts in the morning, between 7:00 am and 1:00 pm;
- The provisioning of the businesses starts in the morning, between 7:00 am and 1:00 pm;
- On Sunday, in the lower part of the favela, the historical "Feira" of Rocinha is held.

It is important to take in account not only the limit conditions previously showed but also another useful statistical analysis published by Lincoln University which reports the hourly distribution of the non-motorized trips. The graph shown below points out the daily rush hours, highlighting a maximum at around 10:00 am and relevant values between 5:00 pm and 7:00 pm.

Using the table of the coefficients related to the habits of the population resident in favelas it is possible to predict WHEN the different kind of trips are made, highlighting the overlays.

Figure 3.1.46 Number of non-motorized trips.

Afterwards, using the refined sample of the bicycle owners, the mobility index based on the realistic and actual situation and the hypothesis of 100% of people that can ride the bicycle it is possible to quantify hour per hour the number of trips, which part of the population makes it and WHY. In the end, it is easy to realize a proper "Bio-clock" of the entire system. To safeguard the weakest part of the population (children above all), and to avoid overlays during the rush hours, the garbage collection and the provisioning of the businesses are confined in only two hours during the morning, starting from 11:00 am until 1:00 pm.

Figure 3.1.47 Results summary

Last, estimated data taken in account to size a proper photovoltaic system for each station are shown below:

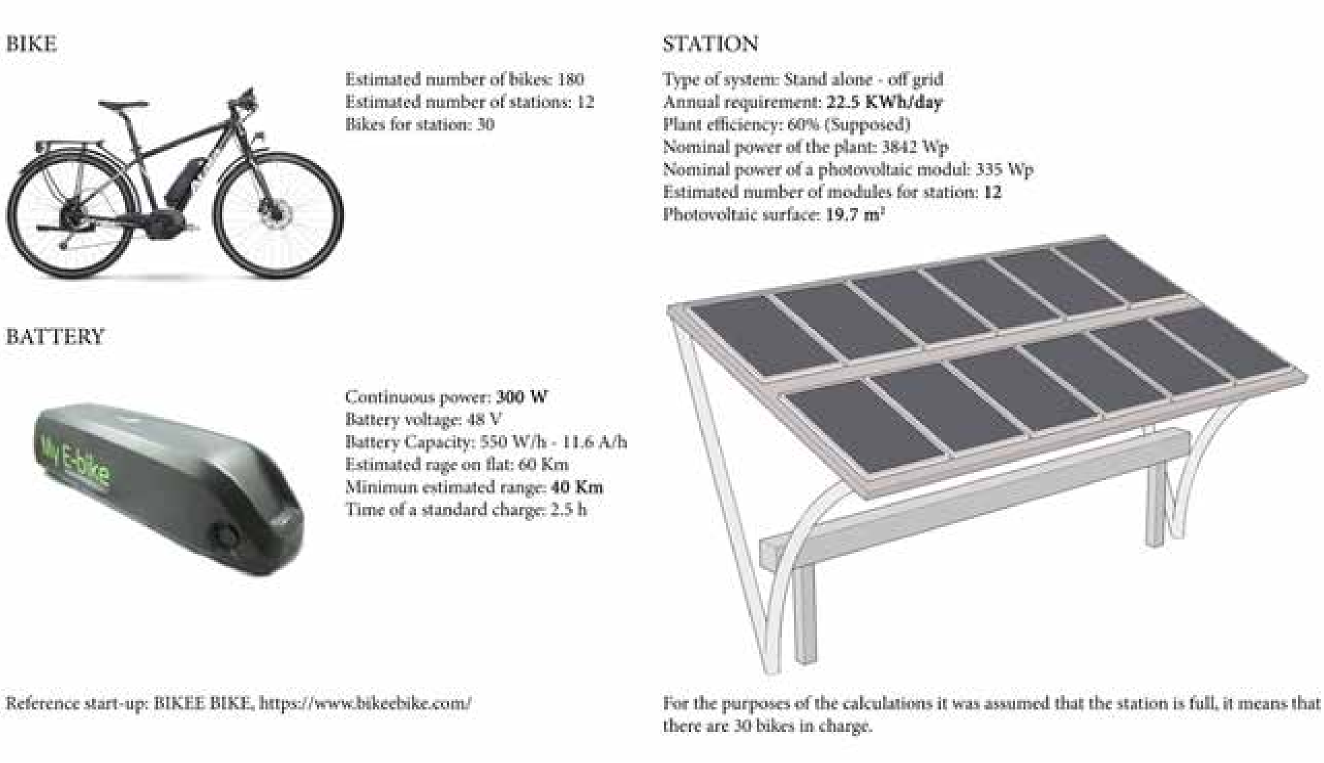


Figure 3.1.48 Photovoltaic station’s system

3.2 Energy

Figure 3.2.1 The Itapu Dam, between Brazil and Paraguay. Source: www.eoi.es

3.2.1 Introduction

Since the 1990s Brazil's energy demand has been steadily increasing, because of this, the Brazilian energy market has radically changed. The main energy companies of the country have been forced to review their pricing policy and to increase the energy costs. This increase has caused to difficulties in supporting energy expenditure for the most vulnerable social groups, despite the presence of cross-subsidies. The favela has responded to this situation with the use of informal and individual connections, called gato, to the public distribution system to keep electricity bills affordable. The gato spread to wealthy families of the favela, to formal areas and to other public services. This practice has only worsened the problem: the gato are often improvised and precarious connections to the public power grid as they are frequently cause of fires in low-income areas of shantytowns. The defective wiring, second-hand and old energy inefficient appliances and the lack of information about rational energy use are the primary cause of the increase in electricity consumption.

Figure 3.2.2 Power lines in Rocinha. Courtesy of Rachele Marchi

The abundance of solar radiation and the frequent clear sky conditions can be used to produce solar energy to improve the energy conditions in Rocinha. The aim is to fulfil basic electrical needs of low-income households and establish PV energy as a viable distributed resource to keep the electricity bills affordable as well as making legal electrical connections and serve the smart grind. The education on the correct use of electrical energy will play an important role for the success of this proposal, and the population will be educated through lessons, workshops and information campaigns.

3.2.2 Brazilian energy context

The Balanço Energético Nacional, BEN, is an annual energy balance written by Ministério de Minas, MM, and Empresa de Pasquisa Energética, EPE. It represents an essential tool for planning the activities and to monitor the national energy sector. The BEN 2016, referred to 2015 data, analyses the main energy sources utilized in Brazil and the ratio of said sources being renewable. The Anuário Estatístico de Energia Elétrica 2016, based on 2015 data, analyses instead the electrical energy consumption in Brazil, particularly the southeast region and Rio de Janeiro.

In 2015, the overall energy generated in Brazil was 299.2 Mtoe (million tonnes of oil equivalent) of

	Total generated energy - year 2015	
Energy source	**Generated energy [Mtoe]**	**Percentage of generated energy**
Non-renewable sources	**175.9**	**58.8**
Oil and oil products	111.6	37.3
Natural gas	40.9	13.7
Coal and coke	17.7	5.9
Nuclear	3.9	1.3
Other non-renewable sources	1.8	1
Renewable energy sources	**123.3**	**41.2**
Hydraulic	33.9	11.3
Firewood and charcoal	24.5	8.2
Sugar cane products	50.6	16.9
Other renewable sources	14.2	4.7
Total generated energy	**299.2**	**100**

Tab. 3.2.1 Total generated energy in Brazil. Source: BEN 2016

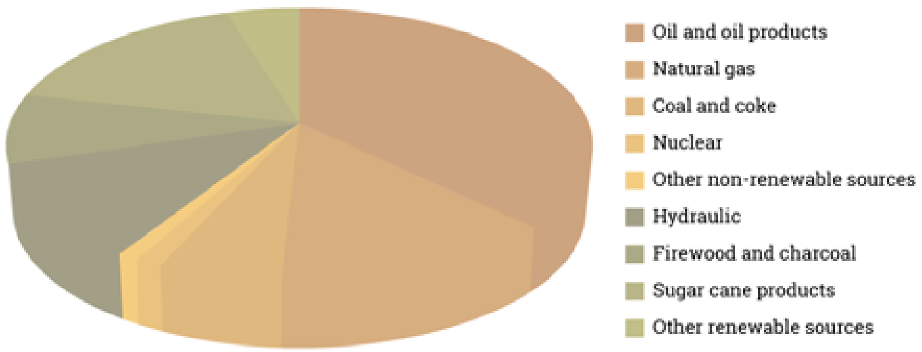


Figure 3.2.3 Total generated energy split in Brazil

which 41.2 % came from renewable sources, whereas the total energy consumption was 260.7 Mtoe. Table 3.2.1 and Figure 3.2.3, show the generated energy, in terms of Mtoe and in terms of percentage by different renewable and non-renewable sources in Brazil in 2015.

Brazil is one of the countries with the highest contribution in terms of renewable sources in its energy needs thanks especially to the huge water resources and the considerable availability of biomass. The category "other renewable energy" includes wind, biomass, biodiesel, biogas and solar, whose exploitation has grown considerably over the last years and it is predicted to continue growing from the current 41.2 % to 47 % of the total Brazilian supply in 2030, according to the National Energy Plan.

The energy consumption per capita in Brazil is equal to 1.27 toe/pop/year, considering Brazil has 205,266,000 inhabitants and a total energy consumption of 260.7 Mtoe in 2015. Table 3.2.2 shows the energy consumption per capita of each energy source exploited in Brazil in 2015, expressed in toe/pop for an easier comparison between all the different sources.

In terms of electrical energy consumption, the Anuário Estatístico de Energia Elétrica 2016,

Final energy consumption by source - year 2015			
Energy source	**Energy consumption [Mtoe]**	**Percentage of total energy consumption [%]**	**Yeary energy consumption by source [toe/pop]**
Natural gas	18.8	7.2	0.09
Firewood	16.7	6.4	0.08
Electricity	44.9	17.2	0.22
Ethyl alcohol	15.9	6.1	0.08
Diesel oil	48.0	18.4	0.23
Fuel oil	3.2	1.2	0.02
Gasoline	23.3	8.9	0.11
Liquored petroleum gas - LPG	8.1	3.1	0.04
Kerosene	3.6	1.4	0.02
Sugar cane products	28.7	11.0	0.14
Other sources (Naphta, Coal coke, etc.)	49.8	19.1	0.24
Total	**260.7**	**100**	**1.27**

Tab. 3.2.2 Final energy consumption source in Brazil. Source: BEN 2016

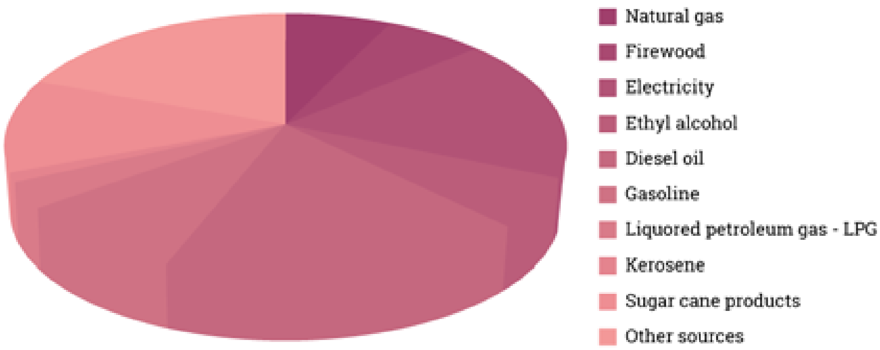


Figure 3.2.4 Energy consumption by source in Brazil

Energy consumption by sector - year 2015	
Sector	**Percentage [%]**
Industrial	32.5
Transportation	32.2
Residential	9.6
Commercial	3.3
Public	1.5
Agricultural	4.4
Energy sector	10.7
Other	5.8
Total	**100**

Tab. 3.2.3 Energy consumption by section. Source: BEN 2016

Total electrical energy generated - year 2015		
Energy source	**Generated energy [GWh]**	**Percentage of total generated energy [%]**
Natural gas	79,490	13.7
Petroleum products	25,662	4.4
Coal	19,096	3.3
Nuclear	14,734	2.5
Hydraulic	359,743	61.9
Wind	21,626	3.7
Solar	59	0.01
Biomass	47,394	8.2
Other	13,741	2.4
Total	**581,486**	**100**

Tab. 3.2.4 Total electrical energy generated. Source: BEN 2016

Energy indicator	Quantity	Rate for renewable
Total energy consumption per capita	1.27 toe/pop/year	41.2 %
Yearly electrical energy consumption per capita	2,547 kWh/pop/year	75.5 %
Monthly electrical energy consumption per capita	212 kWh/pop/month	75.5 %
Southeast region yearly electrical energy consumption per capita	2,729 kWh/pop/year	na
Southeast region monthly electrical energy consumption per capita	227 kWh/pop/month	na
Southeast region monthly electrical energy consumption per household	243 kWh/household/month	na
Rio de Janeiro yearly electrical energy consumption per capita	2,481 kWh/pop/year	na
Rio de Janeiro monthly electrical energy consumption per household	207 kWh/pop/month	na

Tab. 3.2.5 Brazil's energy indicators. Source: BEN 2016

reports an average value per household in the southeast region equal to 243 kWh/house/month and electrical energy consumptions data of Brazil, regions and major cities.

The total electrical energy generation in Brazil in 2015 was 581,486 GWh, of which renewable energy sources represent a staggering 75.5%. Table 3.2.4 shows the energy generated by renewable and non-renewable energy sources in 2015.

As it can be seen in table 3.2.4, electrical energy in Brazil is largely supplied by hydroelectric systems whose share is 61.9 % of the total electrical energy produced. The hydroelectric potential in Brazil is among the top five in the world: the country has almost 20% of the planet's water and it boasts about 11% of global hydropower production. The country's still exploitable hydropower potential is estimated at around 250 GW of installable power. Most of this potential is located in the Amazon basin, while the potential of the northern areas is still not fully exploited.

Regarding solar irradiation Brazil is a privileged country. However, the exploitation of this resource is still negligible because only 26 MW are installed throughout the country. The average

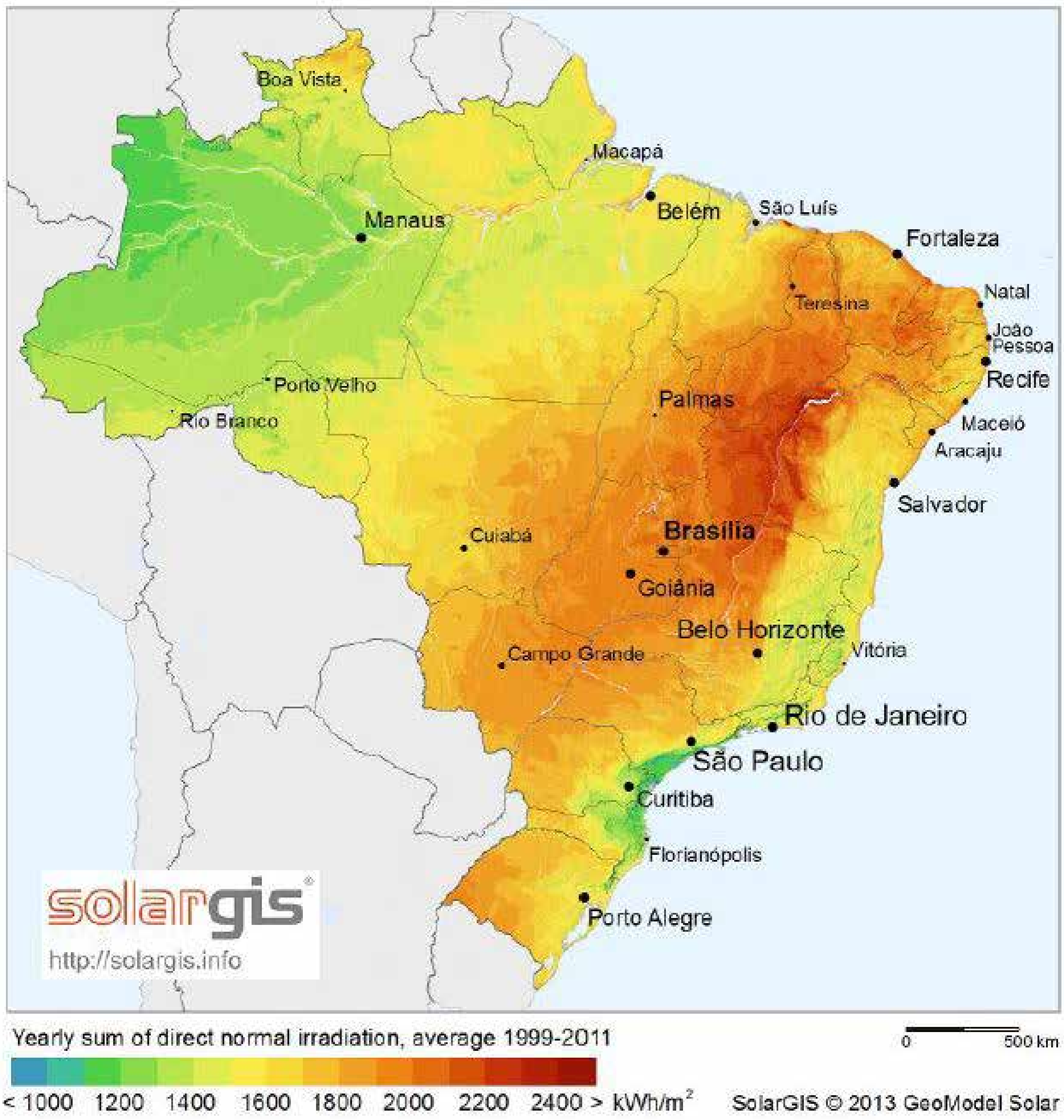


Figure 3.2.5 Yearly sum of direct normal irradiation, average 1999-2011. Source: SolarGIS

producibility estimated by photovoltaic systems is certainly very interesting: the annual solar irradiation reaches its maximum value, about 2,300 kWh/m2, in semi-arid regions of the northeast and the minimum, about 1,100 kWh/m2, in the northwest and southeast areas.

The electrical energy consumed in Brazil in 2015 was of 522,800 GWh, equal to an average yearly consumption of 2,547 kWh/pop/year or to 212 kWh/pop/month. The southeast region is responsible for half of the national electrical energy consumption, and the total electricity consumption in 2015 was of 234,812 GWh. The population living in the region is about 86,051,000 inhabitans, thus the average yearly consumption of electrical energy per capita is 2,729 kWh/pop/year or 227 kWh/pop/month.

The data for Rio de Janeiro are also in line with national data and equal to 2,481 kWh/pop/year, considering a yearly electrical consumption of 41,174 GWh and 16,593,000 inhabitans living there.

3.2.3 The energy context of Rocinha

In response to the increase in energy costs, the solution of the population of the favela has been to steal the electrical energy directly from the overhead cables, this practice called gato has caused several problems. In fact, these precarious and improvised connections cause fires in low-income area of the favela and electrical losses to the public system.

Light, Rio's local company, privately owned since 1996, distributes electricity to four million people in the state of Rio de Janeiro and this make it the fourth largest Brazilian power company in terms of client base. Because of gato practice the company has estimated the non-technical and default losses between 64.1% and 90.4%. This situation is aggravated by the fact that inside the favela the electricity consumption is higher due of defective wiring, second-hand and old energy inefficient appliances for the main end-uses, precarious electrical installations and a lack of information about the correct use of this type of energy. Securing electricity supply, reducing energy consumption, electricity thefts and unpaid bills induce energy companies to implement programs towards low-income households.

In the early 2000s Brazil adopted a performance-based regulation to ensure that fair and reasonable tariffs were paid by all the electricity customers. For households the discount is measured according to the consumption level, so if the consume is 30 kWh per month only 35% of the overall tariff is paid, the discount declines to zero if the consume is more than 220 kWh per month.

The criteria used to define a low-income consumer are based on consumption levels and connection types, but sometimes they are inadequate, for example when consumers with high income and single-phase connections are taken into account. Nevertheless, there is also a large part of the population that, despite being clearly considered low income, is unable to receive a benefit from the subsidized tariff because of its high consumption; this is demonstrated by high rates of unpaid bills.

There are no studies conducted on energy consumption; Thus, the values below have been borrowed from studies about electrical consumption for low-income households in South America. Rocinha's real electrical energy consumptions are reported in table 3.2.5.

Energy indicator	Quantity
Monthly electrical energy consumption per household	150-250 kWh/household/month
Yearly electrical energy consumption per household	1,800-3,000 kWh/household/year
Monthly electrical energy consumption per capita	38-63 kWh/pop/month
Yearly electrical energy consumption per capita	456-756 kWh/pop/year

Tab. 3.2.6 Rocinha's energy indicators. Source: PolimiparaRocinha

3.2.4 Case studies in Brazil

The Brazilian government and energy companies are forcing the transition towards the energy regulation to reduce electricity thefts and illegal connections. PV panels can be used to reduce informal and illegal connections from the power grid and they can provide an opportunity to establish photovoltaic energy as a viable and popular distributed resource to keep the electricity bills affordable. Table 3.2.6 shows some projects and initiatives on the installation of PV systems and measures to contain electricity consumption of low-income households, applied in Brazil. Some of these projects involve the installation of photovoltaic panels and the substitution of old meter, second-hand or old energy inefficient appliances to reduce energy consumption and leakages. All projects include information and training initiatives to educate the population about the social, economic and environmental benefits of solar energy and the opportunity of energy savings.

Project or initiative	What?	Where?	Project status
RevoluSolar	PV panels installation	Rio de Janeiro, favela Morro da Babilônia	Ongoing
Parque Madureira-ENGIE	PV panels installation	Rio de Janeiro, Madureira Park	Completed
LPT - Luz para Todos (Light for all)	PV panels installation (rural areas)	Brazil	Ongoing
Smart Microgrid project	PV panels and storage system installation (Microgrid project)	Fortaleza, Brazil	Ongoing
Low-Income Energy Efficiency Programs	Old appliances substitution	Brazil	Completed/Ongoing
Program for the Transformation of Consumers into Clients	Electric grid installation and electricity loss reduction	São Paulo, Brazil	Completed
COELBA Agent Project	Old appliances substitution	Salvador de Bahia, Brazil	Completed

Tab. 3.2.7 Project and initiatives for energy consumption reduction thoughout Brazil. Source: PolimiparaRocinha

One of the aforementioned projects deserve special consideration, as it shares some characteristics with the Rocinha context: the RevuSolar project. RevuSolar is a cooperative that deals with production and management of renewable energy in the community of Babilônia, a favela located in the Leme region of the city of Rio de Janeiro. The NGO was founded in 2015 by a group of six residents aiming to bring sustainable power to the people

Figure 3.2.6 Revusolar project. Courtesy of PolimiparaRocinha

Figure 3.2.7 Smart Microgrid project. Source: www.enel.com.br

of the favela in response to the rising prices of the bills. The project for this favela came about through volunteer work, involving community leaders, electricians and entrepreneurs of the "Association of inhabitans of Babilônia", the residents themselves, as well as external supporters. In addition to generating energy, the project also aims to inform and educate the local population about the social, economic and environmental benefits of using solar energy. The goal of RevoluSolar is the creation of the first renewable energy production cooperative in Brazil. The cooperative already receives the interest and support of the Organization of Brazilian Cooperatives (OCB). It also receives support from Viva Rio, the Frente para uma nova Política Energética do Brasil, the Fundação Heinrich Boell and the GIZ. As a product of the partnership with Solarize, the electrician and vice president of RevoluSolar, Adalberto Almeida, became the first solar installer in the community. The installation of the panels has been financed in part by the Agência Estadual de Fomento (AgeRio), which has offered microcredits to residents of the favela. According to the RevoluSolar calculations, the investment for the two installed PV systems will be paid in 6 years, after which the electricity produced by the solar panels will be free distributed.

3.2.5 The project for Rocinha

The proposed project requires the design of PV systems to be installed on the rooftop of the favela's buildings, not only to keep electricity bills affordable for low-income households but at the same time to create also an opportunity for a regular, secure, and economically advantageous connections to the power grid. PV systems can be further equipped with batteries connected to the power grid, to cover the electrical energy consumption of household as well as to fulfil electrical needs of city's services as public lighting, electrical vehicles for urban transportation, systems for water pumping, irrigation and water purification, etc., or simply to manage buildings' load shifting. An important key of the proposal is education. For the success of the proposal in Rocinha, as shown in the case study of the favela Babilônia, community involvement plays a fundamental role. Information campaigns, workshops and professional courses will be offered to the inhabitans of the favela, as to make them aware of the solar energy potential for the favela's energy business.

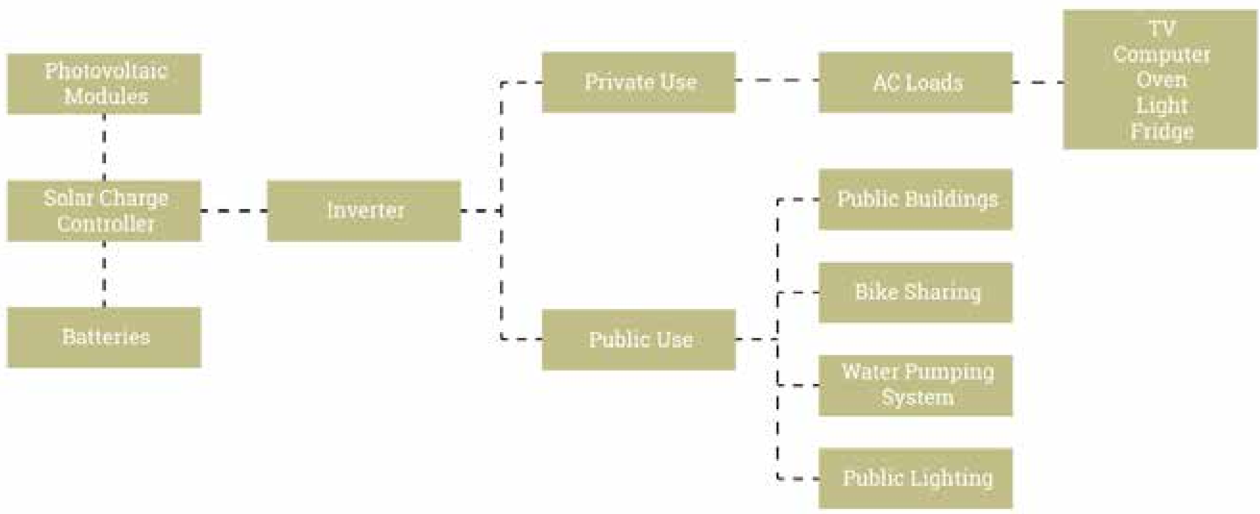


Figure 3.2.8 Rocinha intervention scheme

3.2.6 Stakeholder and financing

To deal with the situation of Rocinha, several actors as Energy companies, public authorities, university, non-governmental organizations (NGOs) have to be identified. A short overview of stakeholders, identified by the analysis of the energy companies and a previous project held in Brazil and in Rio de Janeiro is presented in Table 3.2.8.

Stakeholder	Description
ABSOLAR	Associação Brasileira de Energia Solar Fotovoltaica
Light	Energy company present in Rio de Janeiro
Enel Distribuição	Energy company present in the state of Rio de Janeiro
ANEEL	Agência Nacional de Energia Elétrica
ENGIE	Leading independent private power generator in the country
OCB	Organização de Cooperativas do Brasil
Viva Rio	NGO that builds peace, inclusion and justice with innovative projects in areas marked by poverty and violence
FNPE	Fronte para uma nova Política Energeticas do Brasil
Heinrich Boell Foundation	Legally independent political foundation, Part of the global Green political movement
Axis Renovaveis	Company specializing in photovoltaic solar energy
ABGD	Associaçao de Geração Distribuída
Catavento Consultoria	Energy consulting company
FGV Energia	Energy research center within Fundação Getúlio Vargas

Tab. 3.2.8 Pontential stakeholders for Rocinha. Source: PolimiparaRocinha

3.2.7 Intervention in Area 1

3.2.7.1 Introduction

Photovoltaic (PV) systems can offer a cost-effective mode for fulfilling basic electrical needs of households and city's services. The project foresees the design of cheap PV modules to be installed mostly on the rooftop of the favela's buildings, but also on street lighting lampposts. PV panels can be used as a way to reduce informal and illegal connections to the power grid and a way to keep the electricity bill affordable, especially for low-income households.

In fact, the Brazilian government and energy companies are forcing the transition toward the energy regulation to reduce electricity thefts and illegal connections. The installation of PV systems can provide an opportunity to establish photovoltaic energy as a viable and popular distributed resource to keep the electricity bills affordable. The promotion of solar technologies across the country will contribute immensely to poverty reduction through local communities benefiting from employment opportunities, skills development, investment opportunities and technology transfer.

PV systems can be further equipped with batteries connected to the power grid, in order to serve several public systems, as public lighting, electrical vehicles for urban transportation, systems for water pumping, irrigation and water purification, etc., or simply to manage buildings' load shifting.

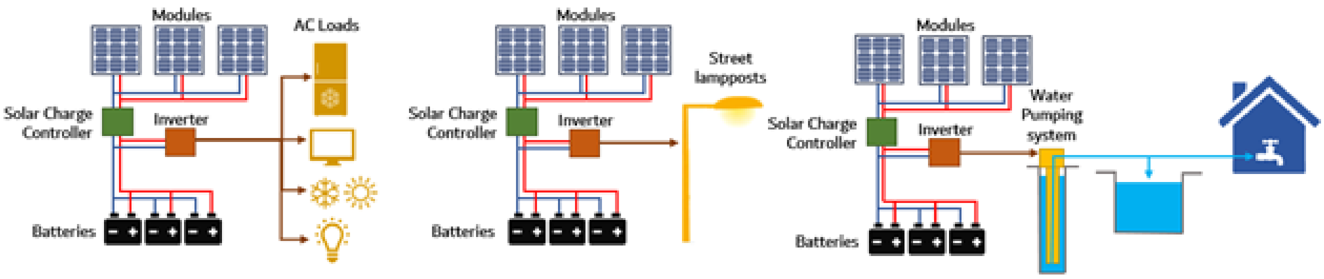


Figure 3.2.9 PV system for domestic and public needs. Courtesy of PolimiparaRocinha

To be commercially viable for low-income households, PV systems need to be cheap, safe, durable, easy to assemble, operate and manage for all. Then, the PV panel will be accompanied by a simple installation guide, that describe the components, their installation in detail, and their maintenance. Customer training will consist of informing the citizens how to operate and to optimize life and efficiency of the delivered system.

The objective is to offer a cost-effective mode of supplying electrical energy for basic electrical needs to favela's households, while at the same time creating the opportunity of regular, secure, more stable, and economically advantageous connections to the power grid, as well as several community services.

3.2.7.1 Solar radiation analysis

The first step to properly design a new smart energy grid inside Area 1 was to conduct a solar radiation analysis, highlighting the rooftops with the greatest solar potential. Since the urban landscape of Rocinha is ever-changing, with the inhabitants adding new storeys to their building as the household grows, and the addition of solar panels on the rooftop would prevent such an expansion, two criteria were used for the selection:

1. **Solar potential**: obviously, the rooftops with the highest solar potential are the priority;
2. **Height**: as the buildings with less storey are more likely to grow in the future, buildings with at least four storeys were prioritized.

Further, to encourage the inhabitants to have PV panels installed on their roofs, it was decided that the households that accepted their emplacement will have their energy load added to the grid, thus effectively covering their elecricity bill with solar energy.

This choice was made due to the realization, from several surveys and analyses of past interventions, that inhabitants of a favela are more likely to accept changes in their lifestyle when receiving an immediate and tangible benefit from it.

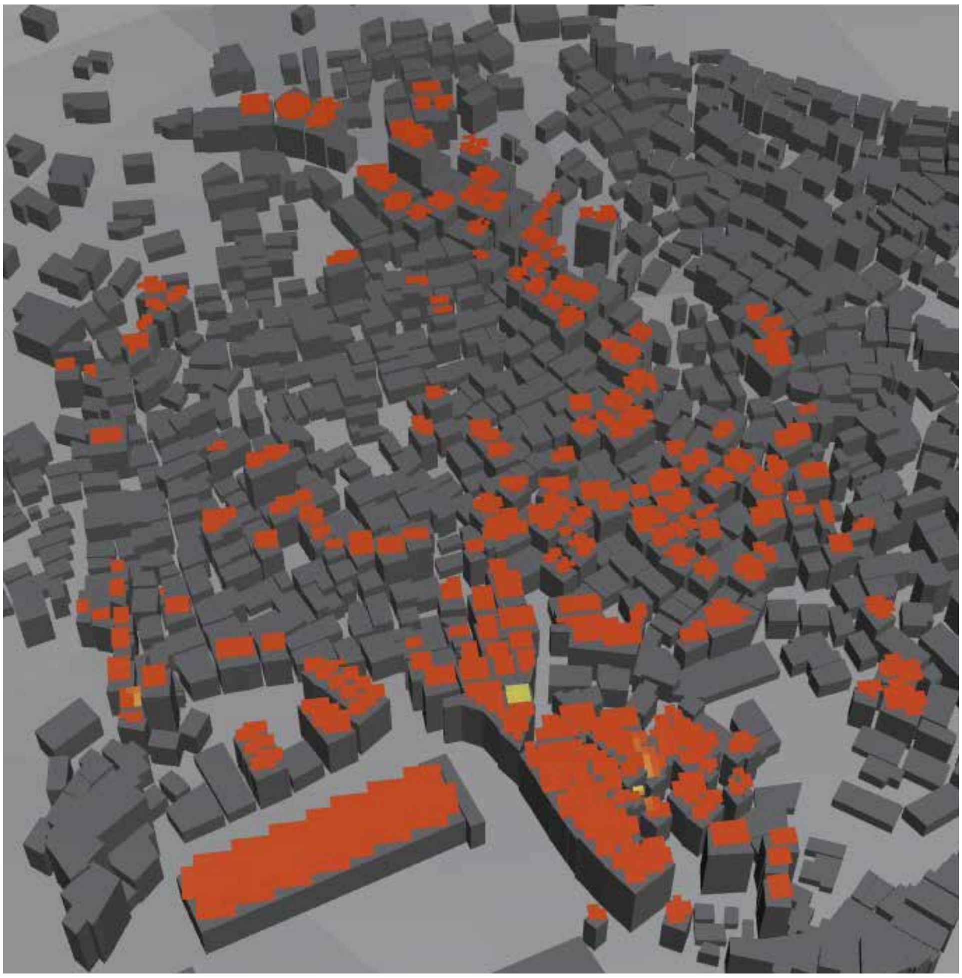


Figure 3.2.10 Solar potential map of Area 1: selected buildings. Courtesy of PolimiparaRocinha

3.2.7.2 Flow managment system

As mentioned, the ultimate objective of this intervention is to build a smart enegy grid in Area 1. In other words, it is necessary to design a flow managment system to handel the various parts of the system. The flow management system (FMS) is a system of computer-aided tools to monitor, control, and optimize the information flows coming from different sectors such as energy (production and consumption), services, transport, soil and green, food, etc.

With the installation of photovoltaic (PV) panels, the replacement of the existing metres, and the installation of electrical energy storage systems as batteries, this management system is designed to reduce energy consumption, increase reliability, predict electrical system performance, optimize energy usage, and maximize self-consumption to reduce costs. Moreover, this system can also improve services for citizens as street lighting, electrical local urban transportation, or systems for water pumping, irrigation and water purification, etc. Other information about waste, soil and green, food etc. can be managed through this system and an online platform. The system is made up of five basic parts, as detailed below:

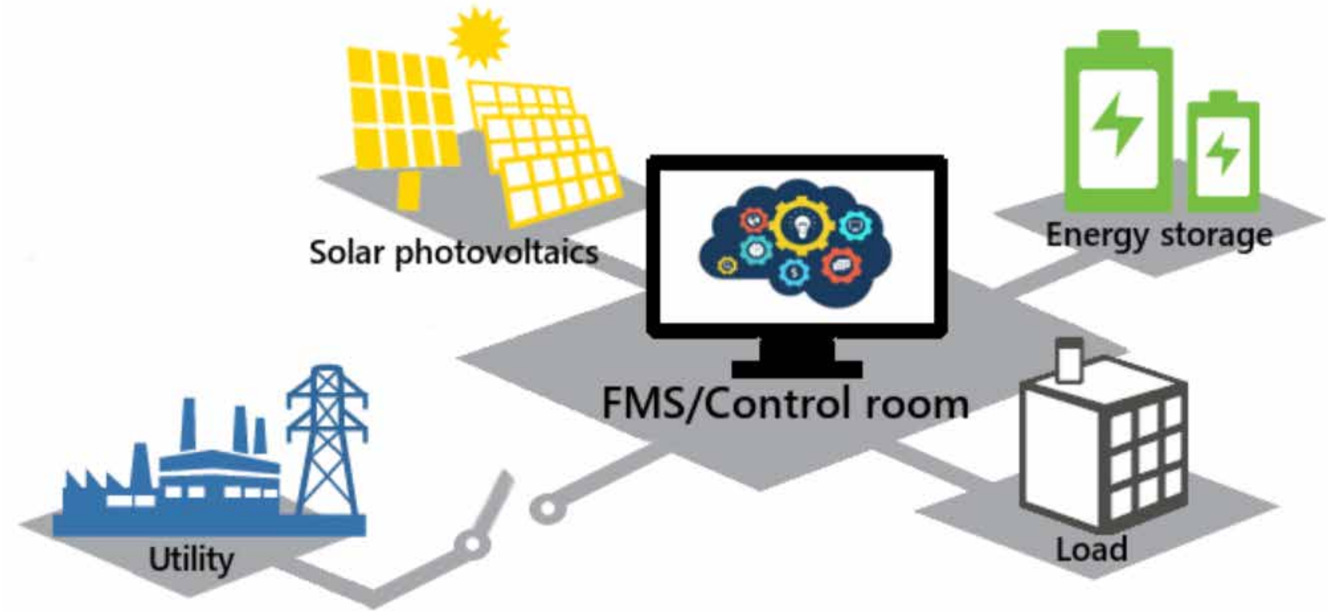


Figure 3.2.11 Flow managment system scheme. Courtesy of PolimiparaRocinha

- **Solar photovoltaics**: the PV panels will be the clean energy producer, the installation of which had been detailed above;
- **Energy storage**: to properly manage the energy output from the PV panels, it will be necessary to install a battery system within Area 1, namely in the school "CIEP Doutor Bento Rubião", as the energy demand and production thoughout the day (and the year besides) isn't constant. An energy storage system will guarantee a constant output into the grid;
- **Load**: in Area 1, the load is comprised of three parts: the household whose roofs house the PV panels, the school "CIEP Doutor Bento Rubião" and the new public lighting system;
- **Utility**: it represents the broadest category, encompassing all those systems that needs electric energy to function, such as E-bikes, public lighting, hydroponic gardens etc. In particular, the connection to the national energy grid can be turned on/off depending on the daily necessity of the favela
- **FMS/Control room**: the figurative "brain" of the smart grid, the control room will manage the energy flow in Area 1. It has been decided that it should be installed inside the school, where it can be best managed.

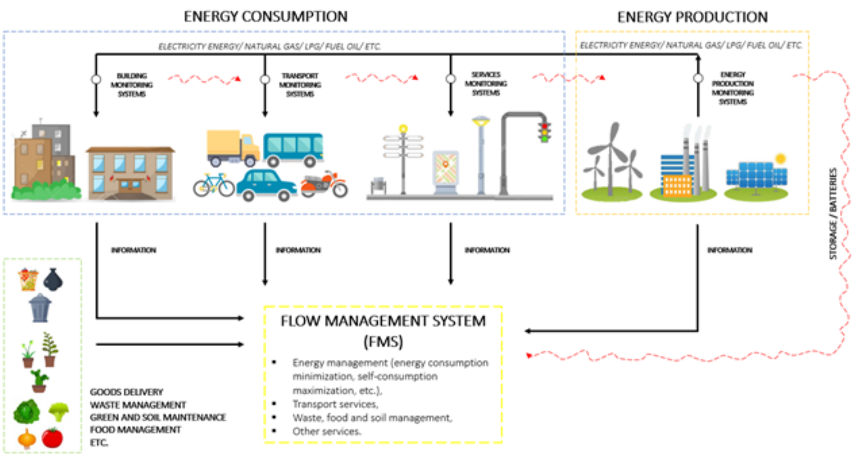


Figure 3.2.12 Flow managment system (FMS). Courtesy of PolimiparaRocinha

This system can be exploited by citizens if technological tools such as computers, smartphones, tablets etc. are available. Otherwise, in absence of technological tools, information boxes may be foreseen in the area of interest, where to apply for the different services as: booking electrical motorbike or cars, require the collection of waste, report problems, input data about the quality of the public services and their opinions, map that gathers organic food producers, etc.

The objective is the exploitation of solar energy, introduction of an innovative and more efficient system to reduce energy consumptions, optimize energy usage, and maximize self-consumption. To create the right conditions and field for digital networks for collection of data as well as interactivity and functional benefits for users.

The relationships between the various parts of the smart grid are detailed in the scheme below.

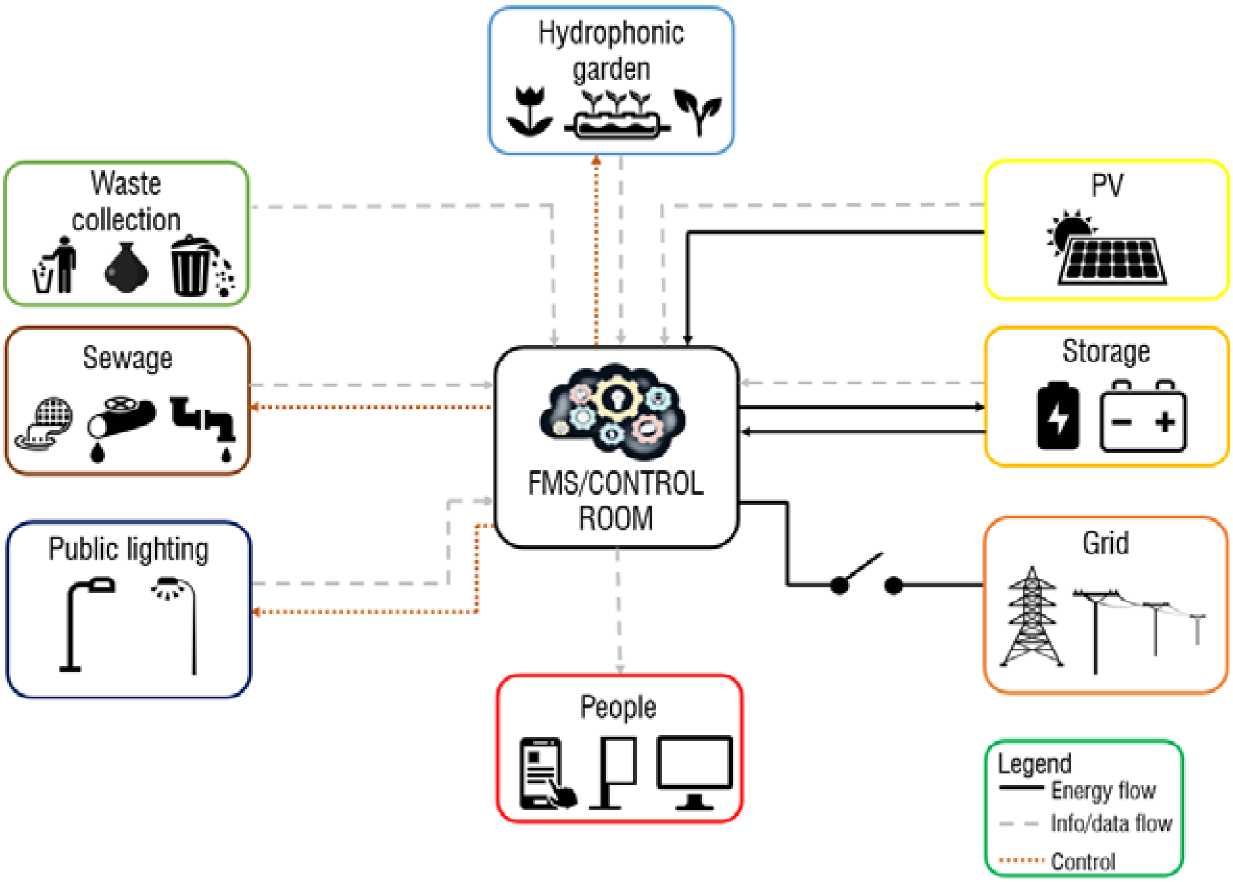


Figure 3.2.13 Flow managment system scheme. Courtesy of PolimiparaRocinha

3.2.7.3 Intervention

Following the guidelines enstablished in the paragraphs above, the intervention in Area 1 will be detailed in the maps shown here. Figures 3.2.12 shows the new power grid to be built in Area 1, connecting the buildings with PV panel to the control room and the storage batteries, both of which are located in the "CIEP Doutor Bento Rubião", as mentioned above. The 3D overview of Figure 3.2.15 exemplifies well how the PV panels are spread among the tallest and more "open" buildings, as well as those closest, whenever possible, to the area identified by the first IMM analysis, which will allow workers an easier acces to the selected buildings.

Figure 3.2.13 shows the main loads of the intervention site, namely the buildings with PV panels on their roofs, the public school and the new public lighting system arrayed along the new

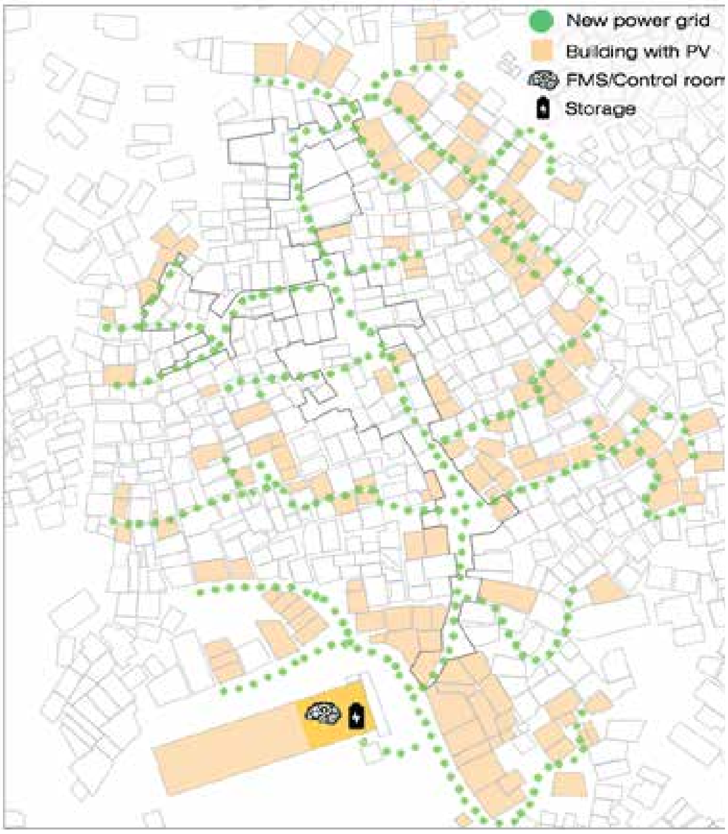


Figure 3.2.14 Area 1 new power grid: buildings with PV panels. Courtesy of PolimiparaRocinha

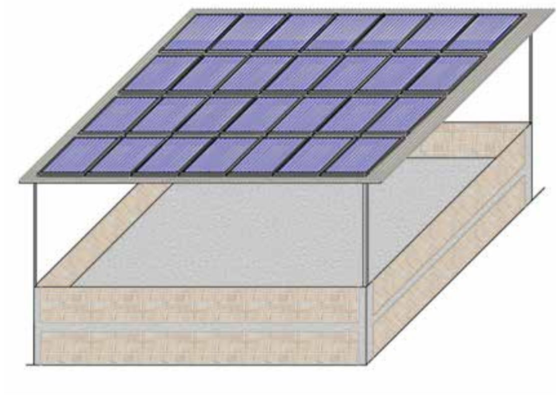


Figure 3.2.15 PV panels installation mode 1. Courtesy of PolimiparaRocinha

Figure 3.2.16 PV panels installation mode 2. Courtesy of PolimiparaRocinha

Figure 3.2.17 Area 1 new power grid: loads. Courtesy of PolimiparaRocinha

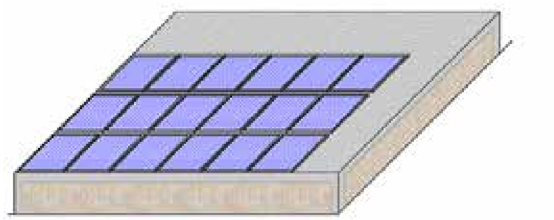


Figure 3.2.18 PV panels installation mode 3. Courtesy of PolimiparaRocinha

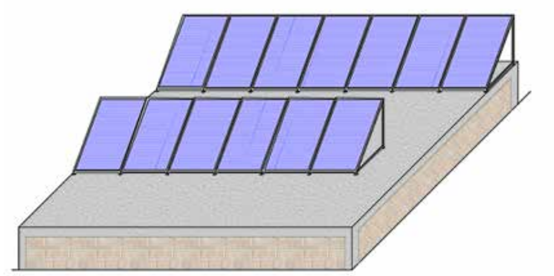


Figure 3.2.19 PV panels installation mode 4. Courtesy of PolimiparaRocinha

route connecting Villa Verde to Rua Dionéia and the area individuated by the first IMM analysis. As public lighting is essentially non-existant inside the more densely built parts of Rocinha, the installation of street lamps alongside the new route will greatly improve the safety of Area 1, especially at nighttime.

Figure 3.2.14 shows the sewage and waste collection systems information points spread along the new route, which will increase the efficiency of both. It should be noticed that all said point are located along the new main route, so that they may be easily accessible to the inhabitants of Area 1.

The total surface of the new PV panels has been calculated by the PolimiparaRocinha team so it can bear all the aforementioned loads, either supplying the necessary energy directly or, especially during summertime, the season with the lowest solar potential, using the energy stored in the battery units contained in the CIEP.

3.2.7.4 Conclusions

The installation of the new smart grid goes beyond merely providing clean energy to a fraction of Area 1's population, and Rocinha besides, it is, in fact, just as important, as an educational initiative, along with the initiatives for food and proper waste disposal, both of which will be detailed in the following paragraphs.

Many times during the surveys it has been highlighted how most of the inhabitants of Rocinha, lack an awareness for sustainable development. Thus, in this project, it is paramount to implement projects that can show an immediate (especially economic) return and therefore invite the people to replicate them thoughout Rocinha, not only improving their standard of living, but doing so in a sustainable way.

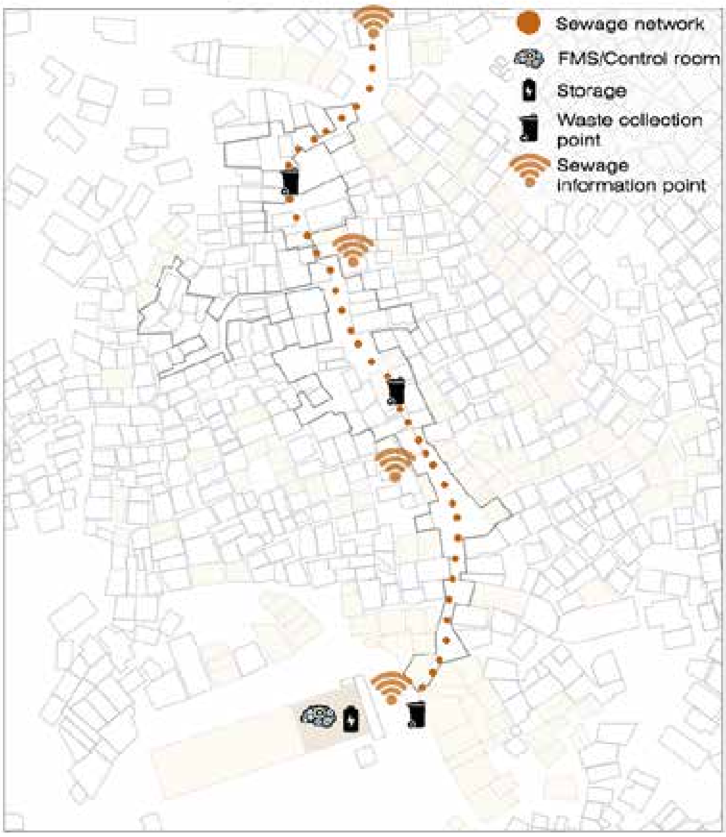


Figure 3.2.20 Area 1 new power grid: sewage/waste networks. Courtesy of PolimiparaRocinha

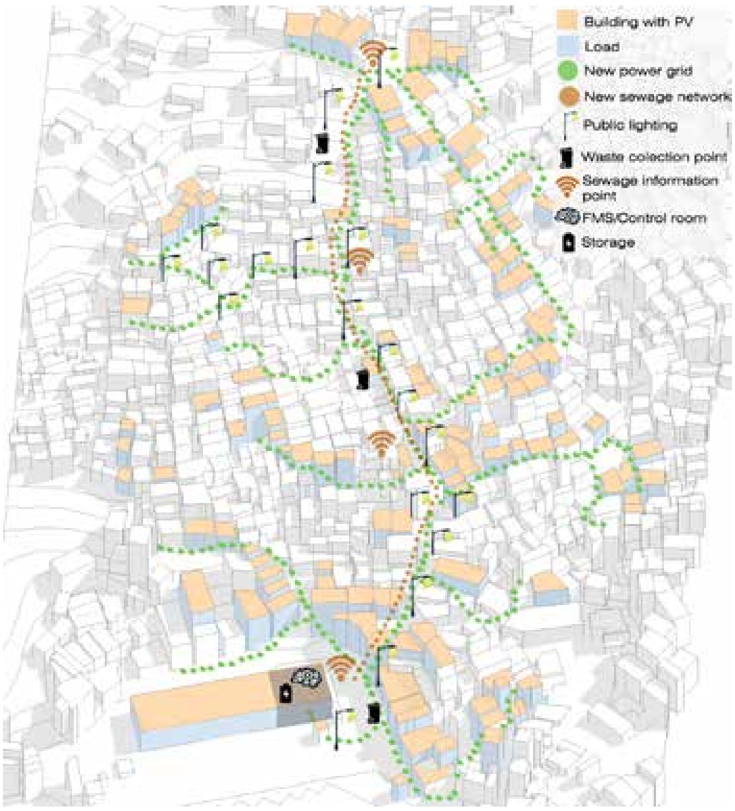


Figure 3.2.21 Area 1 new power grid: overview. Courtesy of PolimiparaRocinha

3.3 Water

3.3.1 Water adduction and purification

3.3.1.1 Introduction

Water management systems are one of the main critical issues of Rocinha which lead to several problems in terms of sanitation and health of the inhabitants. Because of the topography of the favela and all the narrow accesses, public services needed to adapt to the context in an unconventional way. As the population of the favela is usually not considered by the government when planning a of water supply system, it is necessary to first check the availability (namely, amount of water and pressure) of the main system that feeds that sector of the city to supply the population of the favela. The efficiency of the water pressure in the network that will supply the favela system is fundamental, depending on the difference in height between the feeder tank, or booster, and the highest points of the favela. In favelas built on tall hills (as is Rocinha) it is necessary, in order not to have not serviced areas, to create specific tanks for the community. A water consumption per capita and population growth of the "favelado" should be calculated as it is for the rest of the city. The analysis of the demographic indicators for the sanitation plans is likewise essential. This can become a problem since population estimates for Rocinha range from 70,000 to over 300,000, though, in our experience, the most likely number sit somewhere around 200,000. Meanwhile, service companies normally stuck to official data, which severely underestimates reality. Next to the issue of availability is also another problem: the vast majority of Rocinha does not have access to a reliable potable water supply due to the age of the current pipe network and the severe pollution of the main rivers which supply the Metropolitan city of Rio de Janeiro. Starting from the description of the entire system and passing through the technical verifications made by a Brazilian engineering studio, this chapter will introduce and analyse the possible solution for improving the quality of the water supplied.

Figure 3.3.1 Water spring in Rocinha. Picture taken by Arianna Trombini

3.3.1.2 Description of the system

The regional scale

The Rio Guandu: supplying system for the Metro City and the pollution problem

The potable water supply for at least 80% of the population of the Metropolitan region of Rio de Janeiro comes from the waters of the Guandu River. To ensure that the so-called raw water flowing in the river does not reach certain levels of pollution, it is treated in the largest ETA (water treatment plant) in the World, the Guandu ETA, even recorded in 2006 Guinness World Records.

According to several journalistic investigations and numerous specialized sources, the situation in the entire water supply system shows different critical issues. The waters of the Rio Paraíba do Sul have high levels of pollution, mainly due to the release of sanitary sewage by the municipalities that are upstream from Santa Cecília, but the distance between the catchment of their waters and the treatment plant (ETA) causes most of this pollution to be reduced by the river's natural self-purification process. However, near the treatment station, Rio Guandu receives water from the polluted rivers of Queimados (the Rio Abel, the Rio Poços, the Rio Queimados and the polluted streams of Seropédica). All the pollution data could be taken from the "Relatorio sobre a situaçao da bacia", a document developed by the Comitè da Bacia Hidrografica in 2011-2012. The Rio Poços e Queimados near ETA are often covered by floating vegetation, because these rivers have a very high concentration

Figure 3.3.2 ETA Guandu. Source: www.oglobo.globo.com

of organic substances that feed the plants. The Rio Poços is one of the most polluted of all macroregions in the Rio Guandu basin. It descends, forming a large artificial lagoon, and joins the Rio Guandu. In the original Master Plan for Water Supply, prepared by the engineer Jorge Rios for CEDAE, it was planned to divert the Rio Poços downstream from the ETA water intake because all this pollution could cause a collapse in the water supply of the municipalities of the RMRJ. This has not yet happened with the Guandu ETA, since the lack of sewage treatment is still compensated by the large amount of dilution water from the Rio Paraíba do Sul. However, the water supply capacity of the Rio Paraíba do Sul to Rio Guandu is limited by the capacity of the Santa Cecília elevation and the water supply in the important cities downstream, such as São Fidélis, Cambuci and Campos dos Goytacazes.

Another problem is the sand: there are places where large digging holes are opened for the extraction of sand from the soil, removing the vegetation cover and, often, from the bed and along the banks of the Rio Guandu. Although it is an illegal practice, many excavations are still in operation. Extraction is prohibited within the "Area de Proteçao Ambiental" (APA) of the Rio Guandu, which covers a strip of land of up to five hundred meters on both banks of the river. This practice promotes the silting of the river, because much of the waste from this process ends in its bed, which reduces the flow of water and increases the concentration of pollution, facilitates the occurrence of floods and increases the amount of waste to be withdrawn from the water during the treatment.

Estação de Tratamento de Água do Guandu (ETA)

In August 1955 it was inaugurated the first stage of the "Estação de Tratamento de Água do Guandu" (ETA). Successively the second stage (1963) and the third stage of the ETA, completed in 1965, were built. Each step was designed to produce 4,600 l/s, reaching from the Cara de Cão pit the ETA Guandu with a total capacity of 13,800 l/s. In 1969, the American Agency for International Development carried out studies that pointed out the need of expansion in two phases: the first with works of adaptation in ETA to reach 24,000 l/s, capable of meet the demand until 1980. The second with the construction of a new ETA to meet the demand until 1995. In 1982, after this new expansion, the Guandu became the largest water production park from Latin America.

In 1955, to start the construction of the ETA Guandu, structures of catchment were built near the old Estrada Rio-São Paulo, at km 22. However, the need of an expansion and more general operational safety led the construction of a newer and more robust structure, which occurred in 1965. The construction of the new water outlet necessitated to build a canal deviation that has been incorporated into the structures for collection, forming a fluvial island. On the right arm of the river (diversion channel) an auxiliary dam was built with three floodgates. On the main branch of the river the main dam with 7 floodgates was built. Both dams have the function of regularizing and maintaining the water level for abstraction. Immediately upstream of the main dam the water outlet was built, then doubled in 1994. The catchment structure is composed of floating dams, catchment basin, purge channels, two water intakes protected by railing, as well as tunnels to drain water to the sanders. ETA Guandu has 13 flocculators, 9 conventional horizontal flow, 6 vertical ascending flow lamellar decanters and 132 filters. ETA Guandu also has a significant daily consumption of chemical products:

- Aluminium sulphate: 140 t.
- Ferric chloride: 30 t.
- Chlorine: 15 t.
- Virgin lime: 25 t.
- Fluosilicic acid: 10 t.

Those chemical products are used for different phases of treatment. These are: chemical coagulation, flocculation, decantation, filtration, disinfection by chlorine, pH correction and finally the application of fluoride to aid in combating dental caries.

Elevatória do Lameirão

At the end of the purification process the water is taken to the "Elevatória do Lameirão" through a large pressurized tunnel with section of 14 m² and extension of 11 km. The water pumped into the Elevatory flows through two shafts (vertical tunnels) carved out of rock, with a 2.75 m diameter and a height of 117 m. From this point the water flows in the free conduit regime (by gravity). Immediately after the arrival of the water, these two tunnels join in a "Y" forming a single tunnel-channel with section equivalent to 22 m². This tunnel takes a course of 32 km, starting

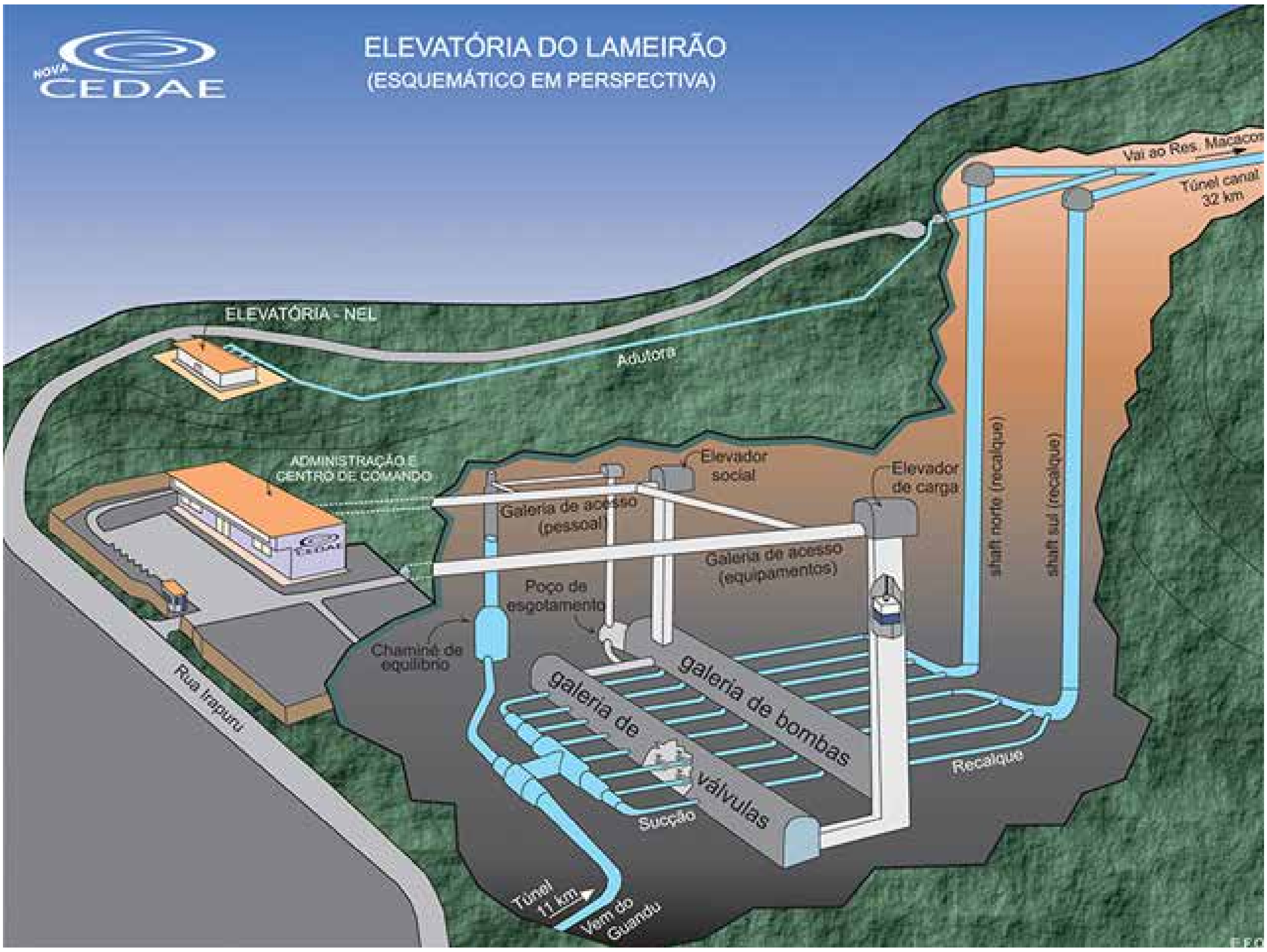


Figure 3.3.3 Elevatória do Lameirão. Source: CEDAE

in Santíssimo and ending at the reservoir of the Macacos in Gávea. The construction of this channel tunnel required a study aiming to take advantage of the topography and existing rocky massifs to conduct water by gravity to a considerable extent. In the tunnel course, some valleys forced the construction of 3 bridge-channels linking one mount to another.

The Elevatory is responsible for the supply of Bangu, Anchieta, Nilópolis, Acari, Leopoldina, Jacarepaguá, Barra da Tijuca, Recreio dos Bandeirantes, Tijuca, Center and south of the City, where Rocinha is located.

The local scale

The Planave S.A. diagnosis (2012)

More interesting for the analysis of our case study is the local scale of the potable water supplying system that serves the entire favela. In parallel to the PAC works of the 2012, the "Empresa de Obras Publicas do Rio de Janeiro" commissioned to Planave S.A. an engineering diagnosis of Rocinha, describing the context of the favela and pointing out the most important critical issues with possible solutions to be applied, especially in the fields of water and waste management and environmental risks.

The diagnosis states that the supplying system is composed of an old network (probably of the 60s-70s) and a more recent one installed between 1994 and 2000 by the CEDAE in the PROSANEAR program. With the help of an accurate photographic documentation it is possible to individuate the exact location and the state of conservation of the different reservoirs and water lift stations which compose the water supplying system (each pipe needs to be considered as made of cast iron):

Figure 3.3.4 Water lift station EE1. Source: Planave S.A.

Figure 3.3.5 Reservoirs R1 and R1-1. Source: Planave S.A.

Figure 3.3.6 Water lift station EE2. Source: Planave S.A.

Water lift station EE1

It is the main lift station of the system. it receives pressurized water (1 atm) by a DN500 pipe and pumps it to the first tanks of Rocinha (R1 and R1-1) with the help of 3 motor-pumps with 112 kW of power. It is localized in Rua Marques de Sao Vicente and the entire machine has a maximum flow of 139 L/s. Recent documentations read on the government website (04-29-2014) report an intervention of replacement of the motor-pumps with new and more effective ones which reaches a maximum flow value of 160 L/s.

Reservoirs R1 and R1-1

The pumped water reaches two reservoirs (R1 and R1-1), both with a maximum capacity of 100 m^3, through a DN200 and a DN250 pipe. R1 and R1-1 have a limited capacity because they do not serve directly houses in the favela (except for a small quantity used to supply some "condominios" located in Alto Gavea neighbourhood). Water is directly taken to the EE2 water lift station.

Water lift station EE2

It is the lift station which pumps the water to reservoirs R2, R2-1 and R2-2. The system is composed by 3 motor-pumps with 56 kW of power which grant a maximum flow of 139 L/s through a DN300 pipe. Recent documentations read on the government website (04-29-2014) report an intervention of replacement of the motor-pumps with new and more effective ones which reaches a maximum flow value of 160 L/s.

Reservoirs R2, R2-1 and R2-2

Located on the crest of Rocinha, there is an important distinction between the tanks: the R2 reservoir is the biggest of the favela, with a maximum capacity of 1,750 m3, and supplies the vast majority of the neighbourhoods through gravity (non-pressurized water); R2-1 and R2-2 have a maximum capacity respectively of 50 m3 and 150 m3, supplying part of the residences which compose the Vila Cruzado neighbourhood and other "bairros" of Rocinha located in higher levels with the help of the lift stations EE3 and EE4. While the reservoir R2 is supplied by a DN200 pipe with a maximum flow of 97 L/s, R2-1 and R2-2 are linked to the lift station EE2 with a DN250 pipe (42 L/s of maximum flow).

Lift stations EE3 and EE4 and reservoirs R3 and R4

Water lift stations EE3 and EE4 and located in the same place and supplied by the same DN200 pipe with a maximum flow of 39 L/s, but they operate distinctly. EE3 serves the reservoir R3, located in the highest part of Vila Laboriaux neighbourhood, through a DN100 pipe with a maximum flow of 6 L/s. It has a maximum capacity of 40 m3 to serve Vila Laboriaux and part of Vila Cruzado neighbourhoods, but it suffers of frequent landslides. EE4 serves the reservoir R4, the second of the favela in terms of size with a maximum capacity of 450 m3, through a DN200 pipe with a maximum flow of 33 L/s.

Figure 3.3.7 Reservoirs R2, R2-1 and R2-2's position. Source: Google Earth

The R7 system

In the lowest part of the favela, the R7 System (reservoir and booster) was built for the Rocinha supplementation and maintenance contract between 2000 and 2002. This system would partly serve Roupa Suja and Rua Dois (partly) neighbourhoods through an EE7 booster that was built but not came into operation. The reservoir was built, but the repression line did not come under load and today there are constructions on it. The area of the reservoir has been almost invaded by buildings and its access is interdicted.

Figure 3.3.8 Lift stations EE3 and EE4. Source: Planave S.A.

The scheme showed in the next page displays the different locations of the water lift stations and the reservoirs, a general diagram of the hydraulic connection and the technical values updated to 04-29-2014 used to design the system. The values which are not verified are highlighted in red. In the next sections will be presented the method of verification used to verify the system and a possible solution for purifying the water supplied in Rocinha.

3.3.1.3 Verification of the existing system in terms of quantity

The Planave S.A. verification (2012)

To verify the existing system, it was necessary to register the number of inhabitants to supply with potable water. Admitting a coefficient of 3 persons per domicile, it was possible to consider an approximate number of inhabitants of the favela based on the registration of the number of buildings to serve. The problem of the approximation of the demographic data of Rocinha is highlighted here, because the Planave S.A. took a value of about 104,000 of residents calculated using the coefficient previously introduced and a building registration made by the "Secretaria de Estado da Casa Civil". Said value is rather different than other data collection which is possible to take into account (the Rocinha's population estimation ranges anywhere from a 70,000 to a possible 300,000 value). For the purposes of this work it is reasonable to think that the local population reaches value of about 200,000 units, but to analyse the verifications which Planave S.A. had done in 2012 it is crucial to maintain the same total number of inhabitants and the same distribution of the population in the different neighbourhoods.

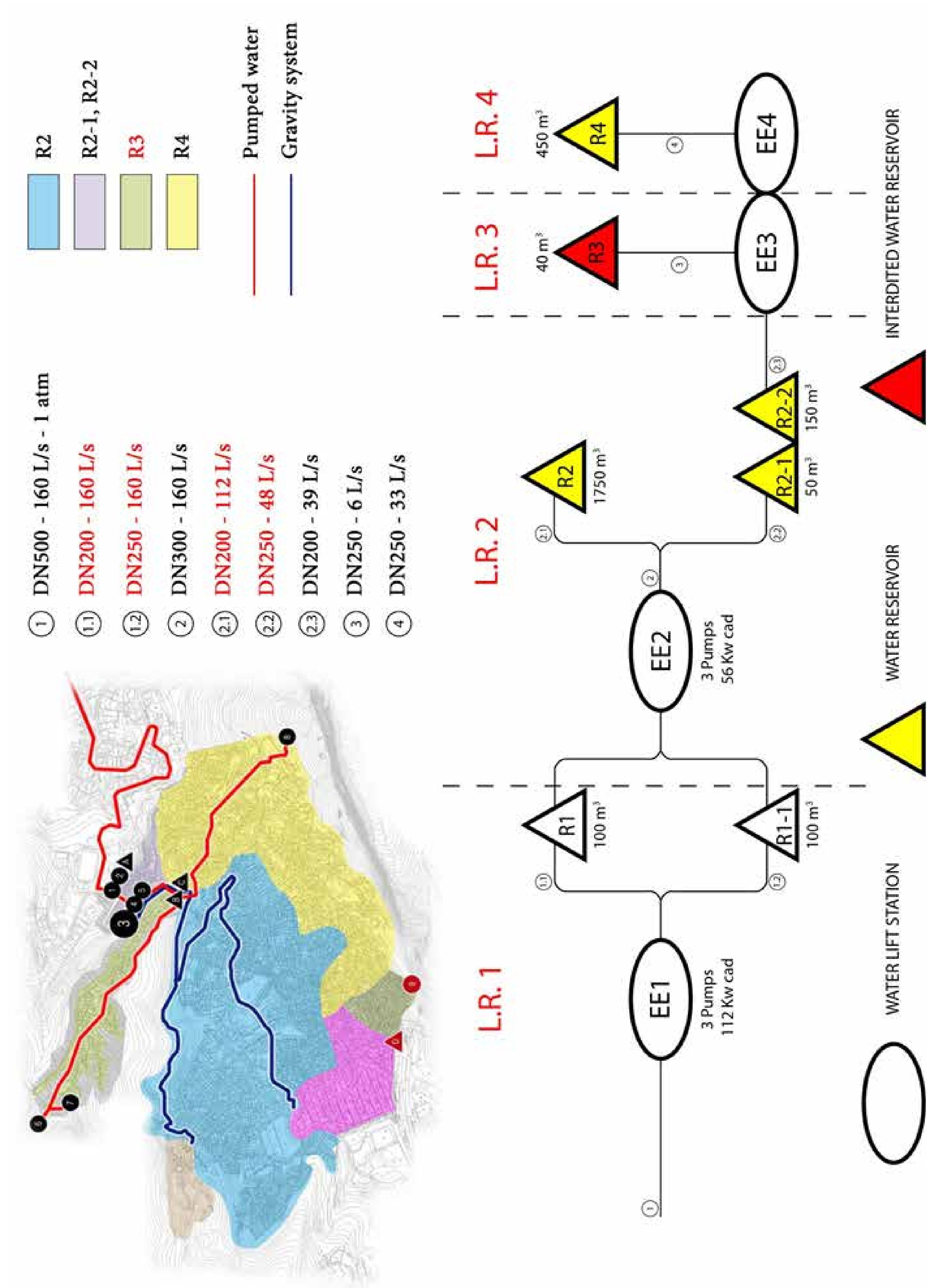


Figure 3.3.9 Water lift stations and reservoirs in Rocinha. Source: Planave S.A.

Calculation methodology

To verify the system, it is important to have information about the water consumption curve of Rocinha. Because of the informality of the favela system and the general lack of reliable information, a hypothesis of a sinusoidal curve was used (as it is recommended in the technical literature TSUTIYA, 2005):

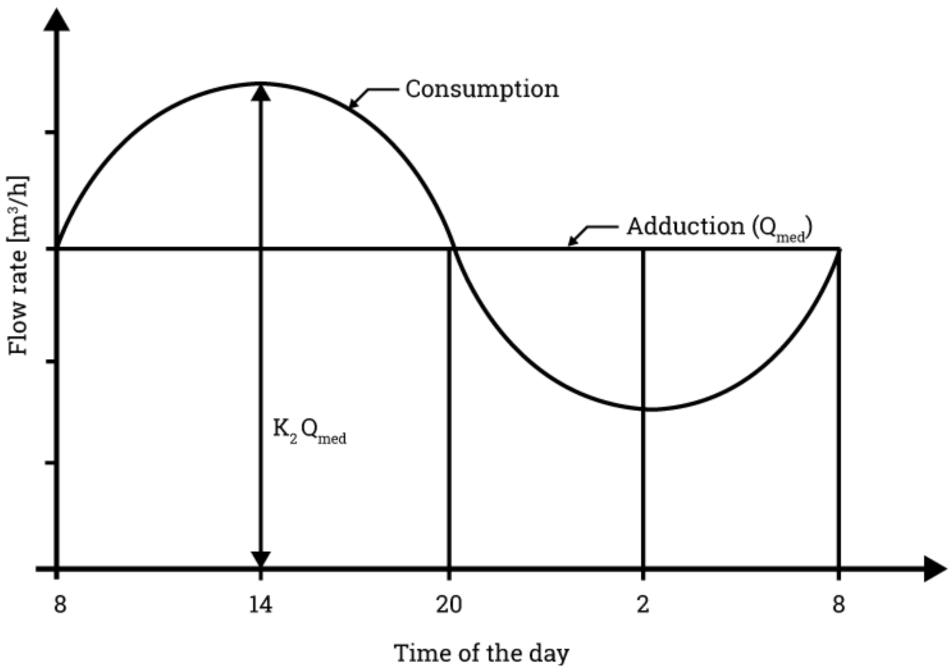


Figure 3.3.10 Water consumption curve of Rocinha

If V is the volume of water consumed on a day of greatest consumption, V/24 represents the average flow on this day per unit of time in hours. The sinusoidal form admitted as consumption variation is described in the equation below, where K2 is the coefficient for the hour of greatest consumption:

$$Q = (K2 - 1) \cdot x \cdot \frac{V}{24} \cdot \sin \frac{\pi}{12} + \frac{V}{24}$$

It is possible to evaluate the minimum capacity per reservoir in m^3:

$$C = \int_{8}^{20} Q dt - \frac{V}{24} \cdot x \cdot 12$$

Between the 8th and the 20th hour of a day consumptions are more than the level of adduction. The calculated volume will be the same during the night hours, where the consumptions are below the adduction value. The solution of the equation written above is:

$$C = \frac{K2 - 1}{\pi}$$

Where:

- C = Minimum capacity of the reservoir [m^3];
- V = Daily consumed volume [m^3];
- K2 = Coefficient of the hour of greatest consumption. Normally, K2 equals to an average value (1,5), which refers to a value of 16% of consumed volume during the day with the highest consumption.

Considering a daily value of 120 L/inhabitant and the necessity to store about 16% of the daily consumed volume, it is possible to verify the capacity of the reservoirs of Rocinha using the formula:

$$C_{min} = n°population \cdot 120 \ L/inhabitants, day \cdot K1 \cdot 0.16$$

Where:

- K1 = 1.20 is a safety factor.

Verification of the reservoirs

Considering all the simplifications which occur using the method of calculation previously presented and the reasonable underestimation of the population of Rocinha, the results of the verifications are shown below:

R2-1/R2-2 system	
Designed capacity	200 m³
Minimum needed capacity	
Population supplied	1,782 inhabitants
Per capita	120 L/Inhabitans, day
K1	1.20
Minimum percentage	0.16%
Volume needed	**41.06 m³**
VERIFIED	

Tab. 3.3.1 R2-1/R2-2 system verification

R2 system	
Designed capacity	1750 m³
Minimum needed capacity	
Population supplied	58,345 inhabitants
Per capita	120 L/Inhabitans, day
K1	1.20
Minimum percentage	0.16%
Volume needed	**1,344.46 m³**
VERIFIED	

Tab. 3.3.2 R2 system verification

R3 system	
Designed capacity	40 m³
Minimum needed capacity	
Population supplied	3,716 inhabitants
Per capita	120 L/Inhabitans, day
K1	1.20
Minimum percentage	0.16%
Volume needed	**85.62 m³**
NON-VERIFIED	

Tab. 3.3.3 R3 system verification

R4 system	
Designed capacity	450 m³
Minimum needed capacity	
Population supplied	19,614 inhabitants
Per capita	120 L/Inhabitans, day
K1	1.20
Minimum percentage	0.16%
Volume needed	**451.90 m³**
NON-VERIFIED	

Tab. 3.3.4 R4 system verification

The results shown above point out the necessity to modify the R3 system, although the diagnosis states that it is possible to supply the Vila Laboriaux neighborhood with the help of the R2 reservoir and new motor-pumps to provision the population with directly pressurized water. Furthermore, it is reasonable to state that the R4 reservoir, considering a larger sample of population, is not adequate to supply the inhabitants of Rocinha. Possible general solutions could be the direct intervention in R4 and R3 reservoir or the definitive installation of the R7 reservoir and the EE7 booster in the lowest part of the favela.

Verification of the pipes

Due to the lack of information about the efficiency of the motor-pumps and rear pressures, the only possibility to verify the pipes of the entire system is to calculate the water flow velocity and comparing the results to a maximum value of 2.0 m/s (because we are considering pressurized water). With the equation of Bresse:

$$D_{econ.} = 1.2 \cdot Q^{0.5}$$

It is possible to calculate the ideal diameter of the pipes in function of the water flow in case of a possible replacement.

L.R.1	
Designed pipes	
Total adduction	0.160 m^3/s
Area	DN200 + DN250
Total	0.0804 m^2
Flow velocity	1.99 m/s
VERIFIED	
$D_{econ.}$	0.48 m
NON-VERIFIED (DN500 or equivalent needed)	

Tab. 3.3.5 L.R.1 pipes verification

L.R.2.1	
Designed pipes	
Total adduction	0.112 m^3/s
Area	DN200
Total	0.0314 m^2
Flow velocity	3.56 m/s
VERIFIED	
$D_{econ.}$	0.48 m
NON-VERIFIED (DN400 or equivalent needed)	

Tab. 3.3.6 L.R.2 pipes verification

L.R.2.2	
Designed pipes	
Total adduction	0.048 m^3/s
Area	DN250
Total	0.0490 m^2
Flow velocity	0.97 m/s
VERIFIED	
$D_{econ.}$	0.262 m
VERIFIED (DN300 would be better)	

Tab. 3.3.7 L.R.2.2 pipes verification

L.R.3	
Designed pipes	
Total adduction	0.006 m^3/s
Area	DN100
Total	0.0078 m^2
Flow velocity	0.76 m/s
VERIFIED	
$D_{econ.}$	0.092 m
VERIFIED	

Tab. 3.3.8 L.R.3 pipes verification

In the verifications showed above the new parameters related to the renovation of the motor-pumps of the EE1 and EE2 booster are considered. It is possible to see that the introduction of bigger values of water flow in L.R.1 and L.R.2 aggravates the situation if at the same time the pipes are not replaced, because the velocity is destined to increase. The verifications point out the problems of water adduction, which cause a critical issue of quantity of water in Rocinha. The technical solutions are easy to imagine but not to apply because of the morphology of the favela and due to political and social reasons. In the next

L.R.4	
Designed pipes	
Total adduction	0.033 m^3/s
Area	DN200
Total	0.0314 m^2
Flow velocity	1.05 m/s
VERIFIED	
$D_{econ.}$	0.217 m
VERIFIED (DN225 would be better)	

Tab. 3.3.9 L.R.4 pipes verification

section the topic of the quality of potable water in Rocinha will be discussed.

3.3.1.4 Direct investigation phase

The partnership with "BrianzAcque"

After the first preliminary data collection, it became apparent that, on this aspect, the entire "PolimiparaRocinha" project needed a specialist approach and technical support from an institution, a partner that deals with these specific problems daily. Following this realisation, a collaboration was born between Politecnico di Milano and "Brianzacque", the operator of the entire public water supply chain in Monza and Brianza province. It is a company owned and directly controlled by the local municipalities, which are also members, and they control the depuration, the water supply and the sewage system in that region. Their precious collaboration allowed us to access their important know-how and to validate and refine the initial design assumptions.

Meeting with Ing. Ferazzini

After a meeting with Enrico Boerci, "Brianzacque" president and CEO, to summarily define the goals of our collaboration, their Design Office has been identified as the most suitable structure for the operational development of the project. In particular, the valuable expertise of Ing. Ferazzini, head of "Brianzacque" Design Office, was paramount for this work.

The first meeting with him was set on the 3rd of May, first illustrating him the general situation in the favela and sharing the first preliminary data, then explain the first impression:

1. The quality of water in the favela is unknown. Rocinha inhabitants argue that the quality of water is not satisfactory, and it could even be the cause of epidemics inside the favela.
2. There are no data available on the state of the distribution network up to the end user, up to the tap of a favela inhabitant. It is certainly known the quality of the water coming out of the ETA Guandù, drinkable for the Brazilian norm, but it is over 40 km, as the crow flies, from the favela. Plus, it can be easily assumed that the Rocinha water distribution network was made in a rather artisanal way by the same inhabitants of the favela during the years. It is therefore impossible to guarantee if there are losses.

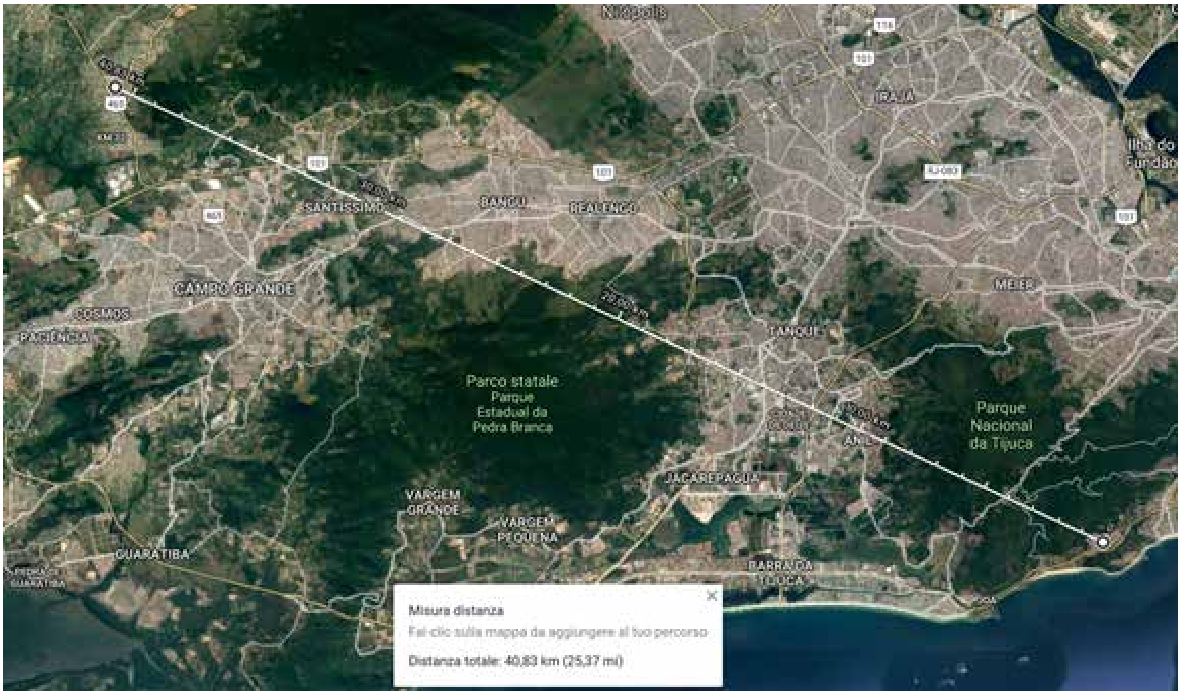


Figure 3.3.11 Distance between Rocinha and ETA Guandu. Source: Google Earth

3. Looking the data collected and listened to the direct testimony of Barbara Olivi, there is water shortage in some parts of the favela. As shown before, some reservoirs are undersized, creating provisioning problems.

Discussing with the Ing. Ferazzini, it was agreed that the data collected up to that time were insufficient. It was necessary to understand the current situation better to develop an effective strategy based on factual data, rather than rumours and hearsay.

Water sample analysis: the organization

Therefore, it became necessary to carry out analyses on samples of water collected in favela (at least two) to understand the water distribution network status.

And so it was: two water collection kits, with specific characteristics, were sent by airmail from Italy to Brazil to help the collection. Once the kits were received, Barbara Olivi proceeded to carry out the water samples in two different spots of the favela, one at her home and the other near the tank, as shown in the image below.

This way, it was thought that significant differences could be identified, maybe indicators of problems in the water distribution network.

After evaluating the possibility of using a local analysis laboratory, it was chosen to perform the analysis in Italy, exploiting the presence of the internal laboratory in "Brianzacque". This choice was made due to the impossibility to guarantee the methods used in a Brazilian lab analysis.

Following this choice, it was necessary to organize and find the fastest way to transfer the samples from Rio de Janeiro to "Brianzacque" labs, to preserve the characteristics of the same.

The help of Marco Contardi, professor from "Fundação Getulio Vargas", was fundamental to carry the sample within the timeframe required by the laboratory to avoid its degradation. He met Barbara, who delivered the collected samples, at the base of the favela, next to Sao Conrado metro station. At that point, he took charge of handing them over to the lab, coming back to Italy.

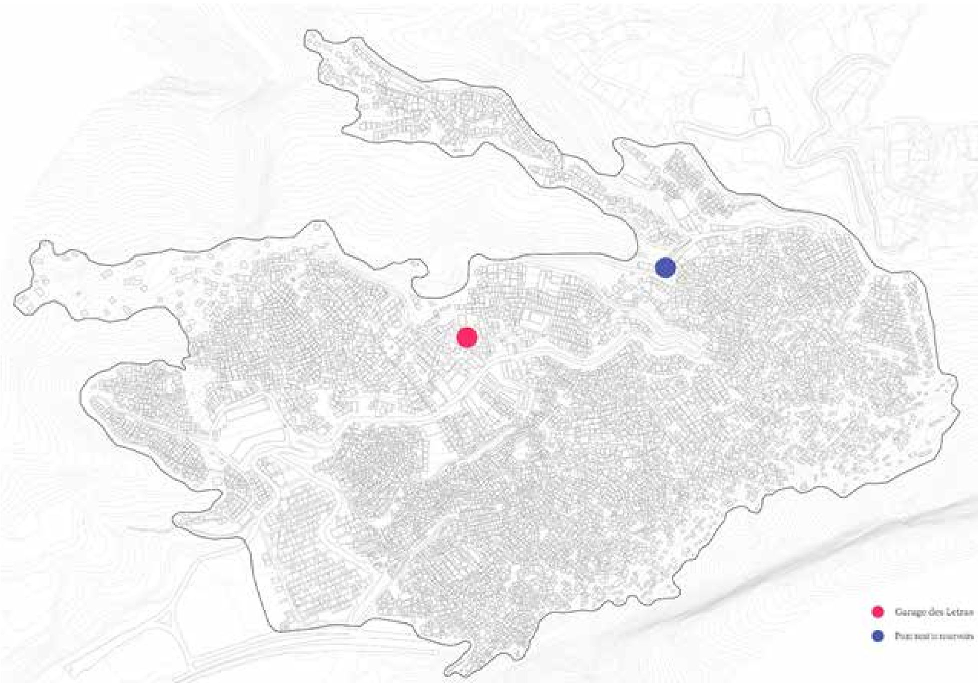


Figure 3.3.12 Water samples location

Water sample analysis: the results

The results came in after two weeks of survey. The research carried out concerned 78 parameters, both physical nature, physicochemical properties and that related to bacteriological aspects. Below, it is possible to see some abstracts of the tests report, made by the lab, with the most interesting data. All data are compared with the Italian limits of law, since it was impossible to find Brazilian legislation on the subject.

BrianzAcque

Brianzacque srl
Gruppo Laboratori Analisi
Viale Enrico Fermi, 105 20900 Monza
tel. 039 26 230 336

Rapporto di prova N° 1 .ES del 01/07/2018

Codice di accettazione campione: *4168/Poli18*

Oggetto sottoposto a prova: *Acqua destinata al consumo unamo prelevata in Favela*

Dati forniti dal cliente

Punto Prelievo: Garage das Le tras
Descrizione Punto Prelievo: Garage das Le tras
Tipo di campione: Campione istantaneo
Comune: Rio de Janeiro
Codice indentificativo campione:
Prelevatore: Ass. Il sorriso dei miei bimbi (B.Olivi)

DATA E ORA APERTURA CAMPIONE: 18/06/2018 14:00:00

Data prelievo: 16/06/2018 **Data e ora consegna:** 18/06/2018 13:00:00 **Data inizio analisi:** 18/06/2018 **Data fine analisi:** 22/06/2018

Prelievo e consegna campione Campione prelevato e consegnato dal cliente in N°4 aliquote

Procedura campionamento : A cura del cliente

Tipo di Prova e Metodo di riferimento	Risultato:	Unita' di misura:	Valore di riferimento	Normativa	Laboratorio	
Cloro attivo libero Lange LCK 310	> 1	mg/l	0,2	D. Lgs 152/06 (Parte terza, Allegato 5, Tabella 3.);acque superficiali	SEDE B	✔
Cloroformio UNI EN ISO 10301:1999 sez. 3	62	µg/l	30	Dlgs 31/2001;Dm Salute 14 giugno 2017	SEDE B	✔
Tensioattivi Anionici (a) Lange LCK 332	8,7	mg/l	0,05	DECRETO 10 febbraio 2015;acque minerali	SEDE B	✔

Figure 3.3.13 Water sample 1 data. Courtesy of Brianzacque

Considering where water came from, it was expected to be a low-quality water, with significant bacteria counts. Instead, the "microbiology was flat", there was no significative data regarding the microbiological aspects. This result was surprising but could be explained by the high level of chlorine, an antibacterial chemical product known by everyone for his pungent smell, used extensively in swimming pool. As point of fact, the levels of Chlorine registered by the analysis of both samples from Rocinha were three times the normal value used for a pool.

This high value can also explain the presence of Chloroform, twice over the limit in both samples, because it is a by-product of chlorination.

The third parameters instead show the level of Anionic Surfactant, a family of essential chemicals to allow detergents to become water-soluble. In both withdrawal, this limit is exceeded by 100 to 180 times. This phenomenon can be attributed to a structural shortage of ETA Guandu plant, which it does not intercept these chemicals, surely present in the Guandu river.

Below it is possible to see the same values on the other sample.

Comparing the analyses between them, there is no significant variation and there are no other parameters worth noting, in addition to those listed above.

BrianzAcque

Brianzacque srl
Gruppo Laboratori Analisi
Viale Enrico Fermi, 105 20900 Monza
tel. 039 26 230 336

Rapporto di prova N° 2 .ES del 01/07/2018

Codice di accettazione campione: ***4169/Poli18***

Oggetto sottoposto a prova: ***Acqua destinata al consumo unamo prelevata in Favela***

Dati forniti dal cliente

Punto Prelievo: GAVEA

Descrizione Punto Prelievo: GAVEA

Tipo di campione: Campione istantaneo

Comune: Rio de Janeiro

Codice indentificativo campione:

Prelevatore: Ass. Il sorriso dei miei bimbi (B.Olivi)

DATA E ORA APERTURA CAMPIONE: 18/06/2018 14:00:00

Data prelievo: 16/06/2018 **Data e ora consegna:** 18/06/2018 13:00:00 **Data inizio analisi:** 18/06/2018 **Data fine analisi:** 22/06/2018

Prelievo e consegna campione Campione prelevato e consegnato dal cliente in N°4 aliquote

Procedura campionamento : A cura del cliente

Tipo di Prova e Metodo di riferimento	Risultato:	Unita' di misura:	Valore di riferimento	Normativa	Laboratorio	
Cloro attivo libero Lange LCK 310	> 1	mg/l	0,2	D. Lgs 152/06 (Parte terza, Allegato 5, Tabella 3.);acque superficiali	SEDE B	☑
Cloroformio UNI EN ISO 10301:1999 sez. 3	60	µg/l	30	Dlgs 31/2001;Dm Salute 14 giugno 2017	SEDE B	☑
Tensioattivi Anionici (a) Lange LCK 332	4,7	mg/l	0,05	DECRETO 10 febbraio 2015;acque minerali	SEDE B	☑

Figure 3.3.14 Water sample 2 data. Courtesy of Brianzacque

Water sample analysis: some consideration

Firstly, it must be considered that the results are most likely affected by errors attributable to the long journey and to the climatic conditions during the sampling, occurred during a thunderstorm.

Looking at these parameters, it seems that the situation is better than expected. The absence of bacteria doesn't seem to confirm the initial assumptions envisaged by the inhabitants, so the prime suspect of the epidemics that happen periodically continue to be the lack of an adequate sewage system.

Having said that, the high level of Anionic Surfactant and Chlorine are worth noting. It is impossible that such levels of these substances do not create damage to the human body in the long term.

Chloric water at high dosages is a common practice also in Africa, but the objective of the project must be the reduction of the concentration of Chlorine and the elimination of Anionic Surfactant.

3.3.1.5 Intervention phase

Guidelines

Due to the type of intervention required, what will be proposed below should be taken as a guideline, a road map, because it is more an infrastructural intervention than plant installation, which needs more political and economic efforts than technical knowledge.

Figure 3.3.15 Rocinha's water spring location

The only way to improve the quality of water and reduce the concentration of Chlorine and Anionic Surfactant is the dilution process, which is the introduction of water into the system from another supplying source.

During the survey inside the favela, there was potable water from a natural source, located up to the favela. It is a natural water source currently used by the population because it is considered safe and with a better quality than the water coming out of the tap. There're no data about it, which would require a direct investigation analysis, the general impression of the population can be taken as starting point. In other words, there exist a water supply directly above the favela that is almost certainly drinkable, probably because of soil filtration.

The proposals can be divide in two phases, depending on the type of chemical product:

- The water mentioned before can be used through the creation of a "Wells Field", a series of wells placed next to the favela. This idea responds to the problem of water shortage and provides it for the process of dilution for Chlorine and Anionic Surfactant.
- To completely eliminate the amount of anionic Surfactant, a specific plant could be installed to solve this problem.

A geological survey of that region exists, but the information is rather lacking. It is fundamental to make a thorough study that it would identify the best points where to create the necessary wells. Their ideal location would be up to the favela, to use the gravity to move the amount of water required. If not, it would be necessary to install pumps.

The lack of this information allows us to approach the solution only at a theoretical level, without being able to give a physical dimension of our intervention.

Wells Field

In order to calculate the minimum number of wells needed, it is necessary to understand and measure the water shortage phenomena. The starting data can only be the number of inhabitants, estimated at 200,000 people, the water entering the system, equal to 160 L/s, and the amount of water per day, estimated at 120 l/d.

The analysis starts from an ideal situation: the system is new and it's day zero, the first working day of system. So, all tanks are full, and their level will drop slowly.

Population	Water per person [L/d]	Water flow [L/d]	Water flow [m³/d]
200,000	120	24,000	1,000

Tab. 3.3.10 Water consumption per hour

Q reservoir [L/s]	Q reservoir [L/h]	Q reservoir [m³/h]
160	576,000	576

Tab. 3.3.11 Amount of water replaceable per hour

	V [m³]
R2	1,750
R2-1	50
R2-2	150
R3	40
R4	450
Total	2,440

Tab. 3.3.12 Maximum amount of water in the reservoirs

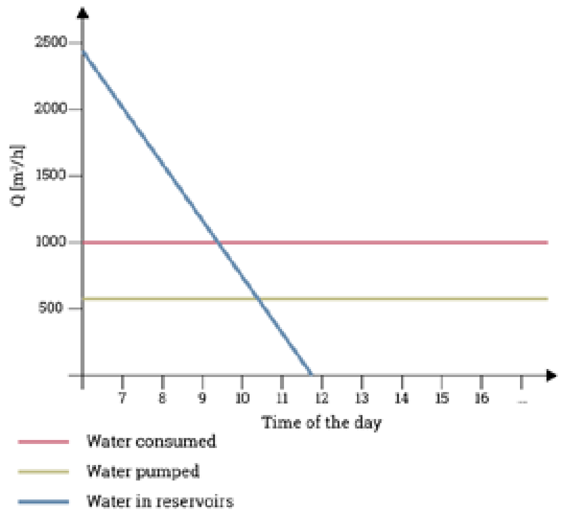


Figure 3.3.16 Water level trend per hour

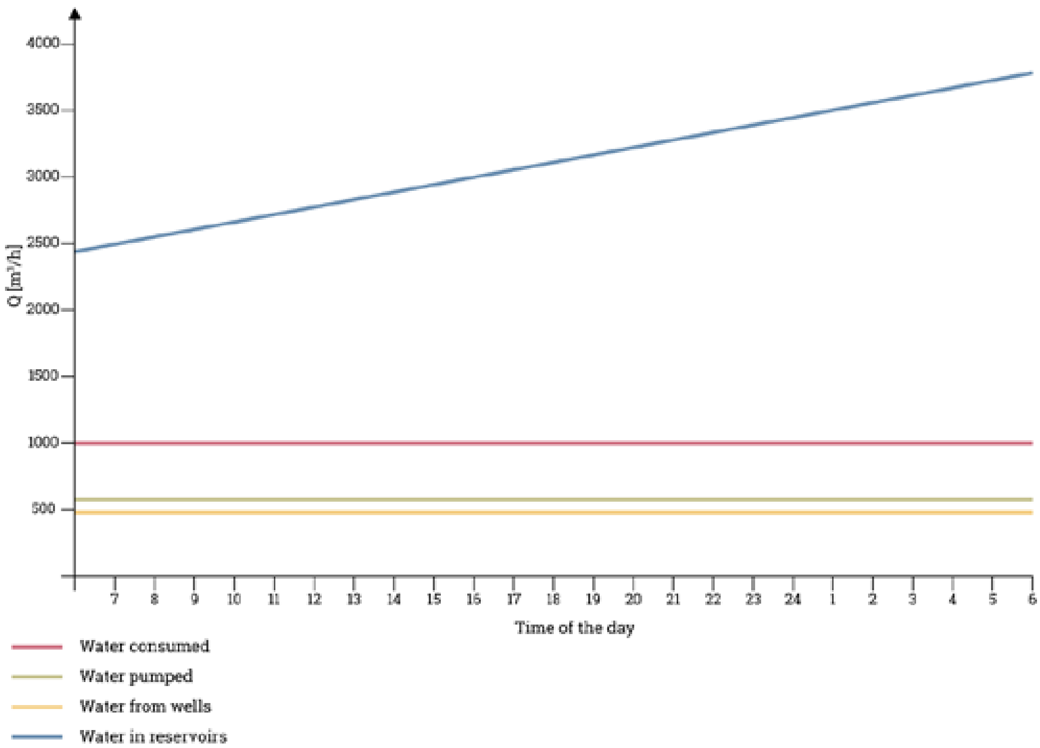


Figure 3.3.17 Water level trend per hour with wells

It is easy to understand then that the current system is lacking and ideally suffers failure after a few hours. It is necessary to replace the amount of water consumed, to balance the outputs with the inputs.

According to the opinion of Ing. Ferazzini, each well can guarantee from 80 m^3 to 120 m^3 of fresh water. So, using the lowest data, it is easy to hypothesize the number of wells and repeat the same calculations.

Water per well [m^3/h]	n. of wells	Water from wells [m^3/h]	Water from wells [m^3/s]	$D_{econ.}$ [m]	DN
80	6	480	0.133	0.438	450

Tab. 3.3.13 Diameter of wells' pipes

The ideal diameter of the new pipe is calculated using the equation of Bresse:

$$D_{econ.} = 1.2 \cdot Q^{0.5}$$

Where:

- $D_{econ.}$ is the minimum diameter of the new pipe [m];
- Q is the flow [m^3/s].

It is easy to see that the system seems have more water that necessary with 6 new wells. It is a preliminary calculation, because we don't know the exact consumption hour by hour neither the losses of the system.

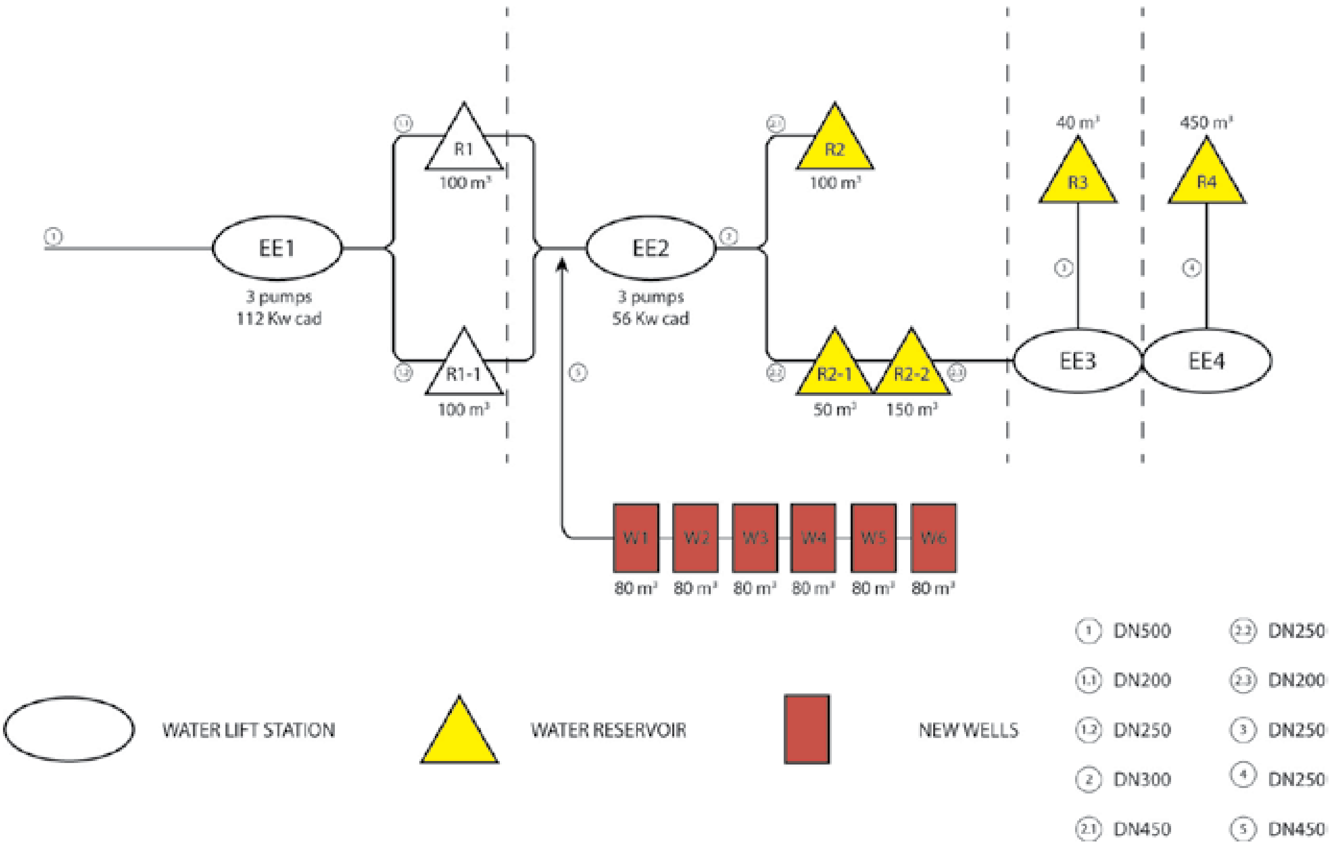


Figure 3.3.18 Water depuration network scheme

Using the equation of Bresse, we calculated the dimension of the new pipe that it will serve the networking of water from wells. Below it is possible to see the updated network scheme.

Depuration plant for Anionic Surfactant

In the opinion of Ing. Ferazzini, a classical system with mechanical filtration (sand) + absorption (activated carbons) will be the best solution. This evaluation was made according to the previous experiences of Brianzacque and after having heard specialized companies in the field.

It is now impossible to think where this plant can be placed, so we have to speak about it hypothetically. Due to the high amount of water, the plant would be of considerable size, thus, a large area will be needed.

In case of extreme necessity, it is possible to consider reducing the size of the system to adapt it to the area, removing the part of the sand filters.

Distribution network

As we showed at the beginning, the network system is also lacking, and it would need some structural interventions. Some existing pipelines are undersized, insufficient for the current requirements, and they were placed without considering the development rate of the favela.

Moreover, it is easy to think there could be losses between the reservoirs and the final user, as well as points where Pathogens and chemicals can pollute water. To solve drastically all these problems, it is recommended the construction of a new distribution network.

Assuming it would be a multi-annual intervention, A possible roadmap would be to build the main distribution pipelines, then redo the connections to the houses, while, possibly, the construction of the sewage system. To this end, we could exploit the subdivision of the favela provided by the IMM to program such intervention.

Figure 3.3.19 “Water House” in Monza. Source: www.monzatoday.it

Once the main distribution network has been built, a “Water House” could be installed for each IMM area. The integrated filtration and purification systems of the “Water House” would guarantee an additional safety on the quality standards of the public service provided. These systems would therefore act as provisional terminals for the new distribution network, as long as the new domestic connections are not made.

Once the connection phase of all the households has been completed, the “Water House” can be removed or left as a public service for the neighbourhood. It will be essential to place the different “Water Houses” in positions that make their use as easy as possible to the greatest number of people.

3.3.2 Sewerage

3.3.2.1 Introduction

Figure 3.3.20 Discharge of sewage directly into a talvegue. Source: CONEN, 2012

One of the most important issues to be found during the analysis of Rocinha, as already discussed, is water management, wastewater and rainwater both. All waters produced by urban agglomerations (from both the households and public meeting places) and rainwater are defined as waste waters. They can be furtherly divided into:

• **Foul water**: all waste water from private or public toilets;

• **Greywater**: all waste water generated by households or office buildings without faecal contamination;

• **Waters generated by rainfalls**.

All waste waters from the urban agglomeration should be collected into the sewers, which convey them in the downstream pipe network and bound through pumping stations to outfalls. There are two types of gravity sanitary sewer systems:

• **Combined sewer**: they collect both urban waste water and rainfall waters. This system has a lot of advantages such as reduced production cost and ease of inspection, though the water inside the pipes is comparatively slower, which can be cause of deposits.

• **Separate sewerage**: they consist in the separate collection of municipal wastewaters (blackwater from toilets, greywater and industrial wastewater) and surface run-off (rainwater). This system prevents the mixing of the relatively little polluted surface run-off with chemical and microbial pollutants from the municipal wastewater. This way, only the foul water and the greywater are led to treatment stations. Furthermore, the wastewaters' flow's speed is such that prevents deposits. On the other hand, since the wastewaters and rainwater are collected in separate sewerage, the system has higher costs and smaller pipes.

Currently in Rocinha there isn't an effective sewerage and drainage system. Indeed, most of urban waste water from houses and public meeting places are dumped in the talvegues, in which only rainwater should flow. As it is, the mix between these waste waters is dangerous, as they can cause floods, dangerous both for the public health and for the lives of the population of the favela.

Additionally, drainage water from roads, car parks and courtyards, due to the lack of a drainage system, is also polluted, since they come into contact with waste and materials of various kinds and can, therefore, pose a threat to the health and environment.

The problem can be solved with the installation of separate sewerages, to follow Brazil's own design standard, and extending the current sewage network in areas of the favela where it is either absent or undersized compared to the amount of water it must collect, said system, once installed, must also receive proper maintenance.

This project attempts to give some general guidelines that can be applied in the intervention areas as well as throughout the rest of favela. The hope is that it can become a support to all the professionals who will be involved in future sanitation's project. Moreover, this project answers to DOPs number 3 (implement water management) and 4 (prevent the negative impact of waste).

First, to build a correct project of sewerage, the current sewage network must be analysed so that the critical issues and failings of the system can be understood, both for the wastewater and rain water.

3.3.2.2 Wastewater Treatment

Current situation

The current sewerage has been retooled several times due the significant demographic growth of Rocinha in the last decade. The last project implemented was PROSANEAR in 2010.

Nowadays the favela is divided in two basins, the São Conrado basin and the Gávea basin, that collect respectively 80% and 20% of sewage. The São Conrado basin brings the waste waters to the pumping station that leads sewage from São Conrado to the EE of Leblon. Here, through another pumping station and piping, the slurry is lead to Ipanema. Meanwhile, in the Gávea basin, there are two pumping station located in Rua Sergio Porto and in Estrada da Gávea, that bring the waste waters to Elevatória Saturnino de Brito. Here, through another pumping station and piping, the slurry is lead to Lagoa Rodrigo de Freitas.

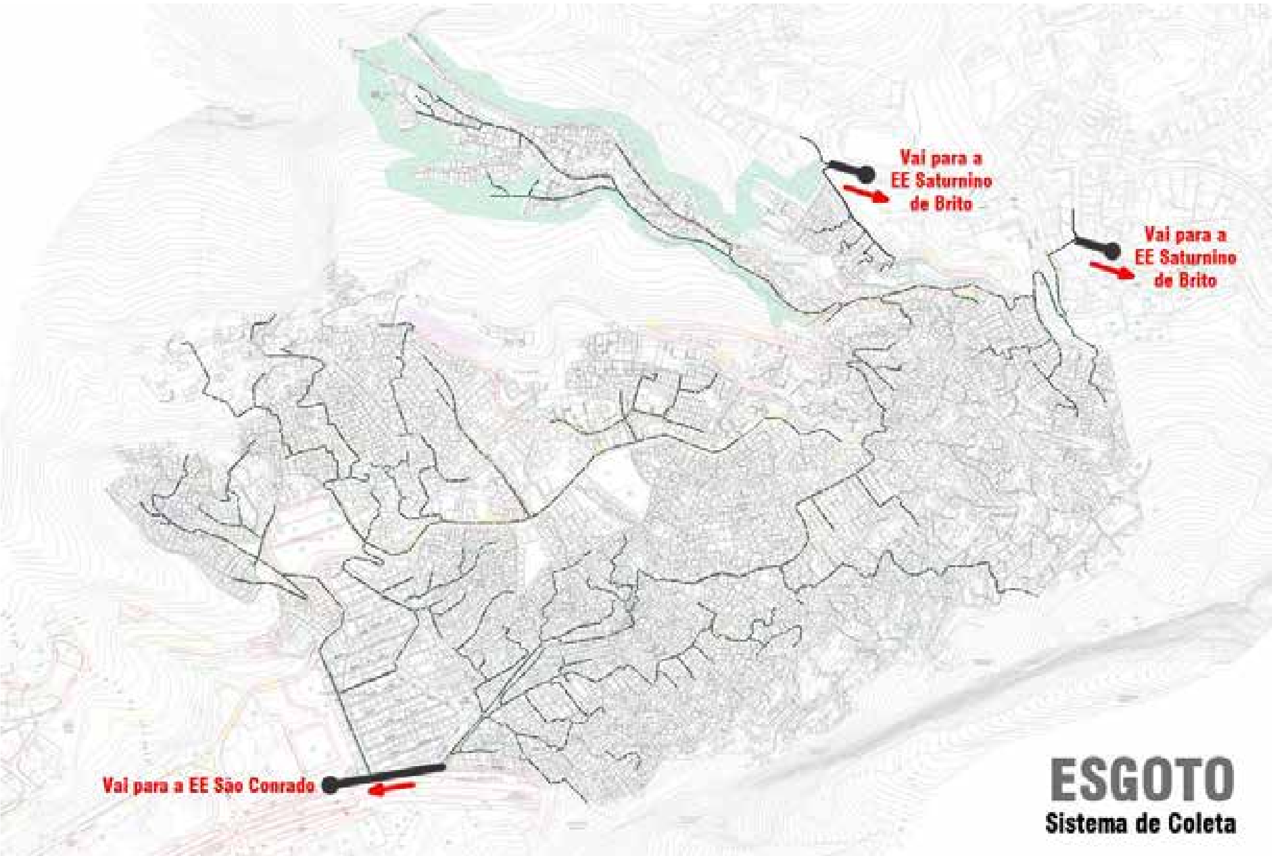


Figure 3.3.21 Existing sewage system. Source: Cadastro CEDAE

The current network is developed on the concept of "condomínios", based on the idea of main and secondary network. This system divides the community in small groupings of houses, taking the name of "condomínios", that directly discharge in the main network. In each "condomínios" there is a secondary network that connect every house to sewerage.

The main network has been built with pipes from 150 mm to 600 mm of diameter in PVC, extended for 29.2 km. While the secondary network, extended for 73.2 km, originally had piping of 100 mm in PVC, but it has been recently replaced with pipes of 150 mm of diameter.

Nowadays, according to the 2010 IBGE census, the houses with an appropriate connection to sewerage system or to rain water drainage system are only 86%, while the remaining 14% dumps the waste waters into a septic tank or cesspool or, sometime, directly in the streets. In fact, in some parts of the favela, due to narrow streets, the sewerage system hasn't been built, so the sewage is discharged directly in the talvegues or in sewerages built by population.

Figure 3.3.22 Main discharge pipe

Figure 3.3.23 Main discharge pipe, Av. Niemeyer. Source: CONEN, 2012

Figure 3.3.24 Main discharge pipe, São Conrado/Leblon. Source: CONEN, 2012

System's problem

From the analysis and the studies previous discussed, what stands out is that the current network for waste water collection doesn't connect adequately all urban neighbourhoods. Indeed, a lot of houses aren't connected to the system, consequently, most of the slurry is not collected by the public network CEDAE, which leads wastewater to treatment stations. In fact, except for Estrada da Gávea, in Rocinha, due to the narrow streets, there often is no sewerage system to speak of. Furthermore, in some parts of the favela the sewerage has been built by population, and in other parts of Rocinha the waste water and the rain water are collected by the same network, which is often overloaded and causes overflows, due to heavy rains. Moreover, the buildings, in the proximity of the talvegues, dump directly in the open canals. In the talvegues, it is easy to find trash accumulation and dirty water stagnation, consequently, the air has the highest insalubrity values. Thus, due to the problem of waste water collection, most slurry is dumped directly in the streets, where it stagnates till when the rain, thanks to the terrain slope, scrub it away and carry everything in the drainage system channels.

Furthermore, in Rocinha there isn't a proper maintenance of the current network of waste water collection, aggravating the already precarious situation.

All these problems connected to the waste water collection network are dangerous for the public health and influence the life expectation of population. This data is obviously connected with the roads and streets healthiness, that every day people walk, where it is simple to find an open sewer, collected garbage and house's drains. Moreover, the frequent lack of sunlight at street level, due to the buildings' close proximity, added to the tropical climate, characterized by a high humidity rate all the year, becomes the "perfect" conditions for the growth of tuberculosis and the outbreak of other infectious diseases.

Figure 3.3.25 Canal do Valão. Source: CONEN, 2012

Figure 3.3.26 House over a talvegue. Source: CONEN, 2012

Intervention

To solve the abovementioned sewerage problems, it is necessary to design a new sewage system. This new network must not only connect all the houses to sewerage and all the existing sewers pieces, but also replace the sewerage built by population. Furthermore, in this new network the waste water and the rain water must be separated, consequently, the slurry must be led into an underground piping, while the rain water dumped in the existing talvegues.

Firstly, to design a new sewage system, the topography of the area and the obstacles present in the analysed context must be analysed, as buildings, gradients, dense urban areas, talvegues ecc. Then, the position of the main pipes will be traced. In particular, depending on the slope, it will be possible to calculate the most suitable hydraulic sections, also taking into account the minimum size that prevents the piping from occlusion. Moreover, adequate leaps, posed for the high gradients values, will have the advantage of establishing inspection points for the removal of solids that may have been introduced into the pipelines.

Moreover, the future pipe network will have standard dimensions, because the water that flows into them will have a maximum value and not variable, due to the aqueduct dimensions, from where the domestic use water is taken. However, the possibility of an increase of water in the sewerage pipes must be considered, studying the possibility to use a portion of the rainwater from the roofs (the exact area to be connected should be computed considering the rainfalls) to wash the pipes during storms.

The pipes must be easy to install and move, remove and inspect, and they must be protected from damages, impacts, and sunlight. The outfall of the developed network should be the treatment plant, before dumping the waters into the environment.

3.3.2.3 Intervention in Area 1

Introduction

As discussed above, wastewater management, collected both from rainwater and urban wastewater from households and public buildings, is one of Rocinha's most dire emergencies.

The existing CEDAE public sewage system remains inadequate, as, for the most part, it fails to properly connect to all households and public buildings of a given area. Instead, the remaining wastewater is collected either by a locally built informal sewage network or dumped directly into the existing talvegues network, neither an acceptable solution, especially from a public hygiene standpoint.

Moreover, Rocinha lacks separate sewerage for municipal wastewaters (blackwater from toilets, greywater and industrial wastewater) and for surface run-off. Despite such separation being prescribed by Brazil's own sewerage design standards.

On top of that, those households either too isolated, located in extremely narrow streets or too far from talvegues, resort to improper disposal of wastewater directly into the streets, where it stagnates until rainfalls and the sloping terrain wash it away and into the drainage system channels, with high sanitary risks.

Current Sewage System Description

The only official map available detailing the current public sewage system existing in Rocinha is the Cadastro Cedea. The sewerage network only covers a fraction of the favela's thousands of households and has been built with pipes of 150 mmm in diameter, serving small groupings of houses named "condomínios".

These branches convey into the main conduit located underneath Estrada da Gávea, with a diameter of 600 mm. The Cadastro mentions neither the pipes' material, the depth at which they are positioned, the way they connect to the "condomínios", nor their degradation.

Broadly speaking, the current sewerage built in Area 1 can be split in two basins, both converging

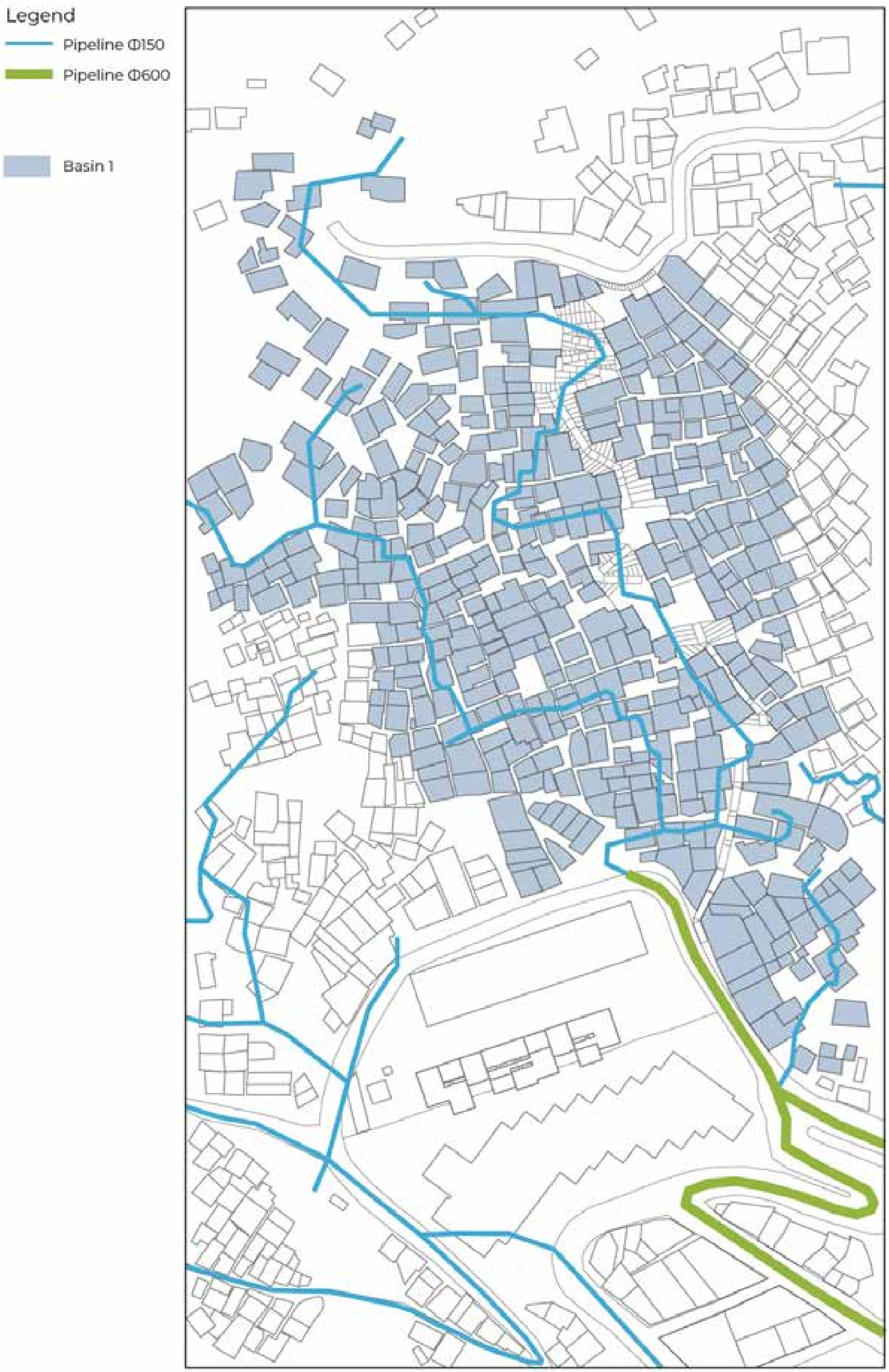


Figure 3.3.27 Sewage system in Area 1: currente situation

to the lower right of the area, where Estrada da Gávea lays.

The branches of the basin to the South-West (Basin 2) mostly gather the wastewater from the buildings clustered around Rampa da Villa Verde and Escala da Villa Verde, presumably collecting also the streams coming from the three buildings bordered by Villa Verde: the school, the gas depot and the UPA. As this basin is relatively far from the urban intervention area, it has been excluded from the subsequent analyses.

The other basin (Basin 1) covers almost half of Area 1, beginning at the intersection with Villa Verde and Estrada da Gávea's hairpin bend, first branching North-West along the former and North to a number of households, then climbing the area steep terrain all the way past Rua Dionéia. This basin will be the focus of the following analyses, as its main branch runs almost parallel to the new planned connection between Villa Verde and Rua Dionéia, facilitating the possibility of an intervention and expansion of the existing sewage network.

On a side note, the beginning of the two branches visible to the right, both collect into a third basin outside Area 1.

Intervention guidelines

The analysis and study below have been conducted with the help of professor Stefano Mambretti, associate professor of hydraulics of DICA (Department of Civil Engineering and Environment at Politecnico di Milano), who has provided guidelines in the designing and dimensioning of the elements.

Following professor Mambretti's suggestion, the wastewater network has been split from the rainwater network. The former as the aforementioned underground piping network, while the latter will be redirected into the existing talvegues. The pipes will also have standard dimensions, as the maximum flow introduced into the network is dictated by the capacity of the aqueduct, from which the water for domestic use is taken.

Furthermore, the total flow introduced into the network will take into account the so-called "first rainwater", which represents the first 5 mm of run-down rainwater uniformly distributed over the entire roofs' surfaces. Said flow collects large amounts of sand, acids and pollutants of various kind and cannot be disposed of in the drainage network, as per Brazil's sanitary regulations. This flow increase also serves to wash the piping network during storms in order to avoid the sedimentation phenomena that can lead to occlusions.

Finally, the pipes must be easy to install, move, remove and inspect, as well as be protected from damage, impact and sunlight. Consequently, the sewerage has been positioned, when possible, along the existing streets.

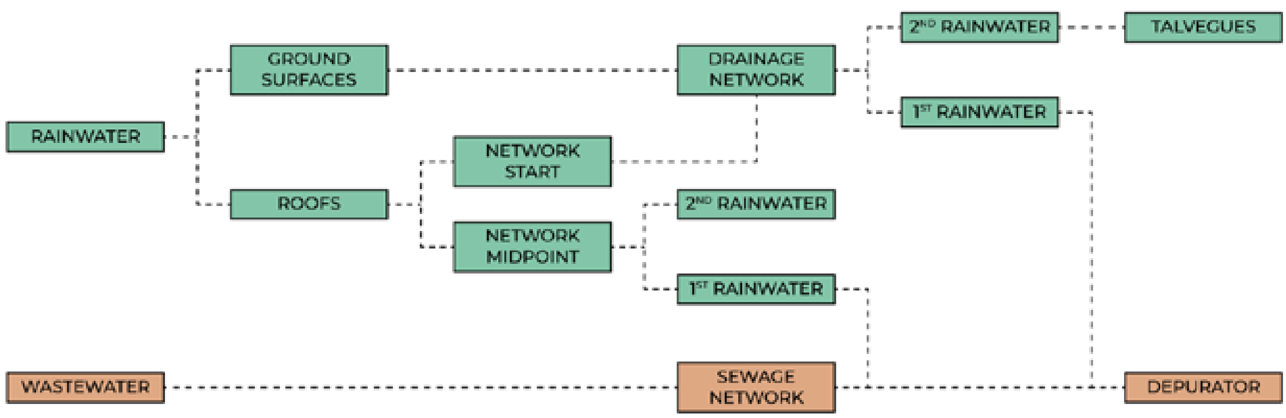


Figure 3.3.28 Water networks' scheme

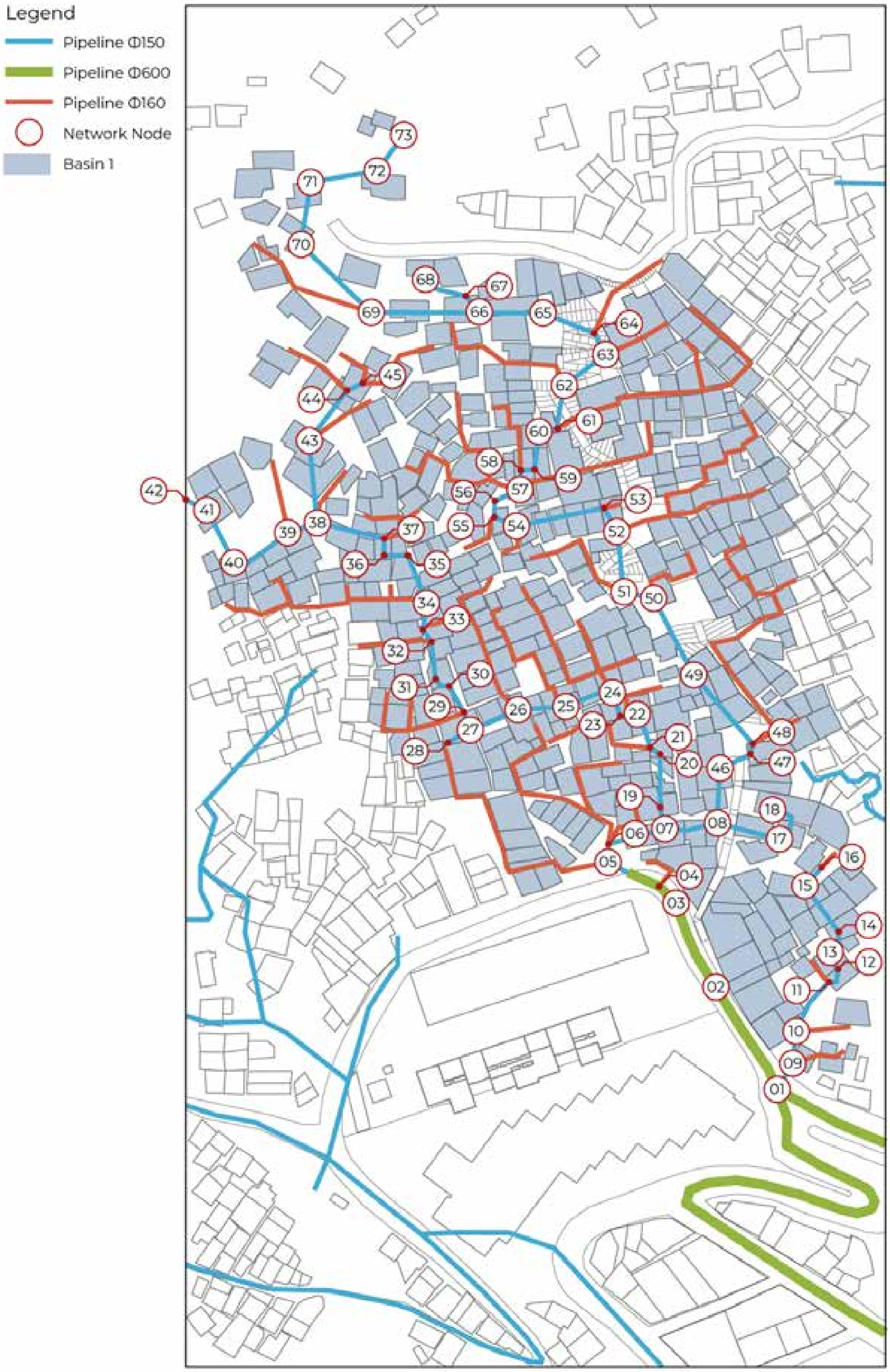


Figure 3.3.29 Sewage system in Area 1: intervention

3.3.2.4 Intervention in Basin 1

The intervention on Basin 1's sewage network aims first at designing the necessary additional branches to connect the existing sewerage with all households the basin can potentially sustain, then the existing pipe network will be verified to confirm whether it can take the increased flow of wastewater.

Following the guidelines established with professor Mambretti, it was decided that the new sewage network's pipes will be made of prefabricated PVC elements. This choice has been made mostly due to the lightness of the material, which makes the pipes easier to transport and manage inside an urban landscape as complex as Rocinha, over heavier and bulkier prefabricated elements in ceramic or concrete. PVC possesses also an adequate mechanical and corrosion resistance, while remaining relatively cheap. As mentioned above, the rainwater and wastewater network will work as parallel systems, with only the first rainwater flowing from one system to the other, as shown in the diagram above.

The prefabricated pipes that constitute the new branches of the sewerage network of Basin 1 are all 160 mm of diameter. These dimensions not only consider Rocinha's urban context (rocky terrain, extreme slopes and narrow streets), but allow also the flow of domestic waste with a considerable safety margin, the latter taking into account the additional flow coming from the first rainwater, while avoiding overflow during the rain season. This diameter also decreases the possibility of occlusions, either by the sedimentation or improper disposal of waste into the sewerage.

The new branches have been designed to reach all neighbourhoods and households contained within Basin 1, positioned, when possible, along the existing streets. The individual houses will be connected to these branches directly though a PVC sewage collector and a PVC siphoning sump pit. Further, as good practice requires, an inspection pit will be placed at each direction changes and intersection of two or more pipes, and every 25 metres, so that operators will be able to access the sewerage and verify its correct functioning periodically and, if necessary, remove solids that may have been introduced into the pipelines.

Having designed the additional piping, and thus increased the flow of wastewater coming into the existing network, it was necessary to verify whether the existing pipelines could hold the additional intake or supplementary interventions were required. Seventy-three sewage section were identified in Basin 1, each assumed to take wastewater from the nearest households. In other words, by approximating the number of inhabitants per house, it was possible to calculate the flow of domestic waste for each section.

The current daily average value of water available in Rocinha was set at 150 LPCD (Litre per capita per day), as approximately 80% is collected into the sewers, the value becomes 120 LPCD. To obtain the daily maximum value, the result needs to be multiplied by 1.5. The average and maximum flow rate for each section is obtained multiplying these two values by the number of inhabitants of a section.

The results are summarized in the chart below.

Section	Height drop [m]	Lenght [m]	Slope [m/m]	$Q_{wastewater}$ [L/s]
73-72	4.29	14.48	0.30	0.03
72-71	9.73	22.92	0.42	0.00
71-70	8.04	21.21	0.38	1.11
70-69	11.22	32.24	0.35	0.10
69-66	7.36	34.36	0.21	0.10

Tab. 3.3.14 Wastewater flow in the sewerage system, sections 73-72 to 69-66

Section	Height drop [m]	Lenght [m]	Slope [m/m]	$Q_{wastewater}$ [L/s]
68-67	9.11	16.80	0.54	0.03
67-66	2.00	6.72	0.30	0.09
66-65	0.19	19.74	0.01	0.07
65-64	0.63	17.30	0.04	0.16
64-63	4.01	8.50	0.47	0.28
63-62	9.61	18.52	0.52	0.22
62-61	8.61	16.16	0.53	0.80
61-60	2.41	6.29	0.38	0.42
60-59	6.97	14.23	0.49	0.47
59-58	0.31	4.30	0.07	0.07
58-57	1.24	6.07	0.20	0.31
57-56	0.75	8.61	0.09	0.10
56-55	0.41	5.10	0.08	0.23
55-54	3.76	8.26	0.45	0.06
54-53	3.94	28.04	0.14	0.09
53-52	0.51	8.39	0.06	0.74
52-51	5.81	19.88	0.29	0.32
51-50	3.43	10.22	0.34	0.55
50-49	11.22	29.01	0.39	0.19
49-48	12.28	31.68	0.39	0.96
48-47	0.51	3.26	0.16	0.79
47-46	2.95	11.20	0.26	0.10
46-8	7.21	18.46	0.39	0.13
18-17	4.67	16.58	0.28	0.19
17-8	4.10	20.42	0.20	0.04
8-7	8.21	19.52	0.42	0.35
45-44	0.00	5.53	0.00	0.07
44-43	3.49	19.68	0.18	0.13
43-38	16.91	30.65	0.55	0.06
42-41	1.43	7.52	0.19	0.00
41-40	9.39	20.65	0.45	0.10
40-39	4.84	21.29	0.23	0.06
39-38	0.18	9.50	0.02	0.04
38-37	1.66	21.37	0.08	0.15
37-36	1.00	5.36	0.19	0.28
36-35	1.11	7.57	0.15	0.15
35-34	7.97	17.61	0.45	0.13
34-33	3.69	9.14	0.40	0.69

Tab. 3.3.15 Wastewater flow in the sewerage system, sections 68-67 to 34-33

Section	Height drop [m]	Lenght [m]	Slope [m/m]	Q [L/s]
33-32	3.50	5.88	0.60	0.25
32-31	6.20	13.87	0.45	0.06
31-30	2.13	5.85	0.36	0.29
30-29	6.78	12.16	0.56	0.09
29-27	1.00	5.78	0.17	0.44
28-27	0.00	7.93	0.00	0.10
27-26	1.05	16.09	0.07	0.04
26-25	0.89	14.85	0.06	0.20
25-24	0.84	15.68	0.05	0.60
24-23	2.07	8.39	0.25	0.55
23-22	4.39	7.80	0.56	0.18
22-21	5.77	12.70	0.45	0.10
21-20	1.00	3.84	0.26	0.31
20-19	10.24	18.89	0.54	0.13
19-7	6.69	12.02	0.56	0.47
7-6	1.79	18.01	0.10	0.18
6-5	3.49	5.72	0.61	1.11
5-4	6.77	22.65	0.30	0.50
4-3	0.23	7.26	0.03	0.18
3-2	0.92	28.88	0.03	0.16
2-1	1.12	37.06	0.03	1.04
16-15	1.05	7.72	0.14	0.09
15-14	12.66	22.99	0.55	0.06
14-13	5.08	10.18	0.50	0.36
13-12	0.10	5.99	0.02	0.15
12-11	0.10	6.36	0.02	0.18
11-10	3.61	19.28	0.19	0.07
10-9	1.06	9.90	0.11	0.28
9-1	1.70	9.38	0.18	0.12
Nodo 1				**1.15**

Tab. 3.3.16 Wastewater flow in the sewerage system, sections 33-32 to 9-1

The cross-sectional average velocity for each section in relation to the percentage of tube filling is calculated using the Strickler formula:

$$v = k_s \cdot R_h^{\frac{2}{3}} \cdot i^{\frac{1}{2}}$$

Where:

- v is the velocity [m/s];
- k_s is the Strickler coefficient (80 for PVC pipes);
- R_h is the hydraulic radius [m];

- i is the slope [m/m].

Then, using the discharge formula, the volumetric flow rate is obtained:

$$Q = v \cdot A$$

Where:

- Q is the flow rate [m³/s];
- A is the wet area [m²].

This way, by comparing the flow rate resulting from this formula with the one obtained from the daily average water available, the flow velocity, the filling, the wet area, the wet radius and the hydraulic radius of each section have been obtained.

D [m]	k_s	Fill	h [m]	Wet area [m²]	Wet radius [m]	Hydraulic radius [m]	Slope [m/m]	V [m²/s]	$Q_{Tot.}$ [L/s]
0.15	80	0.29	0.0435	0.0043	0.1706	0.0252	0.42	4.46	19.18

Tab. 3.3.17 Example of velocity calculation for a section (Section 8-7, 29% filling)

It should be noted that the cross-sectional average velocity must not exceed 5 m/s to avoid pressure surges (water hammer) and high exfoliation rates, the latter causing premature aging of the pipes. Conversely, the filling percentages must not exceed 85%, to prevent overflow during heavy rain periods.

As discussed previously, a small percentage of rainwater (first rainwater) must flow into the sewage system in order to periodically wash the pipelines, though always within the safety margins detailed above.

To estimate the amount of first rainwater that can be introduced in the sewerage, the piping's final section was considered to reach the maximum capacity allowed (85%), thus obtaining the theoretical maximum flow. To reach said flow, the rainwater coming from houses closer to the start of each branch were prioritized, thus guaranteeing the complete cleaning of the pipes. First and second rainwater are separated by using a floodway sump pit of storm water.

First rainwater was calculated simply multiplying by 5 mm the surfaces of each roof, as detailed in the chart below.

Node	Roof area [m²]	First rainwater [m³]	t [min]	Q_{FRW} [L/s]
2	15.12	0.08	2.80	0.45
3	52.21	0.26	2.80	1.55
4	15.91	0.08	2.80	0.47
5	27.95	0.14	2.80	0.83
6	9.12	0.05	2.80	0.27
7	50.16	0.25	2.80	1.49
8	33.36	0.17	2.80	0.99
9	16.18	0.08	2.80	0.48
10	44.59	0.22	2.80	1.33
12	8.36	0.04	2.80	0.25

Tab. 3.3.18 Flow from first rainwater, part I

Node	Roof area [m²]	First rainwater [m³]	t [min]	Q_{FRW} [L/s]
13	17.78	0.09	2.80	0.53
14	17.16	0.09	2.80	0.51
16	55.89	0.28	2.80	1.66
18	46.04	0.23	2.80	1.37
19	25.68	0.13	2.80	0.76
20	18.37	0.09	2.80	0.55
21	19.95	0.10	2.80	0.59
22	27.57	0.14	2.80	0.82
23	13.70	0.07	2.80	0.41
24	18.11	0.09	2.80	0.54
25	17.39	0.09	2.80	0.52
26	19.31	0.10	2.80	0.57
28	41.10	0.21	2.80	1.22
29	4.57	0.02	2.80	0.14
30	16.18	0.08	2.80	0.48
31	26.13	0.13	2.80	0.78
32	20.54	0.10	2.80	0.61
33	17.67	0.09	2.80	0.53
34	13.22	0.07	2.80	0.39
35	23.51	0.12	2.80	0.70
36	27.12	0.14	2.80	0.81
37	21.59	0.11	2.80	0.64
38	28.19	0.14	2.80	0.84
39	34.89	0.17	2.80	1.04
40	22.70	0.11	2.80	0.68
41	54.69	0.27	2.80	1.63
43	53.13	0.27	2.80	1.58
44	45.50	0.23	2.80	1.35
45	38.89	0.19	2.80	1.16
46	57.06	0.29	2.80	1.70
47	67.94	0.34	2.80	2.02
48	11.08	0.06	2.80	0.33
49	19.55	0.10	2.80	0.58
50	21.76	0.11	2.80	0.65
51	8.50	0.04	2.80	0.25
52	23.56	0.12	2.80	0.70
53	15.72	0.08	2.80	0.47
54	23.83	0.12	2.80	0.71

Tab. 3.3.19 Flow from first rainwater, part II

Node	Roof area [m²]	First rainwater [m³]	t [min]	Q_{FRW} [L/s]
55	37.06	0.19	2.80	1.10
56	18.86	0.09	2.80	0.56
57	35.83	0.18	2.80	1.07
58	24.76	0.12	2.80	0.74
59	44.06	0.22	2.80	1.31
60	20.37	0.10	2.80	0.61
61	9.96	0.05	2.80	0.30
62	8.53	0.04	2.80	0.25
63	42.68	0.21	2.80	1.27
64	34.52	0.17	2.80	1.03
65	65.73	0.33	2.80	1.96
66	40.00	0.20	2.80	1.19
67	50.62	0.25	2.80	1.51
69	28.45	0.14	2.80	0.85
70	28.57	0.14	2.80	0.85
73	22.85	0.11	2.80	0.68

Tab. 3.3.20 Flow from first rainwater, part III

All previous calculations on the existing sewerage network were repeated, adding the first rainwater, as summarized in the chart below. It should be noted that, as the velocity of sections 7-6, 6-5 and 5-4 exceeded 5 m/s, it was necessary to decrease the slope though the introduction of three jump sump pits to dissipate the kinetic energy, and thus the velocity. The first two pits are two metres deep, while the latter is three.

The chart below shows the final values of water flow and velocity.

Section	$Q_{Tot.}$ [L/s]	V [m²/s]	Fill	h [m]	Wet area [m²]
73-72	0.71	1.47	0.07	0.0105	0.0005
72-71	0.71	1.60	0.06	0.0090	0.0004
71-70	1.82	2.18	0.10	0.0150	0.0009
70-69	1.92	2.31	0.11	0.0165	0.0011
69-66	2.02	1.87	0.12	0.0180	0.0012
68-67	1.29	2.38	0.08	0.0120	0.0007
67-66	1.37	1.85	0.09	0.0135	0.0008
66-65	3.47	0.72	0.33	0.0495	0.0051
65-64	3.63	1.18	0.24	0.0360	0.0033
64-63	3.91	3.04	0.14	0.0210	0.0015
63-62	4.13	3.19	0.14	0.0210	0.0015
62-61	5.18	3.43	0.15	0.0225	0.0017

Tab. 3.3.21 Final flow and velocity, sections 73-72 to 62-61

Section	$Q_{Tot.}$ [L/s]	V [m²/s]	Fill	h [m]	Wet area [m²]
61-60	5.90	3.10	0.17	0.0255	0.0020
60-59	6.97	3.51	0.17	0.0255	0.0020
59-58	7.05	1.81	0.28	0.0420	0.0041
58-57	8.09	2.72	0.23	0.0345	0.0031
57-56	8.19	2.02	0.29	0.0435	0.0043
56-55	8.99	2.01	0.31	0.0465	0.0047
55-54	9.04	3.70	0.20	0.0300	0.0025
54-53	9.84	2.53	0.28	0.0420	0.0041
53-52	11.05	1.91	0.37	0.0555	0.0059
52-51	12.07	3.50	0.26	0.0390	0.0037
51-50	12.88	3.76	0.26	0.0390	0.0037
50-49	13.72	3.94	0.25	0.0375	0.0035
49-48	15.26	4.05	0.27	0.0405	0.0038
48-47	16.38	2.99	0.35	0.0525	0.0055
47-46	16.48	3.65	0.31	0.0465	0.0047
46-8	16.61	4.22	0.28	0.0420	0.0041
18-17	1.56	1.88	0.10	0.0150	0.0009
17-8	1.60	1.76	0.11	0.0165	0.0011
8-7	18.57	4.46	0.29	0.0435	0.0043
45-44	1.23	0.19	0.40	0.0600	0.0066
44-43	1.36	1.49	0.10	0.0150	0.0009
43-38	1.42	2.40	0.08	0.0120	0.0007
42-41	0.00	0.62	0.02	0.0030	0.0001
41-40	0.10	1.32	0.03	0.0045	0.0002
40-39	0.84	1.54	0.08	0.0120	0.0007
39-38	0.88	0.61	0.14	0.0210	0.0015
38-37	2.45	1.40	0.17	0.0255	0.0020
37-36	3.36	2.03	0.15	0.0255	0.0017
36-35	4.32	2.01	0.18	0.0270	0.0022
35-34	5.15	3.16	0.15	0.0225	0.0017
34-33	6.23	3.19	0.18	0.0255	0.0020
33-32	7.00	3.87	0.15	0.0255	0.0020
32-31	7.67	3.50	0.17	0.0270	0.0022
31-30	8.74	3.42	0.17	0.0315	0.0027

Tab. 3.3.22 Final flow and velocity, sections 61-60 to 31-30

Section	$Q_{Tot.}$ [L/s]	V [m²/s]	Fill	h [m]	Wet area [m²]
30-29	9.31	3.95	0.18	0.0285	0.0023
29-27	9.88	2.70	0.21	0.0390	0.0037
28-27	1.33	0.19	0.19	0.0645	0.0073
27-26	11.25	1.98	0.26	0.0555	0.0059
26-25	12.03	1.95	0.39	0.0585	0.0064
25-24	13.15	1.90	0.42	0.0630	0.0070
24-23	14.24	3.42	0.29	0.0435	0.0043
23-22	14.82	4.64	0.24	0.0360	0.0033
22-21	14.92	4.27	0.25	0.0375	0.0035
21-20	15.82	3.57	0.30	0.0450	0.0045
20-19	16.50	4.77	0.26	0.0390	0.0037
19-7	17.73	4.83	0.25	0.0375	0.0035
7-6	36.30	3.09	0.64	0.0960	0.0119
6-5	37.68	3.95	0.37	0.0555	0.0059
5-4	38.18	4.78	0.43	0.0645	0.0073
4-3	38.82	4.03	0.65	0.3900	9.70
3-2	38.99	4.04	0.65	0.3900	9.70
2-1	40.47	3.93	0.71	0.4260	10.37
16-15	1.75	1.48	0.12	0.0180	0.0012
15-14	1.81	2.52	0.09	0.0135	0.0008
14-13	2.68	2.77	0.11	0.0165	0.0011
13-12	3.36	0.87	0.28	0.0420	0.0041
12-11	3.78	0.88	0.30	0.0450	0.0045
11-10	3.86	2.17	0.17	0.0255	0.0020
10-9	4.13	1.79	0.20	0.0300	0.0025
9-1	4.73	2.23	0.18	0.0270	0.0022

Tab. 3.3.23 Final flow and velocity, sections 30-29 to 9-1

3.3.2.5 Conclusions

The results of the analysis exceed expectations, as the existing sewage system is, for all practical purposes, already primed to receive all the wastewater from Basin 1 and keep functioning, with the exception of a few metres at the bottom of the basin.

On the other hand, implementing the proposed connections necessary to plug all households of Basin 1 in the existing network is no small feat, as, even discounting the extreme slope of Area 1, it is often impossible to properly connect all buildings just laying pipes along the streets and some sewerage would need extensive earthworks.

It is also important to note that all of the information on the current sewage system come from the Cadastro Cedea and conducting an in-depth survey would be paramount to attest the results of this analysis.

3.3.2.6 Sewerage network configurations

As there are no detailed survey of Area 1, and Rocinha besides, it is impossible to properly design the piping calculated in the previous paragraphs. Still, the following pages will provide a few possible configurations and design for the sewerage network that can illustrate how to solve some of the issue of building inside an urban environment as peculiar as a favela.

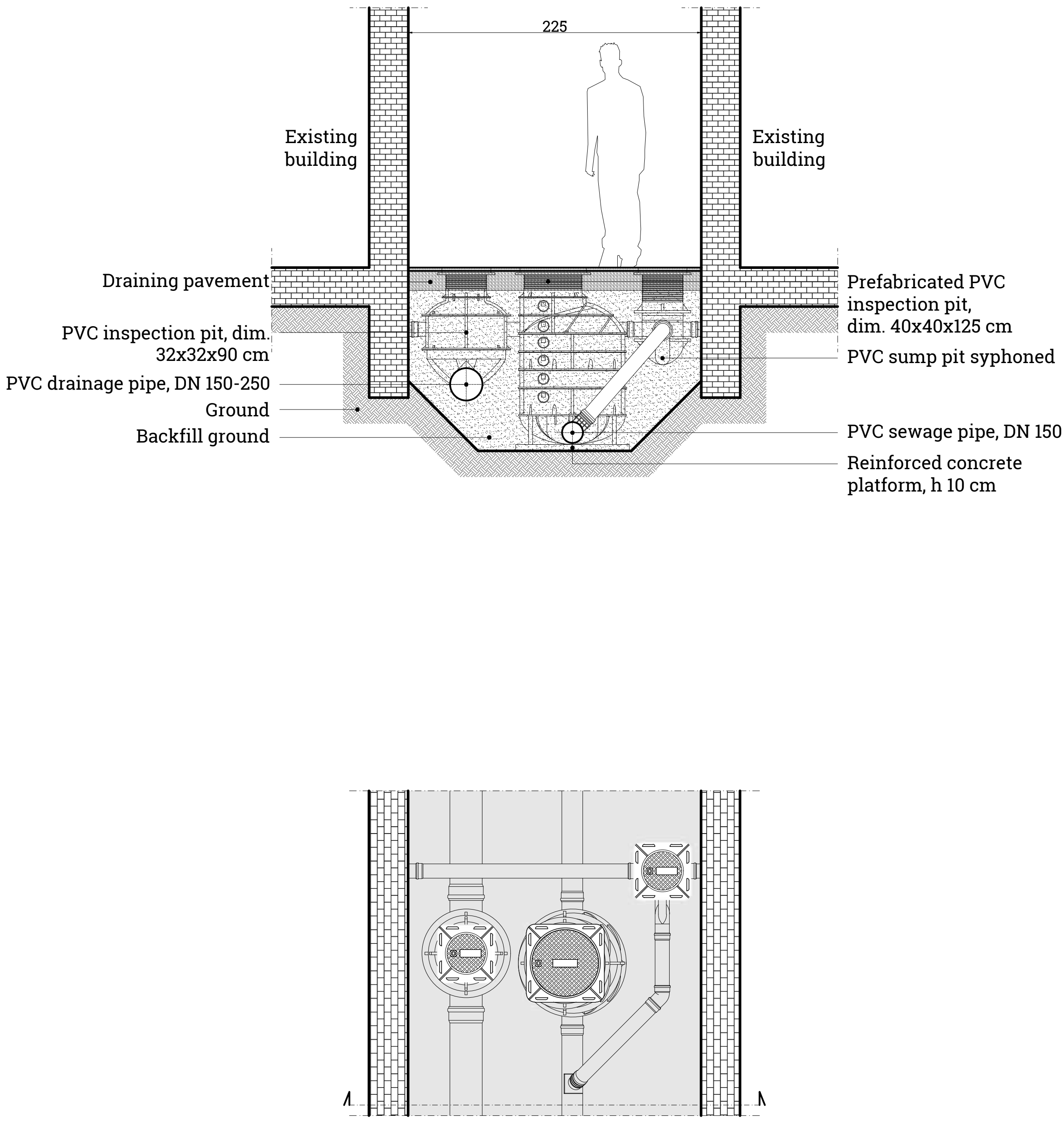


Figure 3.3.30 Sewage system: design configuration 1.1, scale 1:50

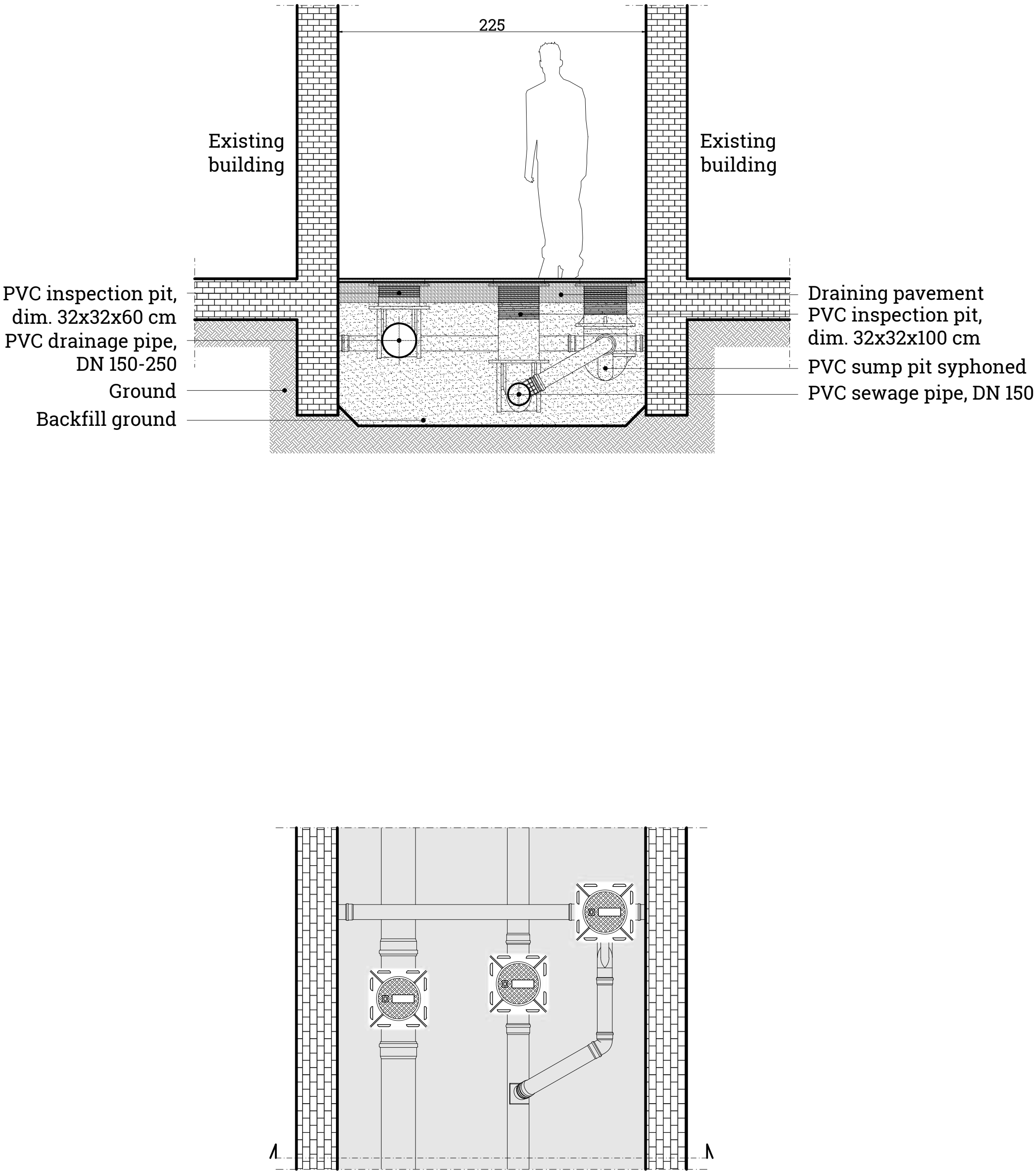
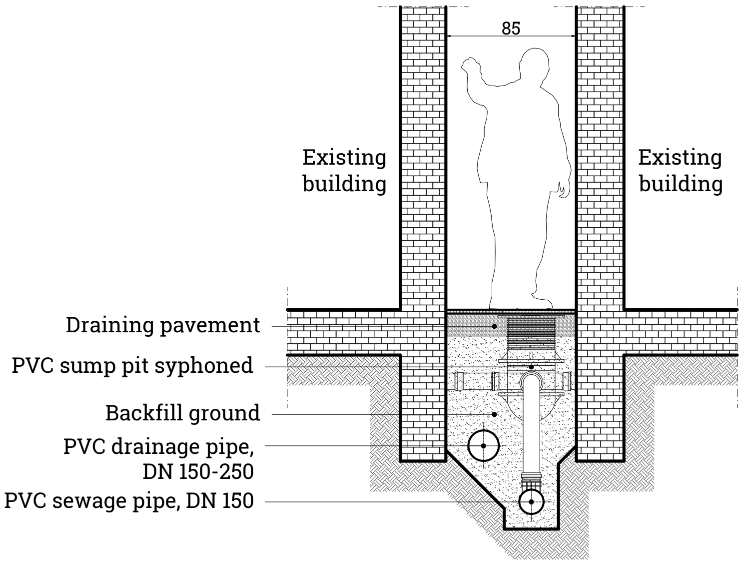


Figure 3.3.31 Sewage system: design configuration 1.2, scale 1:50



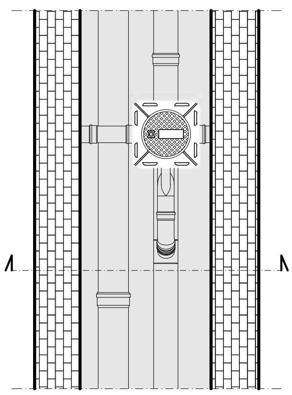
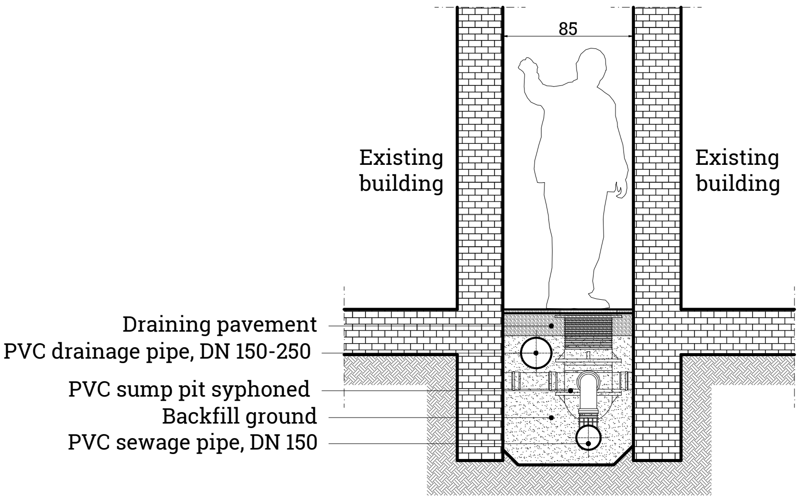


Figure 3.3.32 Sewage system: design configuration 2.1, scale 1:50



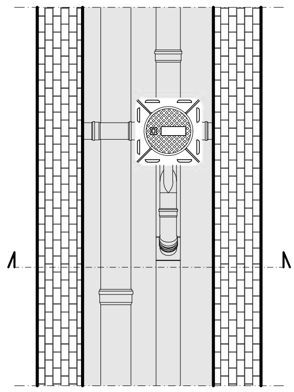
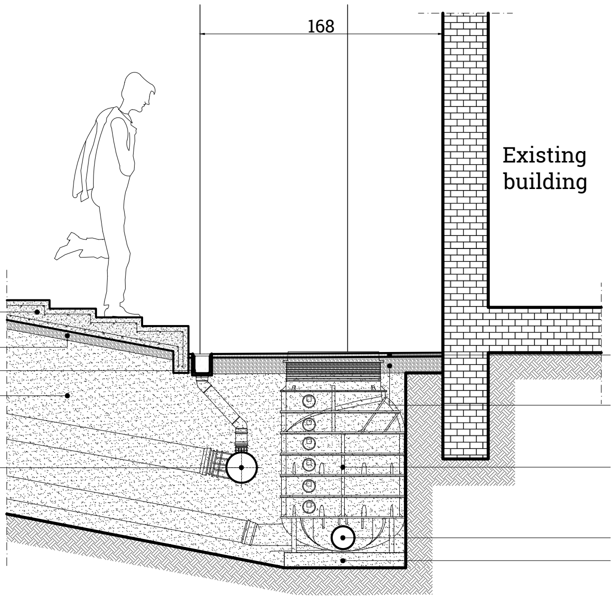


Figure 3.3.33 Sewage system: design configuration 2.2, scale 1:50



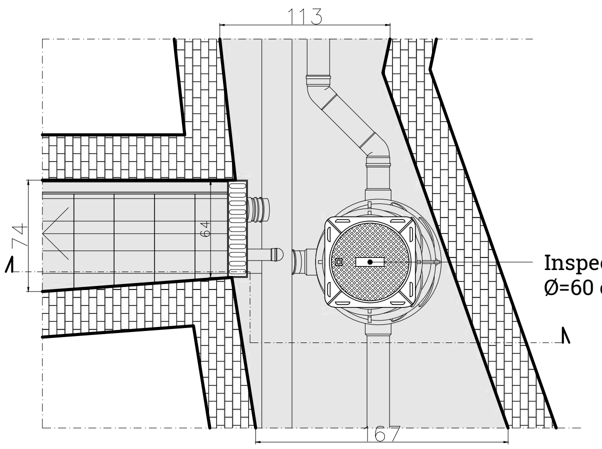
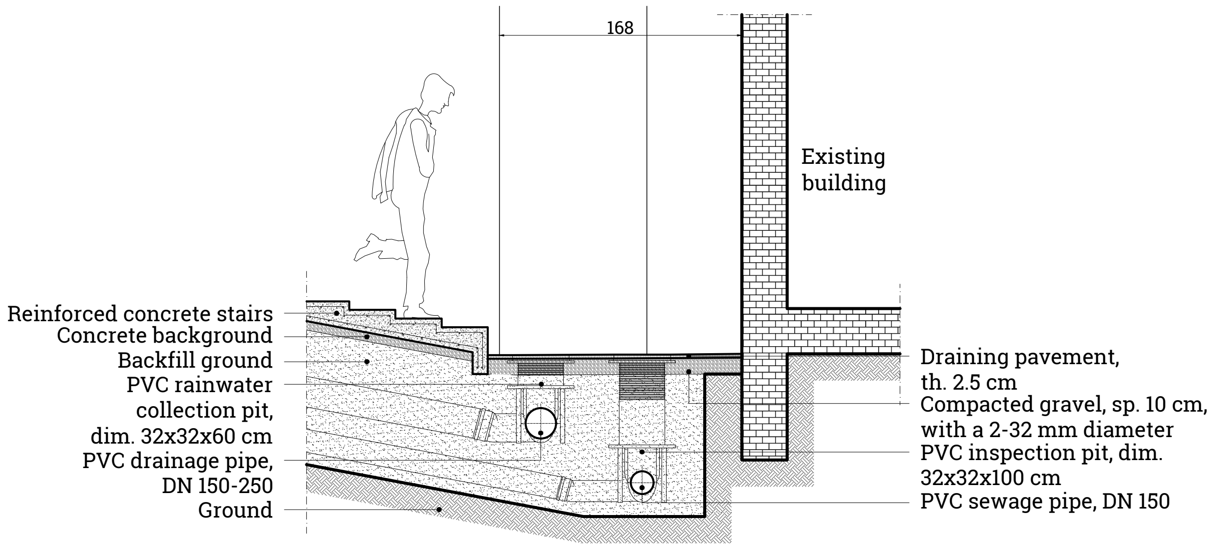


Figure 3.3.34 Sewage system: design configuration 3.1, scale 1:50



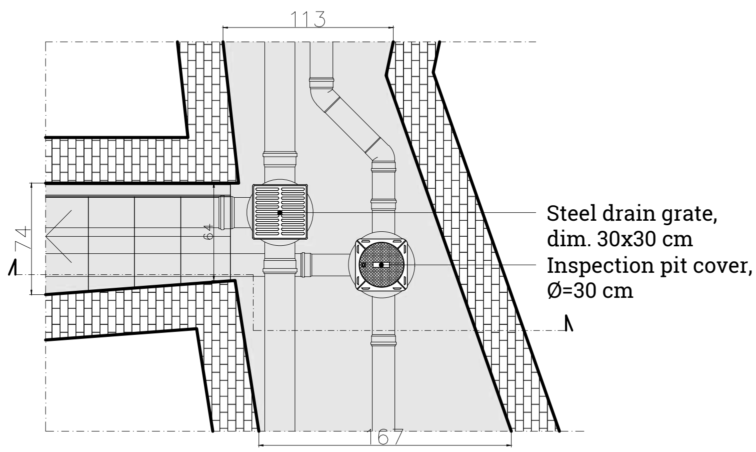
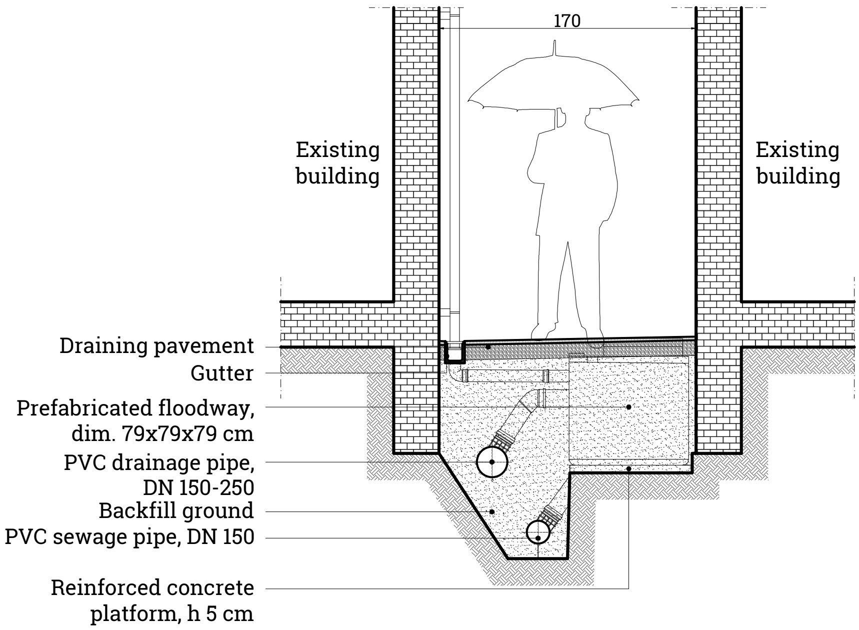


Figure 3.3.35 Sewage system: design configuration 3.2, scale 1:50



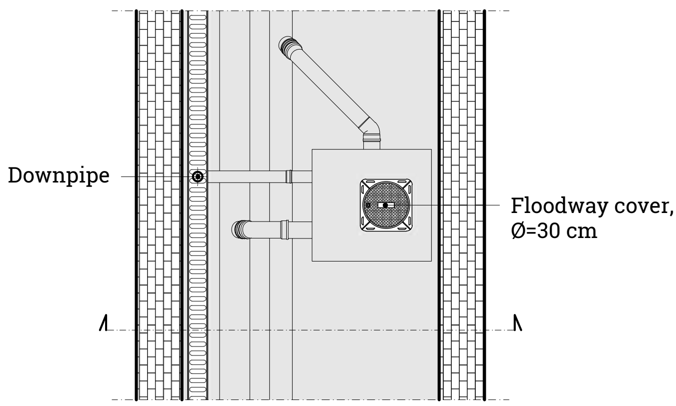
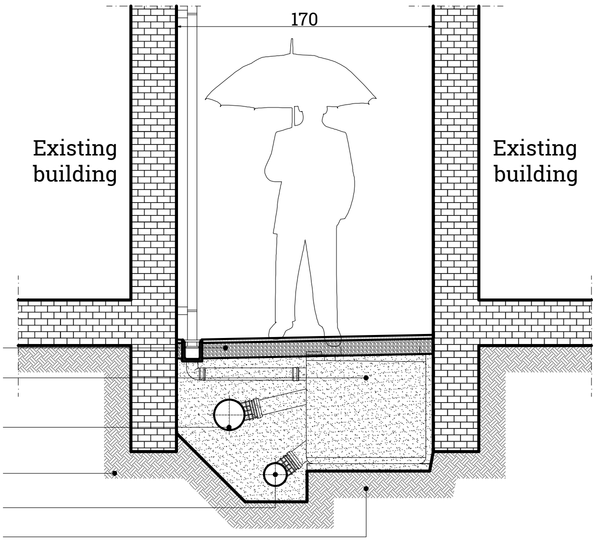


Figure 3.3.36 Sewage system: design configuration 4.1, scale 1:50



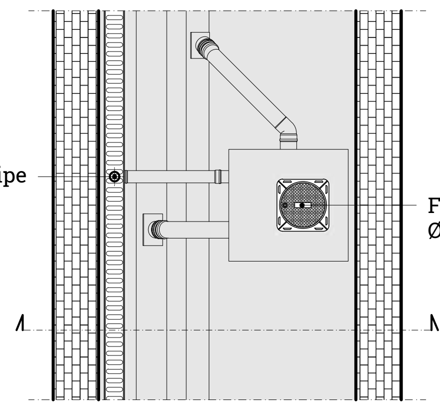


Figure 3.3.37 Sewage system: design configuration 4.2, scale 1:50

3.3.3 Drainage

Figure 3.3.38 Flooding in Rocinha. Source: www.lifeinrocinha.blogspot.com

3.3.3.1 Introduction

Water management is one of the critical issues of Rocinha and the source of several problems in terms of sanitation and health of the inhabitants, as the lack of a proper water drainage system is the cause of drain problems which could lead to the formation of runoff phenomena during periods of intense rain. This situation is a great risk for the inhabitants' safety due to the favela's topography (narrow streets coupled with extremely sloped terrain) and the concentration of heavy rain phenomena during the summer season (normally in Brazil the rain season starts in December and lasts until the end of February). The almost total lack of vegetation, caused by the high density of buildings inside the favela, limits the drainage effect of the nutrient retention of the natural soil which could be an effective answer to the main problem.

3.3.3.2 The "Talvegues" system

Talvegues are part of the pre-existent heavy rains' mitigation system. Taking the data collected in the Planave S.A. diagnosis, Rocinha is sprawled across two hillsides: one toward the Barrio da Gavea, the other to São Conrado. The latter covers around 80% of the community and presents several "talvegues" built with waterproof stone layers. A good number of those canals are close to Campo Esperança, creating a flow that reaches the São Conrado beach passing through the favela, after passing through the Treatment Unit. The São Conrado basin presents a huge number of "talvegues" positioned depending on the Rocinha's topography, creating three main drainage basins:

- Basin 2 has an area of 48 ha and includes the following "talvegues": Morro do Laboriaux, Alto da Dioneia e Vila Verde.
- Basin 3 has an area of 62 ha and includes tributary "talvegues" of the main Rocinha canal, the Valão.
- Basin 4 has an area of 16 ha and includes the "talvegue Goerio" artificially created at the bottom of the stone massif Morro Dois Irmãos.

The "talvegue" system of Rocinha acts as a possible answer of the problem of concentrate heavy rainfalls, but it is insufficient due to the waste management and sewage problems: the basins of the canals are very often occupied by non-recycled waste thrown inside the channels by the inhabitants; furthermore, the canals are used as main collectors of the sewage system. In the end, the "talvegues" are overloaded and do not function as a proper solution to the problems explained before.

The aim of this chapter is to design a proper drainage system in a case study area exploiting the presence of the "talvegues" and using simple and implementable technological solutions to slow down the runoff phenomena or deal with it in a correct way. At the end, a summary of best practices will be showed to implement these projects in other areas of the favela (from the micro to the macro scale). The interventions will be studied starting from the statistical data and basins of the Rocinha valley shown below.

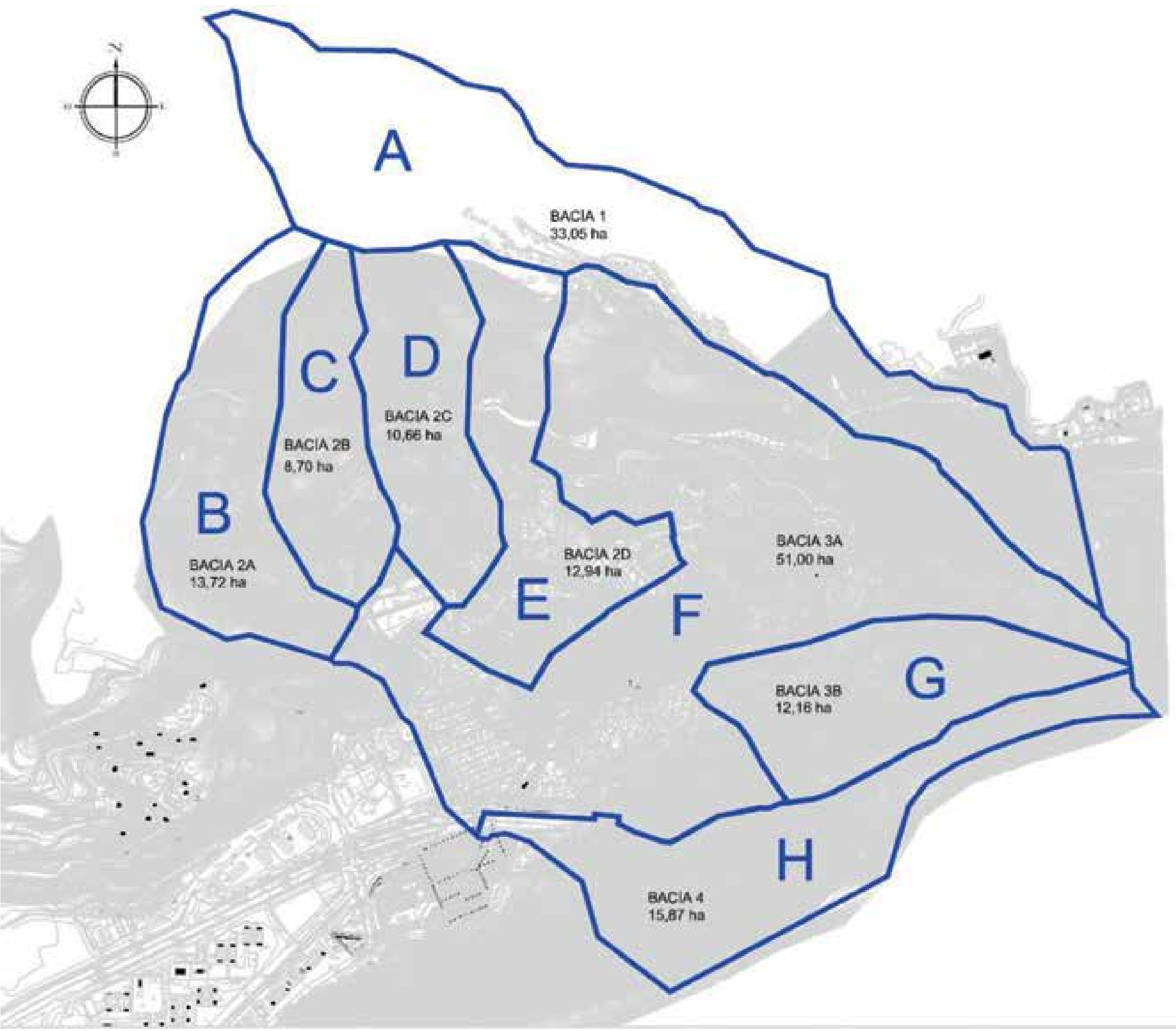


Figure 3.3.39 Basins' map. Source: CONEN, 2012

3.3.3.3 Stormwater management

As mentioned, stormwater management is one of the main issues in urban areas. Unmanaged stormwater runoff, during and after intense rainstorms, is one of the most significant direct risks for people life and an important source of environmental pollution and health hazard. This is even truer in areas where urbanization is the result of unplanned, self-organized processes, as in Rocinha.

In these contexts, dominated by impermeable surfaces and with inadequate drainage structures, rainstorms produce flash floods and the runoff is mainly conveyed into the streets. In most cases, the absence of street gutters and even sidewalks, combined with steep sloping street, makes walking or moving by bikes or other kind of transportation dangerous for people.

For an optimal and efficient management of stormwater, it seems appropriate to distinguish external contributions to runoff from internal ones. External contributions are due to runoff from natural vegetated slopes surrounding the urbanized area; internal contribution is generated by overland flow in the impervious surfaces inside the urban area.

3.3.3.4 Management of external stormwater runoff

To achieve a proper stormwater management, therefore reducing the risk of flooding, it is mandatory to limit external component of runoff as much as possible. This aim can be achieved by building open channels along the borders of urbanized area, collecting water from the vegetated area outside and discharging it entirely downstream of the urban area, in the existing main drainage channels. The map below shows the actual "talvegues" network: the exploitation of the non-obstructed channels is crucial, and it is important to evaluate the effective capacity of each "talvegue" to design proper solutions:

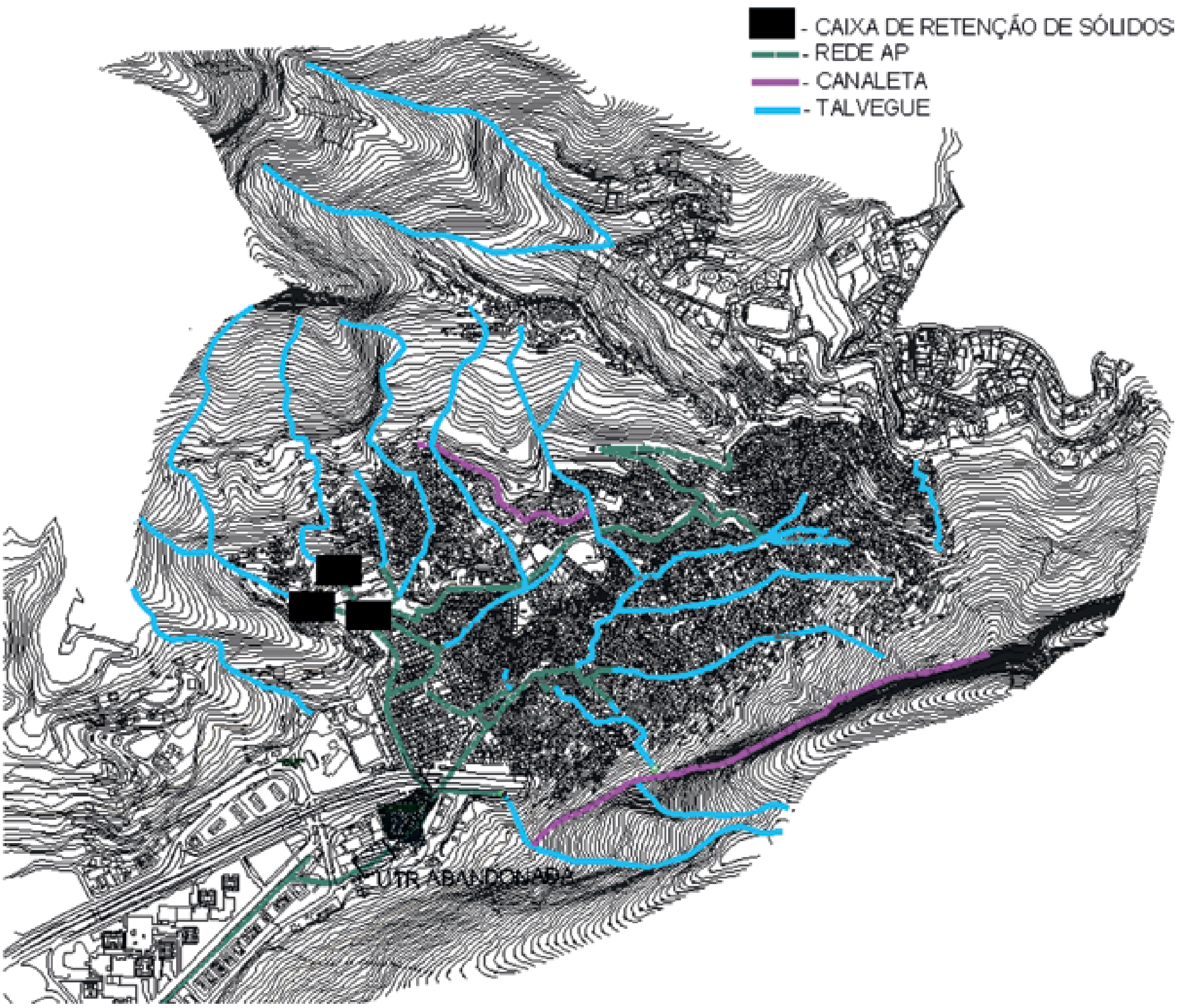


Figure 3.3.40 Existing drainage network. Source: CONEN, 2012

3.3.3.5 Management of internal stormwater runoff

Because of the limited intervention area inside the urban context, it is important to focus the efforts on the possible internal solutions to manage the stormwater runoff. Traditional solutions to internal stormwater management, mainly based on complete coupling of street gutters and underground piped networks, does not seem to be completely suitable for Rocinha. Most of streets are narrow and irregular and the risk of pipe choking is significant, due to the relevant solid component in water flows.

An effective strategy for stormwater management should address these issues in the simplest way, to be adapted to the continuous urban changes and to be applied in phases. Thanks to the collaboration of the DICA department of Politecnico di Milano working on the project and the assistance of professor Gianfranco Becciu, three different levels of intervention based on the width of the streets are individuated and discussed below:

First level

In wider streets the traditional coupling of street gutters and buried pipes and channels is the best solution. The two systems are coupled by inlets along the street sides or by transverse grates, according to slopes and flow paths. These streets are mainly in the lower part of Rocinha and water flows are significant and rich of transported solid matters. Although the projected pipe dimensions and flow velocity in these cases should make obstructions unlikely, the adoption of inlet grates and manholes with sediment chamber or bucket is suggested.

Second level

In secondary streets (under 5 m of width) flows are to be directed, helped by street re-shaping, to one or both street sides and then conveyed downstream to the main streets. Sidewalks and gutters must be built where they are absent, with proper dimensions to achieve both a safe walking and a central part of the street free from water flows.

Third level

In the remaining streets, too narrow and generally too steep to limit the surface runoff to street sides alone, flows are not specifically managed. To improve present conditions, however, sidewalks at least on one side must be built where possible and house inlets must be modified in order to make them floodproof. Downstream of narrow streets, whose runoff is conveyed by street surface and/or gutters, before crossing of main streets with underground drainage pipes, cross grated inlets along all the street width must be used.

3.3.3.6 Basic data

Nutrient retention: upstream and run off assessment

Thanks to the model studied by the DAStU researchers it was possible to obtain an ES mapping showing a nutrient retention model of Rocinha, which aims: *"to map nutrient sources from watersheds and their transport to the stream. This spatial information can be used to assess the service of nutrient retention by natural vegetation. The retention service is of particular interest for surface water quality issues and can be valued in economic or social terms (e.g. avoided treatment costs, improved water security through access to clean drinking water) [...] The model uses a mass balance approach, describing the movement of mass of nutrient through space. Sources of nutrient across the landscape, also called nutrient loads, are determined based on the LULC map and associated loading rates. Nutrient loads can then be divided into sediment-bound and dissolved parts, which will be transported through surface and subsurface flow, respectively. At the watershed/subwatershed outlet, the nutrient export is computed as the sum of the pixel-level contributions."* (Nelson et al., 2011).

More than for the final output of the model, the ES mapping was used for the intermediate ones to assess the upstream water yield and runoff process:

- **Upstream water yield** is the water upstream not retained by soil from which it must flow into a pixel before it's considered part of a stream. This is used to generate a stream layer from the DTM and the run-off process start to route the flow-paths that uses the DEM to track the gravitational run-off model. The run-off does not consider if the water routes moves via surface, subsurface or baseflows;

- **Runoff process** interact with the land use model and impermeable surfaces. Each land use has a coefficient of nutrient load and retention. This intermediate output provides information on the creation of streams in the area where the land use is composed by water bodies. The more streams generated by runoff model overlaps the water bodies in the land use, the more results will be reliable in the way the nutrient is routed to the contamination points.

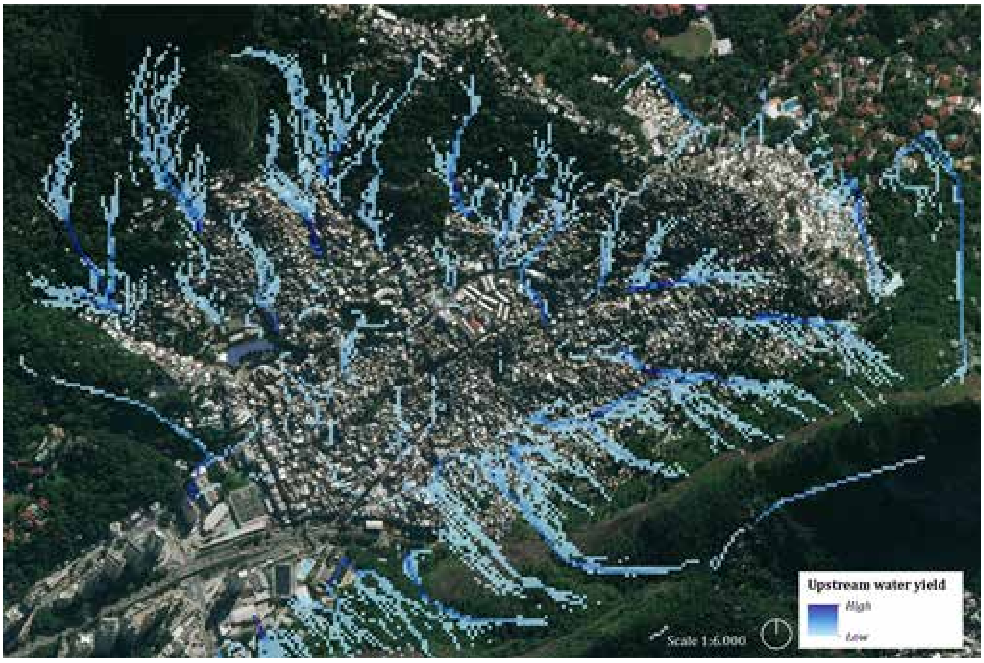


Figure 3.3.41 Rocinha's upstream water yield, scale 1:6000. Source: PolimiparaRocinha

Figure 3.3.42 Rocinha's runoff index, scale 1:6000. Source: PolimiparaRocinha

The two outputs show what happens when the rain is so intensive it cannot be absorbed by the soil, starting to flow downhill as runoff due to gravity. Considering the geo-morphological and urban conditions of Rocinha, it is necessary to evaluate the stability of a landslide under various loading conditions (for example considering a heavy rainfall) that could impact and limit the stability of the slope causing damage to the existing buildings and to the resident population.

Starting from the output previously obtained, six areas called "catchment areas" were selected and analyzed in detail. Each area had a quantitative estimation (in millimetres) of the upstream water for each pixel. Considering that a pixel is 6.4 x 6.4 metres and that 1 mm corresponds to 1 litre/m^2, it was possible to evaluate the water quantity stored in each catchment area.

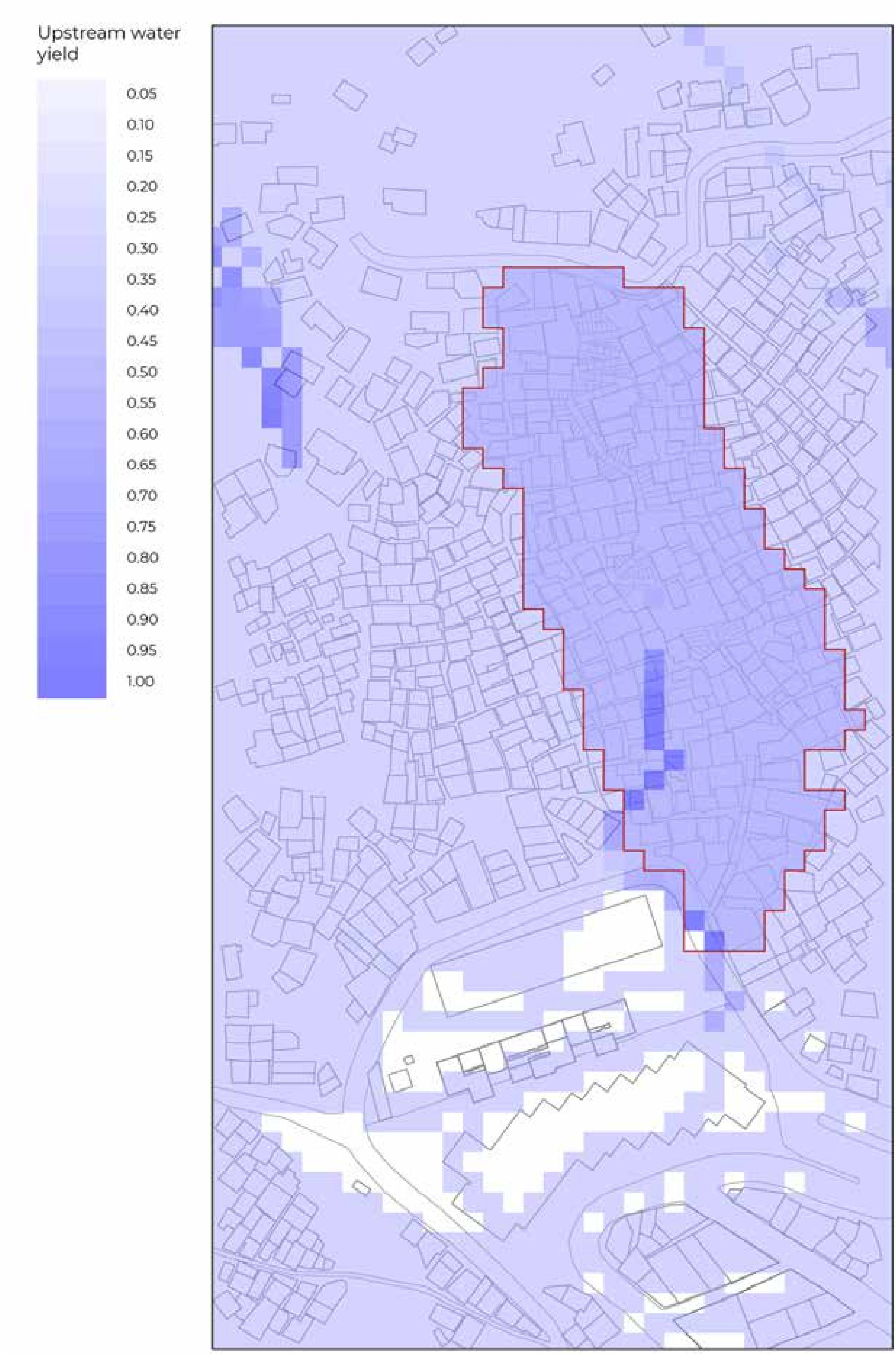


Figure 3.3.43 Area 1's upstream water yield

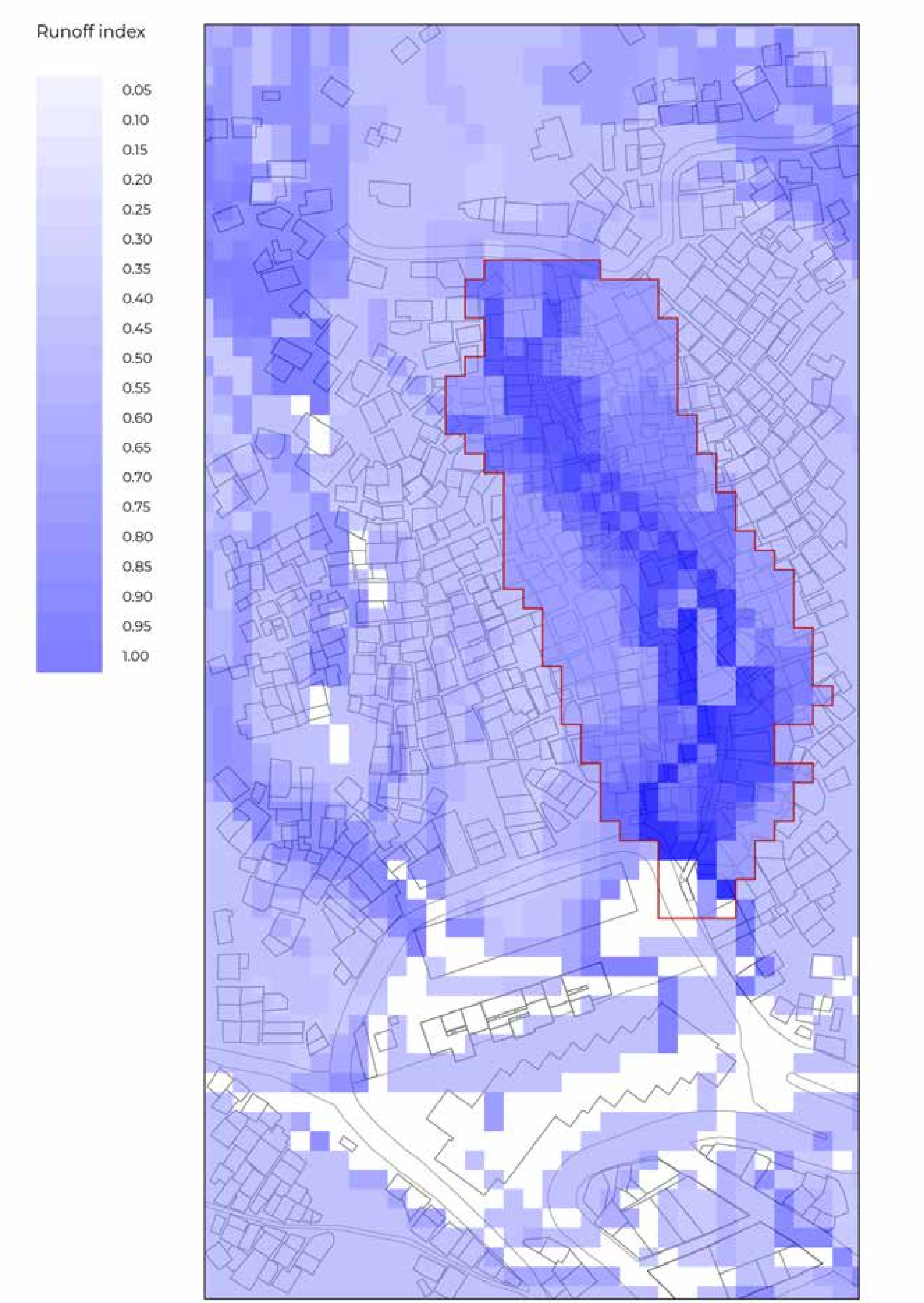


Figure 3.3.44 Area 1's runoff index

This spatial analysis allowed for the evaluation of the most precise boundary to consider in order to design the pipes composing the drainage system which needs to be implemented in the case study area. In Area 1, a new drainage network has been designed along the new urban path connecting Villa Verde with Rua Dionéia, replacing the existing talvegue with a more efficient system catching the flow from all nearby households and surfaces.

3.3.3.7 Pluviometrical data and possibility curves

Theory and used methodology

Rocinha has its own pluviometric station, where data are collected. Among the 33 stations in the municipality of Rio de Janeiro, Rocinha is the second one for rain episodes intensity, the worst of which occurs in December. To calculate the water flow, an appropriate outflows-inflows model was used to define the entity of hydrologic quantities, depending on an assigned probability of occurrence, between rainfall events characterized by the same percentage of occurrence. It is therefore necessary to know which elements contribute to the formation of the flow within the basin considered, namely:

- historic flow data, if they are available, of the analyzed basin;
- rain data;
- basin geologic, hydrologic, topographic characteristics;
- existing canals dimensions and distribution.

To determine the flow to use for the verification of channels and pipes, a premise on the duration of the different events is necessary. The meteorological events are conventionally classified into:

- **Short duration events**: they have an average duration lower than one hour, characterized by strong intensity and therefore develop high flow rates at the closing section of the catchment area;
- **Long duration events**: they have a duration longer than a single hour, lower intensity but develop high volumes at the closing section of the river basin.
- **More days events**: they are analyzed to consider the different basin evolutionary trend for rain events exceeding 24 hours, with intensity and volume characteristics similar to the events above.

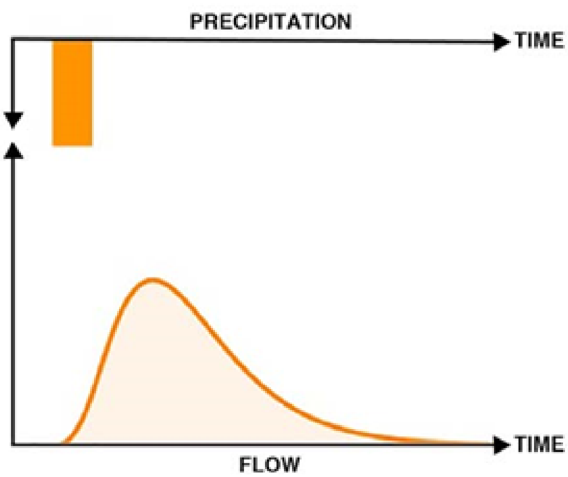


Figure 3.3.45 Pluviometric possibilty curve

To define the heights of precipitation corresponding to these rainfall events pluviometric possibility curves (CPP), elaborated starting from the rain height recordings made in the pluviometric stations, are used. The purpose of data statistical processing is the determination of two coefficients that characterize the pluviometric possibility equations:

- a [mm/hn]
- n

$$h = a \cdot (t_n)^n$$

Brazil uses a methodology which determines pluviometric possibility curves with equations of 4 parameters. For the calculation of the meteoric flows and the verification of existing

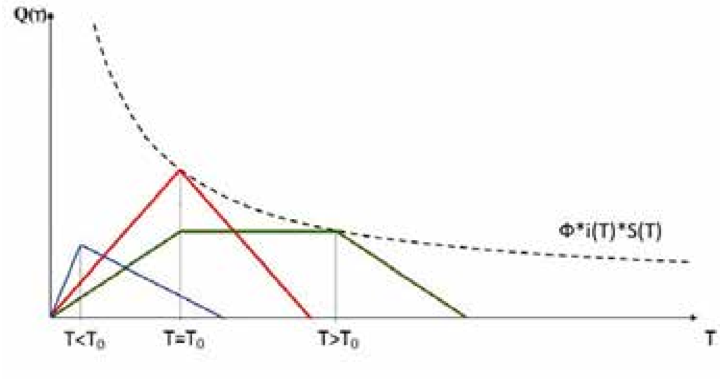


Figure 3.3.46 Rainfall-runoff model's graph

canals and designed pipes, a rainfall-runoff model has been adopted.

The model allows to calculate essential characteristics of flood waves in a particular section of the drainage network: the peak discharge, the total volume and the hydrograph shape, starting from statistically significant extreme precipitation.

Therefore, a diagram that represents the water flow inside the sewer network has been obtained, starting from the records of rainfall data (intensity and duration), according to the physical characteristics of the basin and the sewer network to verify.

The Instantaneous Unit Hydrograph (IUH) of a water catchment area represents the system response h (t), that is the hydrograph of flood flow, resulting in a net precipitation of unit volume and infinitesimal duration (and consequently of infinite intensity). Then, the IUH form has been posited as an intrinsic characteristic of the basin, so that its area (the integral) depends by the meteoric event considered.

It is defined Concentration time To the time which a particle of water takes to travel through the path hydraulically longer belonging to the drainage network; in other words, it is the maximum time that the water takes to arrive at the terminal section of the water network from the moment it falls to the ground. It represents the basic time of IUH and the critic time that, given an amount of water, defines the higher flow value in the last section of the water network.

For the flow calculation in each canal of the designed hydraulic network the Rational Method had been used:

$$Q = 2.78 \cdot \Phi \cdot S \cdot a \cdot T_o^{n-1}$$

Where:

- Q is the water flow [L/s];
- Φ is the inflow coefficient;
- S is the collecting surface area [ha];
- a is the characteristic parameter of intensity curve [mm/hn];
- T_o is the concentration time [h];
- n is the characteristic parameter of intensity curve.

Rainfalls' data and pluviometric possibility curves of Rocinha

For the reasons listed above, it was necessary to convert the 4-parameter intensity curve in a 2-parameter curve, in the form h = a (tp)n. To do so, numerical interpolation was applied from some points calculated by the 4-parameter formula for different values of meteoric event duration t (0 to 120 min) and 3 return times T_r (10, 20, 50 years); the output is an exponential function from which it is possible to derive the parameters a and n.

Due to the context of Rocinha (mutable and with an important grow rate of the population and new construction increases), it was decided to consider a return time of 10 years, which represents the probability of achieving a meteorological event equal to the one analyzed. The municipality of Rio de Janeiro has become more and more virtuous in terms of accessibility of public data, so it was rather easy to find on the official website of the municipality www.data.rio the coefficients of the CPP equation of the pluviometric station of Rocinha. The coefficients were obtained using the probability function of Gumbel, a statistical methodology used also in Italy to determine the characteristic parameters a and n:

$$i = \frac{k \cdot T_r^m}{(t \cdot t_0)^n}$$

Where:

- i is the average intensity [mm/h];
- t is the duration time [min];
- T_r is the return time [h];
- k, t_o, m, n are the coefficients to be determined.

Nº ordem	Estação	Latitude	Longitude	Série histórica	K	m	t_o	n	R²	EPE
1	Anchieta	22,83	43,40	1997-2000 2002-2014	2355,79	0,19	31,60	0,89	0,996	3,06
2	Bangu	22,88	43,47	1997-2000 2002-2014	8398,17	0,18	40,71	1,15	0,996	3,50
3	Campo Grande	22,90	43,56	1997-2000 2002-2014	3763,91	0,22	72,80	0,90	0,991	4,69
4	Cidade de Deus	22,95	43,36	1997-2000 2002-2014	1306,84	0,19	19,46	0,79	0,997	2,94
5	Copacabana	22,99	43,19	1997-2000 2002-2014	2140,17	0,19	59,06	0,80	0,990	4,51
6	Gericinó	22,52	43,35	1997-2000 2002-2009	11547,76	0,20	61,63	1,15	0,996	3,51
7	Grajaú	22,92	43,27	1997-2000 2002-2014	5274,55	0,20	52,18	0,98	0,995	4,21
8	Grande Méier	22,89	43,28	1997-2000 2002-2014	1080,84	0,20	13,79	0,74	0,996	3,92
9	Grota Funda	23,01	43,52	1997-2000 2002-2014	478,00	0,20	15,35	0,58	0,992	3,93
10	Guaratiba	23,05	43,59	1998-2000 2002-2003 2005-2014	1107,14	0,22	14,35	0,80	0,995	3,93
11	Ilha do Governador	22,82	43,21	1997-2000 2003-2014	1125,79	0,23	11,24	0,77	0,994	5,57
12	Irajá	22,83	43,34	1997-2000 2002-2014	2181,48	0,18	40,07	0,85	0,995	3,15
13	Itanhangá	23,00	43,30	1997-2000 2002-2012	1949,98	0,17	40,71	0,80	0,997	2,76
14	Jardim Botânico	22,97	43,22	1997-2000 2002-2014	1217,80	0,19	22,66	0,75	0,996	3,25
15	Laranjeiras	22,94	43,19	2002-2014	8518,56	0,21	60,99	1,10	0,994	4,25
16	Madureira	22,87	43,34	1997-2000 2002-2014	2037,43	0,19	30,02	0,84	0,995	3,93
17	Mendanha	22,49	43,31	1997-2000 2002-2009	531,79	0,17	7,06	0,63	0,998	2,29
18	Penha	22,84	43,28	1998-2000 2002-2014	825,89	0,19	14,85	0,71	0,996	2,94
19	Piedade	22,89	43,31	1997-2000 2002-2014	2028,23	0,17	35,82	0,82	0,996	3,39
20	Recreio	23,01	43,44	1997-2000 2002-2014	6396,55	0,19	50,25	1,07	0,996	3,33
21	Riocentro	22,98	43,41	1997-2000 2002-2014	1886,83	0,18	37,42	0,78	0,995	4,01
22	Rocinha	22,99	43,25	1997-2000 2002-2014	10591,31	0,19	77,35	1,09	0,994	4,11
23	Santa Cruz	22,91	43,68	1997-2000 2002-2014	6455,60	0,17	45,89	1,05	0,997	3,09
24	Santa Teresa	22,93	43,20	1997-2000 2002-2014	2076,52	0,20	40,21	0,85	0,994	3,64
25	São Cristóvão	22,90	43,22	2003-2004 2006-2014	1914,43	0,24	26,59	0,84	0,994	5,38
26	Saúde	22,90	43,19	1997-2000 2002-2014	1222,52	0,18	25,00	0,75	0,996	3,11
27	Sepetiba	22,97	43,71	1997-2000 2002-2014	1041,34	0,20	19,14	0,76	0,995	3,27
28	Sumaré	22,57	43,14	1997-2000 2002-2009	1168,19	0,21	19,94	0,70	0,995	4,70
29	Tanque	22,91	43,36	1997-2000 2002-2014	1896,25	0,22	19,49	0,86	0,995	4,85
30	Tijuca	22,93	43,22	1997-2000 2002-2014	712,39	0,21	15,48	0,64	0,995	3,74
31	Urca	22,96	43,17	1997-2000 2002-2014	1999,11	0,19	31,01	0,87	0,997	2,72
32	Vidigal	22,99	43,23	1997-2000 2002-2014	2018,31	0,20	26,65	0,85	0,996	3,74

Figure 3.3.47 Rocinha's pluviometric station data. Source: data.rio

T_r = 10	
t [min]	**i [mm/h]**
5	133.93
10	125.60
20	111.60
30	100.32
40	91.40
50	83.27
60	76.69
75	68.49
90	61.83
105	56.31
120	51.66
a = 254.65	**n = 0.695**

Tab. 3.3.24 Return time 10 years data

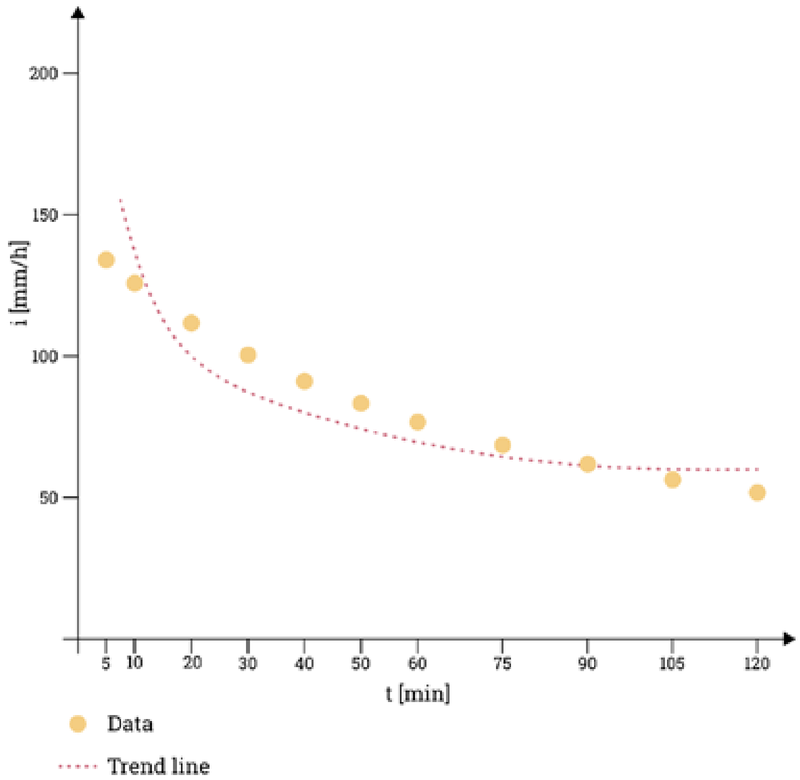


Figure 3.3.48 Return time 10 years graph

T_r = 20	
t [min]	**i [mm/h]**
5	152.78
10	143.27
20	127.31
30	114.44
40	103.85
50	94.99
60	87.48
75	78.14
90	70.53
105	64.23
120	58.93
a = 290.49	**n = 0.695**

Tab. 3.3.25 Return time 20 years data

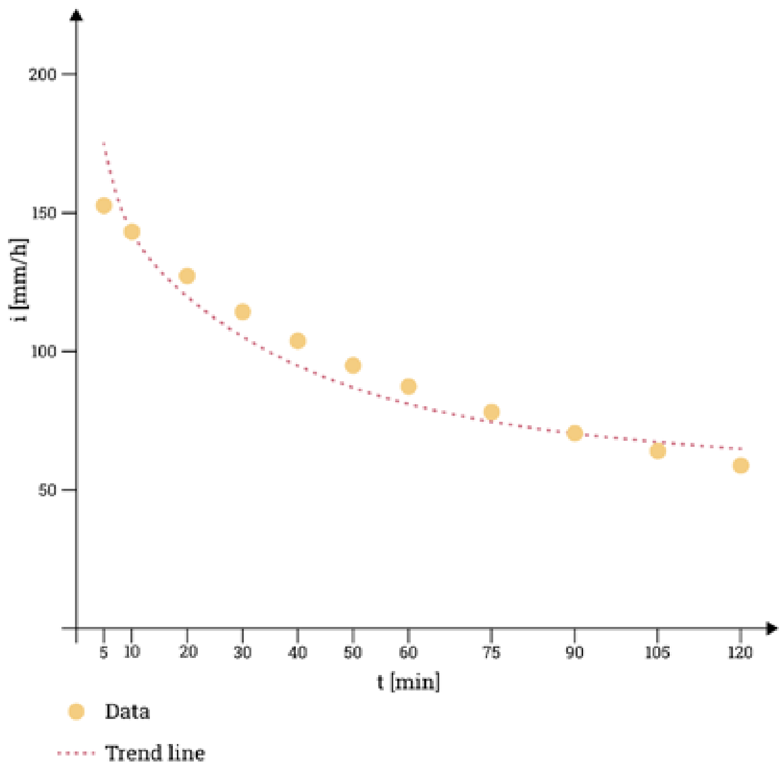


Figure 3.3.49 Return time 20 years graph

T_r = 50	
t [min]	**i [mm/h]**
5	181.84
10	170.52
20	151.52
30	136.20
40	123.60
50	113.06
60	104.12
75	92.99
90	83.95
105	76.45
120	70.14
a = 345.73	**n = 0.695**

Tab. 3.3.26 Return time 50 years data

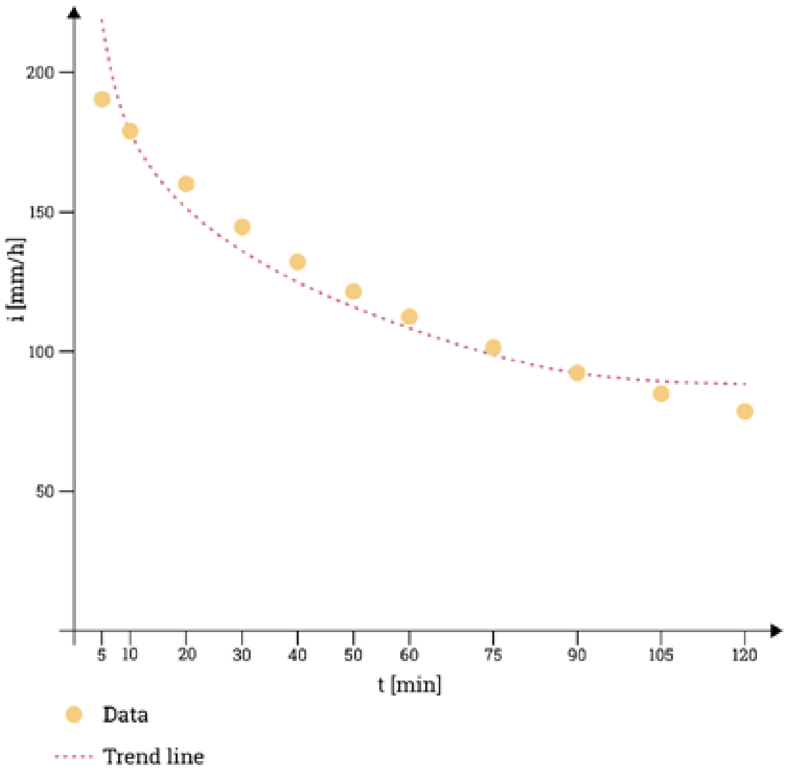


Figure 3.3.50 Return time 50 years graph

3.3.3.8 Design of the drainage system in Area 1

As mentioned, the new drainage network section will be placed within the path of the main urban intervention, along the new route leading from Villa Verde, near the bottom of Area 1, to Rua Dionéia, the main street at the top of the favela. There's a significant height difference between the beginning (129.85 m above sea level) and the endpoint (245.95 m), as well as an extreme slope rate, averaging at 70%.

This basin has an area of 12,480 m^2, of which 8,424 m^2 is occupied by buildings (67.5%), with at least 10% of flat surfaces being green roofs; the new path measures 2,347 m^2 , with 1,681 m^2 being green terraces (71.6%): considering that two different calculation methods will be used, it is important to differentiate the water falling on roofs and on the ground in order to correctly design the pipes and the downpipes of the buildings located inside the selected basin. The next section of this chapter will study in deep the methodology and the calculation made to design the drainage system inside the case study area.

Downpipes: methodology and calculations

Due to the site's morphology, the following analysis use a return time of 10 years and a duration time of 5 minutes, for the high slope rates and impermeability of the soil, leading to a general short adduction time. Further, higher values of rain intensity corresponds to shorter durations.

For a T_r = 10 years and a t = 5 minutes, the rain intensity is equal to 133.93 mm/h. Considering that 1 mm of rain water equals to 1 L/m^2, it is possible to obtain an intensity value of 0.0372 L/m^2/sec. Multiplying the last value by the area of each roof and applying a coefficient K which depends on the characteristics of the surfaces it is possible to calculate the water flow for each building. Following ASN 565.010, two values of K were utilized:

- K = 0,8 as the coefficient for flat surfaces made with concrete slabs;
- K = 0,3 as the coefficient for flat green surfaces.

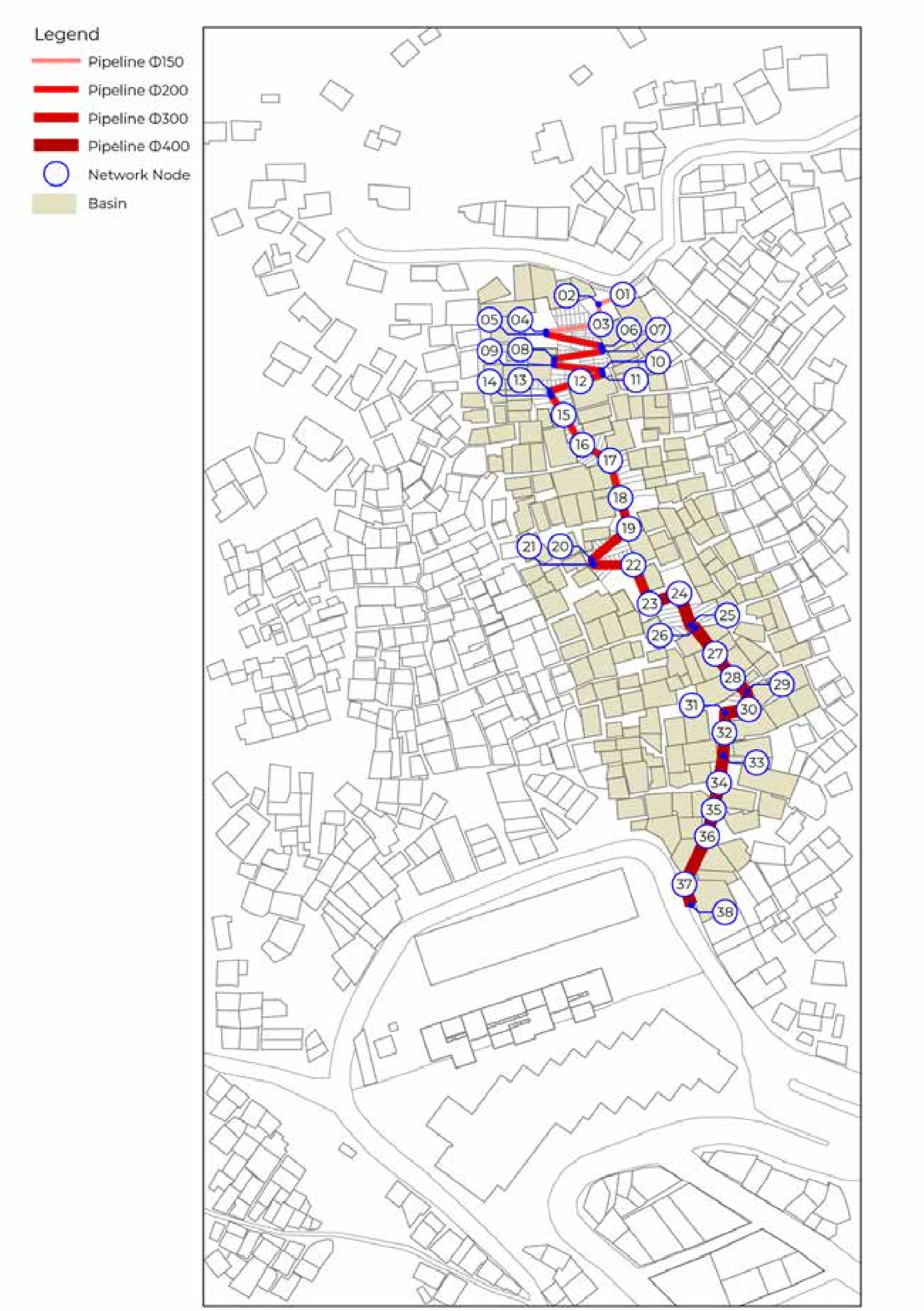


Figure 3.3.51 Drainage system in Area 1: intervention

The total rainwater flow on the roofs is 233.5 L/s, which flows directly into the designed drainage pipes, though after the complete drain of the “first rain water”, which is the dirtiest component to handle as it scrubs the dirt off the surfaces of the roofs and needs to be separated, its flow totals at 41.93 m^3. It is then possible to calculate the drainage time for each roof, applying the proper K coefficient depending on the surface type; this results in a 2.8 minutes time for “normal” roofs and a 7.47 minutes time for green roofs, since the latter exceeds t (5 minutes), the water flow from the green roofs can be discarded from the following calculations because their overall drainage time exceed the critical duration (which correspond to the highest value of Q) used to verify the pipes of the network. As the minimum green roofs’ area inside the intervention is fixed at 900.54 m^2 and the flow needed to cleanse the sewerage network has been calculated in the previous chapter, a flow of 8.38 m^3 can be subtracted from the first rain water, which brings the total to 33.55 m^3.

Knowing the exact values of water flow and the surfaces of each roof, it is possible to size the

ø interno esterno	portata Q	superficie massima in m² evacquabile per i.p. = 15 cm/ora/m²		
mm	l/sec.	K = 1,0	K 0,8	K = 0,6
57/ 63	1,9	46	58	77
69/ 75	3,6	88	110	146
83/ 90	5,0	122	152	203
101/110	8,9	217	271	362
115/125	12,5	305	381	508
147/160	25,0	610	762	1016
187/200	47,0	1146	1433	1910
234/250	85,0	2073	2591	3455
295/315	157,0	3829	4786	6382

Figure 3.3.52 Downpipes diameter per flows. Source: ASN 565.010

downpipes of each building using the table presented below:

The dimensions of the downpipes for each building within the intervention area will be detailed along with the gutters’ below.

Gutters: methodology and calculations

The water flow values from the roofs are also used to determine the gutters’ size for each building. Assuming the usage of standard gutters and a maximum level of filling at 85%, it is important first to analyze the hydraulic radius and the wet area of each pipe and in a second moment the water velocity using the Chezy formula in full pipe condition:

$$v = k_s \cdot R_h^{\frac{2}{3}} \cdot i^{\frac{1}{2}}$$

d [mm]	H [mm]	K_s	Fill [%]	H. radius [m]	Wet area [m²]	Slope [%]	V [m/s]	Q [L/s]
80	**48**	80	85	0.020	0.003	2	0.264	**0.685**
105	**62**	80	85	0.026	0.004	2	0.316	**1.390**
127	**73**	80	85	0.032	0.006	2	0.359	**2.188**
153	**87**	80	85	0.038	0.009	2	0.406	**3.574**
192	**107**	80	85	0.048	0.014	2	0.473	**6.379**
250	**136**	80	85	0.063	0.022	2	0.563	**12.509**

Tab. 3.3.27 Gutters’ capacity

Knowing the wet area and the water velocity it is possible to obtain the maximum capacity of each gutter in m^3/s and L/s:

Basin	Catchment area [m^2]	Rainwater flow [L/s]	Downpipe size [mm]	Gutter size [mm]
1-2	105.16	3.13	69/75	153/87
3-4	34.52	0.39	57/63	80/48
	38.45	0.43	57/63	80/48
	93.45	2.78	69/75	153/87
	65.73	1.96	69/75	127/73
	50.62	1.51	57/63	127/73
	86.70	2.58	69/75	153/87
4-5	92.93	1.04	57/63	105/62
6-7	69.98	2.08	69/75	127/73
8-9	43.93	1.31	57/63	105/62
	40.27	1.20	57/63	105/62
9-10	45.69	1.36	57/63	105/62
	49.90	1.49	57/63	127/73
10-11	27.83	0.83	57/63	105.62
12-13	37.73	0.42	57/63	80/48
	39.77	1.48	57/63	105/62
13-14	25.21	0.75	57/63	105/62
	56.54	1.68	57/63	127/73
14-15	36.57	1.09	57/63	105/62
	21.77	0.65	57/63	80/48
	30.48	0.91	57/63	105/62
	26.71	0.79	57/63	105/62
	31.00	0.92	57/63	105/62
	22.86	0.68	57/63	80/48
	25.84	0.77	57/63	105/62
	24.23	0.72	57/63	105/62
	104.87	1.17	57/63	105/62
	26.86	0.80	57/63	105/62
	35.02	1.04	57/63	105/62
	29.47	0.88	57/63	105/62
15-16	31.58	0.94	57/63	105/62
	46.09	1.37	57/63	105/62
	54.01	1.61	57/63	127/73
	24.76	0.74	57/63	105/62
	26.46	0.79	57/63	105/62

Tab. 3.3.28 Downpipes and gutters dimension, part I

Basin	Catchment area [m^2]	Rainwater flow [L/s]	Downpipe size [mm]	Gutter size [mm]
15-16	57.19	1.70	57/63	127/73
	44.06	1.31	57/63	105/62
	103.94	3.09	69/75	153/87
	46.84	1.39	57/63	105/62
	43.27	0.48	57/63	80/48
	41.06	1.22	57/63	105/62
	32.03	0.95	57/63	105/62
	45.12	1.34	57/63	105/62
	18.78	0.56	57/63	80/48
16-17	71.90	0.80	69/75	105/62
	20.37	0.61	57/63	80/48
	36.06	1.07	57/63	105/62
17-18	31.77	0.95	57/63	105/62
	18.86	0.56	57/63	80/48
	35.83	1.07	57/63	105/62
	106.57	3.17	69/75	153/87
	49.01	0.55	57/63	80/48
	18.84	0.56	57/63	80/48
	36.02	0.40	57/63	80/48
	31.45	0.35	57/63	80/48
	26.93	0.30	57/63	80/48
	20.54	0.23	57/63	80/48
	38.97	1.16	57/63	105/62
	20.03	0.60	57/63	80/48
	27.23	0.81	57/63	105/62
18-19	55.14	1.64	57/63	127/73
	37.59	1.12	57/63	105/62
	39.44	1.17	57/63	105/62
	58.00	1.73	57/63	105/62
	52.34	1.56	57/63	105/62
	41.54	0.46	57/63	80/48
	43.09	1.28	57/63	105/62
	48.61	1.45	57/63	105/62
	47.41	1.41	57/63	105/62
	51.44	1.53	57/63	105/62
	22.78	0.68	57/63	80/48
	25.81	0.77	57/63	80/48
	43.07	1.28	57/63	105/62

Tab. 3.3.29 Downpipes and gutters dimension, part II

Basin	Catchment area [m²]	Rainwater flow [L/s]	Downpipe size [mm]	Gutter size [mm]
19-20	32.38	0.96	57/63	105/62
	40.67	1.21	57/63	105/62
	49.47	1.47	57/63	127/73
	34.95	1.04	57/63	105/62
	8.50	0.25	57/63	80/48
20-21	33.87	1.01	57/63	105/62
	32.31	0.96	57/63	105/62
	34.65	1.03	57/63	105/62
	33.84	0.38	57/63	80/48
21-22	66.70	0.74	57/63	105/62
	30.41	0.90	57/63	105/62
22-23	64.26	1.91	69/75	127/73
	58.58	1.74	57/63	127/73
	32.51	0.36	57/63	80/48
	92.83	2.76	69/75	153/87
	38.66	1.15	57/63	105/62
23-24	40.58	1.21	57/63	105/62
	38.72	0.43	57/63	80/48
	43.75	1.30	57/63	105/62
	42.85	1.28	57/63	105/62
	29.62	0.88	57/63	105/62
	54.36	0.61	57/63	80/48
	21.76	0.65	57/63	80/48
	20.13	0.60	57/63	80/48
	45.02	1.34	57/63	105/62
24-25	40.87	1.22	57/63	105/62
	48.88	1.45	57/63	127/73
	55.51	1.65	57/63	127/73
	51.35	1.53	57/63	127/73
	45.25	0.51	57/63	80/48
	38.43	1.14	57/63	105/62
	38.85	1.16	57/63	105/62
	31.31	0.93	57/63	105/62
	20.09	0.60	57/63	80/48
	29.22	0.87	57/63	105/62
	36.02	1.07	57/63	105/62
26-27	51.41	1.53	57/63	127/73
	65.88	1.96	69/75	127/73

Tab. 3.3.30 Downpipes and gutters dimension, part III

Basin	Catchment area [m^2]	Rainwater flow [L/s]	Downpipe size [mm]	Gutter size [mm]
26-27	38.94	1.16	57/63	105/62
	18.11	0.54	57/63	80/48
	22.08	0.66	57/63	80/48
	48.85	1.45	57/63	127/73
	37.96	1.13	57/63	105/62
	31.53	0.94	57/63	105/62
27-28	33.21	0.99	57/63	105/62
	45.33	1.35	57/63	105/62
	27.57	0.82	57/63	105/62
	36.34	1.08	57/63	105/62
	46.21	1.38	57/63	105/62
	21.71	0.65	57/63	80/48
	11.50	0.34	57/63	80/48
	39.05	1.16	57/63	105/62
	60.64	1.80	57/63	127/73
	60.96	1.81	57/63	127/73
	45.90	1.37	57/63	105/62
	47.66	1.42	57/63	127/73
	36.29	1.08	57/63	105/62
	19.55	0.58	57/63	80/48
	45.68	1.36	57/63	105/62
	49.59	1.48	57/63	127/73
28-29	11.08	0.33	57/63	80/48
	36.10	1.07	57/63	105/62
	52.73	1.57	57/63	127/73
29-30	43.69	1.30	57/63	105/62
	39.27	1.17	57/63	105/62
	43.89	1.31	57/63	105/62
30-31	98.38	2.93	69/75	153/87
31-32	38.95	1.16	57/63	105/62
	48.05	1.43	57/63	127/73
	82.79	2.46	69/75	153/87
	27.88	0.83	57/63	105/62
32-33	56.94	1.69	57/63	127/73
	24.43	0.73	57/63	105/62
	18.37	0.55	57/63	80/48
	50.25	1.50	57/63	127/73
	26.21	0.78	57/63	105/62

Tab. 3.3.31 Downpipes and gutters dimension, part IV

Basin	Catchment area [m²]	Rainwater flow [L/s]	Downpipe size [mm]	Gutter size [mm]
32-33	57.06	1.70	57/63	127/73
	76.40	2.27	69/75	153/87
	88.37	2.63	69/75	153/87
	71.09	2.12	69/75	153/87
	67.94	2.02	69/75	127/73
	70.80	2.11	69/75	127/73
33-34	42.67	1.27	57/63	105/62
	21.55	0.64	57/63	80/48
	26.79	0.80	57/63	105/62
	72.16	2.15	69/75	153/87
	30.33	0.90	57/63	105/62
	29.59	0.88	57/63	105/62
	32.48	0.97	57/63	105/62
	25.68	0.76	57/63	105/62
	33.36	0.99	57/63	105/62
	50.99	1.52	57/63	127/73
	43.58	1.30	57/63	105/62
	79.21	2.36	69/75	153/87
	46.04	1.37	57/63	105/62
	137.94	4.11	83/90	192/107
34-35	74.46	2.22	57/63	153/87
	59.78	1.78	57/63	127/73
35-36	56.56	1.68	57/63	127/73
	66.53	1.98	69/75	127/73
	50.16	1.49	57/63	127/73
	36.95	1.10	57/63	105/62
	52.21	1.55	57/63	127/73
	66.41	1.98	69/75	127/73
36-37	15.91	0.47	57/63	80/48
	88.11	2.62	69/75	153/87
	69.98	2.08	69/75	127/73
	42.04	1.25	57/63	105/62
	68.06	2.03	69/75	127/73
	67.32	2.00	69/75	127/73
37-38	151.36	4.50	83.90	192/107

Tab. 3.3.32 Downpipes and gutters dimension, part V

The dimensions of the gutters and the downpipes for each building within the intervention area are detailed in the table below, note that the catchment areas are split between roofs and green roofs:

Drainage pipes: methodology and calculations

Each section of the drainage system has its own inflow coefficient Φ based on the quality of the soil of the considered basin; in general, a coefficient between 0.80 and 0.95 was chosen for each section of the drainage system. The other parameters measured for each section are:

- S is the collecting surface area [ha];
- J is the average basin slope [%];
- l is the pipe's lengths [m];
- K_s is the roughness of each pipe [$m^{1/2}s^{-1}$]

Imposing a minimum value of 0.15 m of diameter for each pipe (in order to consider the frequent filling episodes because of the general bad level of waste management), it is possible

$$Q = 2.78 \cdot \Phi \cdot S \cdot a \cdot T_o^{n-1}$$

to verify the correct sizing of the system relating the incoming water flow with the Q value obtained with a filled pipe.

The real water flow value can be obtained using the Rational method:

Where:

- Q is the water flow [L/s];
- Φ is the inflow coefficient;
- a is the characteristic parameter of intensity curve [mm/hn] taken from the CPP previously presented for a T_r of 10 years;
- To is the concentration time [h], obtained adding the Access Time T_{ai} (5 minutes) to the Travel Time T_t (obtained dividing the length of the pipe by the velocity of the water flowing inside it);
- n is the characteristic parameter of intensity curve, taken from the CPP previously

$$v = k_s \cdot R_h^{\frac{2}{3}} \cdot i^{\frac{1}{2}}$$

h/D	V/Vr	Q/Qr
0	0	0
0.05	0.257	0.005
0.1	0.401	0.021
0.15	0.517	0.049
0.2	0.615	0.088
0.25	0.701	0.137
0.3	0.776	0.196
0.35	0.843	0.263
0.4	0.902	0.337
0.45	0.954	0.416
0.5	1	0.5
0.55	1.039	0.586
0.6	1.072	0.672
0.65	1.099	0.756
0.7	1.12	0.837
0.75	1.133	0.912
0.8	1.14	0.977
0.85	1.137	1.03
0.9	1.124	1.066
0.95	1.095	1.074
1	1	1

Figure 3.3.53 Pipes' ratios

presented for a T_r of 10 years.

The Q value in full pipe condition can be obtained multiplying the area of the pipes by the water velocity flowing inside it. It was used the Chezy formula in full pipe condition to get the water velocity:

Knowing the water velocity, it is possible to calculate the Travel Time T_t dividing the length of the pipe by V. To can be obtained adding T_{ai} to T_t (normally T_t needs to be divided by 1.5, but due to the peculiarities of the case study and the extraordinary slope that generates very high speeds this coefficient is omitted).

Once the incoming water flow and the Q value in full pipe condition are obtained, the results are verified using a table which relate the Q ratio value with the filling level of the pipe.

Considering a 70% filling level of the pipe as the maximum value permitted it is possible to verify the diameters of each calculated section. The results of each section verified are shown in the table below:

Basin	Basin Area [ha]	Φ	Slope [%]	Canal Lenght [m]	Diameter [m]	K_s	V [m/s]	Flow [L/s]	Q ratio
1-2	0.01	0.45	52.11%	8.64	**0.15**	60	**4.85**	11.09	**0.13**
2-3	0.01	0.68	49.02%	6.63	**0.15**	60	**4.71**	12.72	**0.15**
3-4	0.03	0.66	55.27%	18.82	**0.15**	60	**5.00**	33.41	**0.38**
4-5	0.04	0.65	11.27%	0.89	**0.20**	60	**2.73**	37.36	**0.44**
5-6	0.04	0.63	36.14%	18.81	**0.20**	60	**4.90**	40.96	**0.27**
6-7	0.04	0.63	13.84%	1.81	**0.20**	60	**3.03**	43.98	**0.46**
7-8	0.05	0.61	35.01%	16.85	**0.20**	60	**4.82**	45.94	**0.30**
8-9	0.05	0.61	12.91%	1.94	**0.20**	60	**2.93**	49.51	**0.54**
9-10	0.06	0.59	36.96%	16.51	**0.20**	60	**4.95**	53.92	**0.35**
10-11	0.06	0.58	24.76%	1.21	**0.20**	60	**4.05**	53.95	**0.42**
11-12	0.06	0.58	35.86%	8.51	**0.20**	60	**4.88**	54.34	**0.35**
12-13	0.07	0.59	33.67%	11.29	**0.20**	60	**4.72**	61.95	**0.42**
13-14	0.07	0.60	15.58%	1.60	**0.20**	60	**3.21**	66.38	**0.66**
14-15	0.08	0.63	36.15%	8.85	**0.20**	60	**4.90**	88.39	**0.58**
15-16	0.09	0.64	36.95%	12.72	**0.20**	60	**4.95**	102.67	**0.66**
16-17	0.10	0.65	33.39%	10.93	**0.20**	60	**4.71**	99.69	**0.67**
17-18	0.11	0.65	36.40%	14.28	**0.30**	60	**4.91**	120.58	**0.78**
18-19	0.13	0.66	19.09%	10.48	**0.30**	60	**4.66**	143.79	**0.44**
19-20	0.13	0.67	18.51%	16.48	**0.30**	60	**4.59**	137.29	**0.42**
20-21	0.13	0.66	14.22%	1.76	**0.30**	60	**4.02**	137.88	**0.48**
21-22	0.14	0.67	21.16%	13.71	**0.30**	60	**4.91**	145.00	**0.42**
22-23	0.16	0.67	15.42%	13.94	**0.35**	60	**4.64**	167.05	**0.37**
23-24	0.18	0.69	12.05%	10.37	**0.40**	60	**4.49**	192.20	**0.34**
24-25	0.19	0.69	12.92%	11.61	**0.40**	60	**4.65**	209.83	**0.36**
25-26	0.19	0.69	7.26%	2.07	**0.40**	60	**3.48**	203.57	**0.47**
26-27	0.20	0.69	13.15%	11.79	**0.40**	60	**4.69**	213.97	**0.36**
27-28	0.20	0.69	10.83%	11.08	**0.40**	60	**4.25**	224.65	**0.42**
28-29	0.20	0.70	14.73%	7.13	**0.40**	60	**4.96**	212.40	**0.34**
29-30	0.20	0.70	8.39%	6.55	**0.40**	60	**3.74**	217.54	**0.46**
30-31	0.21	0.70	12.91%	7.75	**0.40**	60	**4.64**	230.91	**0.40**
31-32	0.21	0.70	13.67%	6.58	**0.40**	60	**4.78**	233.93	**0.39**
32-33	0.22	0.71	10.65%	8.45	**0.40**	60	**4.22**	244.32	**0.46**
33-34	0.22	0.71	11.42%	10.50	**0.40**	60	**4.37**	249.93	**0.46**
34-35	0.22	0.71	11.49%	10.45	**0.40**	60	**4.38**	240.53	**0.44**
35-36	0.22	0.71	11.49%	10.44	**0.40**	60	**4.38**	246.56	**0.45**
36-37	0.23	0.71	14.82%	20.92	**0.40**	60	**4.98**	253.49	**0.41**
37-38	0.23	0.71	2.94%	8.40	**0.40**	60	**2.22**	248.23	**0.89**

Tab. 3.3.33 Drainage pipes dimensioning

3.4 FOOD

Figure 3.4.1 A fish market in Rocinha. Picture taken by Arianna Trombini

3.4.1 Introduction

Food is one of the main Catalyst of the project, in accordance with the IMM's DOP: "Convert the city in a food producer". In fact, creating local farms and improving the production of healthy food on-site, like fruits and vegetables, is a way to change people's eating habits and consequently the existing situation inside the favela.

The main problem is that traditional cultivation ways are not suitable for the informal settlement of Rocinha, characterized by high volume density, complete absence of void spaces and steep slope of the terrain. To solve feasibility problems, some innovative and sustainable strategies for urban agriculture will be introduced in the project, integrated in/with existing buildings, like green roofs, vertical farming and aquaponic. However, without the right education on agricultural production, food nutrients, healthy alimentation and disposal of organic waste, each of these innovative proposals would fail.

Education plays a very important role in the project success and plant the seed for a more sustainable future. For these reasons, drafting an educational path, through events and workshops, is necessary for the community engagement and the social inclusion. Moreover, the selling of the grown products could activate a circular economic system, that could help the development of food production and promote the growth of the favela.

3.4.2 Urban agricolture: case studies in Rio de Janeiro and Rocinha

Urban agriculture, which can be defined as the cultivation of plants and animal husbandry in urban areas, represents the future of food production, since urbanization and uncontrolled cities growth are increasingly relevant topics in modern society. Urban agriculture provides both fresh edible and nonedible products (like aromatic and medical herbs, ornamental plants...), which can be sold directly on site through market stall, saving on transportation fee. It generates employment, even between disadvantaged groups of people, recycles urban waste and strengthens cities' resilience to climate change. Moreover, some practices of urban farming are more productive and more sustainable than traditional farming.

Both present and past experiences of food policies and practices can be found in Rio de Janeiro as well as Rocinha. The knowledge of some case studies, installed in a similar context to the intervention area, will be very useful for the project success. In fact, not only the mistakes already committed can be avoided, but the good ideas already introduced can also be supported and developed. Some examples in Rio de Janeiro are Hortas Cariocas, Urban Organic Farming Project, Rio Food Vision, FoodRoof Rio, GreenMyFavela; and some examples in Rocinha are Eco-Parque Vertical Garden, Eco-Parque Food Garden, Rocinha Mais Verde and Favela Verde. These case studies are briefly described below:

Figure 3.4.2 A Hortas Cariocas stand. Source: www.autossustentavel.com

Figure 3.4.3 A Urban Organic Farming field. Source: www.fondationairliquide.com

- **Hortas Cariocas** is a project which has been financed by Rio de Janeiro's Municipal Environment Department since 2012. Its main objective is to encourage the creation of organic vegetable gardens in low-income communities and public schools, to generate access to healthy food and offer work and economic return to the people involved. The gardeners receive subsidies, the means to create a community garden and a stipend to encourage them to dedicate their time to the project. At the same time, the gardeners must donate half of their total harvest to local public schools while the other half may be consumed or sold. This way, the gardens generate jobs for favela residents and for people working in the schools, as well as providing educational paths for children. After some time receiving the government's subsidies, the gardeners would be able to manage the garden on their own, in a self-sustainable way. GreenMyFavela supports the project Hortas Cariocas, documenting some of the great work they have been doing in the field, and collaborating with them.

- **Urban Organic Farming Project** has been supported by the international NGO Pro-Natura Association, which fights against poverty and protect the environment in developing countries, as well as by The Air Liquide Foundation, since 2014. The main objective is to grow food in the heart of the city with Super Gardens, an urban organic farming project. This new model is started from one of the favela of Alto da Boa Vista and is destined to be replicated in other favelas in Rio and around Brazil. Two types of vegetable garden have been created: three 60 m2 community super gardens to reinforce social cohesion in the neighbourhood and fifty-five individual rooftop mini-gardens that provide food for household consumption. Both generate income for the community.

- **Rio Food Vision** was an independent initiative born in 2013, composed by some local associations and institutions both public and private. The collaboration contributed by strengthening healthy and sustainable food vision and legacy in anticipation of the Olympic and Paralympic games in Rio de Janeiro held in 2016.
- **FoodRoof Rio** is a completely closed aquaponic system, producing fish, vegetables, fruit and herbs. It is lightweight, easy to construct and fits on a small roof. The first FoodRoof has been realized in Cantagalo favela, in Rio de Janeiro, where the place for a traditional cultivation is not enough. The project in Cantagalo failed because the designers and the community didn't think about a protection against the strong solar radiation, which burned the plants and boiled the fish.
- **GreenMyFavela** is an environmental regeneration project located in informal settlements or slum communities of Rio de Janeiro, born from the collaboration between favela residents, families, NGOs, schools, private and public sector, and social innovators. Its purpose is to reclaim degraded land and to create more productive green spaces inside favelas. The project can exist through financing and donations, giving tools, seeds and equipment, and providing volunteer labour.
- **Eco-Parque Vertical Garden** is the first vertical garden within the GreenMyFavela project, placed in a public space at the entrance of the eco-park in Rocinha (at the Portao Vermelho and Rua Dionéia area). It is planted with

Figure 3.4.4 Rio Food Vision logo. Source: www.planetaorganico.com.br

Figure 3.4.5 FoodRoof Rio in Cantagalo. Source: www.cittaideale.eu

Figure 3.4.6 GreenMyFavela garden. Source: www.facebook.com/greenmyfavela

Figure 3.4.7 Rocinha Mais Verde's garden. Source: www.memoria.ebc.com.br

Figure 3.4.8 Favela Verde's volounteers. Source: www.facebook.com/favelaverde.org

a mix of mint and strawberries, adorned with hanging ornamental and succulent plants. The wall, which is approximately 45 meters in length and 3 meters in height, is built with cement block characterized by a concavity for the cultivation. The project is maintained by community volunteers.

- **Eco-Parque Food Garden** is a temporary experiment created by GreenMyFavela in Rochina, where the foraging is applied, the act of finding and harvesting wild food. In this project low maintenance vines, melons, pumpkins, cucumbers, pineapples, papaya, ginger, garlic and jabuticaba, a tropical fruit tree, are planted.

- **Rocinha Mais Verde** was a coproduction between GreenMyFavela, the leader of Rocinha Mundo da Arte NGO Tio Lino, and the Alegria das Crianças, an education center. It was a children's garden which provided a therapeutic respite from the chaos of living in the Valão, a Rocinha neighbourhood. The project was showcased in 2012 at the United Nations Conference on Sustainable Development, Rio+20. At the end, it has fallen into disrepair, for the insecurity of the area, and for the instability befalling the organization with the death of Tio Lino.

- **Favela Verde** is a non-governmental organisation founded in 2011, which works in the upper part of Rocinha, in the Vila Laboriaux neighbourhood, the buffer zone of the Tijuca National Park. It is comprised of young people with training and experiences in different fields. The organization carries out socio-environmental projects, which aim at the urban sustainability and at the coexistence between natural and urban systems. All the projects are developed through processes of participation and social innovation, which bring to the activation of collective intelligence, dialogue, co-creation and action. The participatory dynamics are based on collaborative maps, workshop, questionnaires, interviews and meetings. The three lines of action are: environmental conservation and management, social entrepreneurship and solidarity economy, environmental education and culture.

3.4.3 Aquaponic technology: UFBOX

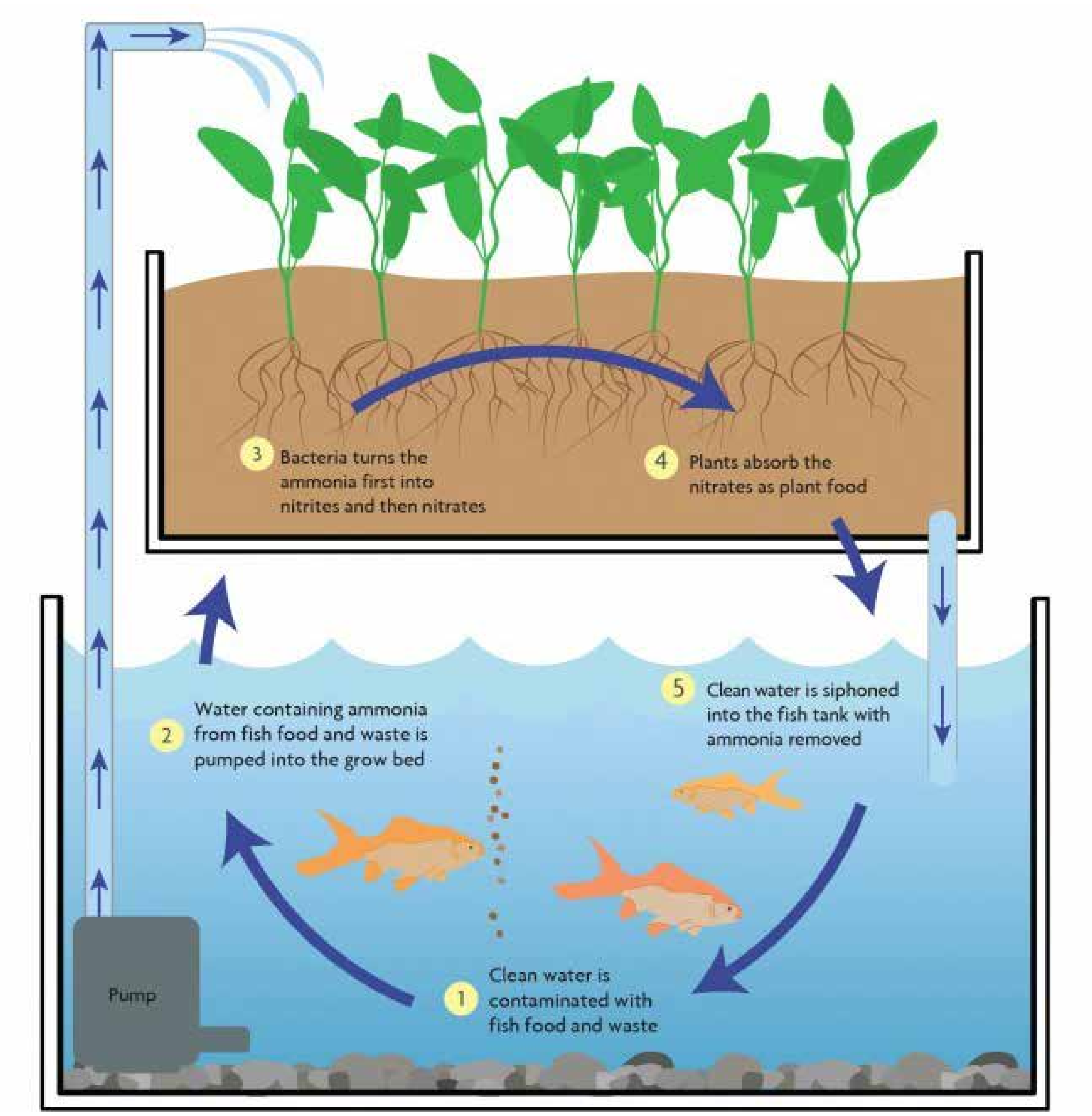


Figure 3.4.9 Aquaponic system circular process

Aquaponic technology is an innovative way of cultivation, used nowadays in different urban contexts and environments thanks its sustainable functioning, which allows the system to work without the precautions used for the traditional cultivation. It is composed by a circular and integrated system, which combines the growth of fishes with that of plants. Fish waste provides an organic food source for the plants and the plants naturally filter the water for the fishes.

- First stage: The fishes release ammonia into the water with their waste, after being normally fed;
- Second stage: A pump lifts the water from the fish tank to the cultivation grow-bed;
- Third stage: The water drips down through the ground and roots before being discharged

Figure 3.4.10 UFU in Bruxelles. Source: www.kaaitheater.be

Figure 3.4.11 Non-functional aquaponic system in Cantagalo favela. Picture taken by Arianna Trombini

into the fish tank;

• Fourth stage: The plants roots absorb the water and nutrients that they need to grow, cleaning the water that fish need.

The system is composed also of bacteria and microbes, which transform the fish waste in plants nutrients. On the cultivation grow-bed surface there are the nitrifying bacteria, which convert ammonia into nitrites first. Instead another kind of bacteria, the Nitrobacteria covert the nitrites into nitrates, the form of nitrogen that plants can use to grow. Consequently, the plants roots absorb water and nitrates, with which they can grow up faster. The water, free of ammonia and nitrates, returns fresh again.

The traditional soil-based gardening can present some problems in a modern city, which the aquaponic system can easily overcome. The pesticide and artificial nutrient usage can be delated. Weeds, pests and soil-borne insects can be avoided. The amount of water required can be significantly reduced because water runs indefinitely in a circle, the only losses are due to transpiration from the plants and evaporation. The food production can be on site, instead traditional farms are often located thousands of miles from where the food is consumed.

In conclusion, the aquaponic system:

• grows plants and fish at the same time;

• eliminates pesticide and artificial nutrients;

• produces fresh fish and vegetables;

• eliminates weeds, pests and insects;

• uses 1/10 of the water of traditional gardening;

• eliminates gardening chores;

• can be put anywhere;

• can be adapted to fit its context's needs;

• it is easy to build;

For each pilot project, a unique model will be made, which can be repeated in each of the favela's intervention areas without significant urban upheavals. This concept will be applied to the aquaponic technology as well, which can be inserted into a container, with the addition of a greenhouse. This way, the system will be mostly independent from the external context and environment, compact, movable and repeatable. An example comes from the prototype developed by UrbanFarmers, a company that provide system and solutions to grow fresh food in the cities, called UFBOX. It is a 20 m2 mobile urban farming unit used for events, teaching and explanation about sustainable urban food. The UFBOX uses the aquaponic technology to produce 60 kg of fresh fish and 120 kg of fresh vegetables per annum. Since 2011, the box has been successfully in operations in several locations throughout Switzerland.

One of this container with a greenhouse on the top has been bought by a technician of the social enterprise VivaRio and put on the top of the Cantagalo favela, in Rio de Janeiro, near its registered office. While it is empty now, VivaRio is interested in the introduction of new projects in Rocinha, as it was discovered during the survey. Therefore, this container could be the first step for the aquaponic introduction in our project.

The following section shows a possible aquaponic functioning within the container:

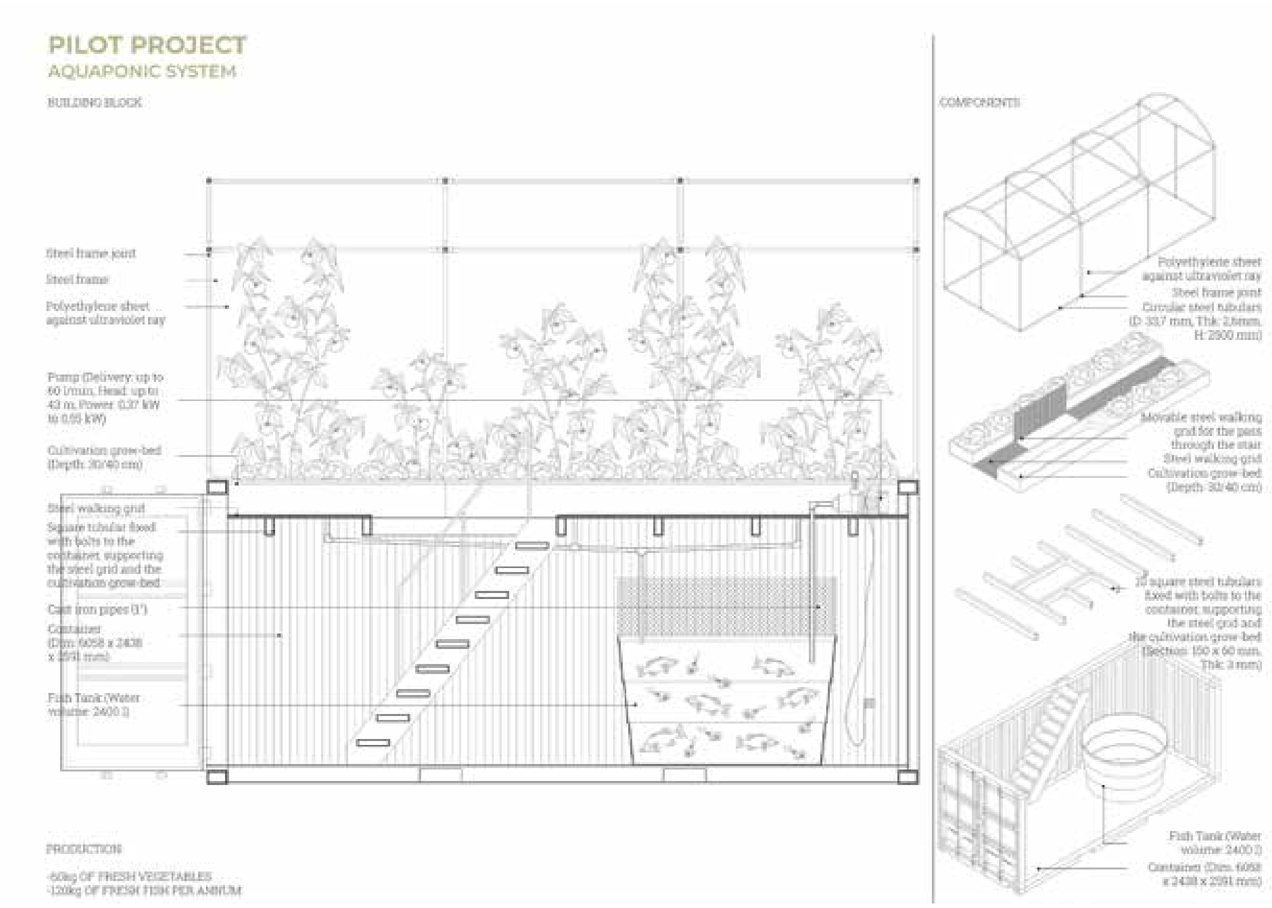


Figure 3.4.12 Aquaponic system technical drawings

The aquaponic is a not expensive system, which is simply composed by a fish tank, a pump, and a cultivation grow-bed. After the finding of the constituent parts, the costs are limited to the system maintenance and to the fish food. The energy consumption is due only to the use of the pump and can be supported by alternative energy, provided by an integrated PV panel.

In accordance with the Brazilian food tradition, the proposal is to farm typical food. Tomatoes, lettuce and beans will be cultivated in the grow-bed and Tilapia, a freshwater fish, will be grow in the fish tank. In according to the UrbanFarmers data, Brazilian consume per person every year 11 kg of fish, 28 kg of vegetables and 57 kg of fruit. Knowing how much a container produces, it is also possible to calculate how many people a container can feed inside the favela.

The container is an independent system, for the most part. But small adaptations and additions might be needed to guarantee that the basic container works properly. For example, shadings must be installed if the container will be located in open space, in order to spare fishes and plants from the direct solar radiation.

3.4.4 Educational path

The aquaponic system is an innovative way of cultivation, unknown to most of the favela inhabitants. After the aquaponic implantation, it is important for the community to know and become familiar with the new tool, in order to use it in a correct way. For this reason, a good educational path is necessary for the success and the promotion of the new project. In our opinion it must be aimed first to the children and young people who attend schools and secondly to every inhabitant who is interested. It is necessary that schools want to promote this path and become our partners. All the schools located in the community were located during the phase one of IMM, along with the identification of all the functions within the favela.

Thereafter, each of them can be called upon to know which are really interested to introduce the awareness teaching in their education programs. Workshops and meetings can be organized by Il Sorriso dei miei Bimbi, by Gastromotiva association (encountered during the survey) and by other NGOs to make known the urban agriculture to all the community. The children and all the residents must be educated first on general topics like agricultural production, food nutrients, healthy alimentation and disposal of organic waste, and after on specific themes like the aquaponic functioning with practical lessons on site.

3.4.5 Community engagement

After the aquaponic system implantation, the community engagement starts with the search, through meetings and events, of volunteers and inhabitants interested in taking charge of aquaponic production. Having received the assignment and started producing fish and vegetables, the gardeners must donate half of their total harvest to local public school while the other half can be sold. This way, children can learn what healthy food means and the gardeners can earn something to manage the aquaponic system on their own in a micro circular economy. After the aquaponic consolidation, the community engagement can proceed, if this innovative cultivation is connected with other projects and initiatives, creating a network of subjects operating on food. A kitchen with a restaurant or a canteen can give an added value to the aquaponic products, transforming them in hot healthy dishes, and can offer job to other favela residents, expanding the number of people involved in the project. Cooking events and workshops can be organized. Moreover, the food waste, obtained from the cultivation, can be used to power the biogas system project, creating a virtuous circle if the produced gas is used to make work the kitchen. At the end it can be said that the food project can improve community relationship and can develop a circular economy inside the favela.

3.4.6 Intervention in Area 1

3.4.6.1 Introduction

As the previous paragraphs underscored multiple times, it is paramount to associate the production of healty food with an education program that can teach the local population both the skills necessary to maintain the plantations within their neighbourhood (both traditional and the aquaponic system), as well as the importance of fruits and vegetables in one's diet.

The school "CIEP Doutor Bento Rubião", already one of the most important functions inside Area 1, becomes then, similarly to the control centre for the FMS discussed in the previous section, a convenient place where most of the food-related initiatives can be placed, for two main reasons: the first is that, when undergoing an education program, a bottom-up approach, starting from the children and young people, has proven, time and again, to be an effective strategy. Additionaly, from a purely utilitarian standpoint, the school building possesses an expansive roof, over 1,200 m^2, which goes mostly unused and can easily house at least two of the proposed initiatives: the aquaponic system and the vegetable boxes' garden, both of which can readily be managed in accordance with the existing staff.

The last initiative, the community fruit gardens, which meeds much more space to be effective, will instead be placed along the new path between Villa Verde and Rua Dionéia, as it will provide many terraces that can easily house as much fruit trees as needed. On a final note, while the aquaponic system is intended mostly as an education initiative, as covering even a fraction of Area 1's requirements would need the implementation of a disproportionate number of UFBOXes, both the vegetable boxes and the community gardens have been sized for the fruit and vegetable consumption of the school, as the major public function within Area 1.

3.4.6.2 Aquaponic

The aquaponic system, extensively described above, will be placed on the roof of the school "CIEP Doutor Bento Rubião", as shown on the map below:

Figure 3.4.13 Aquaponic system location

3.4.6.3 Urban agricolture

Introduction

The first step in the urban agriculture initiative was to choose which products, both fruits and vegetables, could be farmed in Area 1, and Rocinha besides. The analysis cross-referenced the most consumed fruits and vegetables in Brazil with their respective ripening periods, in order to ensure the maximum possible coverage thoughout the entire year. The data for the analysis have been provided by the CEAGESP lists (www.ceagesp.gov.br), while the production data were obtained through IBGE and the prices in Rocinha by a direct survey from Barbara Olivi.

After considering all the available data, 14 fruits and vegetables were deemed the most suitable. Their characteristics are summarized in the tables below:

	Products stagionality											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Banana Cavendish	Medium	Medium	High	High	High	Low	Low	Medium	Medium	Medium	Medium	Low
Strawberry (Morango)	Low	Low	Low	Low	Low	Medium	High	High	Medium	Low	Low	Low
Apple (Maçã Gala Nacional)	Medium	High	High	High	High	Medium	Medium	Medium	Medium	Low	Low	Low
Melon (Melão Amarelo)	Medium	Medium	Medium	Low	Low	Low	Low	Medium	Medium	Medium	High	High
Mango (Manga Tommy)	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	High	High	High
Maracujá Doce	High	Low	Medium	High	Medium	Medium	High	High	Medium	Low	Low	High
Cabbage (Repolho)	Low	Low	High	High	High	Medium	Medium	High	Medium	Medium	Low	Low
Onion (Cebola Nacional)	High	High	High	Low	Low	Low	High	High	High	High	High	High
Lettuce (Alface)	High	High	High	Medium	Medium	Low	Low	Low	Low	Low	Low	Medium
Eggplant (Berinjela Comum)	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	High	Medium
Pepperoni (Pimentão Verde)	High	Medium	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Low	High
Tomato (Tomate)	High	High	Low	High	Low	Low	Low	Medium	Medium	Medium	Medium	High
Zucchini (Abobrinha Brasileira)	High	High	High	High	High	High	Medium	High	Medium	Medium	Low	Low
Sweet potato (Batata Doce Amarela)	Low	Low	High	High	High	High	High	High	Low	Medium	Medium	Low

Production **High** **Medium** **Low**

Tab. 3.4.1 Products stagionality data. Source: CEAGESP

	Production and prices			
	Hectares cultivated [ha]	Annual production [ton]	Annual production [kg/m²]	Price [R$/kg]
Banana Cavendish	24,077	162,327.00	0.67	3.80
Strawberry (Morango)	468	8,614.90	1.84	5.50
Apple (Maçã Gala Nacional)	817	17,525.50	2.15	8.50
Melon (Melão Amarelo)	8,374	147,147.00	1.76	9.90
Mango (Manga Tommy)	255	4,737.00	1.86	4.80
Maracujá Doce	1,052	15,012.00	1.43	6.90
Cabbage (Repolho)	1,207	18,259.70	1.51	6.90
Onion (Cebola Nacional)	1,635	27,753.00	1.70	3.90
Lettuce (Alface)	2,898	54,966.80	1.90	2.50
Eggplant (Berinjela Comum)	2,340	45,747.50	1.96	4.90
Pepperoni (Pimentão Verde)	2,560	55,751.50	2.18	4.90
Tomato (Tomate)	7,346	135,829.10	1.85	4.80
Zucchini (Abobrinha Brasileira)	2,563	62,803.10	2.45	2.90
Sweet potato (Batata Doce Amarela)	2	440.00	2.20	4.20

Tab. 3.4.2 Products production and prices. Sources: IBGE and Barbara Olivi

Vegetable boxes

Following the example of many of the initiatives decribed in detail in previous paragraphs, it has been decided that the easiest way to implement a food program inside Area 1, and Rocinha besides, would be the use of “vegetable boxes”. A vegetable box is a simple reusable container, filled with a cultivation grow-bed, that can easily be assembled and carried around, to be placed on the roofs of both private and public buildings. These containers can either be made of wooden planks or by reusing the many plastic water tanks peppering the roofs of the favela.

Each private households can manage their own small plots of land on their roofs for provate consumption, and simply move them up should they decide to add a storey to their home. This paragraph will not expand upon the use of private vegetable boxes, as it is a phenomenon which cannot easily be quantified and controlled, since it is, as intended, spontaneous.

Instead, the analysis will focus on the implementation of a vegetable boxes’ garden on the roof of the school “CIEP Doutor Bento Rubião”, along with the aquaponic system, creating a small vegetable farm managed by the school, where students can learn the importance of farming and a balanced diet. By the same token, the fruits and vegetable produced therein will be served in the school canteen in order to provide children with healty food on a regular basis.

The products in this garden will be farmed following five possible rotations of ten fruits or vegetables. The rotations are intended to maximize production by, with different products covering each other ripening times. The timetables for the rotations and production are covered in the following tables.

Figure 3.4.14 Vegetable box gardens’ location

Seasonal rotation														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Area [m²]	Production [kg]
1st rotation														
Sweet potato (Batata Doce Amarela)													132.8	292.16
Onion (Cebola Nacional)														225.42
2nd rotation														
Zucchini (Abobrinha Brasiliera)													124.5	305.07
Tomato (Tomate)														230.20
3rd rotation														
Lettuce (Alface)													157.7	299.11
Cabbage (Repolho)														238.57
Eggplant (Berinjela Comum)														308.31
4th rotation														
Pepperoni (Pimentão Verde)													83.0	180.76
Strawberry (Morango)														152.79
5th rotation														
Zucchini (Abobrinha Brasiliera)													99.2	243.08
Melon (Melão Amarelo)														174.31

Tab. 3.4.3 Fruits and vegetables rotations and production on the school's roof

Communal gardens

Since it is impractical to cultivate fruit trees in the vegetable boxes presented above, a different solution was devised for the remaining plantations. As mentioned in the introduction, the construction of the new route between Villa Verde and Rua Dionéia allowed for the creation of multiple terraces, which can be used as communal gardens for the fuit trees; not only going a long way to fulfil the overall goal of increasing green areas throughout the favela, but also provide additional healthy food for Area 1.

As for the products grown in the vegetable boxes, the fruits grown in the communal gardens will be given to the school “CIEP Doutor Bento Rubião”, the central node of the intervention in Area 1. Contrary to the plantations on the school’s roof, these communal gardens are intended to be managed by adults, organized in similar fashion to the experiences recorded at the beginning of this analysis, either as a neighbourhood association or under the umbrella of an NGO.

Fruit trees														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Area [m²]	Production [kg]
Banana Cavendish													304.00	204.96
Maracujá Doce													270.21	385.59
Apple (Maçã Gala Nacional)													398.47	854.76
Mango (Manga Tommy)													329.61	612.30

Tab. 3.4.4 Fruit trees’ production

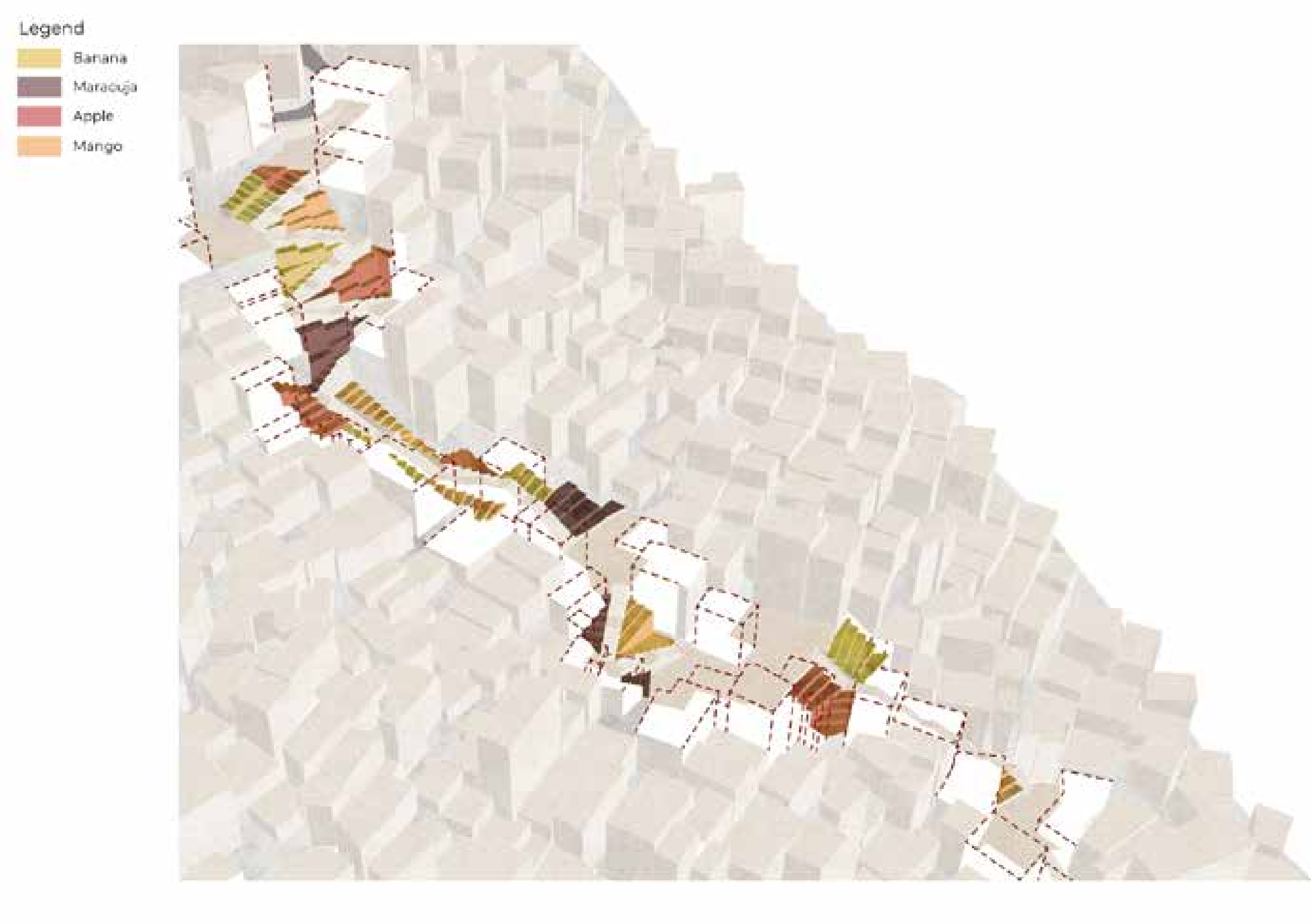


Figure 3.4.15 Communal gardens’ location

3.4.6.4 Conclusions

Unlike most of Rocinha, the plantations in Area 1, in no small part due to the green areas created by the construction of the new route between Villa Verde and Rua Dionéia, can produce a not inconsiderable amount of food, reaching a grand total of 2,384.70 kg of fruits and 2,322.68 kg of vegetables per year; the latter is further increased by the vegetables produced by the acquaponic system (120 kg per year), adding to a final tally of 2,442.68 kg.

Since this product is intended to be served in the school canteen, it was deemed interesting to calculate how many times the students could count on fresh fruits and vegetables during the year. CIEP Doutor Bento Rubião has 550 students, each accounting for a daily consumption of 0.078 kg of fruit and 0.038 kg of vegetables. The calculations shows it is possible for the students to eat fruits and vegetables produced solely in Area 1 at least once a week. Moreover, as it will be necessary to pay the workers tending to the communal gardens and the aquaponic system, the a sufficient surplus had been determined that can be sold to pay their wages and guarantee the continued success of the project. The relevant data are shown below.

	Product	Yearly consumption [kg]	Verified
Served once per day	Fruits	8,580.0	FALSE
	Vegetables	4,180.0	FALSE
Served once per week	Fruits	1,716.0	FALSE
	Vegetables	836.0	TRUE
Served once every two weeks	Fruits	858.0	TRUE
	Vegetables	418.0	TRUE
Served once per month	Fruits	429.0	TRUE
	Vegetables	209.0	TRUE
Served once every two months	Fruits	214.50	TRUE
	Vegetables	104.5	TRUE

Tab. 3.4.5 Fruits and vegetables consumption

	Surplus quantity [kg]	Real quantity [kg]	Profit [R$]
Fruits	763.35	1,955.70	12,842.45
Vegetables	385.34	1,606.68	7,029.21

Tab. 3.4.6 Fruits and vegetables projected profit

3.5 WASTE

3.5.1 Waste managment

Figure 3.5.1 Olho no Lixo's workers collecting waste in Rocinha. Source: www.ecocanto21.com.br

3.5.1.1 Introduction

While Brazil cannot be considered a low-income country, widespread social inequality guarantees the existence of low-income areas or neighbourhood, among which the prime examples are favelas. Managing waste in low-income districts must deal with different challenges (UNHABITAT 2010). Managing waste accounts for 20-40% of municipal costs, of which 70-80% invested in collection and transport; covering these costs through fees becomes an issue within poorer neighbourhood, since the assumption is that most informal communities are unable or unwilling to pay for urban services, often without analysing their actual attitude. Inequities in public services availability is not only the result of this assumption, but also of discrimination. An overreliance on imported technologies often results in the unavailability of spare parts; moreover, it can lead into choosing the wrong vehicles or equipment.

The inclusion of Rocinha in the neighbourhoods of Rio de Janeiro came along with several public services, including healthcare, education and waste management, as well as urban plans and public policies aimed at the favela. However, most of them have only been adopted partially or in an inefficient way, and the existing public services are either lacking or yield unsatisfying results.

Specifically, waste management strategies should focus both on the technical and governance aspect, following a new approach to achieve real change.

Research methodology

To obtain a realistic picture of Rocinha existing waste management system, several aspects of the favela have been analysed, as the latter is just a part of a more complex picture:

1. General context;
2. Waste quantification and characterization;
3. Waste management system;
4. Social aspects.

Since the information concerning favelas is oftentimes lacking or controversial, numerous sources have been used:

- Scientific literature;
- Grey literature ("… not controlled by commercial publishers, i.e., where publishing is not the primary activity of the producing body" Schöpfel, J.; Farace, D.J. (2010). "Grey Literature". It includes documents and reports from both academic and non-academic sources, such as government agencies, civil society organisations (CSOs) and non-governmental organisations (NGOs), as well as theses);
- Newspapers and blogs.

Solid waste management (SWM) is a fundamental service, one that influences heavily the quality of life in an urban environment.

The main guidelines used to sort out existing data and to identify relevant aspects which need further investigation are UNEP's ISWM (http://wedocs.unep.org/handle/20.500.11822/7502) and Wilson's Wasteaware Benchmark (http://davidcwilson.com/waste-management/wasteaware-benchmark-indicators-to-measure-the-performance-of-a-citys-swm-system/). After the information has been gathered, various analyses have been performed to solve the inconsistencies.

3.5..1.2 Waste flow analysis: quantification and characterisation

Quantitative and qualitative data on waste

Most of the data available on Rocinha comes from COMLURB, the official waste management company operating in the Municipality of Rio de Janeiro.

Other data comes from surveys performed by national agencies, such as the "Integrated Solid Waste Management Plan" (PMGIRS, 2015), the "Urban, Environmental and Social diagnostic report" for Rocinha (EMOP, 2012) and other similar reports from the EMOP (Municipal Company for Public Works). The Federal University of Rio de Janeiro also performed a study on behalf of the Prefeitura of Rio de Janeiro on waste management in the city (UFRJ, 2015).

Finally, some data was compiled from many websites, among which the most relevant are:

- Armazém de Dados (http://www.armazemdedados.rio.rj.gov.br/), the official website for open data operated by the Institute Pereira Pasos, Prefeitura of Rio de Janeiro;
- Instituto Brasileiro de Geografia e Estatística (https://www.ibge.gov.br/), the Brazilian institute of geography and statistics;
- Sistema Nacional de Informações sobre Saneamento (http://www.snis.gov.br/), the official website operated by the Ministry of Cities, with annual reports on waste and sanitation.

Analysis

The main goal of the analysis was to identify quantitative indicators to describe the current situation of waste management in Rio de Janeiro, and subsequently Rocinha. The principal challenge was to separate the different streams of waste (collected by public or private actors, disposed or treated, with different origins, etc.).

Results

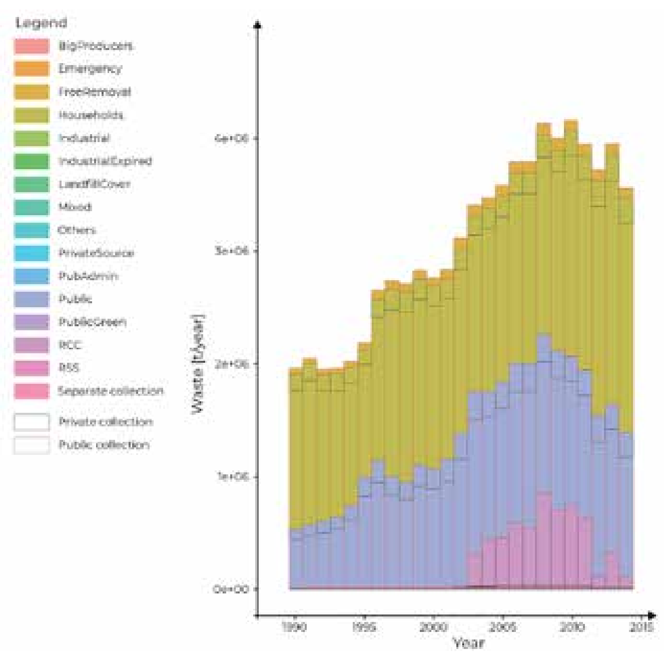


Figure 3.5.2 Municipality of Rio de Janeiro: solid waste streams in the collection phase from 1990 to 2014

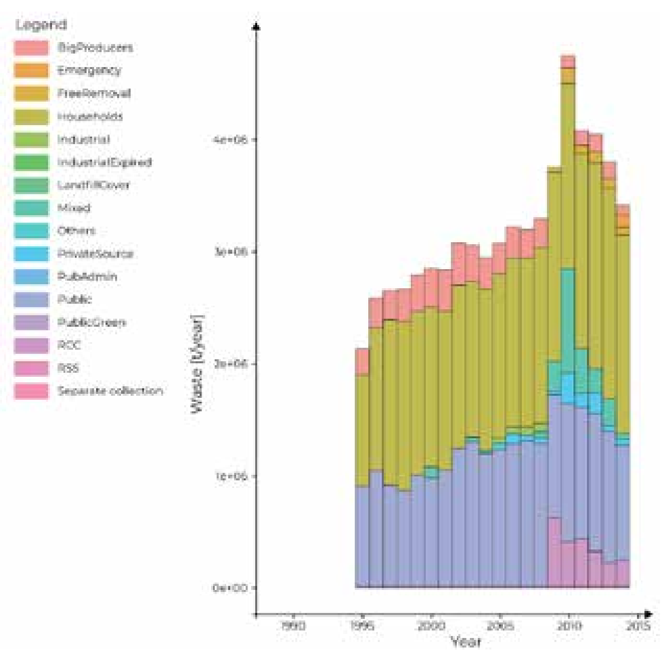


Figure 3.5.3 Municipality of Rio de Janeiro: solid waste streams in the final disposal phase from 1990 to 2014

Quantification

Waste analysis results in the identification of several waste streams (depending on the source of the waste), collected by the COMLURB or by private actors, with several final destinations (from the sanitary landfill to the composting station. Great efforts went into creating a coherent framework.

The primary waste streams identified in the collection phase are described below:

Public waste, which comes from street cleaning and sweeping; here, public waste is presented as separated from green public waste from pruning and cutting (PublicGreen), and bulky waste which is removed by a free service provided by COMLURB (FreeRemoval);

- Households waste, also known as “domestic” waste;
- Construction and Demolition waste (RCC);
- Health-care waste (RSS);
- Separate collection.

It should be noted that information about some streams (e.g. waste from industries and big producers) is only available for the final disposal phase, most likely because they are collected only by private actors.

Rio de Janeiro

In Rio de Janeiro, the private sector accounts for 11% of the total amount of collected Public, PublicGreen and FreeRemoval waste, and for 16% of the total amount of collected Households waste. The role of waste pickers (catadores) have not been considered in these calculations yet, as data available do not take them into account. Data on collected and disposed waste are summarised in Tab. 3.5.1 with reference to the year 2014, while an historical perspective is shown in Figures 3.5.2 and 3.5.3.

	Collected		Disposed	
Source	Quantity [t/year]	Collected by	Quantity [t/year]	Final delivery
Households	230,805	Private	1,772,571	Landfill_All
	1,859,823	Public		
Public	221,547	Private	1,033,622	Landfill_All
	1,057,047	Public		
PublicGreen	17,679	Public	19,038	Landfill_All
FreeRemoval	88,397	Public	70,551	Landfill_All
RCC	70,549	Public	229,202	Landfill_All
RSS	617	Public	34,883	Landfill_All
Separate collection	20,431	Public	-	-
MIxed	-	-	1,261	Recycling
Others	-	-	33,310	Landfill_All
PrivateSource	-	-	18,863	Landfill_All
PubAdmin	-	-	12,640	Landfill_All
BigProducers	-	-	83,768	Landfill_All
Emergency	-	-	110,464	Landfill_All
Total MSW	**3,566,898**		**3,420,172**	

Tab. 3.5.1 Municipality of Rio de Janeiro: solid waste streams in the collection and final disposal phases in 2014

Rocinha

Information on Rocinha is available only for public waste and Households waste collected by COMLURB. Moreover, public waste (Public2) comprises Public, Public Green and FreeRemoval waste.

Using the information available for Rio de Janeiro as starting point, both Public2 and Households waste have been increased takin into account the role of the Private sector, Public2 was split into Public, PublicGreen and FreeRemoval waste, and percentages related to other waste streams (RCC, RSS, Separate collection) have been estimated. The result is summarized in Tab. 3.5.2, while the historical perspective is shown in Figure 3.5.4.

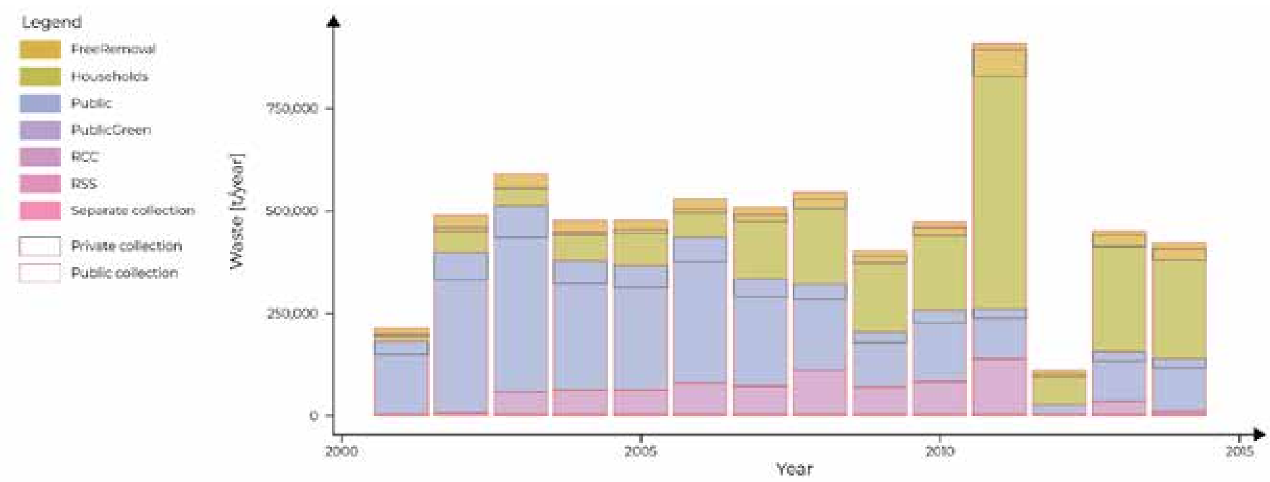


Figure 3.5.4 Rocinha: solid waste streams in the collection phase from 2001 to 2014

Source	Collected	
	Quantity [t/year]	Collected by
Households	2,961	Private
	23,858	Public
Public	2,185	Private
	10,425	Public
PublicGreen	174	Public
FreeRemoval	872	Public
RCC	822	Public
RSS	7	Public
Separate collection	238	Public
Total	41,542	

Tab. 3.5.2 Rocinha: solid waste streams in the collection phase in 2014

As described previously for Rio de Janeiro, Households waste production derives by considering the amount collected by Private and Public sector as 58.70% of the total amount of Households waste. Improperly collected Households waste are set to 18870 t/y. Finally, total produced waste for 2014 is estimated around 60411 t/y (166 t/d), close to the estimate of 152 t/d by EMOP (Domestic waste daily amount (152 t/d) were calculated as the sum of Households waste and other kind of waste, on the assumption of a population of 104644 inhabitants and a production of 1 kg/d/inhab of Households waste and 0.5 kg/d/person of other waste; 2012).

Considering a population of 200,000 inhabitants, the daily per capita production of total solid waste is estimated in 0.78 kg/d/in., while the daily per capita production of Households waste is estimated in 0.59 kg/d/in.

Characterization of Household waste

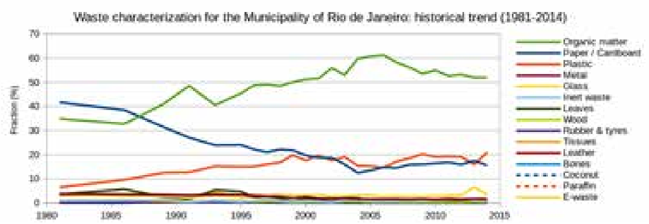


Figure 3.5.5 Waste characterization for the Municipality of Rio de Janeiro: historical trend (1981-2014)

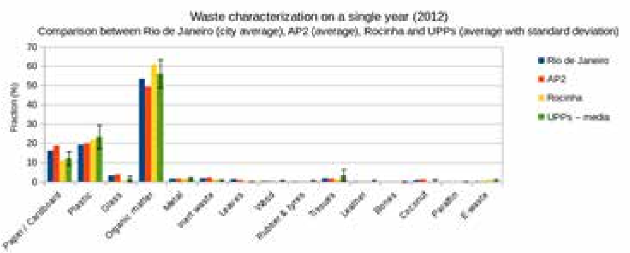


Figure 3.5.6 Waste characterization: comparison, 2012

The first stream to be analysed will be the Households waste, as it is the most significant in Rocinha, accounting for 76% of the total solid waste.

The first analysis of Households waste was performed in 1981 by COMLURB for the whole Municipality of Rio de Janeiro. It is possible to appreciate the historical trends in the amount of each fraction from 1981 to 2014 (Fig. 3.5.5). Paper and cardboard are decreasing, most likely due to the increase of plastic packaging and recycling [Lima and Surliuga, 2000]. The increase of organic matter waste is, supposedly, related to the average income growth [Lima and Surliuga, 2000].

The waste collection system divides the city of Rio de Janeiro in ten areas (Àreas de Planejamento), with Rocinha being part of the AP2. Data concerning AP2 is available from 1994 on.

Data specifically referred to Rocinha is available for a single year (2012) and correspond with a survey performed by COMLURB (GPA) on informal settlements. During this campaign, 21 favelas which included a Pacifying Police Unit (UPPs) were analysed.

Numerical data for both Rio de Janeiro and Rocinha are listed in Tab. 3.5.3, while a comparison between Rio de Janeiro, AP2, Rocinha and an average value calculated for all UPPs with its standard deviation is shown in Fig. 3.5.6. The data paints a coherent picture, and will be the basis for further analyses.

Fraction	Rio de Janeiro	Rocinha
Paper / Cardboard	15.99	11
Plastic	19.14	21.82
Glass	3.28	0.50
Organic matter	53.28	60.67
Metal	1.57	1.69
Inert waste	1.81	1.11
Leaves	1.35	0.52
Wood	0.34	0.00
Rubber and tires	0.22	0.44
Tissues	1.76	1.11
Leather	0.21	0.00
Bones	0.01	0.00
Coconut	0.82	0.00
Paraffin	0.05	0.00
E-waste	0.20	1.04
Total	100	100
Specific weigth [kg/m^3]	133.02	111.17
Moisture content [%]	36.57	39.46

Tab. 3.5.3 Characterization of Households waste in Rio de Janeiro and Rocinha for the year 2012, weight percentage. Source: GPA, 2012

3.5.1.3 Waste managment in Rocinha

Review of source data

The main source of information for this chapter has been the grey literature published by official authorities (PMGIRS, 2016; EMOP, 2012; UFRJ, 2015).

The collection system in Rocinha has been described also by Azevedo (2010), who mentioned a discrepancy between data published by official authorities and the results of direct surveys. His estimates can be used as a point of reference, since he used the same data as Toledo (2009), namely a population of 116000 inhabitants, an average MSW production of 0.85 kg/in./d and an average waste specific weight of 500 kg/m3, due to the observed presence of C&D waste.

Toledo published a plan for the waste management in Rocinha (Plano de Gerenciamento de Resíduos Sólidos da Comunidade da Rocinha - Plano Diretor de Reurbanização) by engaging in a debate with the community, but the document is currently unavailable.

Overview of the Waste management system of Rio de Janeiro

Legal framework and existing programs

In Brazil, there exist a governmental agency responsible for environment, sanitation and waste management for each administrative level [EMOP, 2012]: at the federal level, the Ministry of Environment (MMA - Ministério do Meio Ambiente); at the state level, the state Secretariat (SEA - Secretaria de Estado de Meio Ambiente) and the state Institute of Environment (INEA - Instituto Estadual do Ambiente), at the level of the city of Rio de Janeiro, the municipal Secretariat (SMAC - Secretaria Municipal de Meio Ambiente) and the municipal company for urban hygiene (COMLURB - Companhia Municipal de Limpeza Urbana).

Consequently, the legal framework also goes across these levels. The State Policy for Solid Waste (Política Estadual de Resíduos Sólidos (Lei Estadual no 4.191, de 30.09.2003)) was established for the State of Rio de Janeiro in 2003, followed by the Master plan for waste management (Plano Diretor de Gestão de Resíduos Sólidos da Região Metropolitana do Estado do Rio de Janeiro (Decreto Estadual no 41.122, de 09.01.2008)) in 2008. The National Policy for Solid Waste (Política Nacional de Resíduos Sólidos (Lei Federal no 12.305, de 02.08.2010; Decreto Federal no 7.404, de 23.12.2010)), at federal level, in 2010. At the municipal level, many laws (plans, decrees, etc.) has been issued. The most important of which is probably the law on Integrated Solid Waste Management (Gestão Integrada de Resíduos Sólidos no âmbito do Município do Rio de Janeiro. (Lei Municipal no 4.969, de 03.12.2008)), which sets up the current system under the reverse logistics. Other laws concern the separate collection, the downstream market for waste (with measures on the mandatory use of recycled waste in the municipal public administration) and the informal realities. Alongside direct waste management issues, other laws must be taken into account while describing the waste management system, concerning sustainable development and climate change, water and sanitation and urban planning.

As previously mentioned, Rocinha is and has been involved in numerous development programs, among them, the most important ones related to waste management are listed below.

The Program for the expansion of the separate collection (Programa de Ampliação da Coleta Seletiva 2010 (Prefeitura do Rio de Janeiro - BNDES, Banco Nacional de Desenvolvimento Econômico e Social)) aims at promoting the social and productive inclusion of 1.500 scavengers of recyclable materials, ensuring that 5% of the potentially recyclable materials present in the domestic waste are properly disposed of, through the construction of six Sorting Centres, an awareness program (Divulgação da Coleta Seletiva e Conscientização da População) and trainings promoted by SESCOOP (Contract 10.2.2030.1 between the Municipality (SESCOOP/RJ - Serviço Nacional de Aprendizagem do Cooperativismo no Estado do Rio de Janeiro) and OCB/RJ - Federação e Organização das Cooperativas Brasileiras do Estado do Rio de Janeiro (PMGIRS, 2015; UFRJ, 2015)).

Other initiatives include the Programa de Coleta Seletiva Solidária (Decreto Municipal no 30.624/2009), the Programa "Lixo zero" (which introduces penalties for improper disposal of waste), the Programa Alternativo de Coleta Seletiva (which call for the construction of recyclables collection in the communities with UPPs, through ecopoints, with the participation of residents of the communities themselves; e.g. Light S.A. in Rocinha), the *Projecto Coco Zero* (the recycling of the coconut shells) and *Qualiverde* (a green certificate to obtain discount on fees http://www.rio.rj.gov.br/web/smu/exibeconteudo?id=4368435).

Organisation of the WMS

Since 2011, a new logistic system for waste management has been developed for Rio de Janeiro, split into three phases (collection, temporary storage and final disposal) and involving several actors.

COMLURB is the main stakeholder for the collection of the waste, which is subsequently transferred to Waste Transfer Stations (*Estações de Transferência de Resíduos – ETRs*).

Figure 3.5.7 COMLURB operators in Rocinha. Source: www.gazetadopovo.com.br

ETRs are managed by Ciclus, designated by COMLURB for the construction, operation and maintenance of ETRs until 2026. ETRs receive MSW from Rio de Janeiro, but also from the cities of Itaguaí, Seropédica, Mangaratiba, Queimados and Miguel Pereira. There are seven ETRs, five of which are already licensed and working: Caju, Jacarepaguá, Marechal Hermes, Santa Cruz, Bangu. ETR Caju receives waste from AP1 and AP2, in other words Rocinha.

From ETRs, waste is delivered to the Waste Treatment Center CTR-Rio, located in Seropédica, also operated by Ciclus. Opened in 2011, CTR-Rio occupies an area of 220 hectares and receives waste from multiple municipalities: Itaguaí, Seropédica and Mangaratiba, as well as Rio de Janeiro. The following measures have been implemented in the new sanitary landfill: the waterproofing of cells; a leachate treatment station (biological process and nanofiltration) designed for 1,200 m^3/d (now 500 m^3/d) and the generation of 81,600 Nm^3/d of biogas, currently burned (but plan has been made to use it for energy generation or sold).

The opening of CTR-Rio allowed the closure of the Jardim Gramacho Metropolitan Landfill - AMJG, at Duque de Caxias, which was operated from 1978 until 2012.

In 2014 COMLURB managed for the city of Rio de Janeiro the collection of 8,370 t/d of waste, which corresponded to 91% of an overall 9,227 t/d received by its Transfer Stations (ETRs). This waste stream was sent to CTR-Rio Seropédica (93.2%), CTR-Gericinó received 6.3% (Construction and demolition waste), and separated collection accounted for the 0.5% [PMGIRS, 2017].

Special treatments of different waste streams

Aside from Municipal solid waste (MSW), other waste streams include:

- **Construction and demolition waste** (C&D), which was disposed in the transfer station (ATT - Área de Transbordo e Triagem) of Missões until 2012, and now is delivered to a dedicated area in CTR Gericinó. Big producers recognized by COMLURB and Smac (Grande Gerador, with a production higher than 2 m³/week) follow this stream, while small producers can confer their waste in the MSW system .

- **Organic waste**, which follows different streams:
  - ◊ *Organic compound FERTILURB* produced in the Caju Plant from organic fraction of the waste produced by the Recycling Plant located in the same area; used in the Reforestation and Preservation of Slopes Program or sold;
  - ◊ *Organic waste from big generators* (fruit and vegetables producers) goes to Caju plant;
  - ◊ *Biomethanation*: a pilot plant is being built in the Caju plant;
  - ◊ *Pruning waste from Municipal service*: alternative use of this material (50 t/d) for energetic purposes or for composting is considered to avoid landfill disposal; collaboration with Cologne to build a treatment system (shredding plant, training and technical management).
- **Separate collection**, a program of door-to-door collection which covers 113 out of 160 neighbourhood of Rio de Janeiro (Rocinha excluded) and resulted in the collection of 62.801 t from 2011 to 2015, with 20.431 t only in 2014 (AdD, Tab. 2249).
  - ◊ Recyclables deriving from separate collection are routed to cooperatives and associations of scavengers registered by the municipality, including those operating in Sorting Centers (Centrais de Triagem).
  - ◊ Sorting Centers were created from a partnership in which BNDES funds equipment purchase, while Municipality provides public areas that are assigned for 10 years (renewable) to scavenger's cooperatives. At the present, Irajá and Caju SC result operative, while other are still to be open (Programa de Ampliação da Coleta Seletiva (2010), refers to six Sorting Centers, three located at Centro, Bangu and Campo Grande (30 t/d, 300 scavengers), three located at Penha, Irajá and Jacarepaguá (20 t/d, 200 scavengers)).

In the PMGIRS 2016 future goals are defined: a reduction of 35% of waste disposed in the landfill before 2020; the development of plants for the treatment of organic waste (composting at Caju, industrial plants for biomethane production); the construction of a landfill dedicate to C&D; the treatment of 2,000 t/d of MSW through a mechanical-biological treatment plant (MBT).

Collection system in Rocinha

As stated previously, the waste collection service in Rocinha is performed by COMLURB. After collection, waste is sent to ETR Cajú and then to CTR-Rio Seropédica. [EMOP, 2012]. However, the collection system doesn't guarantee the coverage of the whole Rocinha, with negative impacts pointed out by the EMOP itself (2012): with waste feeding insects, rodents and snails; obstructing the (insufficient) drainage network and, consequently, causing floods with negative repecussions mainly in lower areas of Rocinha; collapsing on buildings when dumped in slopes (domestic and construction and demolition waste) and obstructing sidewalks and streets.

Actors involved in waste collection

Actors involved in street cleaning and waste collection were identified in 2010 (Azevedo, 2010), and their role is still extant, according to most updated source (EMOP, 2012; Carvalho, 2016); these are:

- COMLURB, supervising the street waste collection and the management of collection points;
- SMO (Secretaria Municipal de Obras), overseeing the management of compactor containers and the cleaning of Valão;
- SMAC (Secretaria Municipal de Meio Ambiente), coordinating two groups of "Guardioes dos Rios" (Rivers' watchers), operating next to Rua 2;
- Associação dos Moradores, which manages Garis Comunitarios.

COMLURB (C*ompanhia Municipal de Limpeza Urbana*) is the biggest waste management company in South America and it is a SA with the Prefeitura do Rio de Janeiro as its biggest shareholder (EMOP, 2012). COMLURB oversees several actions, which contribute to waste management:

- domestic waste collection;
- separate collection;
- "Ecopontos" (recycling areas) management;
- cleaning of slopes;
- cleaning of schools;
- streets and squares sweeping;
- maintenance of green spaces (pruning);
- maintenance of street furniture;

COMLURB supervises the collection of waste produced by programs as "Guardiões dos Rios", which perform a periodical cleaning of water bodies, "Sena Limpa", for cleaning of beaches, and "Mutirão Reflorestamento", for restoration and reforestation of degraded areas. It collaborates also with other authorities such as Rio Águas (technical authority for water and wastewater management).

Figure 3.5.8 COMLURB operators in cleaning a talvegue in Rocinha. Source: www.faveladarocinha.com

In 2010, when Azevedo performed his survey, the program "Guardiões dos Rios" for the cleaning of rivers and sewers in Rocinha wasn't active, due to political reasons. At that time, it was managed directly by SMAC, while more recently the Organizaçao da Sociedade Civil de Interesse Publico (OSCIP), Preservar Brasil became the stakeholder for this program (Carvalho, 2016).

An important role is assigned to Garis comunitarios, street-sweepers coming directly from Rocinha and contracted by COMLURB, on recommendation from the Associação dos Moradores. Although the idea of a figure of the community, with strong relationships within its inhabitants, responsible for door-to-door collection is interesting, some critical points should be mentioned.

According to newspapers, several interruptions of the program occurs due to safety issues (O Globo, "Com o fim do 'Gari Comunitário', prefeitura do Rio contratará 1.700 pessoas para limpar favelas", Magalhães L.E., 19/04/2010 (https://oglobo.globo.com/rio/com-fim-do-gari-comunitario-prefeitura-do-rio-contratara-1700-pessoas-para-limpar-favelas-3020764)) and a charge is pending for illicit subcontracting by the Superior Court for Labour (Jornal do Brasil, "Após ordem, COMLURB assina acordo para substituir garis comunitários", 11/05/2010 (http://www.jb.com.br/rio/noticias/2010/05/11/apos-ordem-COMLURB-assina-acordo-para-substituir-garis-comunitarios/)). Another issue has been the repression of workers' right to strike (Rio On Watch, "I Was Fired Because I Dared to Leave the Slave Quarters", Célio Gari, 21/05/2015 (http://www.rioonwatch.org/?p=22069)). Generally speaking, lack of clear rules and organization, a difficult financial management and scarce expertise are the main issues (Azevedo, 2010; Carvalho, 2016).

Equipment, frequency and routes of waste collection

According to COMLURB, in "pacified" favelas compactor equipped with elevator are used, to move inside narrow streets [COMLURB1 2016].

Several types of containers are located alongside streets, whose size vary whether collection is performed through vehicles or manually. All the waste collected by Garis and tractors reaches a compactor container located next to Auto Estrada Lagoa Barra, but more compactor containers are located within Rocinha. Compactor containers represent a safety issue, as they aren't fitted with any protection to prevent people or children to get close to the mechanism (EMOP, 2012).

Staff and equipment by COMLURB involved in Rocinha are specified in Tab. 6, along with an attempt to assess the number of vehicles and workers, while considering of different sources. It should be noted, however, that these figures are subjected to rapid changes.

Collection is performed either twice a day or, oftentimes, on a daily frequency (Sunday included), on the other hand, collection is performed every second day in difficultly accessible zones (COMLURB1 2016).

Truck routes include Ápia, Estrada da Gávea e Caminho do Boiadeiro, while other areas are accessible by small tractors, as it is shown in Fig. 3.5.9 [EMOP, 2012]. Besides street-sweeping, Garis comunitarios oversee collection in streets not accessible by vehicles: in 2010, they operated small tractors owned by COMLURB, performing 4-6 trips per week (Azevedo, 2010). A tipping truck (Compactadores 19m^3) was also operated twice for day (Azevedo, 2010).

Other detailed information is presented in the report on Rocinha (EMOP, 2012). While these reports do not contain up-to-date information, they can further the understanding of the overall waste management system.

Collection points: location and declared capacity

The location of collection points was mapped in 2010, along with critical points (improper accumulation, dumpsites...) (Azevedo, 2010). Figure 3.5.9 shows the tractors routes, the skip containers ("caçamba Dempster") for construction and demolition wastes, the location of compactor containers (C1 and C2). Most of the critical points were located within Rocinha's boundaries, near the forest, far from the collection points managed by COMLURB.

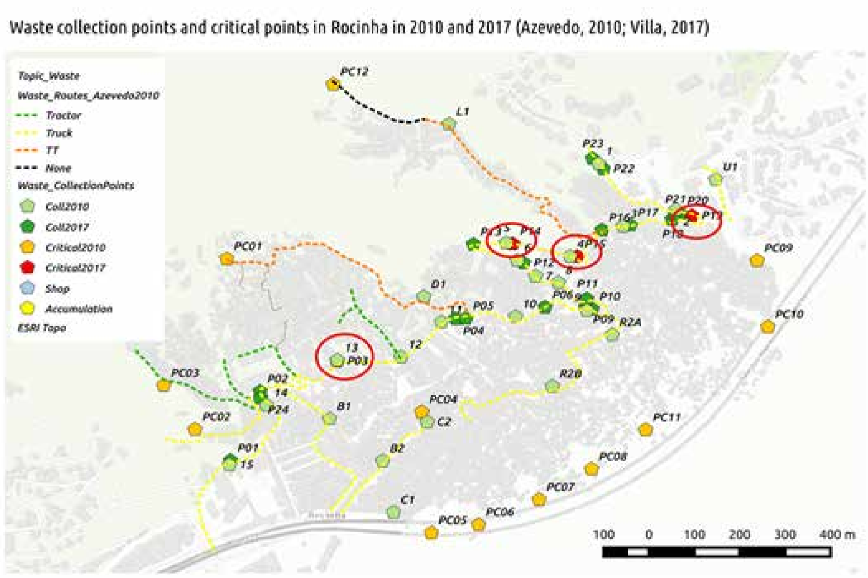


Figure 3.5.9 Waste collection points, critical points and collection routes in Rocinha

Equipment	Single item volume [m^3]	Number of items	Total volume [m^3]
Compactor containers (big)	19.00	3	57.00
Compactor containers (small)	6.00	1	6.00
Skip containers	7.00	12	84.00
Dustbin	0.24	78	18.72
Dumpster	1.75	40	70.00
Total			235.72

Tab. 3.5.4 Evaluation of installed capacity based on COMLURB and EMOP, 2012 data

English	Portuguese	Number			Image
		(1)	(2)	(3)	
Cleaning service employees:					
Officer	Agente de limpieza urbana	1	91	100	
Garbage collector	Garis	48			
Community worker	Trabalhadores (garis) communitarios	-	46	50	
Vehicles & trucks					
Minitractor	Tratores articulados	2	1	3	
Tractor loader	Pá carregadeira	2	2	2 (bobcat)	
Garbage tricycle	Triciclo	1	1	-	
Garbage compactor truck (7-5 m^2)	Caminhões compacta-dores	4	5	5	
Skip loader truck (simple)	Poliguindaste simples	1	1	-	
Skip loader truck (double)	Poliguindaste duplo	2	2	-	
Roll-on-roll-off truck	Caçamba roll-on-roll-off	1	1	1	

Tab. 3.5.5 Rocinha: collection staff and equipment of COMLURB, part I

English	Portuguese	Number			Image
		(1)	(2)	(3)	
Vehicles & trucks					
Tipping truck (19 m³)	Caminhões basculantes	2	6	4	
Tipping truck mini	Caminhão minibasculante	1	-	-	
Equipment					
Container foundations	Bases para contêineres	6	-	-	-
Compactor containers (15-19 m³)	Caixas compactadoras	4	4	3	
Compactor containers (6-7 m³)	Caixas compactadoras	-	-	1	
Skip containers (5-7m³)	Caixas metalicas	11	8	12	
Dustbin (0.240 m³)	Contêineres	-	78	-	
Dumpster (1.75 m³)	Laranjões	-	40	-	

Tab. 3.5.6 Rocinha: collection staff and equipment of COMLURB, part II

Conclusions

A general overview on waste collection in Rocinha can be obtained, using both the Censo Demográfico 2010 (IBGE, 2010) and the Censo Domiciliar do Rocinha (EMOP, 2010). Both refer to 2010, mentioning a population ranging from 69,161 to 73,410 inhabitants, and several households in which interviews were performed between 23,352 to 25,135. They included a question on waste collection or disposal, considering the door-to-door collection and the disposal in street containers as appropriate. The Censo Domiciliar distinguishes also between door-to-door collection when performed by the COMLURB or garis comunitarios.

Results report an amount of properly collected waste ranging from 93.5% (EMOP, 2010) to 98% (IBGE, 2010), which would only leave a small amount thrown in empty terrains, in rivers or in the sea, buried and burnt.

As the following paragraphs will clarify, these quantitative data do not properly address the reality of the situation, missing key information as the quality of the collection, the frequency of the service, the overall hygienic conditions, as well as running into a general reluctance of the interviewees to answer these questions.

A detailed report of the same EMOP mentioned in fact that 23% of waste not being properly collected (According to EMOP (2012), the percentage of 77% of waste properly collected comes from the Censo Demografico (IBGE, 2010), but analysis on disaggregated data produced another result (the aforementioned 98%)), and described how waste is, in fact, accumulating in several areas in the hillside or in drains, and how collection points alongside the Estrada da Gávea are permanently saturated and often damaged (EMOP, 2012).

A topic worth mentioning is construction and demolition waste (C&D). As reported by both Azevedo (2010) and EMOP (2012), a system of big containers (Dempster) was planned to collect C&D, but, once installed, it was impossible to maintain the separation between C&D and Household waste, as both were thrown into the Dempsters. Consequently, the Households characterization performed by COMLURB in 2012 is probably missing this aspect.

Another issue arises with the distinction between Households waste and commercial waste, as pointed out in Carvalho (2016; Pag. 94). In her thesis, she describes how the current legislation divides waste producers in small (up to 60 kg or 120 L per day) and big (above 60 kg per day) producers (https://leismunicipais.com.br/a1/rj/r/rio-de-janeiro/decreto/2009/3080/30794/decreto-n-30794-2009-altera-a-estrutura-organizacional-da-empresa-municipal-de-limpeza-urbana-COMLURB). While collection is provided by COMLURB for small producers as well as for households, big producers should contract a private company (Clean Ambiental being the most known).

A restaurant owner interviewed by Carvalho (2016) pointed out that in 2015 COMLURB started to fine people for improper waste disposal, and described the present situation as cleaner, even if some people still continues to dispose of commercial waste in street containers (due to lack of control); he also mentioned the tariff from Clean Ambiental (370 R$/month for 3 bags/day; 770 R$/month for 8 bags/day) and his kind of waste (mainly bean skins, food waste and salad); finally, he pointed out that part of the discarded food goes to poor people, and that there are scavengers separating directly cans from bins.

3.5.1.4 Assessment of stakeholders and initiatives

It is widely recognized that a waste management system is more likely to be successful if a high level of engagement of the community is reached. As the recent work of Ceppi (2017) confirmed, Rocinha is a very complex urban system, in which multiple actors (from public authorities to drug dealers) are involved. Thus, not only many of the past renovation projects have not been successful, but people trust in the public authorities has reached rock bottom.

To kickstart any beneficial project in Rocinha, it is paramount to identify and contact several actors (public authorities, academy, civil society organisations (CSOs) and non-governmental organisations (NGOs), companies, scavengers from the informal sector).

A comprehensive list of associations operating in Rocinha in several fields (from environment to leisure to sports) can be obtained by the following documents:

- stakeholders' maps (PDS, 2011, pag. 114);
- associations and engagement in the favela (EMOP C.D. Relatório, 2010, pag. 139);
- existing projects and involved realities (UFRJ, 2015, pag. 34).

Stakeholders

Along with the stakeholders shown below (Tab. 3.5.7), it will be necessary to also consider primary schools for environmental awareness programs and the Agente de Saude, a key figure in public health, which can represent a good strategy of communication inside Rocinha.

Public administration	Academy	CSOs and NGOs	Companies	Informal sector
• Administrative Region for Rocinha; • Secretaria Municipal de Meio Ambiente (SMAC); • Secretaria de Educação (SME) • Secretaria Municipal de Obras (SMO); • COMLURB (Companhia de Limpeza Urbana); • Câmara Técnica Setorial Permanente de Gestão de Resíduos do CONSEMAC – Conselho Municipal de Meio Ambiente.	• Universidade Federal do Rio de Janeiro (UFRJ); • Núcleo de Solidariedade Técnica (SOLTEC); • Incubadora Tecnológica de Cooperativas Populares (ITCP); • Portal Saneamento Básico (University of São Paulo); • Pontificia Universidad Catolica (PUC).	• UPMMR - União Pro Melhoramento dos Moradores da Rocinha; • Associação dos Moradores • Organizaçao da Sociedade Civil de Interesse Publico (OSCIP) Preservar Brasil; • Rocinha Sem Fronteiras; • Viva Rio Socioambiental; • Grupo de Moradores da Rocinha.	• Portal Residuos Solidos; • Web-Resol; • SESCOOP/RJ; • OCB/RJ; • Rede Recicla Rio.	• Rocinha Recycla; • Progetto Cataforte I e II.

Tab. 3.5.7 Stakeholders for waste management activities in Rocinha

Current initiatives in Rocinha

Some state-sponsored programs include initiatives for waste management potentially applied also to Rocinha. While the favela is often mentioned in these programs, knowing whether or not the initiatives went beyond the initial proclamation is difficult. Other times, some projects are only described in newspapers or blogs.

- Application of institutional programs:
  - ◊ Plano de Desenvolvimento Sustentável (2011) propose the "Transformation of waste in reddit" through the "creation of cooperatives and associations working with recycling", without clarifying how it will be financed;
  - ◊ Programa de Ampliação da Coleta Seletiva (2010), though it most likely does not involve Rocinha;
  - ◊ Programa Alternativo de Coleta Seletiva in communities with UPPs;
  - ◊ Programa de Coleta Seletiva Solidária (D.M. 30.624/2009);
  - ◊ Programa "Lixo zero", which prescribes penalties for improper waste disposal.
- Awareness practical actions in Rocinha:
  - ◊ De Olho no Lixo (2016), a subsidiary of the NGO Viva Rio Socioambiental in cooperation with SMAC, that gave birth to several activities, such as Rocinha Recycla, Funk Verde, Ecomoda;
  - ◊ Lixo Zero (Zero Waste, 2016), an initiative to share solutions and promote awareness;
  - ◊ Tio Lino (2006), an artist from Rocinha who recycled solid waste;
  - ◊ An educational game proposed by COMLURB.

- Reuse, recycling and energy recovery practical actions in Rocinha:
  - ◊ Estaçao Rociclagem (2013), a company which made brooms from plastic bottles (PET);
  - ◊ Projecto Oleo Zero (2015), collection of waste oil from kitchens (schools, restaurants, etc.);
  - ◊ Fabrica verde (2012), E-Waste fix & reuse project;
  - ◊ Ecoponto Rocinha (Light   discount on electric bill), 2015.

3.5.1.5 A project for Rocinha

General overview

As previously stated, the issue of waste management in Rocinha is very complex, due to the social situation, the shortage of funds and the geomorphological and urban characteristics of the neighbourhood.

Rocinha's extremely dense urban texture results in a high production of Households waste. Narrow alleys and lack of open spaces make it difficult to find an appropriate location for containers in nearly the whole favela. For the most part, waste is disposed of in containers located along the few vehicle accessible streets, such as the Estrada da Gavea, but, when moving away from the main roads, waste is left on sidewalks and empty terrain or thrown inside drains and sewers. The containers' capacity is evidently insufficient for Rocinha's daily waste production, and the same can be said for the frequency of collection. While their location would allow their handling by vehicles and trucks, it hardly provides safe access for pedestrians. Moreover, the practice to leave waste wherever is convenient, derives not only from the physical distance between single households and containers, but also from the inhabitants' cultural background, as most people coming from rural areas were used to dispose of their (mainly organic) waste in their courtyard, a practice that obviously cannot persist in Rocinha.

To proceed with a correct approach, it is necessary to distinguish between sanitation and hygiene (Dr. Guéladio Cissé, CeTAmb Lab, December 21st, 2016). The former refers to infrastructural and managerial choices which generate an efficient waste management system, while the latter to behavioural changes and good practices by the citizens. These aspects are complementary, even more so in a context in which public institutions are often both inefficient and corrupt. A related topic is the availability of resources and social inequality. While clear numerical data to properly evaluate the difference between Rocinha and other neighbourhoods are unavailable. However, all references are unanimous in describing the situation as critical and point to a lack of proper equipment.

The lively civil society of Rocinha generated in the last years many activities related to waste management (e.g. the recent restoration of Caixinha square by Favela Verde), very valuable on the side of engagement. Proposed solutions should tackle both the environmental awareness of citizens and the massive amount of improperly disposed waste at the same time.

Review of previous strategies

Some of the waste management strategies proposed in the past are still worth mentioning. The "Relatório de Diagnóstico Urbano, Ambiental e Social" (EMOP, 2012) suggested an integration between different approaches and actors, along with underground containers to sidestep the problem of space.

A detailed plan was proposed by Azevedo B.D. and Cardoso C. ("Plano de Gerenciamento de Resíduos Sólidos da Rocinha"). Even if the document is unavailable, it's still possible to have an idea of the actions proposed based on the thesis of the former author (Azevedo, 2010), who divided roles and responsibilities between three main actors: companies, local communities and public authorities. Azevedo outlined in detail numerous actions, from the mostly practical ones (e.g. the purchasing of computers for gari comunitarios to optimize the collection management), to the suggestion of a coordination strategy. The plan was never implemented, due to conflict between the state and municipal management (Silva, 2014).

Proposed strategy

The proposal is to build a collection system parallel to the existing services performed by COMLURB, aiming to divert valuable materials from general waste collection.

The diversion of recyclables will not negatively affect COMLURB, since, apparently, the waste collected from Rocinha does not reach any separation plant. The recovery and recycling of valuable materials may become a source of income for both the individuals and the community; to reach this goal, the involvement of the local cooperative of scavengers will be crucial. A small fraction of the waste will be treated inside Rocinha itself, even if this percentage will vary depending on land availability. Recycling waste on site requires space for storage and treatment processes, which is one of the big constraints in Rocinha.

The diversion of waste from the existing system should lead to decreased costs for collection. Thus, COMLURB should be involved and asked for a different management of the collection, in order to cover more areas, or for an institutional or economical support of other projects.

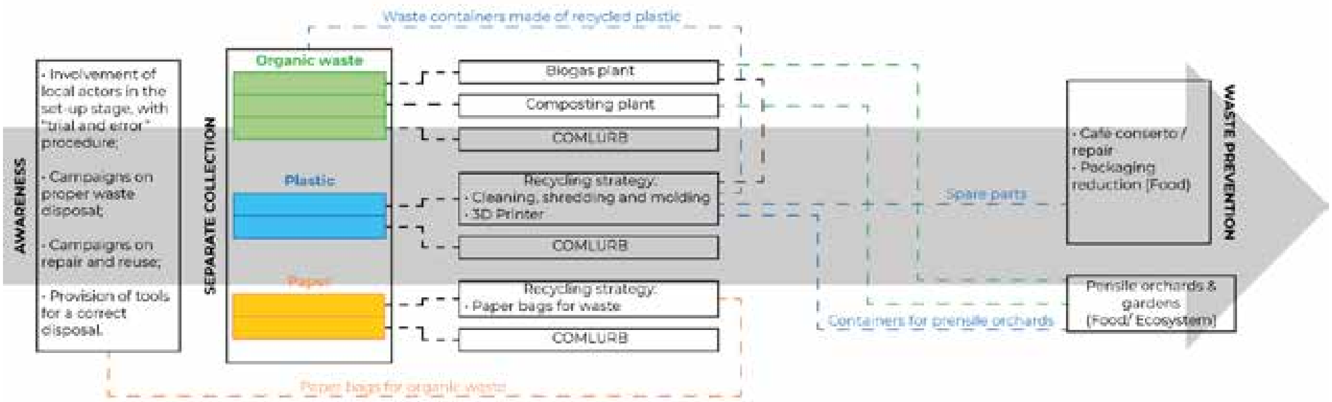


Figure 3.5.10 Strategic map for waste management in Rocinha

Awareness

A campaign within the community for spreading awareness about the benefits of waste collection should involve local actors at all stages, starting from the "set-up" phase, with a "trial and error" procedure that will permit to correct errors while implementing the project. Since a separate collection project is unlikely to work if the inhabitants do not actively participate in it.

The process of engagement of the population should be followed by a professional, such as a sociologist or an anthropologist.

Collection stage

Promoting separate collection at single household level is important to obtain high quality secondary raw materials from organic waste and other fractions. Moreover, it provides a safer working environment for collection workers.

The main steps of the strategy are listed below:

- organic waste: large quantities of organic waste are being produced each day in Rocinha. In the first stage, organic waste can be disposed in already existing containers, with just a small amount separated and transformed in compost;

- recyclable waste (plastic, paper, metals, e-waste, etc.): These fractions have a high (potential) economic value. The cooperative of scavengers "De Olho no Lixo" should be involved in the collection and subsequent management, and containers for recyclable waste could be installed in strategic places;
- awareness programs will be needed to achieve a good separate collection.

The location of separate collection points must be evaluated on a case-by-case basis: while containers could be placed along the streets, they could also be in schools or inside shops, when feasible.

Treatment stage

Both anaerobic digestion and composting plants can be used to treat a fraction of organic waste. The choice between these solutions should be done in cooperation with the local population, considering the land availability and management options. The potential market for the compost should be evaluated, considering both already existing local needs and Polimiporocinha activities.

Concerning recyclable waste (plastic, paper, metal, e-waste, etc.), local treatment depends on several factors, as well as the willingness and ability of the cooperative to collaborate.

The following chapters will analyse some of these solution, with particular attention to the proposal for an anaerobic biodigester plant and a machine that converts plastic materials into kerosene.

3.5.2 Biogas plant

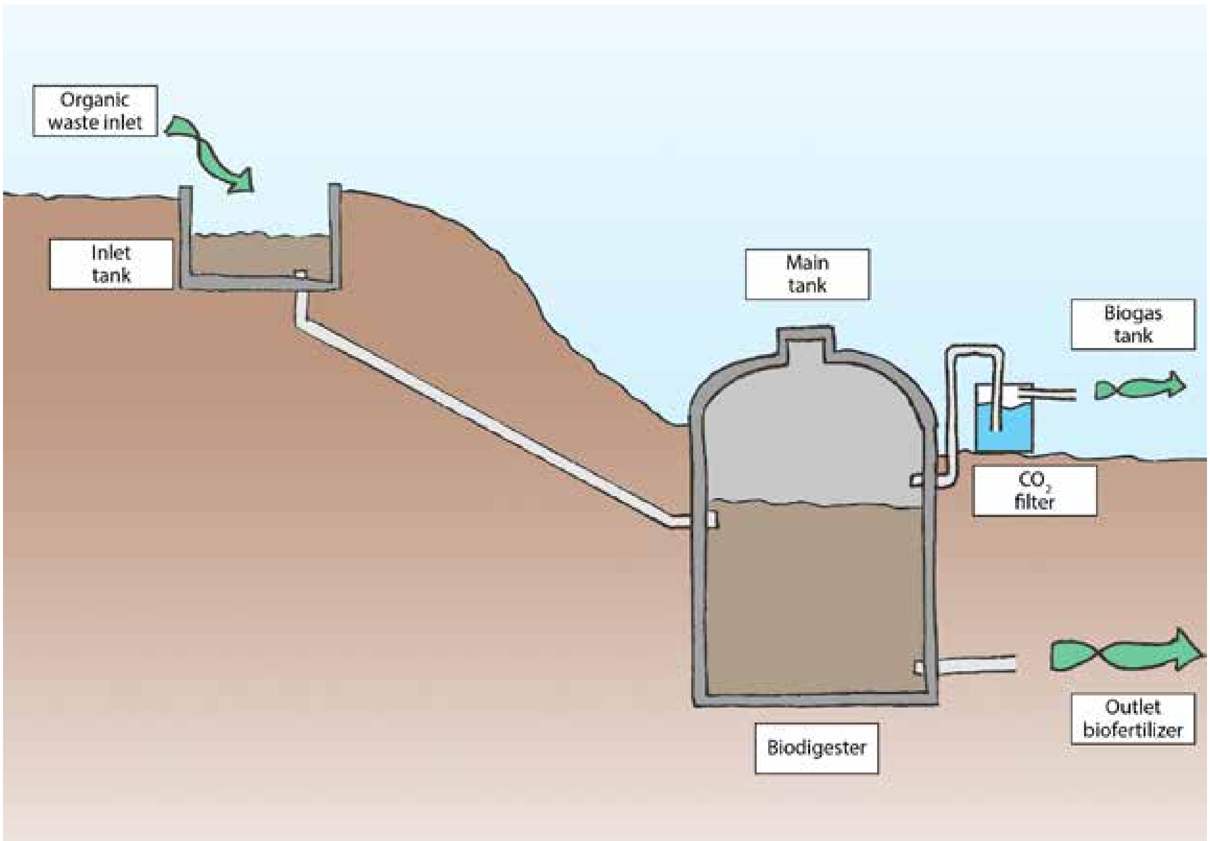


Figure 3.5.11 Biogas process schematization

3.5.2.1 Introduction

Waste disposal, as already discussed, is one of the major issues for the favela. A solution can be found in the use of a biodigester tank for biogas and biofertilizer production, that not only recycles organic waste, but transforms it from a problem to an opportunity, both economically and for the environment. Thus, it answers to DOPs:

- number 4: prevent the negative impact of waste;
- number 7: fostering the local energy production, it has been implemented as one of the project's strategies.

3.5.2.2. Historical and regional overview

To date, solid waste management remains one of the most pressing issues faced by contemporary civilization, both from an economical and environmental point of view.

Reportedly, scientific interest into production of gas through natural decomposition of organic matter dates back to the 17th century. The first known anaerobic digester was built in a leper colony in India in 1859. The technology developed further in England first to generate fuel for gas lamps (1895), then for sedimentation and sludge treatment (1904). Research of anaerobic digestion, however, begun in earnest only in the '30s. In recent years, the biodigester has become increasingly widespread around the world both for waste and waterwaste disposal, reduction of landfill emission and "green" energy production through biogas.

This technology is widely used in western Europe, pushed by necessity and legislation, especially in large-scale electric plants connected to livestock farming. In particular, Germany is Europe's largest biogas producer, whose biogas production accounts for almost 13% of the total generated renewable electricity.

In Brazil, the interest in the biodigester technology sparked primarily as a local-scale, simple and cheap solution to dispose of the cattle manure produced daily in the many family-owned farms that exist around the country, as oftentimes said manure is simply thrown away into the fields and pollutes the water-bearing strata. The technology used derives mostly from similar experiences in major developing nations such as China and India and focuses on easy-to-build and maintain tanks, made up of cheap materials (either concrete or bricks), quick to build and produce almost immediate tangible results. One such an example can be found in the Santo Antônio II community, in the Afogados da Ingazeira municipality, state of Pernambuco.

A similar project exists also in the Vale Encantado community, relatively close to Rio de Janeiro. There, two biodigesters have been built, to dispose both the local organic waste and waterwaste. The first, made of concrete, is connected to the communal restaurant, creating a sort of "symbiotic" relationship in which the biogas used for cooking is fuelled by the its own food waste, though recently, inhabitants of the community have been encouraged to dispose of their organic waste into the biodigester. The second, built with bricks, is used to dispose of the community's waterwaste, and fuels a single household, responsible of the biodigester maintenance.

It becomes apparent that, while Brazil is becoming increasingly aware of the possibilities yielded by the biodigester technology in solving its waste and waterwaste management problem, so far construction has been limited to small-scale, almost "prototype" projects, while much needed large-scale projects are yet to enter the picture.

3.5.2.3 Process

At its core, the biodigester tank functions as an anaerobic digester. Anaerobic digestion refers to a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. Once the tank is properly sealed, this fermentation process happens naturally and transforms waste and waterwaste into biogas and biofertilizer.

The ideal temperature for anaerobic digestion is around 35°, which makes it a good technology

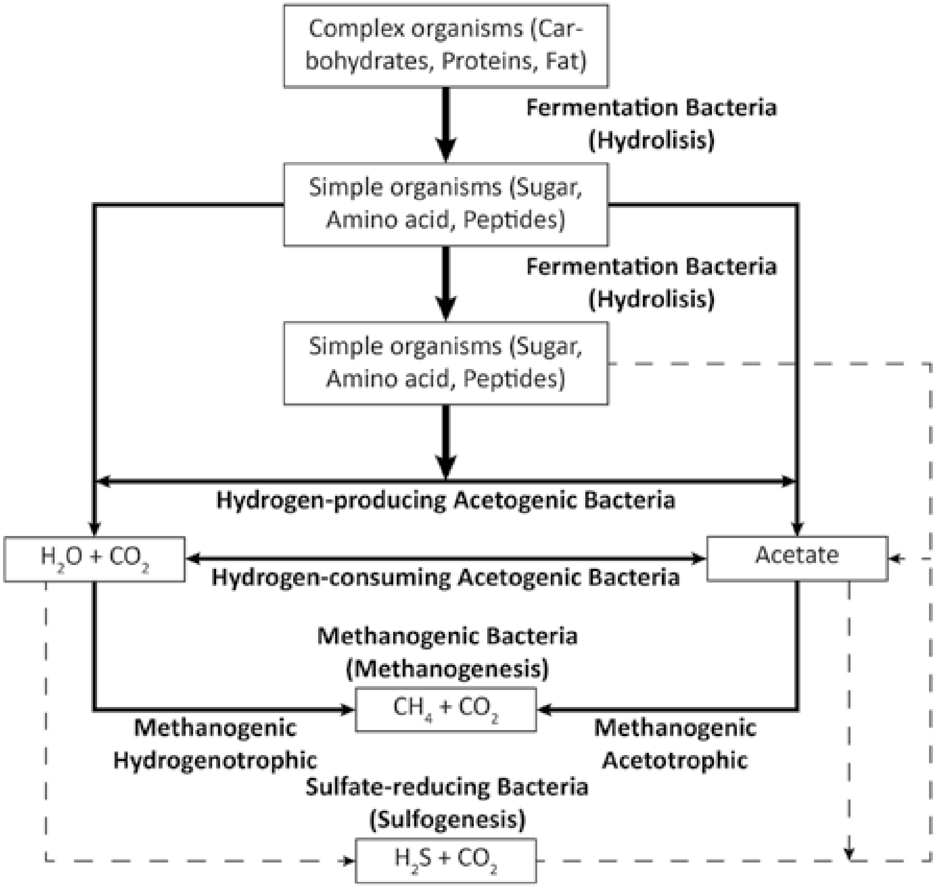


Figure 3.5.12 Biodigestion process schematization

to be used in subtropical regions, such as Brazil. As biogas builds inside the biodigester, pressure increases and helps "pushing" both digestate and gas out of the tank.

The fermentation process makes it so that the digestate is extremely nutrient rich, in fact, the product is so powerful, that it must be diluted with ten parts of water to be used as biofertilizer.

Raw biogas produced from digestion is roughly 60% methane and 29% carbon dioxide with traces of hydrogen sulphide, as reported in more detail in Tab. 3.5.8. The carbon dioxide concentration alone makes it important to have a filter between the biogas and its destination. Biogas has a heat capacity between 5,000 and 7,000 kcal/m^3.

Gas	%	
	Min.	Max.
CH_4	50	70
CO_2	30	40
N_2	0	10
H_2	0	5
O_2	0	1
H_2S	0	1
Water vapour	0.3	

Tab. 3.5.8 Typical raw biogas composition. Source: WALSH JR. et al. (1988) and BRETON et al. (1994)

Fuel	Quantity
Biogas	1.00 m^3
Petrol	0.61 L
Gas	0.45 L
Kerosene	0.58 L
Firewood	1.50 kg
Diesel	0.55 L
Alcohol	0.79 L

Tab. 3.5.9 Biogas heat capacity. Source: WALSH JR. et al. (1988) and BRETON et al. (1994)

The fermentation process also helps to reduce contaminants inside waste and waterwaste, depending on the biodigester operating temperature and hydraulic retention time.

Organism	T [°C]	Retention time [d]	Reduction [%]
Poliovirus	35	2	98.5
Salmonella SopEphi	2-37	6-20	82-98
Salmonella Typhi	22-37	6	99
Mycrobacterium tubercolosis	30	-	100
Ascaris	29	15	90
Cyst parasite	30	10	100

Tab. 3.5.10 Contaminants potential reduction via biodigester. Source: National Academy of Science, 1977 and Massotti, 2002

The proposal is to use the biodigester tank primarily as an organic waste disposal method and to distribute the biogas produced in the fermentation process to social-oriented initiatives (such as a school's cafeteria), and to sell the fertilizer surplus outside the favela itself, which could be withdrawn in selected point along the main roads by the "De Olho no Lixo" cooperative (or similar initiatives) with the use of small vans.

3.5.2.4 A premise on calculations and data

The rapid growth of the favela's population results in an ever-changing cityscape, completely different from a typical European city. Thus, we had to approximate each area's population using a statistic approach.

Since the total number of buildings in the favela is known, along with the number of storey for each, the percentage ratio between them could be derived.

It is fair to assume that each storey of a building corresponds to an apartment. Thus, the mean number of people per floor was calculated, dividing the inhabitants of the favela for the total number of floors. By multiplying the mean number of people for the number of floors in each area individuated by the IMM analysis the former's population can be reasonably estimated.

From the waste management analysis, it is known that the daily organic waste per person is 0.36 kg. With this information, the daily organic waste produced in each area can be easily calculated, by multiplying the former for the estimated population.

Numerous sources put the transformation yield from organic waste to biogas to 0.27 m^3 per ton of Volatile Solids. This value was obtained through the following steps:

$$TS = 0.3\ RW$$

$$VS = 0.9\ TS = 0.9(0.3\ RW) = 0.27\ RW$$

where:

- RW: Raw Matter, the daily organic waste
- TS: Dry Matter, the daily organic waste without water
- VS: Volatile Solids.

As precaution, the worst yield was chosen, from which we obtained the theoretical volume of biogas produced by the plant, converted in weight units using the methane specific gravity. This data was selected because methane represents the largest fraction (at least 50%) of the output gas.

Finally, the amount of biofertilizer produced was derived from the difference between the weight of the organic waste introduced in the plant and the biogas output, assuming the combustion reaction of methane as basis. Using the same chemical reaction, it was possible to obtain the daily kWh production.

To hypothesize each area's need, we took the cafeteria's kitchen of an elementary school in Milan (hosting between 180 and 200 children) as a reference. The needs were matched with the initial biogas output (considering only the IMM areas), and the catchment area enlarged as needed to meet the required yield. The needed output was increased by 30% to account for the non-constant nature of the biogas transformation reaction.

Once the catchment area was finalized, and, subsequently, the buildings and inhabitants within, we could calculate the final production data for both the biogas and the biofertilizer.

Having verified needs and output of the plant, we proceeded to size every component of the system. First, the weight of Raw Matter needed into unit of volume can be calculated. Thus, the minimum volume of the latter is equal to the value of daily organic matter multiplied by 30 days, the amount of time required for the fermentation process to occur. For safety concerns, an additional 10% was added for the main and inlet tanks, and 15% for the biogas tank.

3.5.2.5 Construction

Given the difficulty of navigating the innards of the favela and the lack of local skilled labour, the main leitmotiv of the project is simplicity. Both in the assembly of the biodigester tank, whose parts are made outside the favela as an easy-to-assemble and reproduce technological system for the inhabitants to build, and in its workings, which was achieved by minimizing the number of components involved in the process. Following these guidelines, the system is devoid of mechanical implements, such as pumps, instead functions with gravity and pressure only.

The system is made up of four parts:

- An inlet tank for the organic waste;
- A main tank for the fermentation process;
- A CO_2 filter;
- A gas collection tank.

Once the fermentation process reaches capacity, it is advisable to withdraw the solid part (biofertilizer) directly from the main tank every day, though the system is designed so that it can be drained up to three-four days, depending on the biodigester's dimensions.

Since the favela of Rocinha is located between two mountains, its terrain is both irregular and rocky. This makes very difficult to dig by hand, instead it becomes necessary to use earth-moving machines and thus, verify if they can be brought to the construction site, on a case-by-case basis.

Inlet Tank

The inlet tank should be placed as close to the local waste collection point as possible, the closer to one of the main streets, the better. Since the system works by gravity, it is imperative that the inlet tank is placed above the level of the organic waste entrance spot in the main tank.

First, a concrete basement is constructed, 15 cm in thickness, with a hole in the centre, big enough to house the organic waste pipe. While the concrete is still wet, the inlet tank is attached to the base.

The tank is funnel-shaped, its base diameter is just enough to accommodate the organic waste pipe, which itself has a maximum diameter of 25 cm. While its height and upper diameter depend entirely on the total volume of the tank, as detailed in the drawings. The tank is placed aboveground and made from a single fiberglass mould, provided with an openable plastic lid, to prevent rainwater from accidentally pouring in.

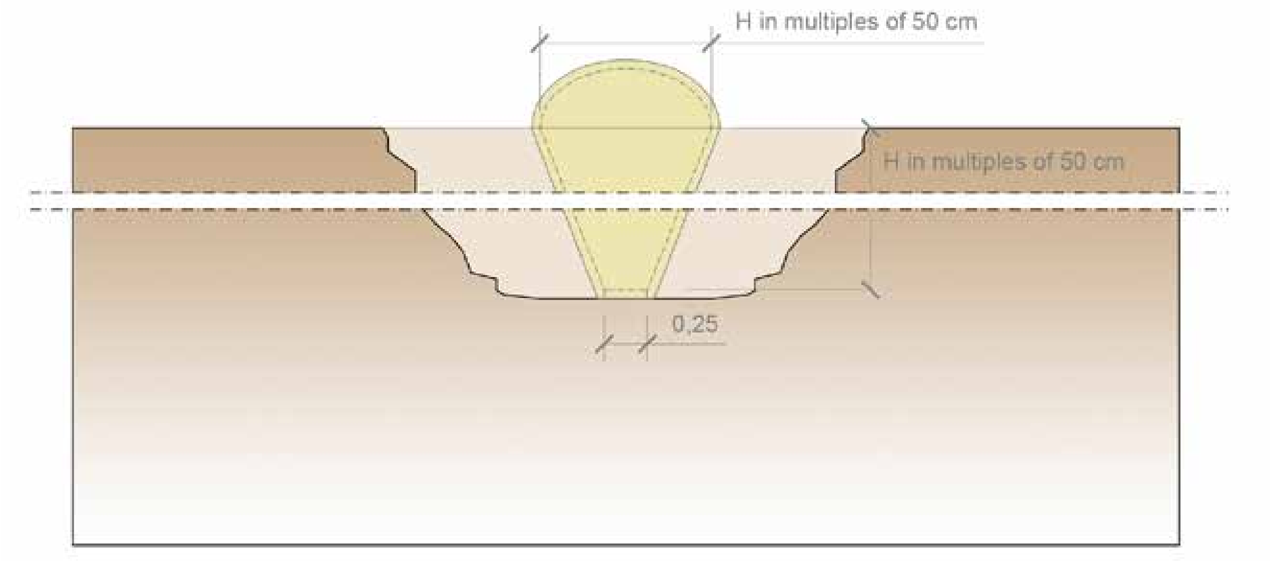


Figure 3.5.13 Biodigester plant: inlet tank

Main Tank

When possible, the biodigester should be put at least 10 meters from the closest building, in order to avoid dangers and health hazards to human beings, though it should not be farther than 50 meters from its recipient, as to avoid excessive performance losses.

The first step is to make an excavation, its bottom is 4.5 meters in diameter, meaning 50 cm larger than the biodigester's base diameter and as deep as the tank's height (which may vary). Once the excavation is complete, the bottom must be levelled out.

A concrete foundation is then laid covering the bottom of the excavation. Depending on the hardness of the soil, the concrete might be reinforced with steel bars. The foundation height should be about 25 cm, thus, once completed, the biodigester will be 25 cm above the ground.

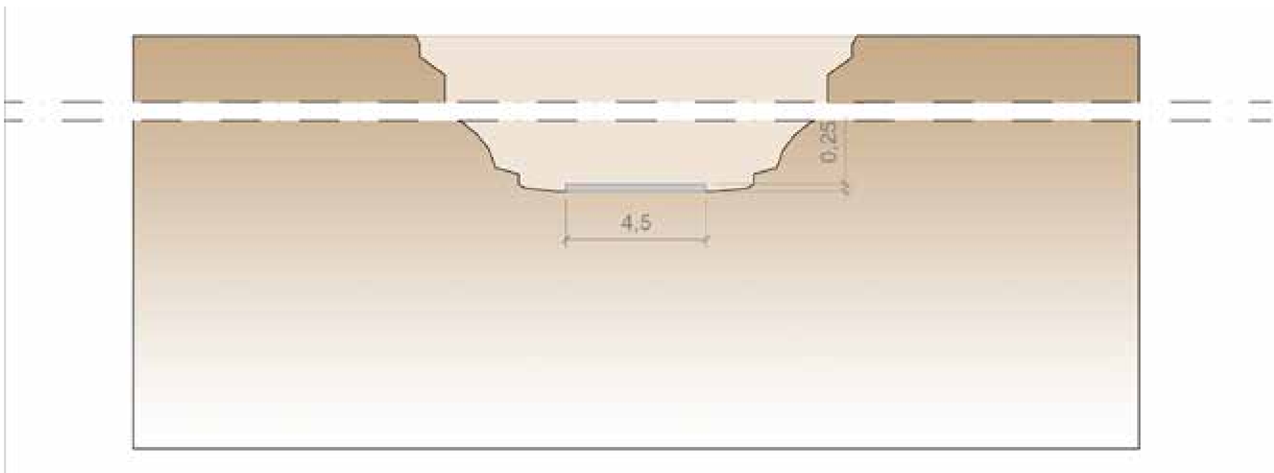


Figure 3.5.14 Biodigester plant: main tank. Phase 1

The main tank is made of prefabricated concrete curved panels, measuring 50 cm in height and 10 cm in thickness. 16 panels form a complete ring of the tank, which is 4 meters in diameter. The panels are tapped, both horizontally and vertically, so they can easily fit with each other. Multiple rings of panels can be stacked until the desired height has been reached. Four of these panels will have holes, large enough to insert the inlet pipe for the organic waste, the outlet pipes for biogas and biofertilizer, whose size must be calculated depending on the tank's volume and the last to be fitted with a pressure indicator.

The panels are cemented to the foundation slab and each other. The panels that will be housing the inlet pipe and the biofertilizer outlet pipe must be placed in the first ring, opposite to each other. Likewise, the panels that housing the biogas outlet pipe and the pressure indicator will be placed in the last ring. Once the designed height has been reached, the tank is sealed both externally and internally with cement.

After the biodigester has been sealed, the various pipes can be inserted into their intended slots, carefully placed so that their ends are positioned above ground level.

Then, a fiberglass dome is placed over the finished cylinder. This dome serves as base for the concrete dome formwork, which

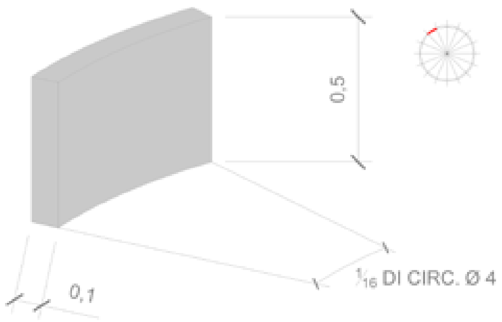


Figure 3.5.15 Concrete panels' specifications

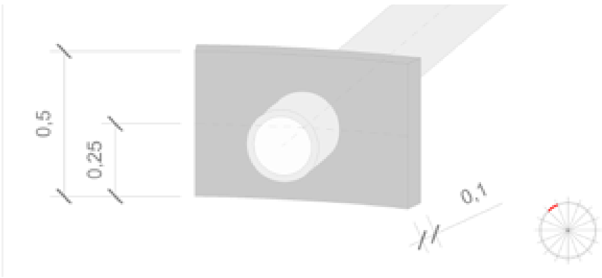


Figure 3.5.16 Concrete panel with PVC pipe

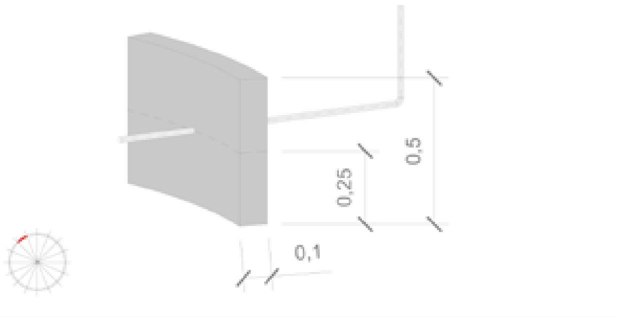


Figure 3.5.17 Concrete panel with copper pipe

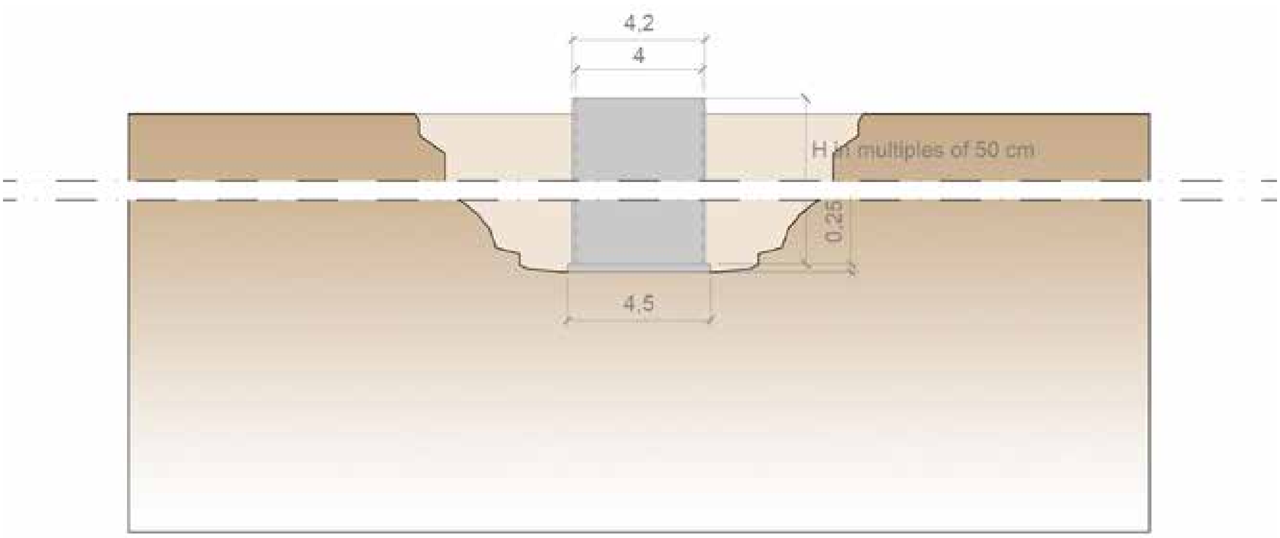


Figure 3.5.18 Biodigester plant: main tank. Phase 2

has the same thickness as the prefabricated panels. A second formwork is placed over the dome and removed after the poured concrete hardened. Both the fiberglass and concrete domes are moulded so to have a manhole at their centre, to inspect the tank when necessary.

Once the main tank is completed, the excavation can be filled.

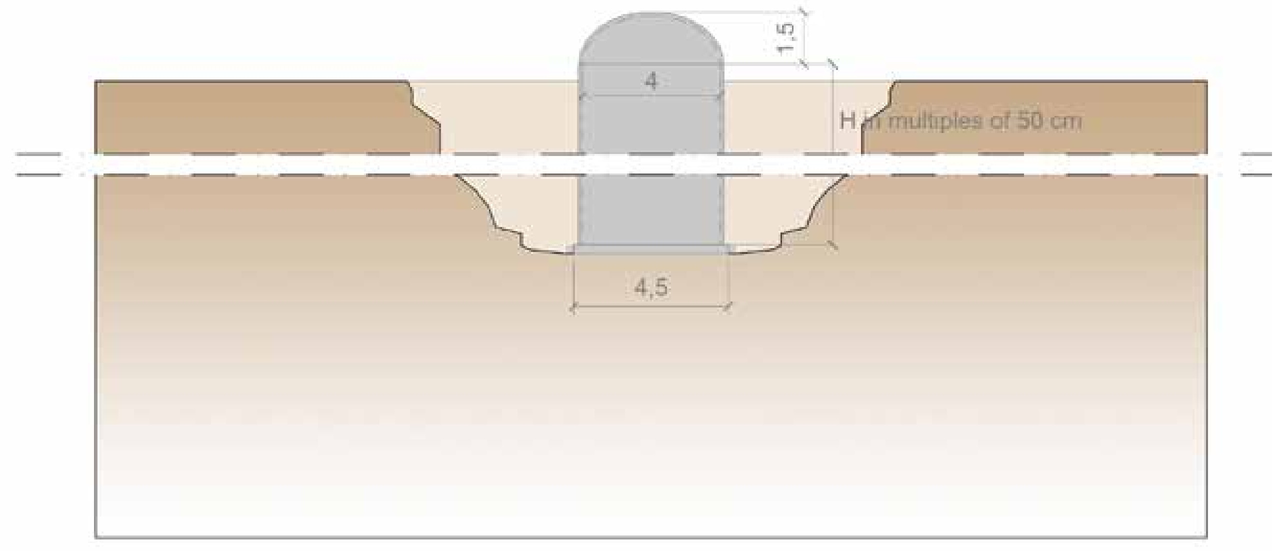


Figure 3.5.19 Biodigester plant: main tank. Phase 3

CO_2 Filter

Since a considerable part of raw biogas is made up of carbon dioxide, it becomes necessary to build a filter between the main tank and the final delivery, to prevent health hazards.

The filter is a simple recycled plastic tank, many of which can be found throughout the favela, filled with water, connected to the biogas outlet pipe. As the pressurised gas passes through the water, it loses most of its CO2 content with a simple chemical reaction.

The resulting gas, now mostly methane, can be thus safely delivered to the biogas tank.

Biogas Tank

Since the biogas production and requirements aren't constant, it's necessary to build a storage tank between the biodigester and the final delivery. The volume of biogas contained in the tank is enough to guarantee the gas consumption for a single day, any eventual excess will be burned with a pilot light. This choice has been made both to limit the dimensions of the tank, an important consideration in an urban context as densely built as Rocinha. And reduce the risks in case of fire or explosion. To better guarantee a continuous process and a constant pressure inside the biogas tank, while accommodating a progressively larger volume as production continues, it becomes necessary for the tank have a variable volume. This resulted in choosing a floating roof tank.

To optimize resource allocation, the excavation for this second tank should be an extension of the main tank's excavation, when possible. Similarly, to the previous tank, the excavation's bottom will be 4.5 meters, 50 cm larger than the storage tank's base diameter and as deep as the tank height. Again, the bottom must be levelled out.

Before laying the concrete foundation, a steel pole is planted into a smaller hole, 50 cm deep, bored at the centre of the excavation. The steel pole's height is the same as the tank, plus the foundation and the aforementioned 50 cm. The pole is then fitted with a steel ring, welded to its surface, placed 60 cm above the foundation floor. Said pole will act as rail for the tank's floating lid. Once the foundation is completed, the pole will be embedded in concrete.

A concrete foundation is then laid covering the entirety of bottom of the excavation. Depending on the hardness of the soil, the concrete might be reinforced with steel bars. The foundation height should be about 25 cm, thus, once completed, the biogas tank will be 25 cm above the ground.

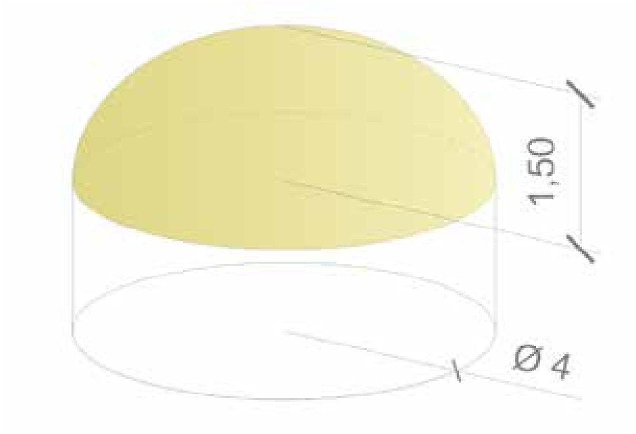


Figure 3.5.20 Fiberglass dome specifications

The storage tank is made of prefabricated concrete curved panels, measuring 50 cm in height and 10 cm in thickness. 8 panels form a complete ring of the tank, which is 2 meters in diameter. The panels are tapped, both horizontally and vertically, so they can easily fit with each other. Multiple rings of panels can be stacked until the desired height has been reached.

The panels are cemented to the foundation slab and each other. The panels that will be housing the inlet and the outlet pipe should be placed in the last ring, opposite to each other. Once the designed height has been reached, the tank is sealed both externally and internally with cement. Once the concrete cylinder is complete, it is filled with water, 50 cm deep.

The plastic lid possesses three holes, one in the centre, to accommodate the steel rail, and two on the sides, to be fitted with the inlet and outlet flexible gas pipes. All the holes must be properly sealed to reduce pressure losses. Once the lid has been fitted into the pole, a second steel ring is welded into it, 20 cm before the rail's end.

Once the storage tank is completed, the excavation can be filled.

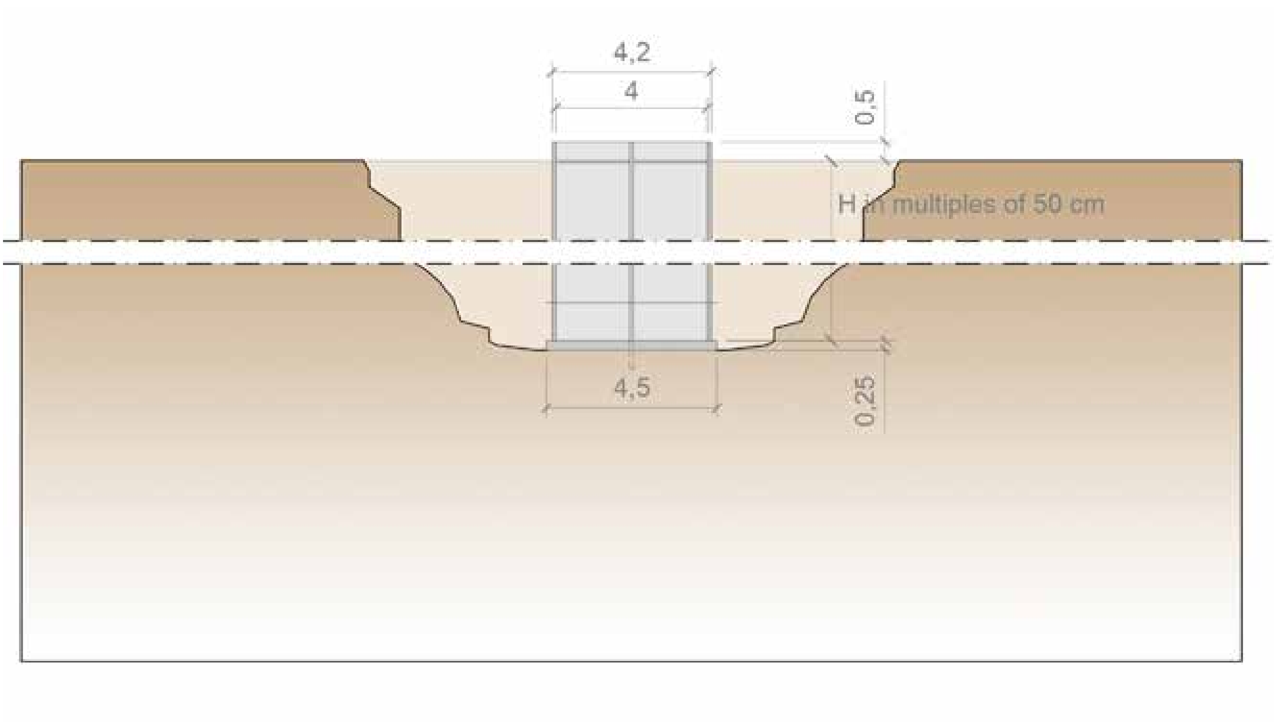


Figure 3.5.21 Biodigester plant: biogas tank

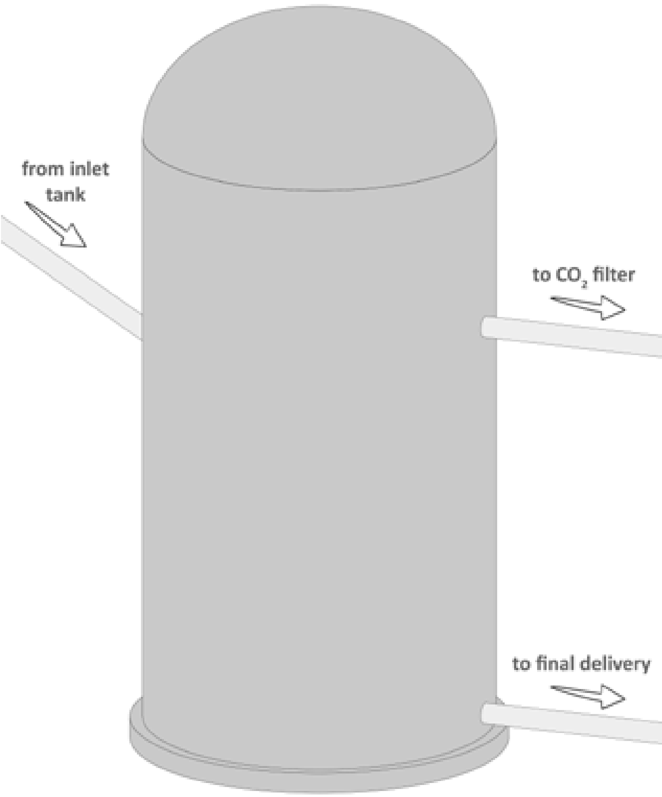


Figure 3.5.22 Biodigester plant: main tank 3D view

Figure 3.5.23 ISUZU L35 Serie Bleu septic tank

Final Delivery

The various parts of the system are connected by PVC pipes. The material has been chosen due to them being cheap, easy-to-build, and having relatively good resistance.

The first pipe connects the inlet tank to the biodigester. Since the first part of the system works by gravity, it must be completely sloped and has to have a diameter big enough to prevent clogging.

Two pipes depart from the main tank: one takes the biofertilizer out and should be sloped as well (if the terrain allows it), the other takes the biogas from it to the filter and after, to the storage tank. Both the aforementioned pipes are pressurized.

From the storage tank, departs the last pipe, taking the biogas to its intended destination.

The biofertilizer is taken away by a small septic truck capable to go through the narrow alleys of the favela, like an "ISUZU L35 Serie Bleu" (dim. 5.3x2.1 m), provided with a pump to facilitate the extraction of the material. The biofertilizer can be sold at approximately 30 € per liquid ton, to which the final user must add the transportation costs.

3.5.2.6 Notes on the method and research employed

Since the biodigester plant is a system just recently employed in Brazil, the research and data we provided are based either on prototype developed by engineers Leonardo Adler and Tito Cals of Universidade Federal do Rio de Janeiro or by applying to Rocinha lessons learned in Italian contexts.

For those reasons, once the plants have been completed, it will be necessary to conduct a series of tests both on the biogas and the biofertilizer to ascertain their quality and, subsequently, their values on the market.

3.2.5.7 Intervention in Area 1

Site of Construction

As previously discussed, the biogas plant requires not only a safe distance of 10 metres minimum from buildings but must also be easily accessible by both people and vehicles, the former for the delivery of organic waste and the latter for the withdrawal of biofertilizer. It is also advisable, when possible, to bury the biogas tank and biodigester at least partially underground, to increase the security of the plant, though the overall cost will increase.

These considerations led to place the plant on the lower right corner of the main intervention area, with the four tanks (inlet, biodigester, filter and biogas) placed sequentially, the first built as close as possible to Villa Verde. This way, the inlet tank is not only close to the main road, but also to the entrance of the new path that connects the lower half of Area 1 with Rua Dionéia, thus the inhabitants can more easily bring their organic waste to the plant.

The biodigester is partially buried underground, so that the organic waste can slide from into it from the inlet tank though the PVC pipes simply by gravity. Similarly, the plant takes advantage of the six metres drop between the project site and the UPA, so that the pipe bringing the biofertilizer out of the tank comes out near the existing parking lot, where the product can e easily collected by the septic truck.

The filter is located simply between the two main tanks.

Finally, the biogas tank is also partially buried, and connected with copper pipes with both the biodigester through the filter and the school's kitchen, its intended final delivery.

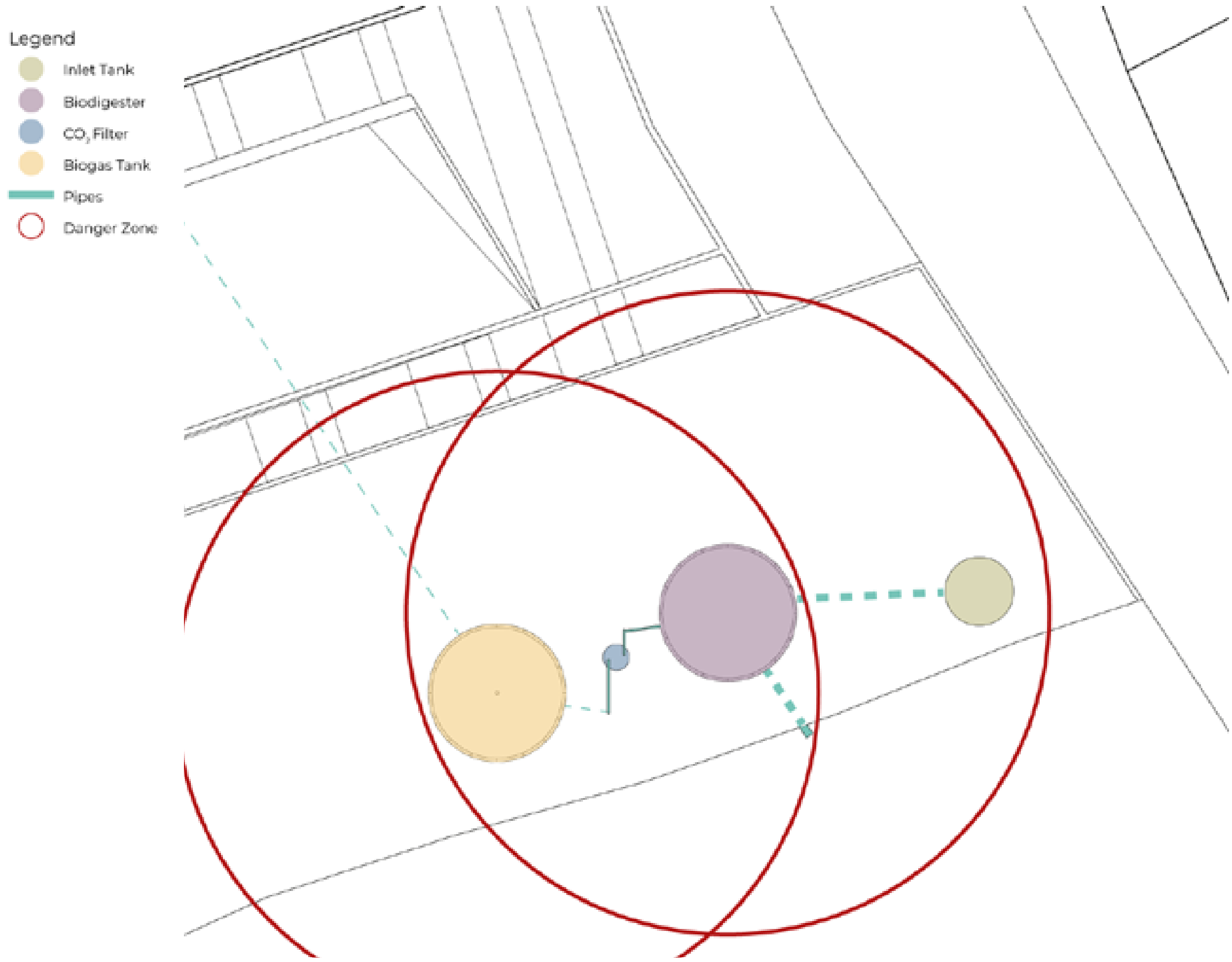


Figure 3.5.24 The biogas plant in Area 1

Consumption and Production

The biogas plant is manly intended as an incentive for the population to recycle their waste (in this instance, organic waste) by showing that recycling can become a source of income, by selling the biofertilizer produced by the plant. In this system, the biogas is merely a by-product of the anaerobic digestion employed by the plant and wouldn't be enough to sustain the gas demands of the entire area, even assuming an absurd 100% recycling rate.

Keeping this in mind, it was decided that the biogas produced by the plant would power the needs a public building, namely, the kitchen of the school "CIEP Doutor Bento Rubião". As it was impossible to acquire specific consumption data, they were estimated by comparing it with similar-sized school kitchens in Italy, obtaining a daily consumption of 490 kW. To stay on the safe side, it was decided to apply a 30% increase to this result (taking into account the possibility of older appliances and losses in the system), finally arriving at a daily consumption of 637 kW.

h per day	Medium power per stove [kW]	Daily consumption [kW]
5	49	245

Tab. 3.5.11 Industrial Kitchen consumption derived from a direct survey in an elementary school for a kitchen with a single industrial stove with four fires. Technical sheets show alternatives ranging from 17 to 51 kW of power. For this system an all-in-one solution with 6 fires and a static stove was chosen. Link: http://www.angelopo.com/it/products/t/14146-fuochi-aperti/

n. of kitchens	Daily consumption [kW]	Oversizing	Total consumption [kW]
2	490	30%	**637**

Tab. 3.5.12 Area 1 daily needs, note that each "kitchen" services 200 users

To calculate the amount of organic waste necessary to satisfy said consumption, this chapter refers to the data acquired during the waste management analysis, which found that 0.36 kg of organic waste are produced daily by every inhabitant. Only the volatile solids fraction of the organic waste is transformed in the anaerobic conversion, namely 0.0972 kg of volatile solids daily per inhabitant. The volatile solids are then converted into m3 of biogas using a transformation factor ("Energia Elettrica e Calore dal Biogas: una concreta opportunità per gli agricoltori", AIEL e Regione Toscana: p. 6) of 0.4, meaning that 0.039 m3 of biogas daily per inhabitant. Of which about 50% is the useful methane fraction, meaning the plant produces 0.019 m3 of methane daily per inhabitant.

Having obtained both daily production per inhabitant and daily consumption of the school, the number of inhabitants necessary to satisfy the former was calculated, namely 3535 people, distributed between 178 buildings. The resulting methane and biofertilizer productions are detailed below, the latter merely being the total organic waste subtracted by the biogas produced by the anaerobic digestion.

Organic waste [kg]	Volatile solids [kg]	Transformation factor	Biogas production [kg]	Biofertilizer production [m^3]	Methane production [m^3]	Total consumption [kW]
1,272.60	343.60	0.40	137.44	1,176.39	68.72	**637.04**

Tab. 3.5.13 Area 1 daily biogas production

Next page is also the map of the buildings that can recycle their organic waste using the biogas plant, chosen for their proximity with Villa Verde or the new path to Rua Dionéia.

Legend

Biogas Plant
Danger Zone
Basin

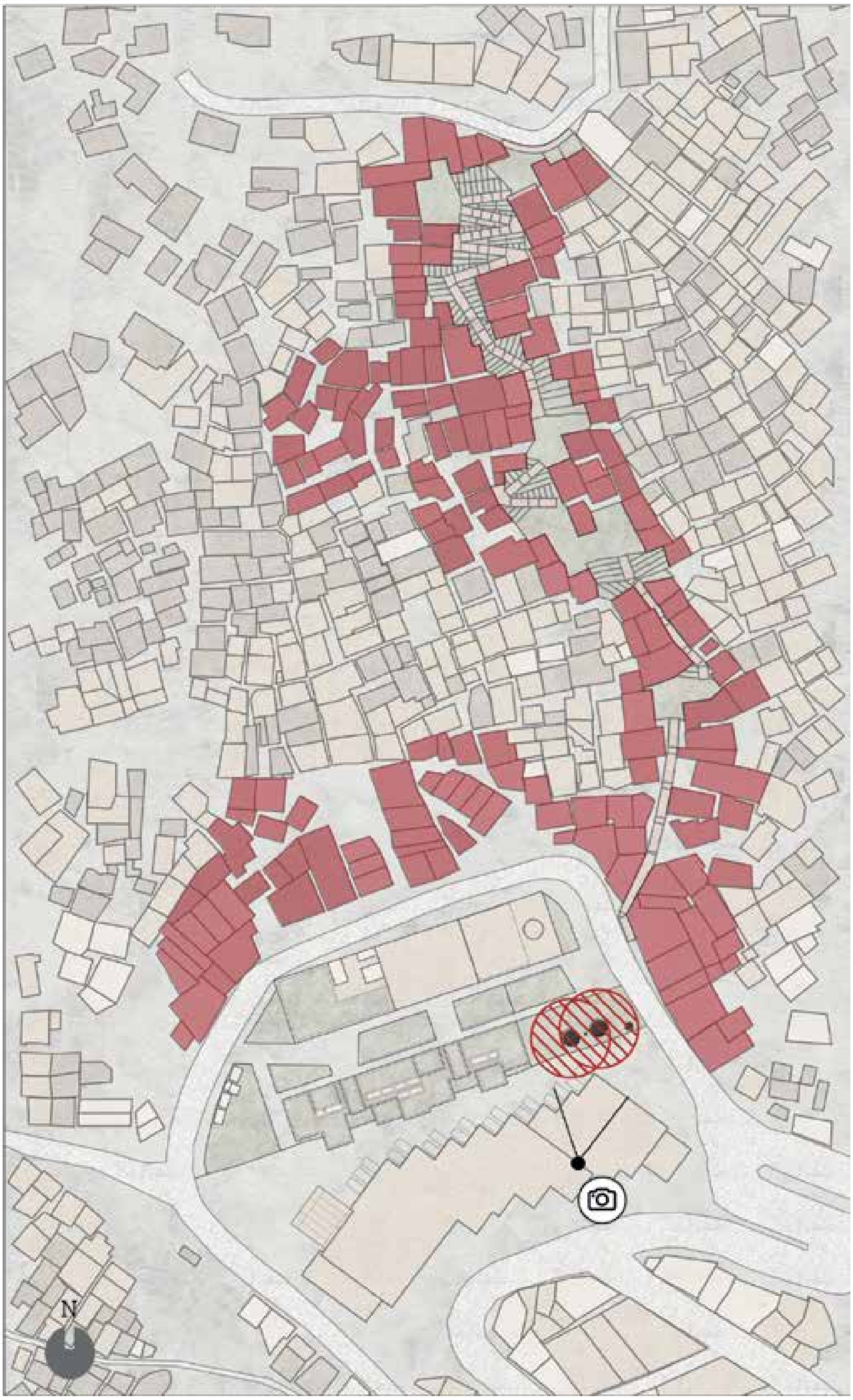


Figure 3.5.25 The biogas plant in Area 1: building needed for organic waste collection

Dimensioning of the Plant

In this section, the three main components of the biogas plant will be sized according to the production/consumption data detailed above. For the construction methods used, refer to the outline presented in the biogas pilot project chapter.

First of all, it was necessary to convert the daily organic waste total from kilograms into m3, using a 0.78 t/m^3 factor (https://www.sciencedirect.com/science/article/pii//S0960148111005957) as well as a retention time of 30 gg, necessary to activate the anaerobic digestion process, below are detailed the volume for each tank and their actual sizes, obtained using the construction detailed previously. On a final not, as written above, each tank has been slightly oversized, to both for security reasons and accomodate an expansion of organic waste collection; respectively, the inlet tank has been oversized by a factor of 0.1, the biodigester by 0.10 and the biogas tank by 0.15.

V_r [m^3]	Waste retention time [gg]	Inlet tank [m^3]	Biodigester tank volume [m^3]	Biogas tank volume [m^3]
1.63	30	1.79	53.84	79.03

Tab. 3.5.14 Biogas plant's components' dimensions

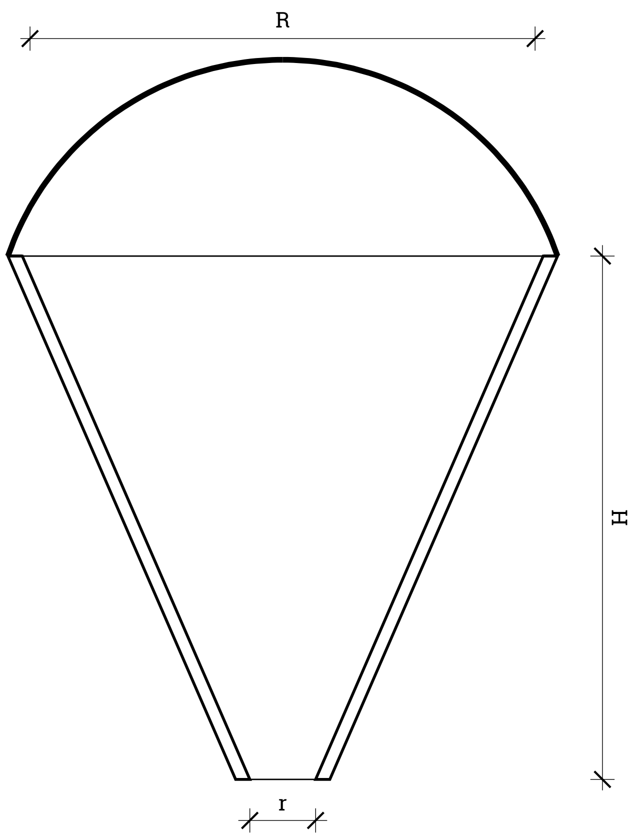


Figure 3.5.26 Inlet tank

r [m]	R [m]	H [m]	V [m^3]
0.125	1.00	2.00	**2.39**

Tab. 3.5.15 Inlet tank's dimensions

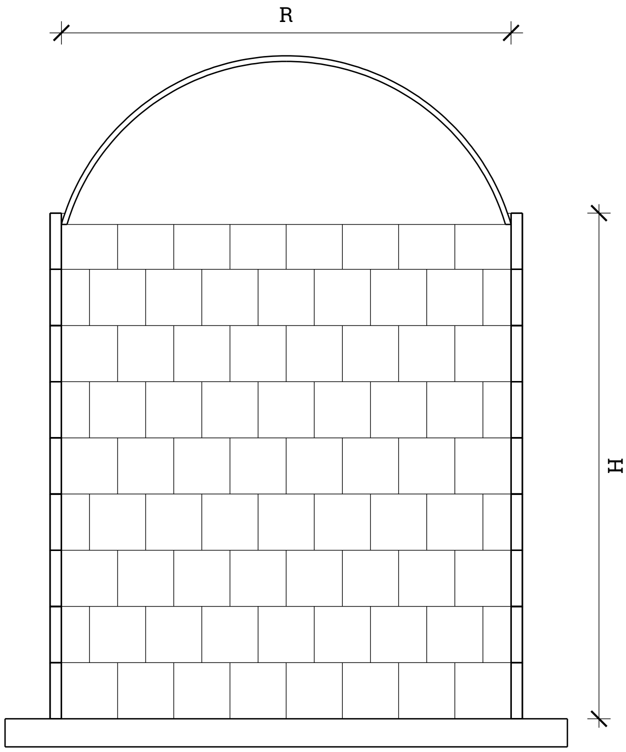


Figure 3.5.27 Biodigester tank

H [m]	R [m]	V [m³]
4.50	2.00	**56.55**

Tab. 3.5.16 Biodigester tank's dimensions

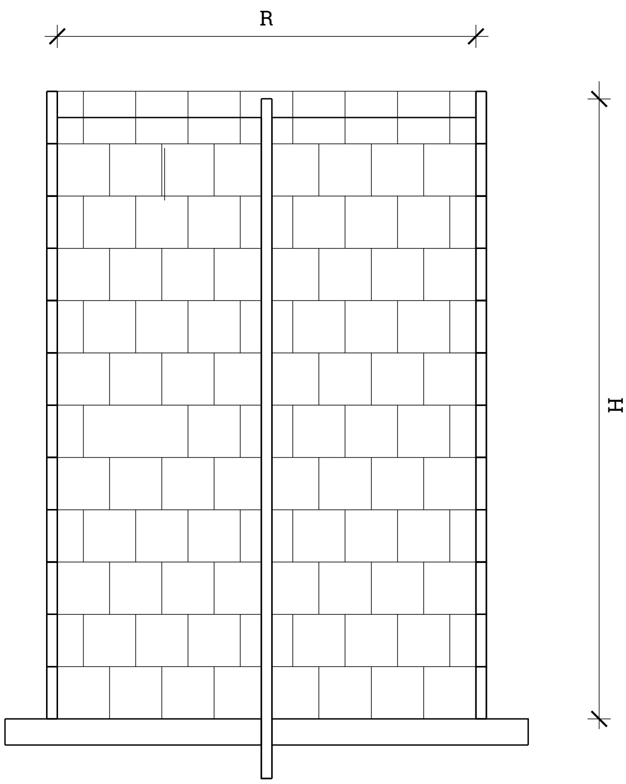


Figure 3.5.28 Biogas tank

H [m]	R [m]	V [m³]
6.50	2.00	**81.68**

Tab. 3.5.17 Biogas tank's dimensions

Costs and profits

Using data provided by the Brazilian federal government for the State of Rio de Janeiro (http://www.caixa.gov.br/site/Paginas/downloads.aspx#categoria_656), it was possible to estimate both the costs of the plant, including the excavation (beside the labour cost, the estimation of which is nigh-impossible in Rocinha) and the possible revenues associated with the sale of biofertilizer.

The total cost of the plant has been estimated in 28,739.60 BRL, or 6,673.90 € (Exchange rate as of March 2019).

While on-site controls must be conducted after the plant is operational to properly assess the quality of the biofertilizer, a conservative estimation places the price of the product at 0.03 €/kg.

In other words, the plant of Area 1 would accrue a revenue of 35.29 € per day (151.97 RL), 1,058.75 € per month (4,559.26 BRL) and 12,881.50 € per year (55,471.19 BRL), more than repaying its material cost one year after construction.

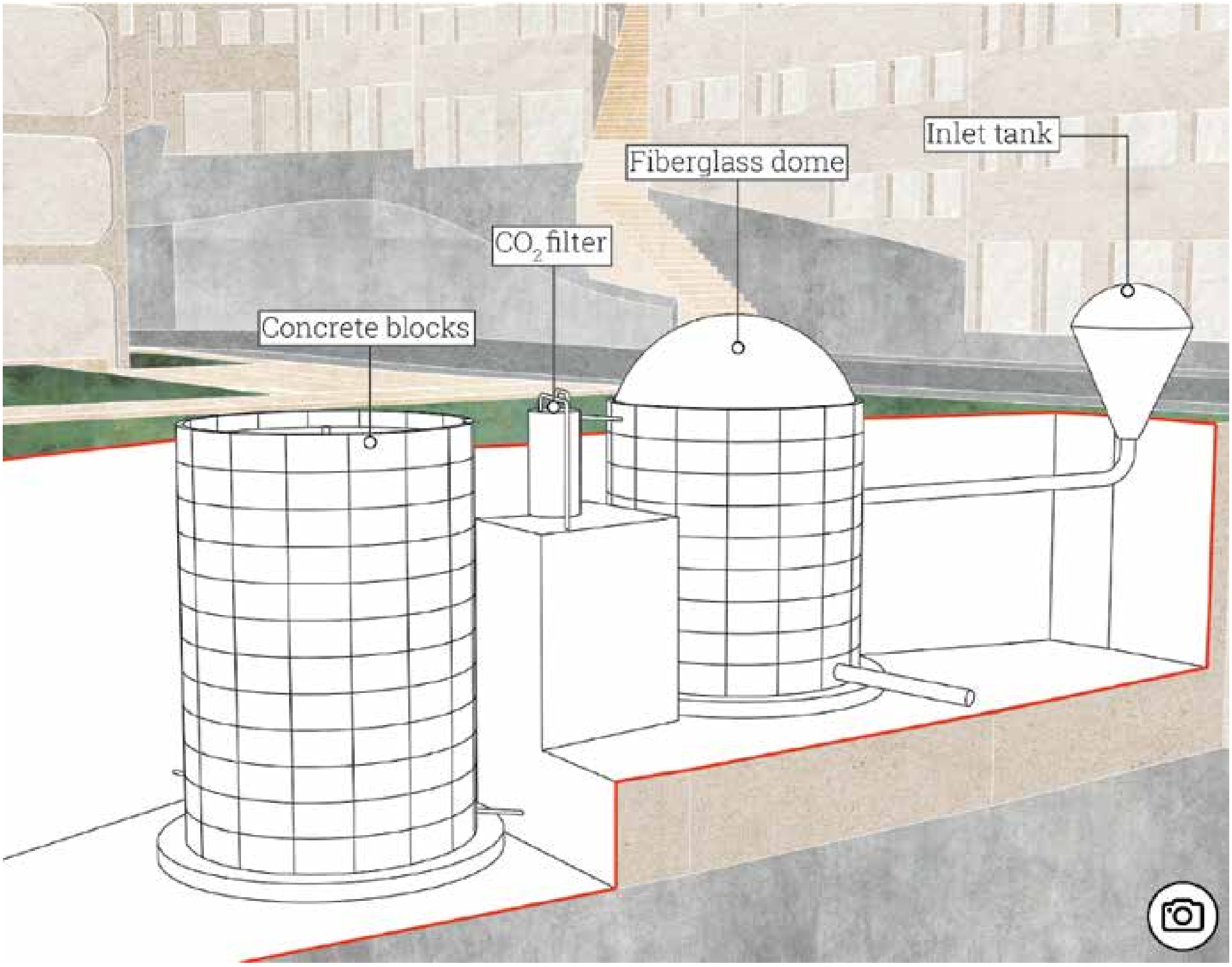


Figure 3.5.29 Biogas plant

Figure 4.1 Night view of Rocinha. Source: www.pictorem.com

4 MASTERPLAN & RETROFITTING

The tortuous paths snaking through the bowels of Rocinha makes reaching the highest parts of the favela a challenge even for its inhabitants. The necessity of new, improved connections has been underscored in the previous urban analysis is, therefore, the main aim of the intervention presented in the next chapter.

At the same time, the pilot projects analysed in the previous chapter will also be included here, presented as the interconnected system they were intended to be, alongside the peculiarities and rationales of the urban intervention proper.

Further, the final phase of the IMM analysis (retrofitting) occupies the last section of this chapter, translating the intervention into numerical values to be compared to those obtained by the initial survey, in order to make the improvements manifest.

Lastly, comes the Masterplan of the architectural project, which serves as an introduction to the final chapter.

4. MASTERPLAN AND RETROFITTING

4.1 Vision and methodology

4.1.1 Introduction

Thanks to the IMM analysis previously conducted, it was possible to highlight the main tracts of the area focus of the project. Unlike the others areas selected, Area 1 has the peculiarity to cross most of the favela longitudinally, thus providing a vision that, also if limited to a single portion of Rocinha, enclose all the possible urban configurations existing in the favela itself. Starting from a first zone (zone 1), located in the lowest part of the area and characterized by the main connections and functions, it is possible to move to an high urbanised and residential part of the site (zone 2) that gradually thin out, following the slope of the land, to the last third (zone 3), sparsely populated and lacking of relevant functions.

The purpose of the intervention analysed in the following chapter is to redevelop, both from an urban, architectural and energetic point of view, the site focus of the project. In order to do so the course of logic will be to summarise the main problems and opportunities of the area and their possible solutions, to evaluate the placement of the pilot projects previously described inside the site and finally to evaluate the real impact of the applied changes thank to the retrofitting phase of IMM analysis.

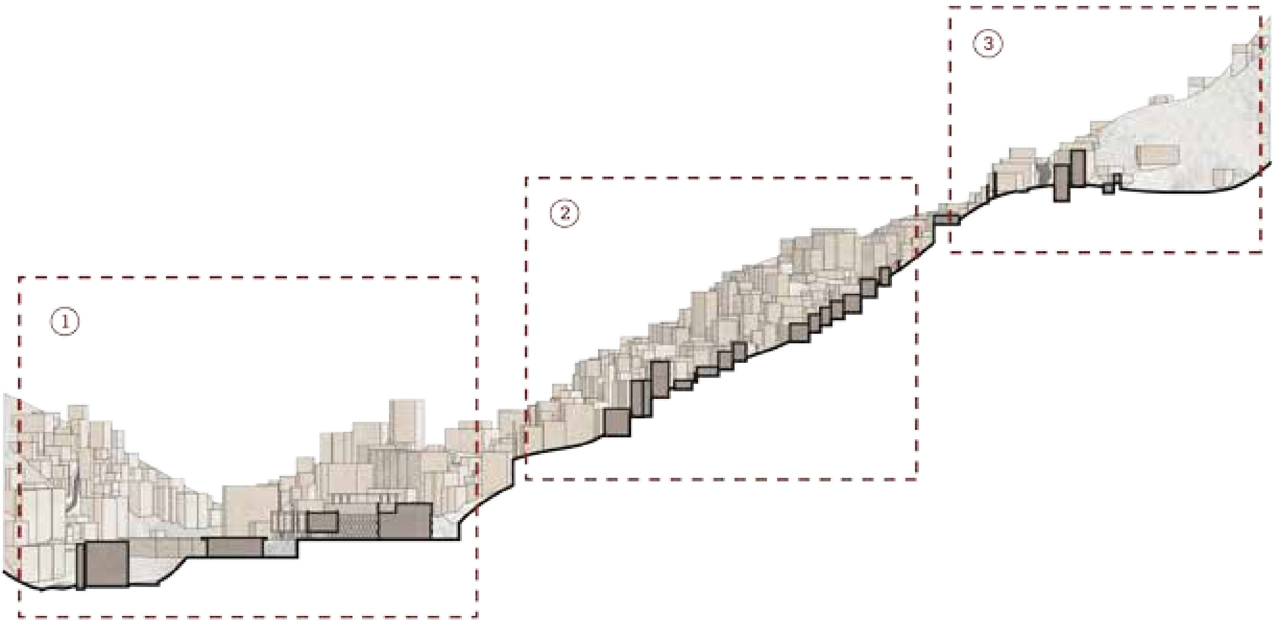


Figure 4.1.1 Section of intervention Area 1

4.1.2 Main problems and opportunities

As previously shown in the IMM analysis, the intervention area 1 displays the following main issues:

The most glaring is the terrain steep. The site in fact has a a significant difference in height between Villa Verde (129.85 m) and Rua Dionéia (257.55 m at its endpoint), over a relatively short distance (around 200 m), which makes Area 1 one of the steepest in the favela, with a slope rate averaging 70%.

This affects also the connections from and to the area. On the one hand the coexistence of two principals roads (Vila Verde and Rua Dioneia), disposed respectively at the top and bottom of the Area, constitute an important benefit for the accessibility to the site, on the other, the rough morphology and the extreme urban density don't allowed a direct way of communication between them. The residents of the area are so forced to use the "Becos", those in some cases has a steep of 60%, in order to reach the main communication routs with the parts of the favela richer of functions.

Functions are indeed another issue of the area. Most of Area 1 presents a densely built urban environment, interrupted only by the major roads mentioned above, as is the case in most of Rocinha, with only the bottom of the area possessing some open spaces. This discontinuity in the otherwise choked urban fabric has been created two massive buildings: the Emergency Care Unit of Rocinha (UPA: Unidade de Pronto Atendimento) and the school "CIEP Doutor Bento Rubião"; by the end of 2018, a third building has been added between these two: a two-storey gas depot owned by "Waldemar Agua e Gas". Despite of these, housing functions important not only to Area, but to the favela as a whole, there is a significant imbalance between residential buildings and secondary functions typical of a high-populated site as the one analysed, 3xcept for few shops and restaurant. Specifically, the disposition of the three building before mentioned, a gas storey between a school ad a hospital, is also not sustainable, especially from a security point of view.

4.1.3 Goals

The knowledge result of the previous considerations helped to formulate answers to those problems considered the most significant in the site.

From an urban point of view, the first goal is to create an adequate connection between Vila Verde and Rua Dioneia in order to increase the secondary connections and guarantee a proper slope during the transit. This intervention will affect the residents in different levels. If it will not be a huge change for the ones who lives in the lower part of the site, already located near the two main roads, it will be increasingly important for the ones in the upper part, forced to a high dispersive itinerary to reach the same connections with the rest of Rocinha and finally to the ones located in the middle of the area, used to have the "becos" as only way of transit.

The second goal is to renovate the area at the base of the site. From an architectural prospective, this will be done by converting the already existing buildings with new functions and by increasing the practicability, from an energetic prospective, by applying to the area the pilot projects already discussed in chapter 3. Area 1 is indeed the only of all the ones selected in Rocinha that allows the simultaneous application of all the pilot projects. This fact offer an excellent sample, even if on local scale, of the possible improvements applicable on the whole favela. These results will be possible thanks to the retrofitting phase of Imm analysis, conducted at the end of the intervention.

The actions both will also have the function of increase the drainage of the soil, creating a connection pattern of green spaces and specific technologies applied to the ground.

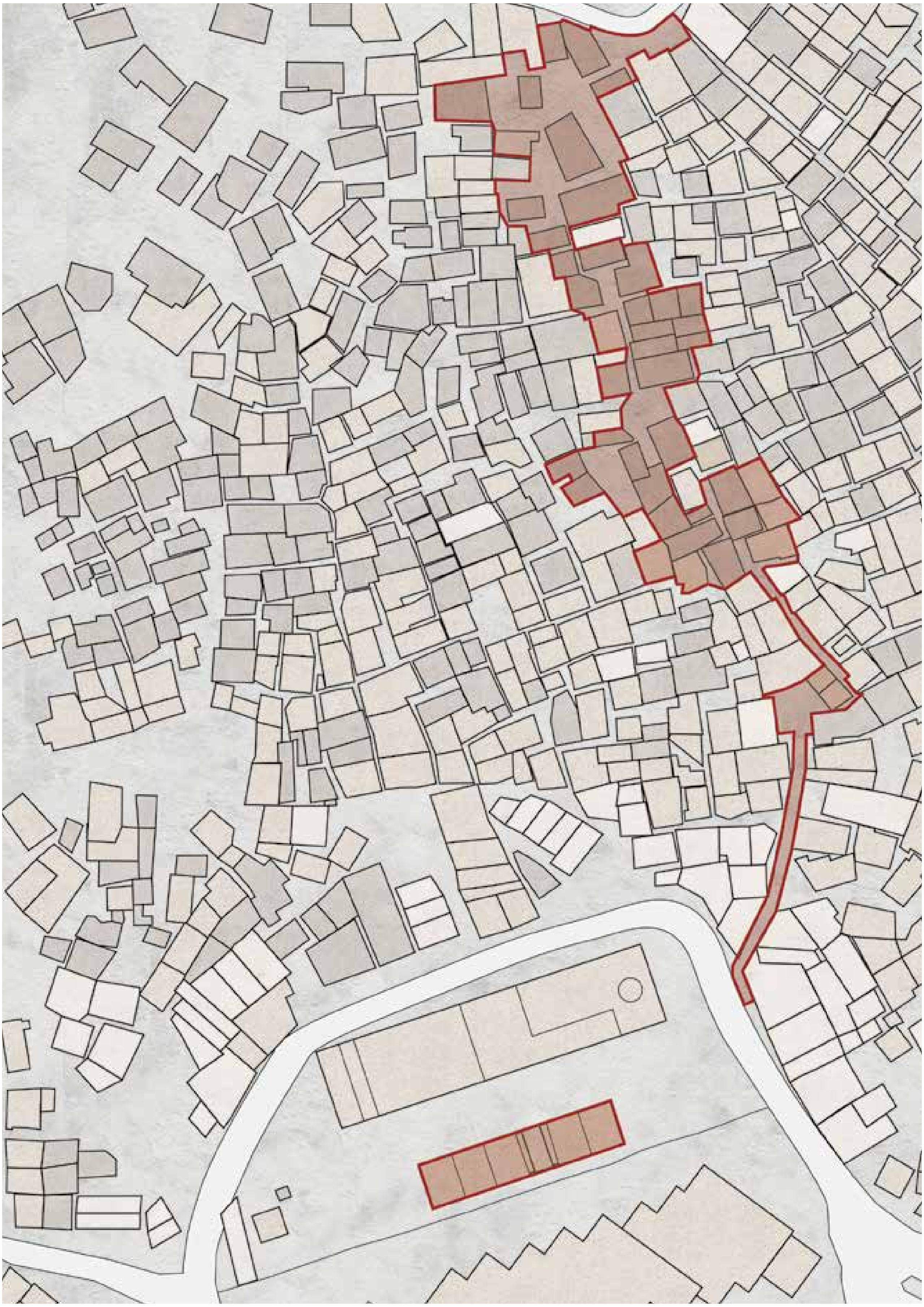


Figure 4.1.2 Actual situation of intervention Area 1

4.1.4 Intervention principles

The opportunity of a direct inspection of Rocinha, combined with the research work done by our colleagues during the previous years and with the interviews to important stakeholders inside the community, allowed to frame the complex balance of the favela whole and to understand the inhabitants' direction of thought.

It appears clear that the respect of demands and of the social context is an essential factor in order to develop an effective design planning. In one hand indeed, Rocinha shows all the problems generated from a poor if not absent urban planning, on the other hand tho inhabitants feeling of belonging to the environment in which they live is very strong. They are more incline so to accept not aggressive changes inside the architectural and urban context. They would feel in fact a different approach like imposed from parties outside the community in order to force itself on the already existing urban environment that even if poor and chaotic, is the outcome of their work and inheritance.

The analysis of previous case studies supports this thesis and highlight an interesting detail: as much as the identification of the problems inside the favela is done correctly, the mode of resolution results inadequate and and characterized by a benighted approach toward such a complex context. The interventions hypnotized born from the right assumption to increase the residential and functional capacity of the site. In order to reach this goal though, they involve massive demolitions of already existing buildings. This fact not only generates discomfort to the population but it usually has a result opposite to the one hypnotized, creating buildings detached from the surrounding environment that population does not use.

The reflection on these issues led to the definition of the guidelines applied to the intervention and the creation of the pilot projects themselves. The changes made in the intervention area 1 will follow a minimally invasive approach on the residential buildings already present on the site. The intervention must also be respectful of the context in terms of both geometry and the type of spaces and functions, ensuring an overall improvement but avoiding distorting the balances already present in the site. The pilot projects, where possible, have been designed so that they can be assembled by the population itself, taking up the philosophy that led to the creation of the favela itself.

For ease of exposure, the urban intervention and redevelopment of the area at the base of the lot will be analyzed separately in the following pages.

4.2 Urban intervention

4.2.1 Introduction

The first intervention analyzed is the urban transformation of the site. As previously explained, the surface of the intervention area is mostly occupied by a dense building texture. The need to connect the two main roads, Rua da Gavea and Strada Dioneia, led to the planning of a route that will cross the entire area longitudinally and replace the original Becos, in order to provide an easier path for the population. Given the considerable steepness of the land, since it was impossible to create a direct connection between the two roads, it was decided to build a route that will combine a system of stairway and terraces. These two systems, combined with the pilot projects of sewerage and food, guarantee a path that in addition to the pure aesthetic and transitory value, goes to increase the drainage and the edible production of the whole area.

4.2.2 Intervention phases

4.2.2.1 Process and cryteria

The current situation of the area is characterized by a building curtain that does not allow easy passages to the inhabitants. In order to create thepath item of the project, it was necessary to relocate some existing buildings inside the site. In armony with the principle of minimum enviroment impact set at the start, the intervention was organized according to the following phases:

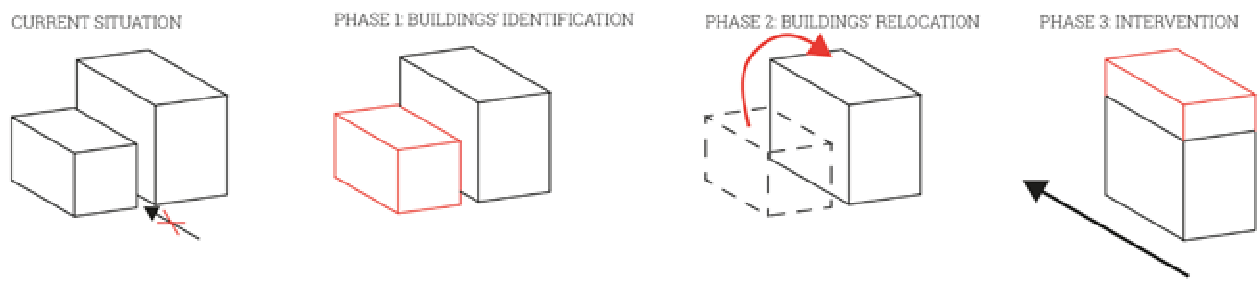


Figure 4.2.1 Intervention phases' scheme

Phase 1: Buildings identification.

In order to create as less disconfort as possible to the population along the route, the criteria about the coiche of the buildings to relocate was conducted starting from selection of buildings of maximum three storeys of elevation, in order to limit the impact of demolitions.

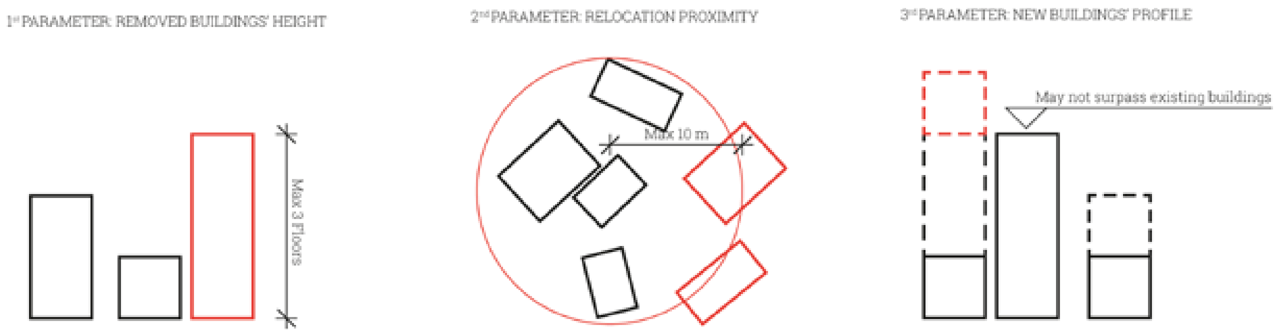


Figure 4.2.2 Buildings' relocation parametres

Phase 2 : Buildings relocation.

The second criteria is to avoid the waste of habitable volume, relocating the buildings previously domolished in a maximum radius of 10 meters from the original localization. This choice also affects the owners of the relocated buildings, who are not in this way forced to move away from an environment familiar to them.

The third parameter is to increase, thanks to the relocation, the planar surfaces of roof level, which allows the use of solar panels or the creation of green roofs. In fact, given the large number of inhabitants and the scarcity of living space, the tendency of the favela is to develop in height. This phenomena, combined with the often inpervious topographical conditions, leads to the creation of an irregular urban grid in height and to the segregation of buildings of lesser height.

It is important to highlight that this process will also affect the building located at the base of the site, currently used as gas storage, thanks to the increase in its size by two units. The intervention in question will be described in more detail in the next chapter.

Phase 3: Intervention.

Thanks to the relocation of the buildings described in the previous paragraph, it is possible to create a transit corridor that connects Rua dioneia and Vila Verde. Due to the steep slope of the land, which in some places reach peaks of 60%, a direct connection between the roads is impossible. It was therefore decided for the construction of a series of ramps and terraces in order to reach accessible slopes. This approach also provides to take full advantage of the gained space. This thanks to the creation of green rest areas, which have both a social function, beeing a meeting place for the residents of the area, and a drainage function for the soil. Furthermore , the project foresee the creation of cultivations of fruit trees on the terraces.

The steps of the ramp will also be covered by the draining panels previously described in the pilot projects chapter. This technology will be also used serve as a point of continuity between the urban intervention and the one of the area located in the lower part of the site, described in detail below.

The following images show the steps of the process applied on the site.

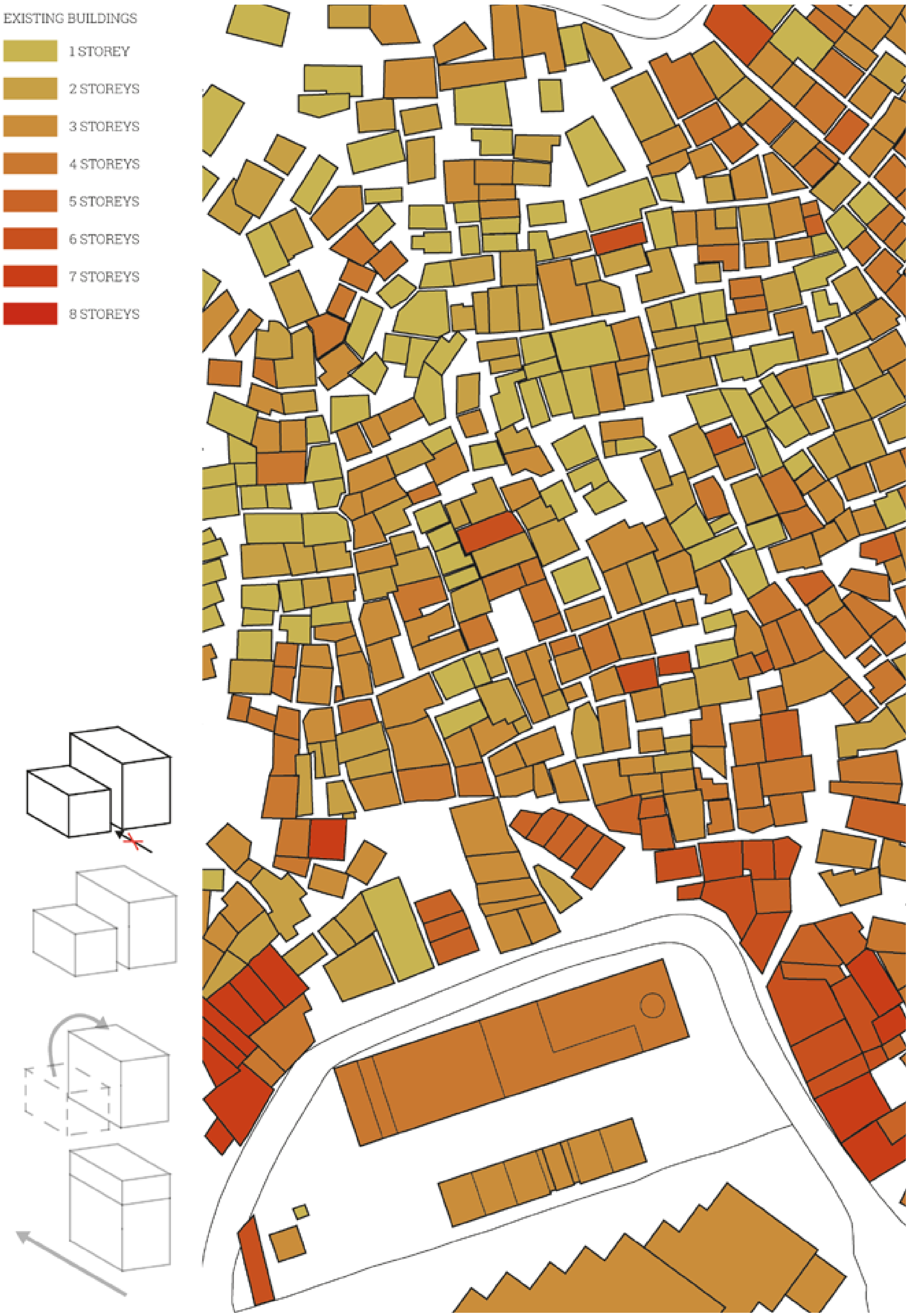


Figure 4.2.3 Map of Area 1.

4.2.2.2 Data analysis phase 1

The following table shows the results obtained from the calculation of the total surface of the buildings selected for removal during the construnction of the intervention:

REMOVED BUILDINGS			
Number	Floor Srf. [m^2]	Storeys	Srf. Tot. [m^2]
1	70.74	6	424,44
2	36.00	3	108.00
3	6.13	1	6.13
4	25.00	4	100.00
5	19.86	4	79.44
6	54.96	1	54.96
7	57.48	3	172.44
8	54.45	1	54.45
9	37.37	1	37.37
10	49.07	1	49.07
11	12.48	1	12.48
12	59.29	2	118.58
13	51.93	2	103.86
14	30.91	2	61.82
15	22.53	1	22.53
16	71.67	2	143.34
17	35.98	2	71.96
18	30.19	2	60.38
19	29.40	2	58.80
20	43.57	2	87.14
21	26.91	2	53.82
22	33.42	2	66.84
23	34.19	1	34.19
24	94.32	1	94.32
25	30.12	1	30.12
26	26.41	2	52.82
27	31.09	2	62.18
Initial habitable surface		2,221. 48 m^2	
Initial open surface		1,341.10 m^2	

Tab 4.2.1 Data analysis phase 1

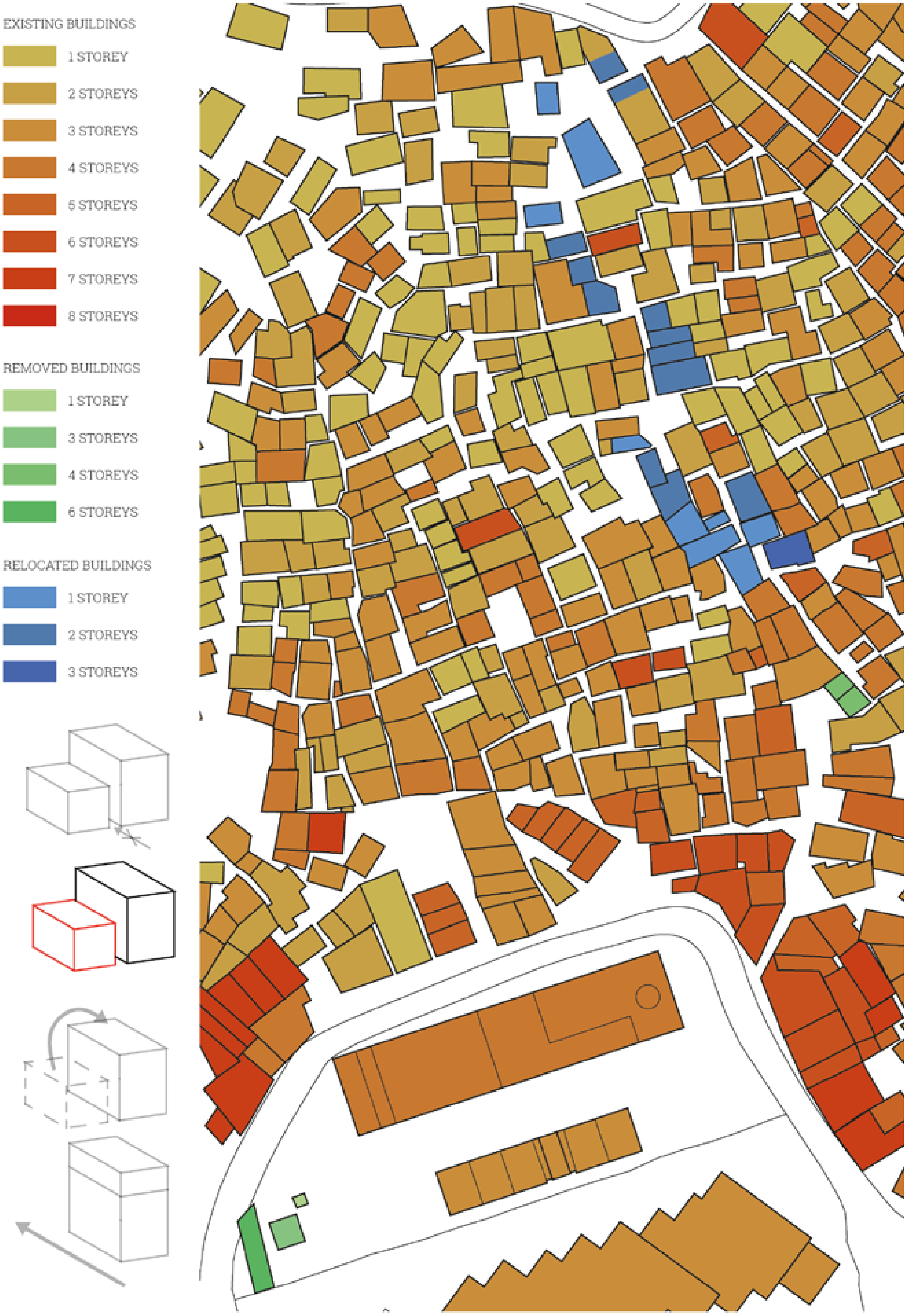


Figure 4.2.4 Map of phase 1: buildings identification

4.2.2.3 Data analysis phase 2

The following table shows the results obtained from the calculation of the total surface of the buildings selected for the relocation during the construction of the intervention:

RELOCATED BUILDINGS			
Number	Floor Srf. [m²]	Storeys	Srf. Tot. [m²]
1	51.35	2	102.70
2	45.25	2	90.50
3	38.20	2	76.40
4	54.36	2	108.72
5	32.50	1	32.50
6	33.83	1	33.83
7	66.70	1	66.70
8	38.71	2	77.42
9	41.54	2	83.08
10	49.00	2	98.00
11	20.54	1	20.54
12	26.93	2	53.86
13	36.02	2	72.04
14	31.44	2	62.88
15	71.90	2	143.80
16	43.27	2	86.54
17	104.87	1	104.87
18	37.73	1	37.73
19	92.92	1	92.92
20	38.45	2	76.90
21	34.52	2	69.04
Habitable Srf. [m²]		1,590.97	
Habitable Srf. [m²]		1,590.97	

REFURBISHED WALDEMAR DEPOT			
Number	Floor Srf. [m²]	Storeys	Srf. Tot. [m²]
Single	40.25	4	161.00
Double	80.50	8	644.00
Triple	78.40	4	313.60
Habitable Srf. [m²]		1,118.60	

Final Habitable Srf. [m²]	2,709.57
Final Open Srf. [m²]	2,267.7

Tab 4.2.2 Data analysis phase 2

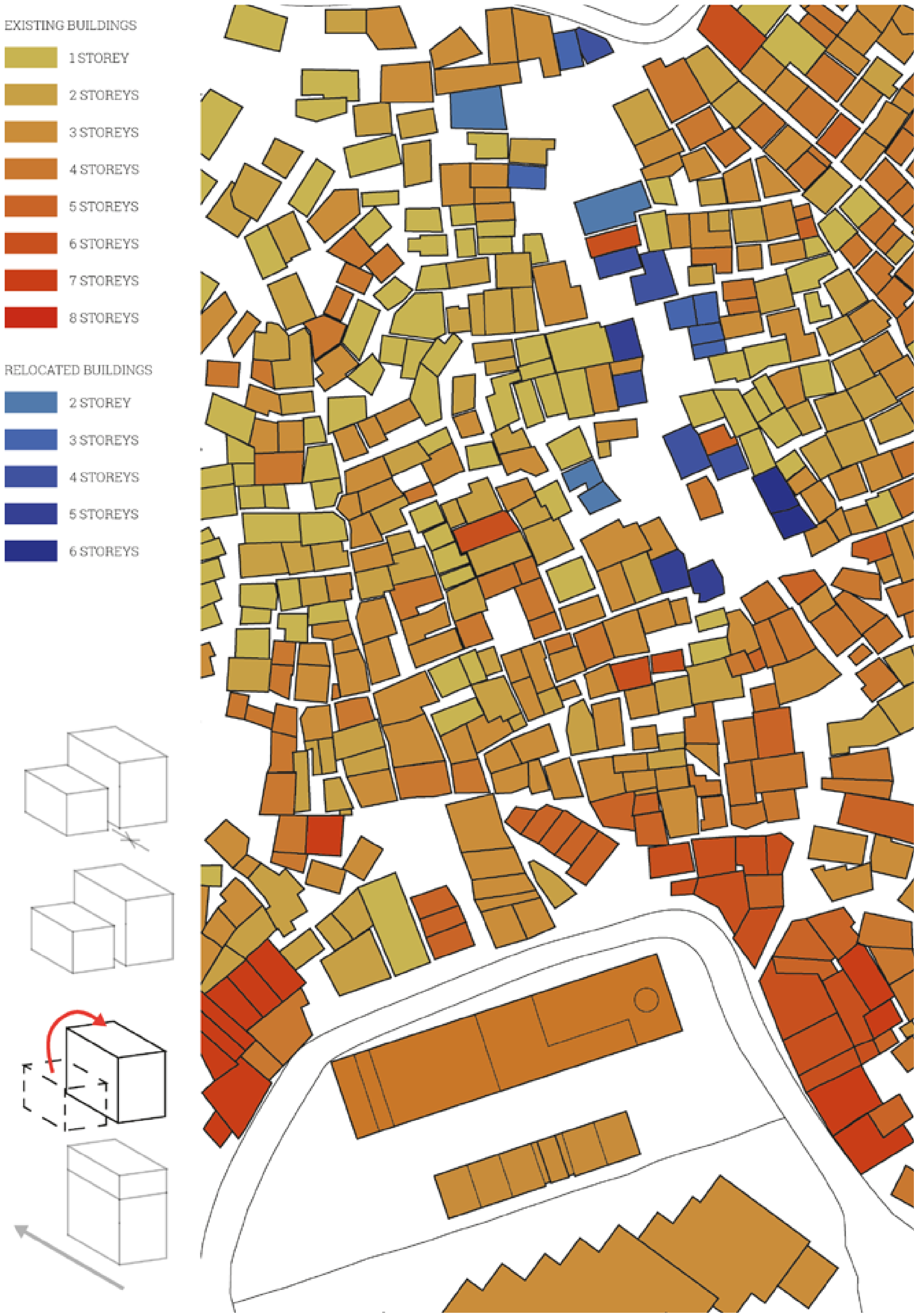


Figure 4.2.5 Map of phase 2: buidings relocation

4.2.2.4 Conclusion

Comparing the results previously obtained it was possible to evaluate the variation of the parameters useful for the purpose of the project. Regarding the habitable surface, the calculations show that not only was it possible to recover the surface lost during the demolition phase, but it was possible to increase it by 18%, with an increment of 1120 m^2.

Another interesting parameter is the open surface, which thanks to the opening given by the walkway is increased by more than 40%, going from 1341 m^2 to 2267 m^2. It is furthermore estimated that the green areas reache to 77% Of this total, , reaching the drainage characteristics required by the project and previously described in chapter 3.

ANALYSIS' RESULT COMPARISON		
Tot Habitable Srf. [m^2]		Increase percentage
Pre-intervention	2,221.48	18%
Post-intervention	2,709.57	
Tot open Srf. [m^2]		Increase percentage
Pre-intervention	1,341.10 m^2	40.86%
Post-intervention	2,267.7 m^2	

Figure 4.2.3 Tab analysis results' comparison

Figure 4.2.6 Analysis' result comparison.

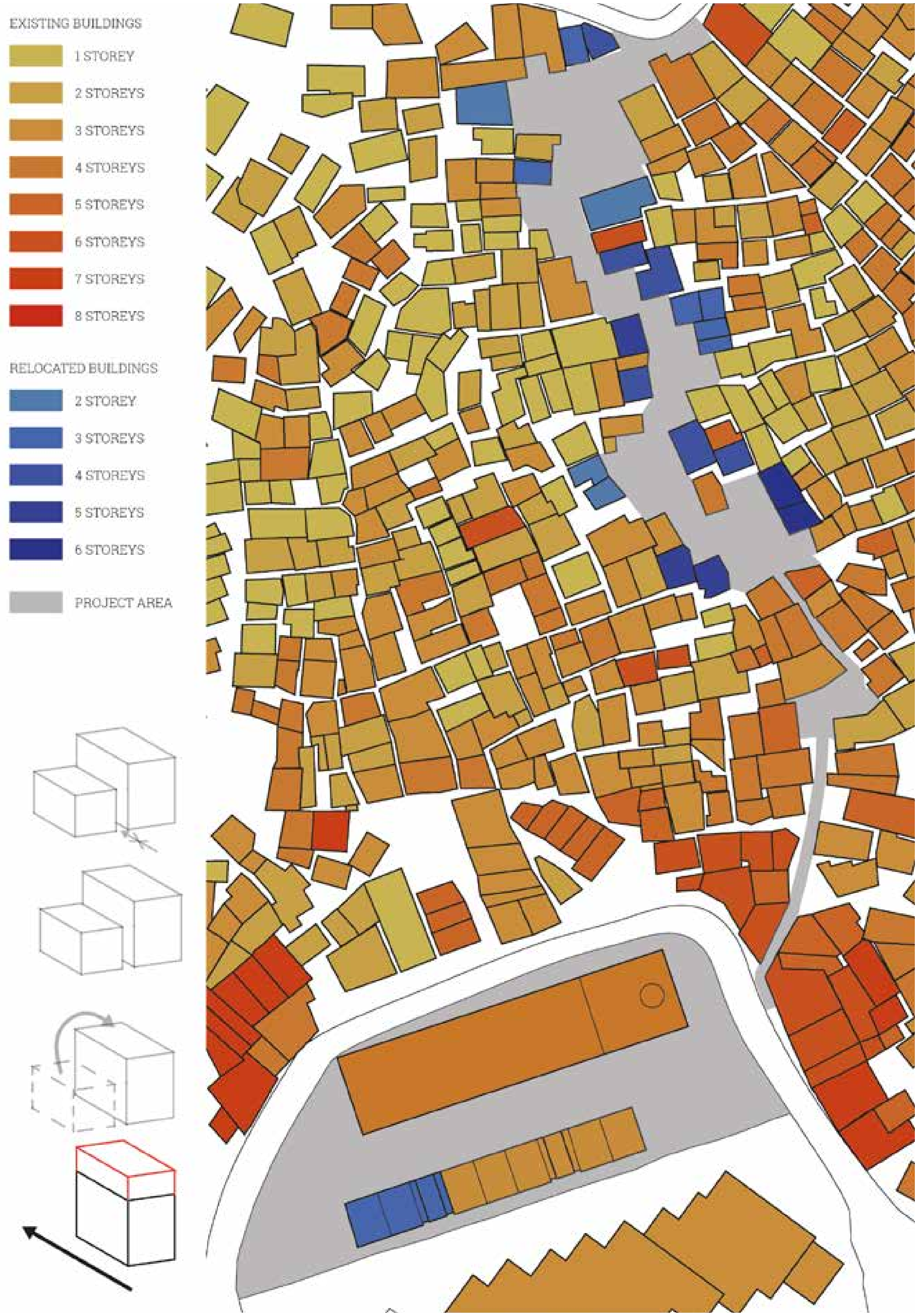


Figure 4.2.7 Map of phase 3: intervention

4.2.3 Intervention functions

4.2.3.1 Sewerage

Rocinha curret sewage system cannot be considered adequate for the favela's needs. Not only does it connect to a fraction of its households, but presents some sections in open air and it's often susceptible to flooding, as these canals are frequently choked by waste improperly disposed of. The area in which the new walkaway connecting Villa Verde to Rua Dionédia will be built, is the perfect opportunity to lay down a new sewerage, connected to and enhancing the existing one, to ameliorate the neighbourhood sanitary condition and waste disposal capabilities.

Figure 4.2.8 Example of sewarage in Rocinha, source: https://www.flickr.com.

4.2.3.2 Drainage

Rocinha arguably posses one of the most densely built urban environment in the world that, combined with its geomorphological characteristics (a bowl-shaped valley with rocky terrain and high slopes) and Brazil's climate, makes flooding an everyday occurance. Thus, it becomes imperative to enhance soil retention in the area. This will be accomplished by building numerous terraces along the walkway, both planted and paved.

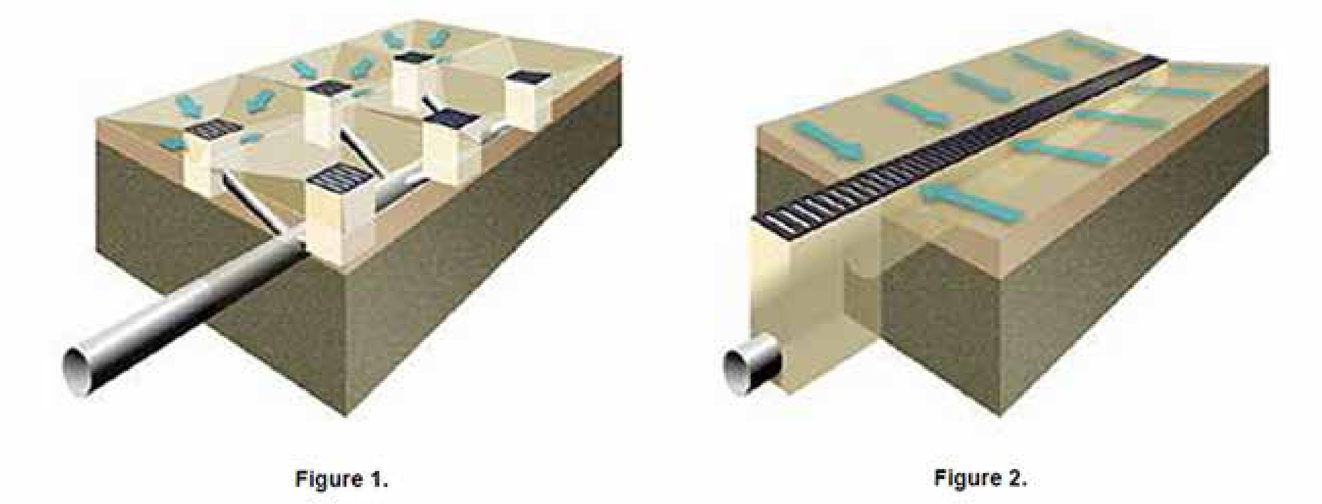


Figure 4.2.9 Drainage system comparison, source: https://www.slotdrainsystems.com.

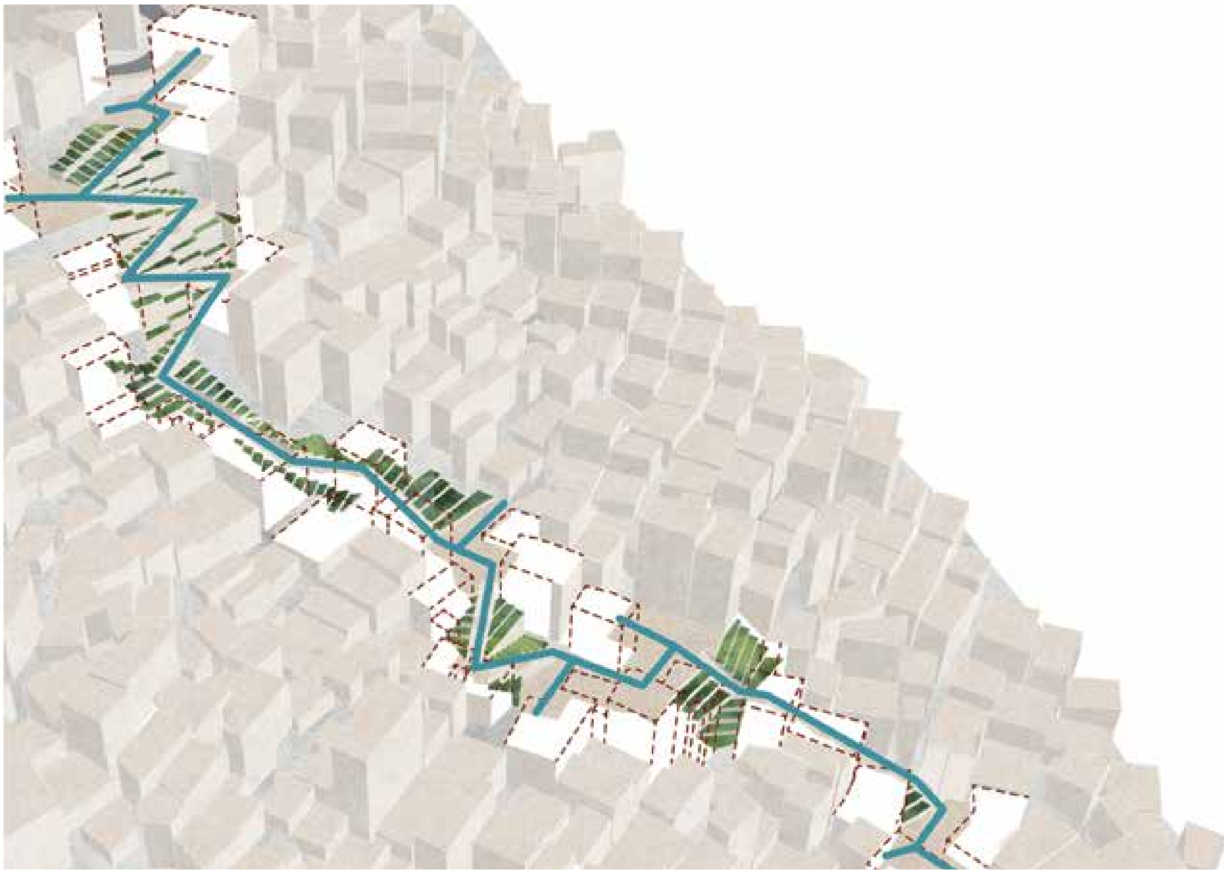


Figure 4.2.10 Urban intervention sewarage map.

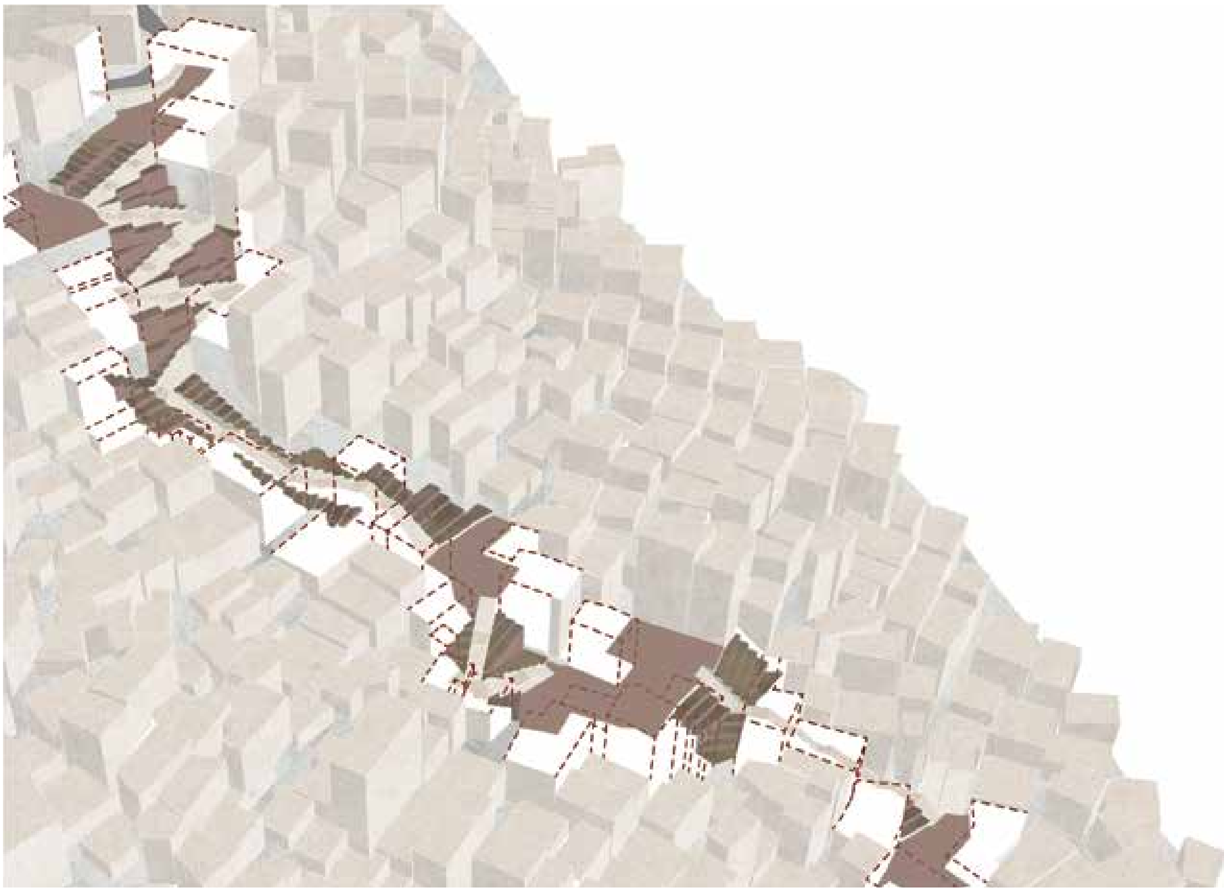


Figure 4.2.11 Urban intervention drainage map.

4.2.3.3 Food

In Portuguese, Rocinha means “little farm”, as its inhabitants used to posses their own vegetable plot. Moreover, it has been shown that, inside the favela, empty spaces with no function will soon be utilized in some fashion. Consequently, the green terraces will not only be used for water drainage, but also as communal gardens for fruit trees. Four type of trees will be planted (apple, banana, mango and maracuja), as those can best provied an year-long harvest.

Figure 4.2.12 A girl selling fruit in Rocinha, Pablo Munini, 2013.

4.2.3.4 Walkability

Rocinha is hardly a pedestrian-friendly environment, the few roads that cross the favela are choked by cars, though most households can be reached only by foot, through narrow and steep alleys. While a slow mobility program using electric bikes will be implemented in the whole favela, it remains important to create better connections for pedestrians inside the neighbourhoods. In the area, this resulted in a walkway connecting Villa Verde with Rua Dionéia.

Figure 4.2.13 Details of Rocinha lanes, Kids of Rocinha, Aurelien Ersnt, 2017.

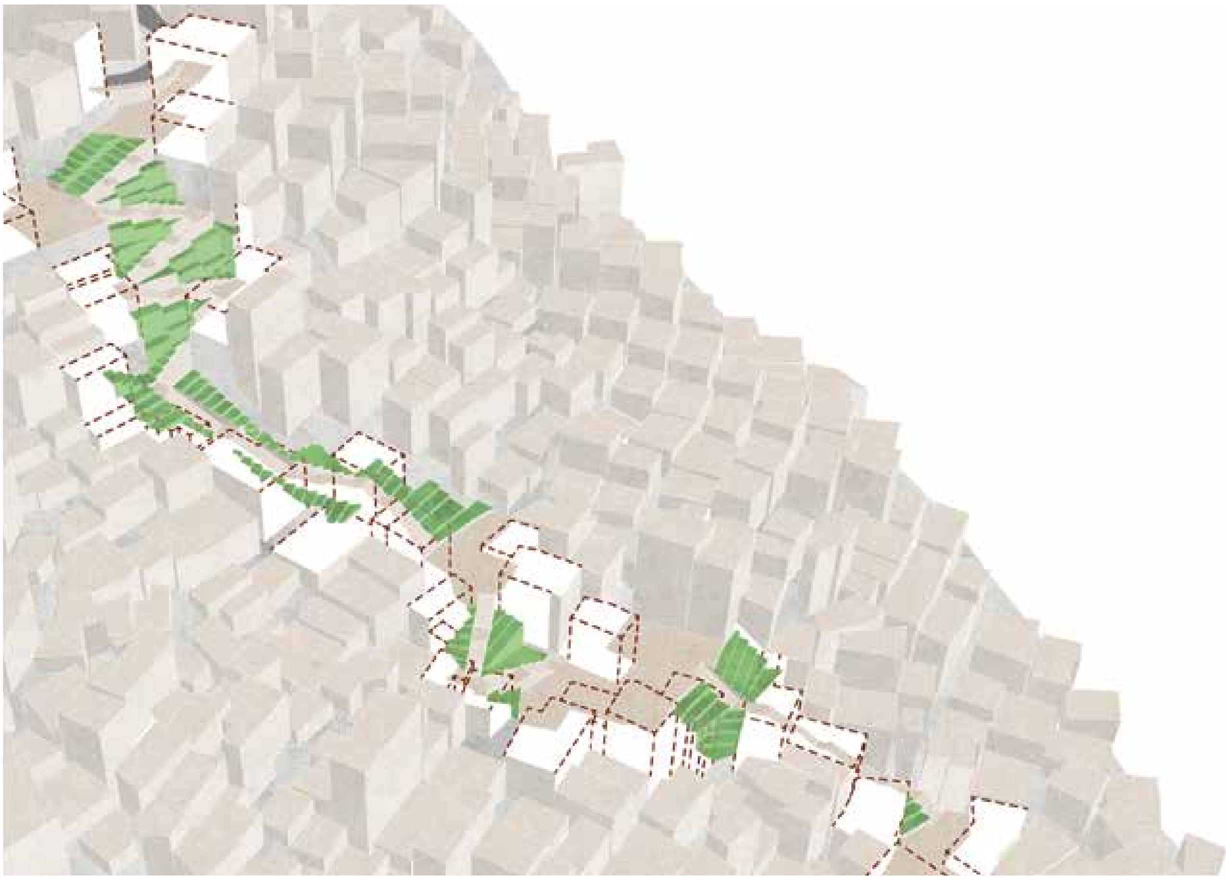


Figure 4.2.14 Urban intervention cultivations map

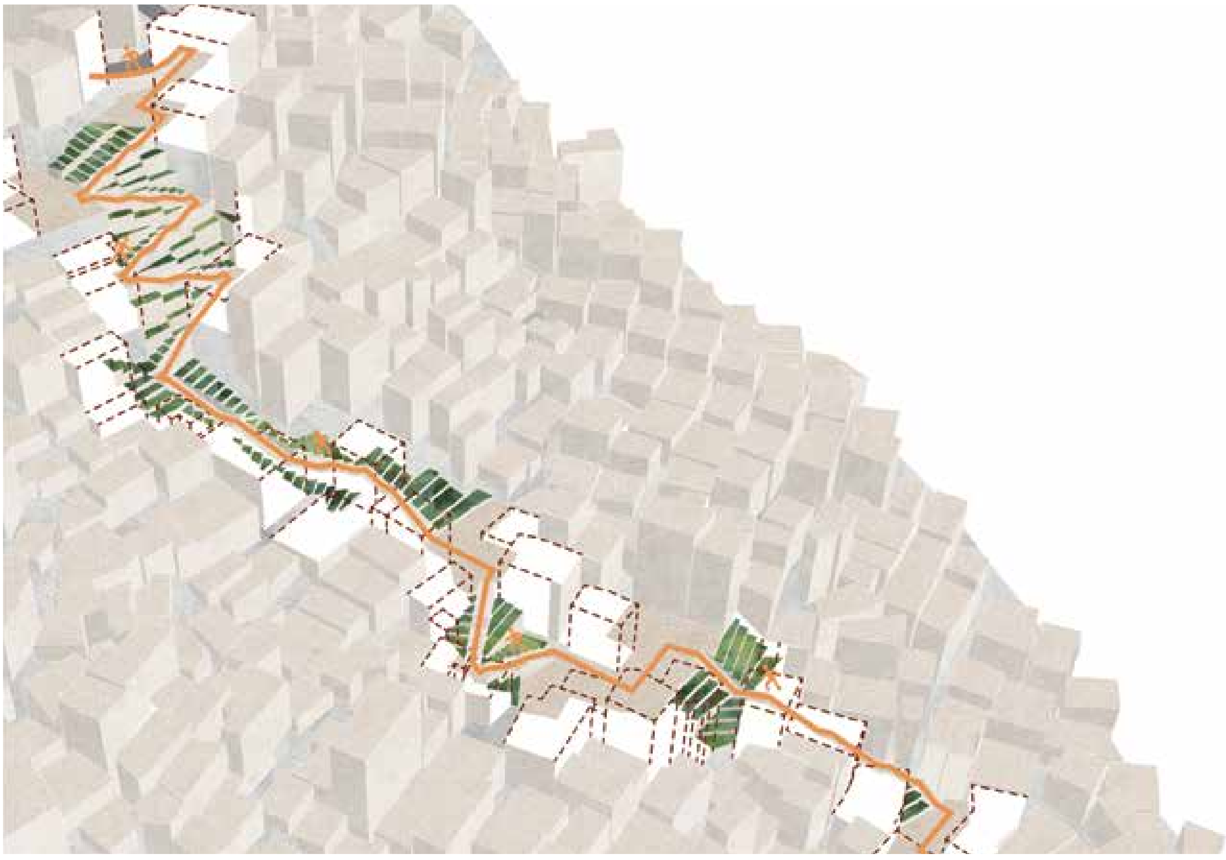


Figure 4.2.15 Urban intervention walkability map

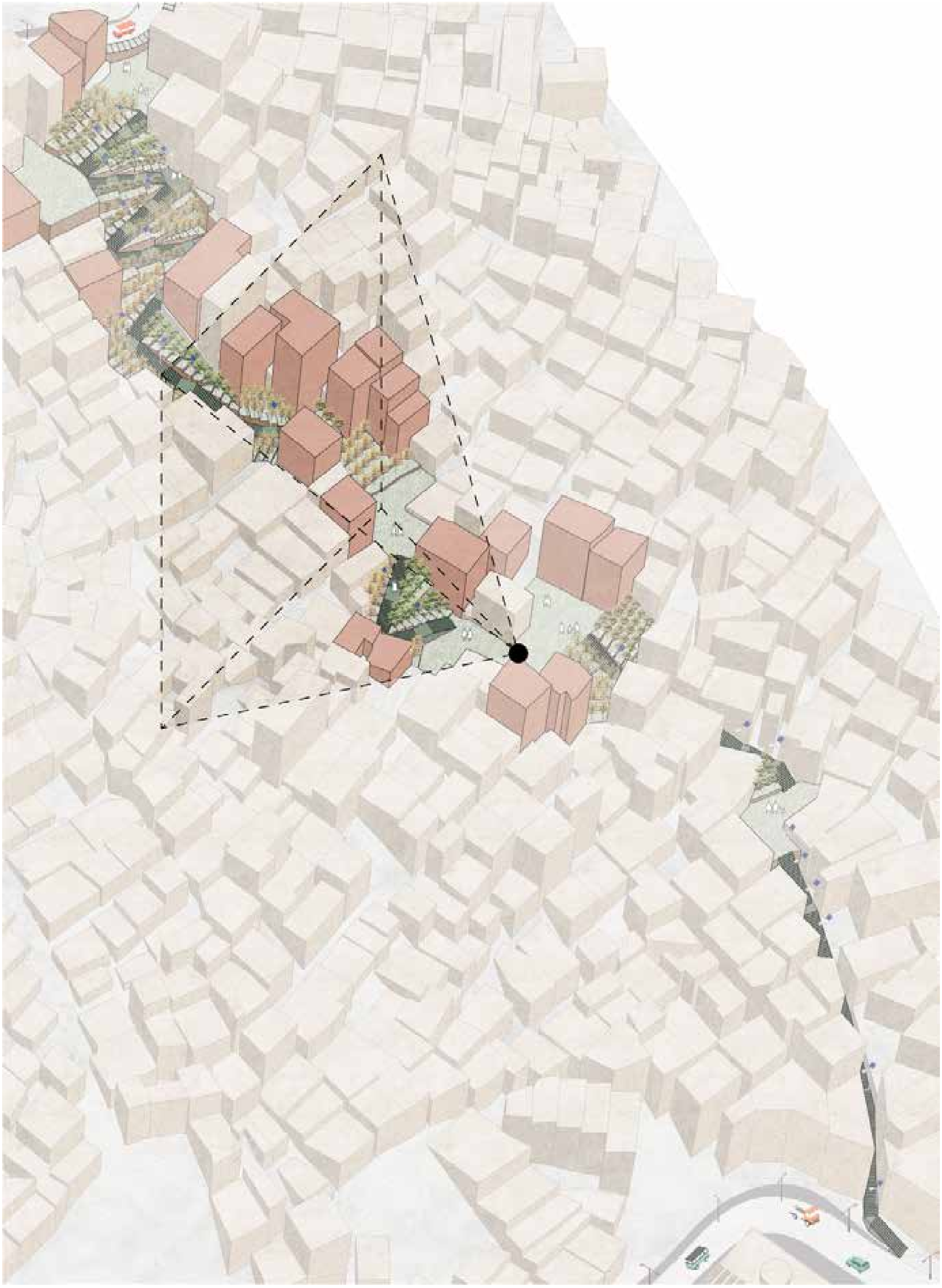


Figure 4.2.16 Urban intervention 3D view

Figure 4.2.17 View of the intervention.

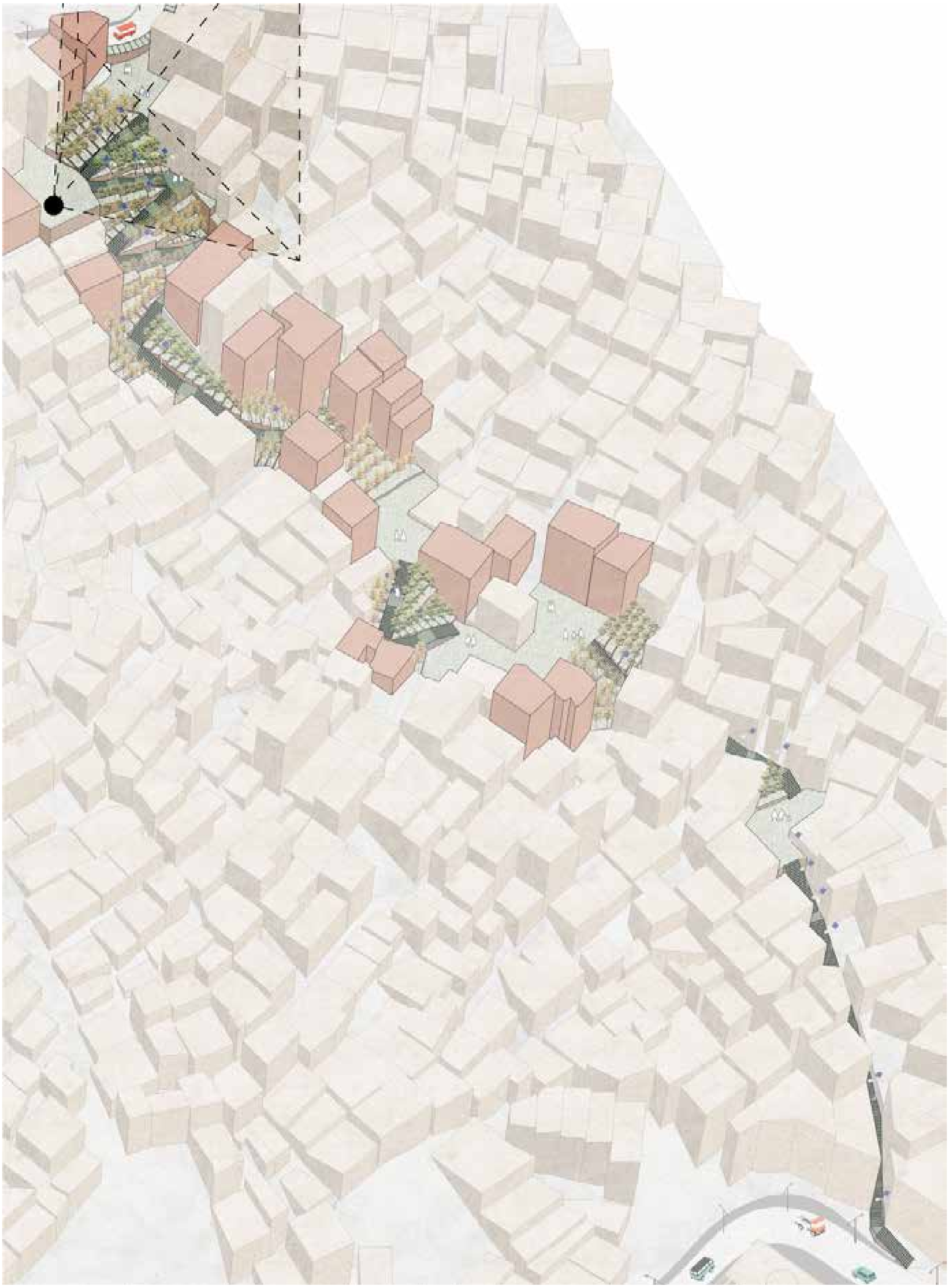


Figure 4.2.18 Urban intervention 3D view

Figure 4.2.19 View of the intervention.

4.3 Refurbishment intervention

4.3.1 Introduction

The following pages describe the intervention made in the lower part of the site. It is interesting to point out how different, if not even opposite, the charactericts of this area and the one subject of the urban intervention previously described are. While in the second there is a built situation of high density and an approach of controlled demolition and relocation of the buildings, the area here analysed occupy a large surface of nearly 4600 m^2 in which most of the space is free. While keeping the same prynciples before explained and goals, the way of intervention will be significantly different. The intervention will renovate the site from an urban and architectural poit of view focusing on the refurbishment of the actual Waldemart gas depot building.

Another important point is the application of the remain pilot projects. Combined with the ones already located in the urban intervention, they offer a clar example of the benefit achievable on a local scale. Area 1 in fact is the only among the ones select that offer the opportunity to use all the pilot projects at the same time. This, moving from the local to the global scale and following the smart grid principle, is a fundamental part of the IMM retrofitting analysis conduct at first on the area subject of study and in a second time on the whole Rocinha.

4.3.2 Masterplan

As previously mentioned, the area in its actual state is mostly free of existing volumes. The only existing buildings are the Ciep Bento Rubiao school, which has a surface of 1225 m^2, and the Waldemart gas storage, 470 m^2. Since both buildings are in a good state of preservation and are still used regularly, it was decided not to demolish but to redevelop them.

As regards the school, the intervention will focus on the roof area, which is not currently used. Here will be located play areas, in order to replace those used nowdays, located ouside the building, with a more protected environment, away from the busy roads those connect the area to the center. The intervention will also provide the creation of educational spaces used by all the classes of the school and the installation of solar panels for an area of approximately 220 m^2. The gas depot will be converted into a residential complex, keeping the existing structure intact, as described in the following chapter.

Concerning the urban changes of the area, the intervention is a natural extension of the one operated in the residential part of the site. This continuity is given in part by the need and desire to create a pedestrian area away from traffic and easy to access and partly from the use of the same drenage technology on the floor. A passage is created between the two existing buildings, divided between green areas with mixed slopes and transit corridors. The green spaces will also have a social function, indeed in the parts of maximum slope, they will serve as seats overlooking the corridors. The alternation of these two kind of areas create a sense of square inside the site that can be used both by the people living in the new residences and by the inhabitants of Rocinha.

4.3.2.1 Pilot projects location

About the biogas plant, the most logic location was near the new residences. This position is useful both in terms of maintenance, being close to Estrada da Gavèa and so easily reachable, both in terms of use, it will infact produce the energy necessary for the functioning of the public canteen located at the ground floor of the building.

On the left part of the area there are the bike sharing station and the water house, also close to Estrada da Gavèa and easy reachable. The botanical boxes and the aquaponic system, are instead located on the roof of the school and use with an educational purpose for the children.

Figure 4.3.1 Masterplan.

4.4 Retrofitting

4.4.1. Introduction

The effects of the urban intervention and the implementation of the pilot projects on Area 1 can be measured through the implementation of the final phase of the IMM analysis, the retrofitting phase. As mentioned previously, the retrofitting phase consists of repeating the same analyses of the investigation phase on the modified CAS (Complex Adaptive System), thereby translating the effects of the interventions planned for Area 1 into numerical values, which, in turn, can be compared to the ones obtained for the extant CAS. By design, the changes brought by this project are small-scale and aim to disturb the existing urban environment as little as possible, though they possess a great potential for replication and sustainability. Therefore, the improvements measured by the retrofitting phase are, while inevitably small, still noticeable.

4.4.2 Results and considerations

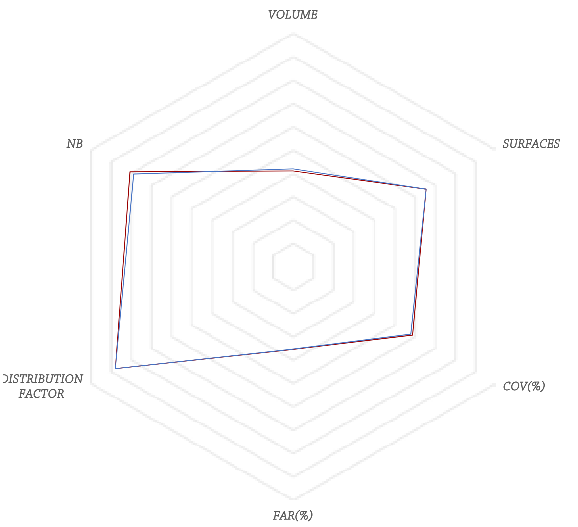


Figure 4.4.1 Porosity spectrum diagram.

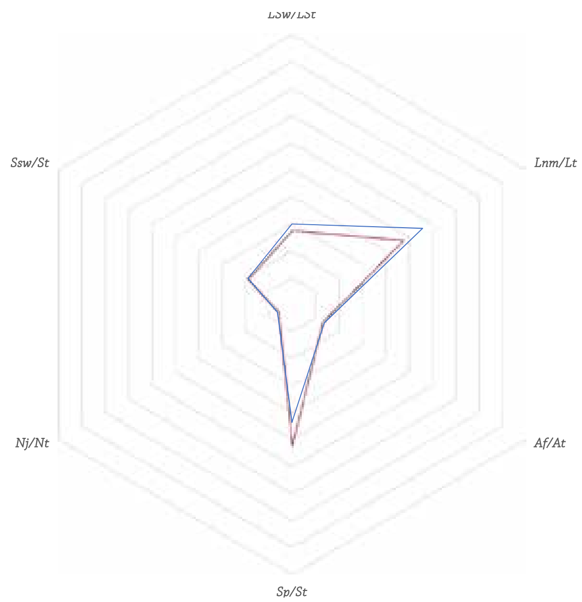


Figure 4.4.2 Proximity spectrum diagram.

As discussed while analysing the results of the investigation phase, the greatest changes come from the reduction (as slight as it is) of the urban density along the new pathway between Villa Verde and Rua Dionéia by removing a number of selected households. This intervention is followed by a marked increase of the accessible green areas that exist inside Area 1, which, for all intents and purposes, didn't exist before the intervention.

The changes listed above are most apparent in the Porosity, Proximity and Permeability graphs shown beside. The Porosity graph shows a reduction of almost 10% in paved streets (substituted by green areas) and the same increase in non-motorised paths length; the Proximity graph highlights a slight reduction in the number of buildings per hectare; and finally the Permeability graph reports an increase in 5% to the Directness and the same reduction in Constrictivity, though with an increase in Tortuosity.

The Interface and Effectiveness maps also help visualize the changes in the urban landscape, with the first making the two new paths cutting through the old street network very apparent, especially the improved connection between the school and the residential building linking the two halves of Villa Verde; while the second shows a marked increase and spread in its values, especially noticeable as the scale, which previously went up to 9, going up to 11.

On the flip side, the lower part of Area 1 remains the dominant attraction pole still, an enstablished fact that no improved connection between the two halves can change significantly, though it is reasonable to hypothesize that an easier access to Rua Dionéia may attract more activities on the

Figure 4.4.3 Permeability spectrum diagram.

upper part of Area 1, as evidenced by the slight improvement on the Effectiveness map, already mentioned above.

In fact, if anything, the urban isle surrounded by Villa Verde has increased its attraction force, as most pilot projects were concentrated therein, while the benefits of those that have been placed along the new route (the Sewerage and Drainage systems, specifically) are more difficult to quantify and visualise through the maps resulting from the retrofitting analysis.

On the other hand, the improvement of the lower part of Area 1 becomes especially evident by looking at the Transportation and Function maps, as a new bus and bicycle stops have been added to the former and a handful of new functions (the Biogas plant and the Water house among theme) to the latter.

Furthermore, these results should not be judged only on their own, but, by replicating the model represent by Area 1 throughout the entirety of Rocinha, these changes can improve the CAS parameters beyond the simple sum of their parts, and bring the favela closer to a sustainable urban environment, while bettering its inhabitants' lives.

Figure 4.4.4 IMM data connection in Rocinha, Source: IMMdesignlab.

Figure 4.4.5 IMM Retrofitting ,Volume-voids map of intervention area n°1.

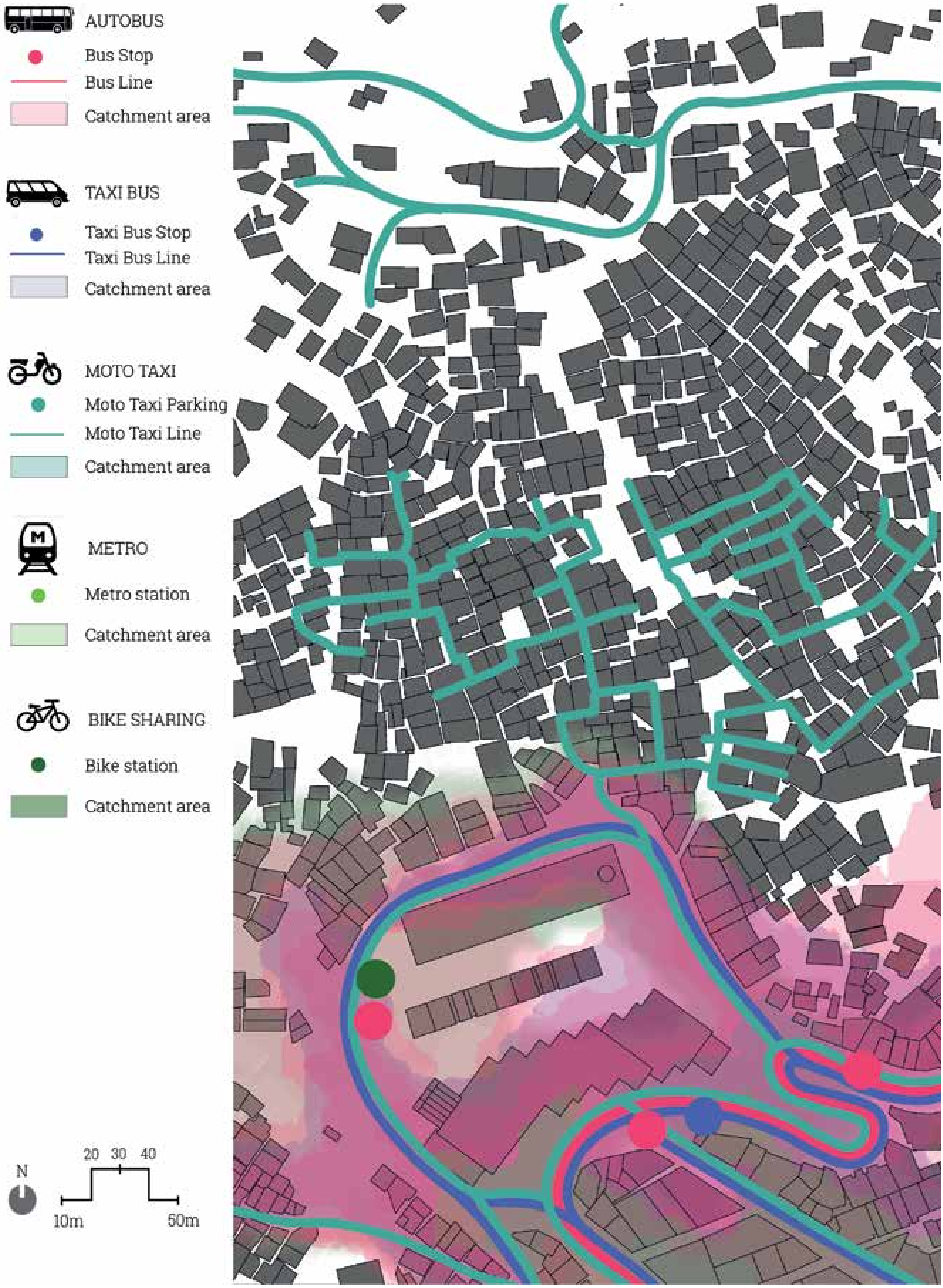


Figure 4.4.6 IMM Retrofitting Transportation map of intervention area n°1.

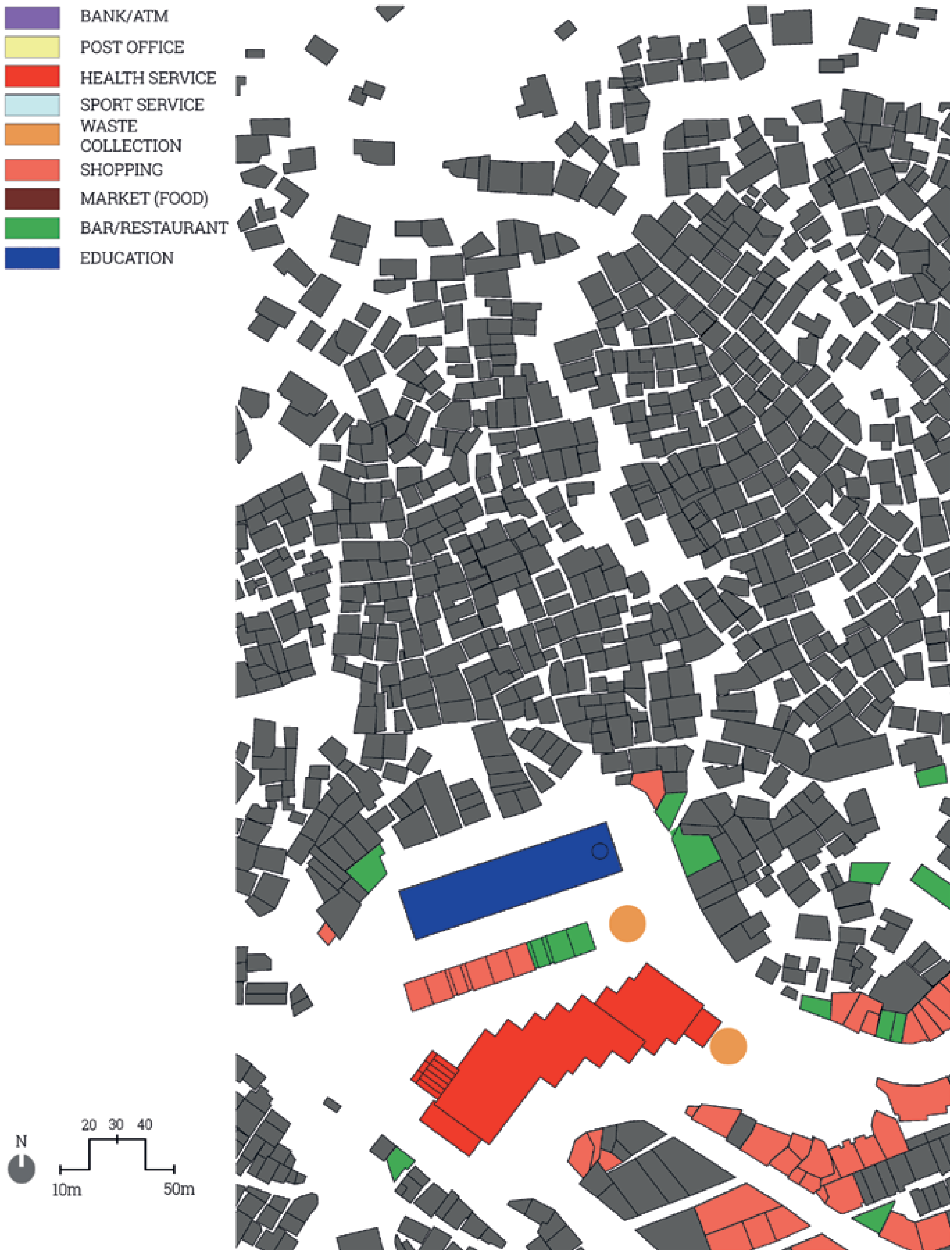


Figure 4.4.7 IMM Retrofitting Function map of intervention area n°1.

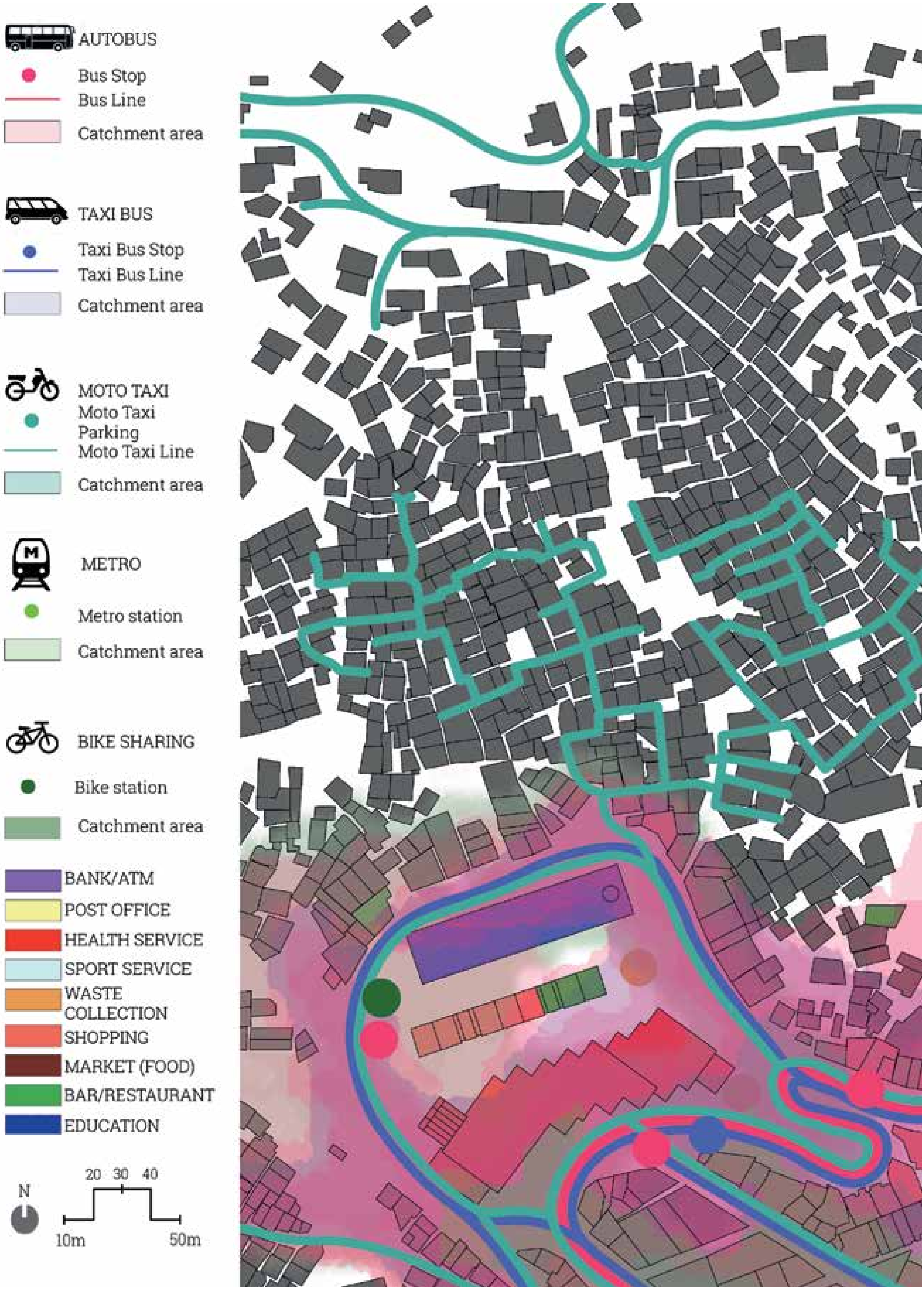


Figure 4.4.8 IMM Retrofitting Accessibility map of intervention area n°1.

Figure 4.4.9 IMM Retrofitting Diversity map of intervention area n°1.

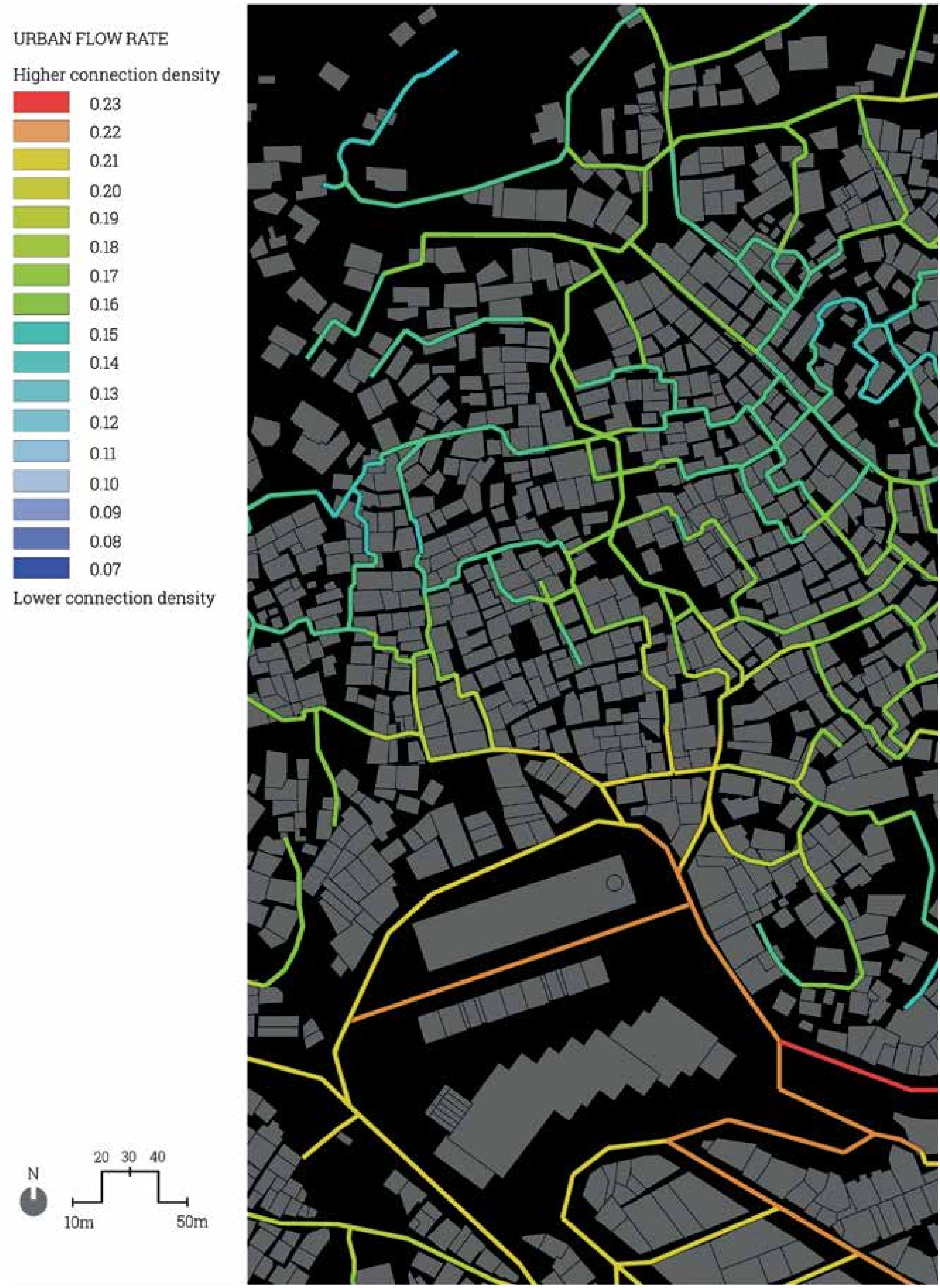


Figure 4.4.10 IMM Retrofitting Interface map of intervention area n°1.

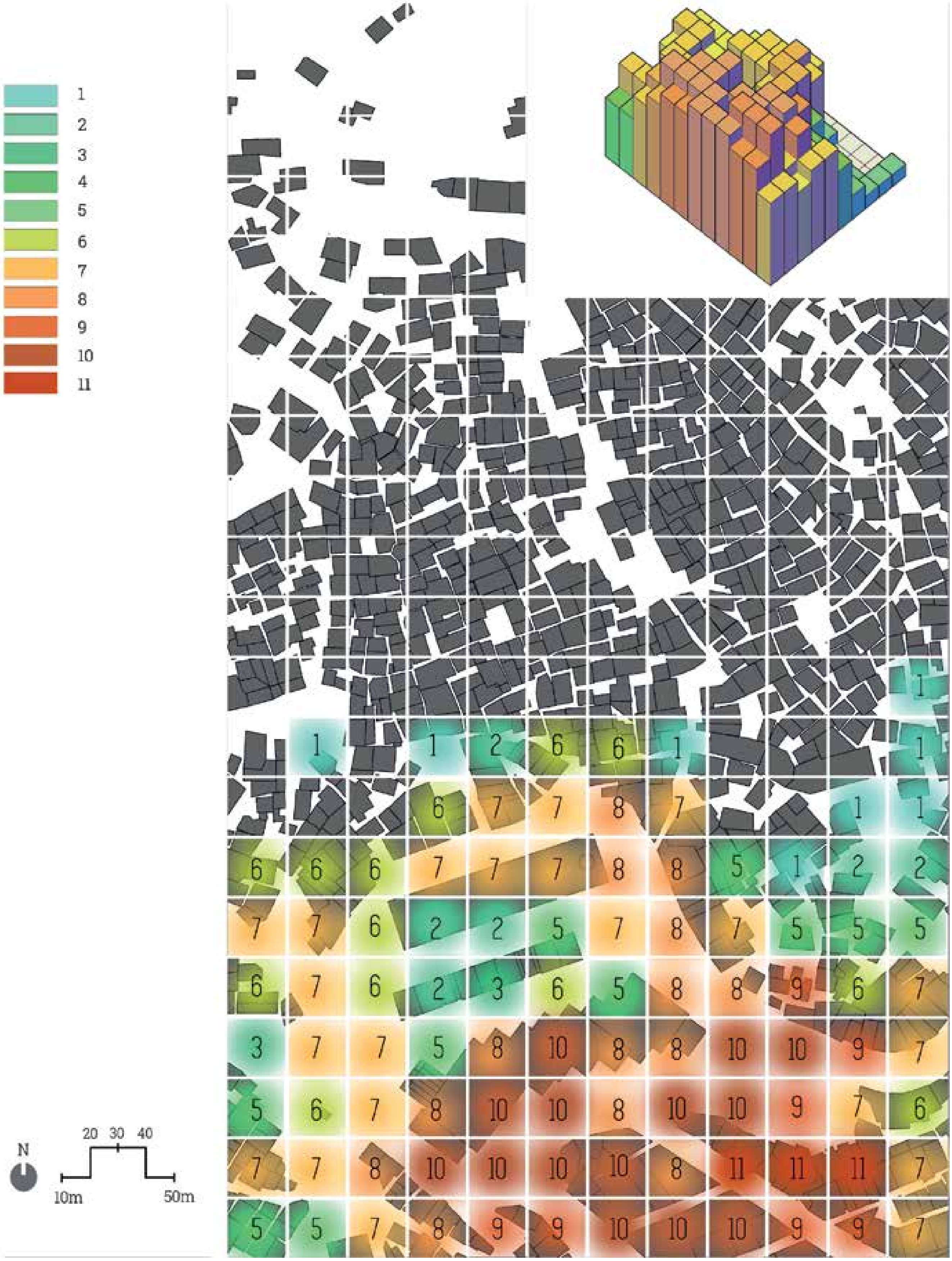


Figure 4.4.11 IMM Retrofitting Effectivness map of intervention area n°1.

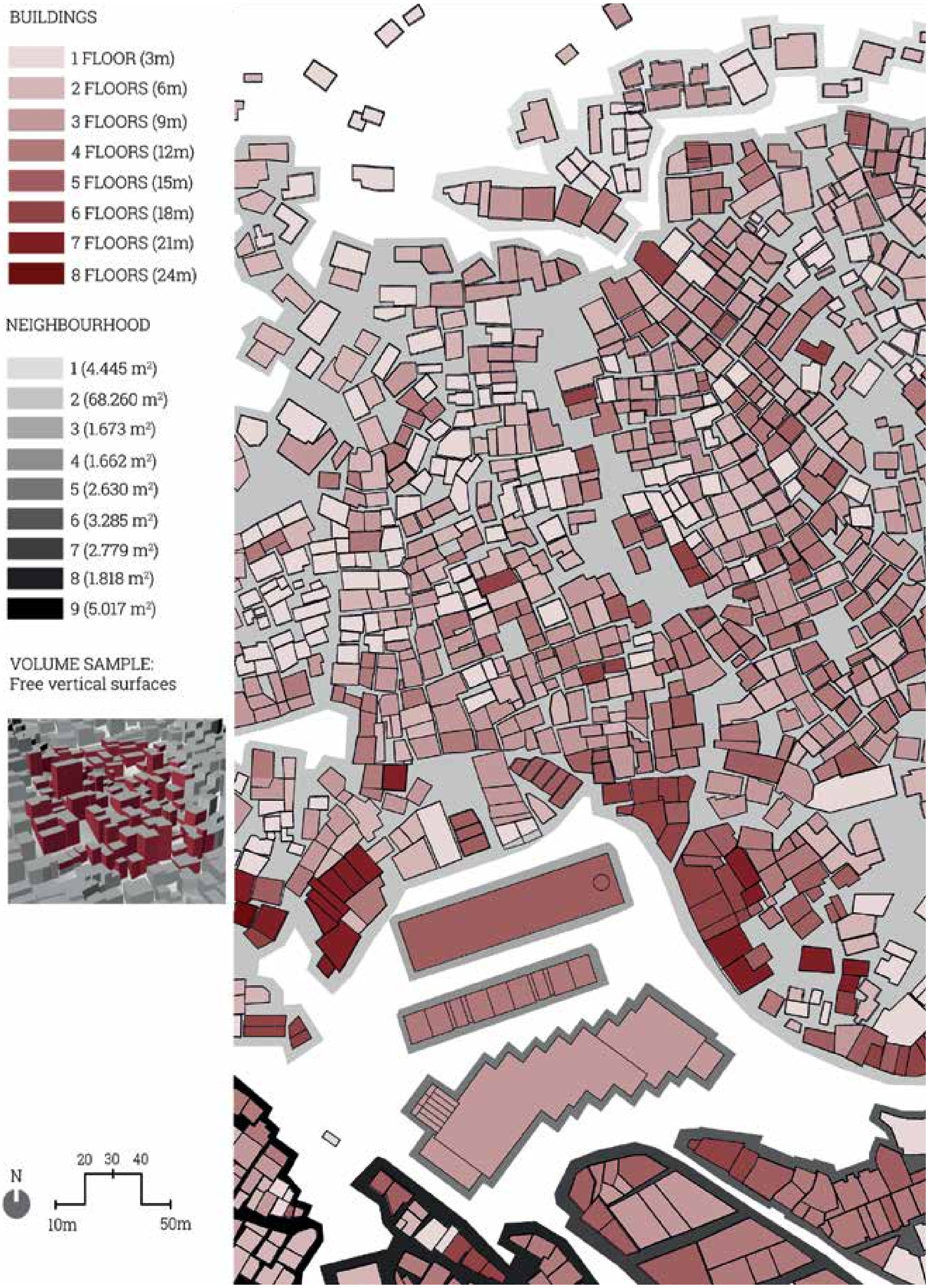


Figure 4.4.12 IMM Retrofitting Porosity map of intervention area n°1.

Figure 4.4.13 IMM Retrofitting Proximity map of intervention area n°1.

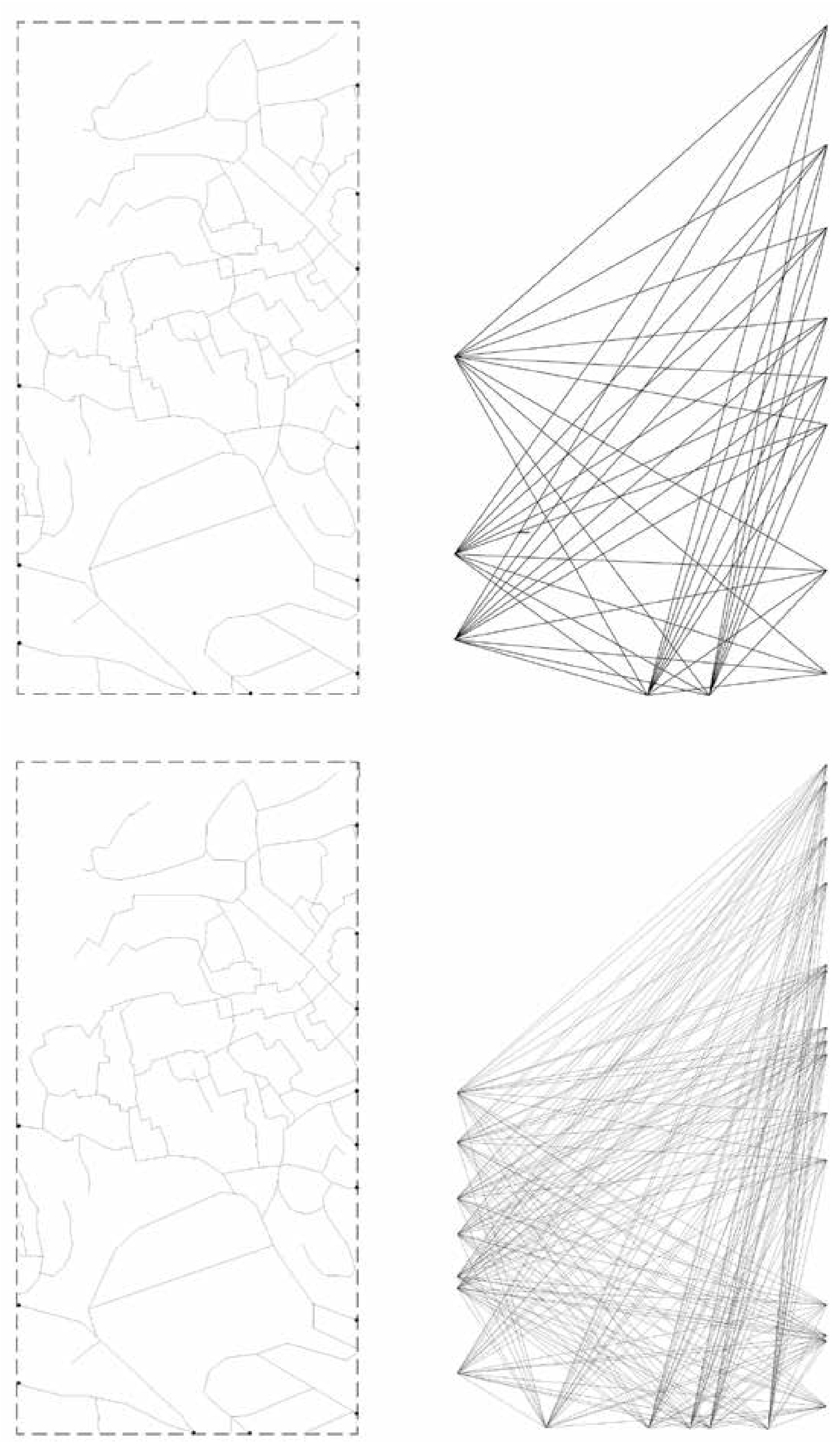


Figure 4.4.14 IMM Retrofitting Permeability Directness data processing.

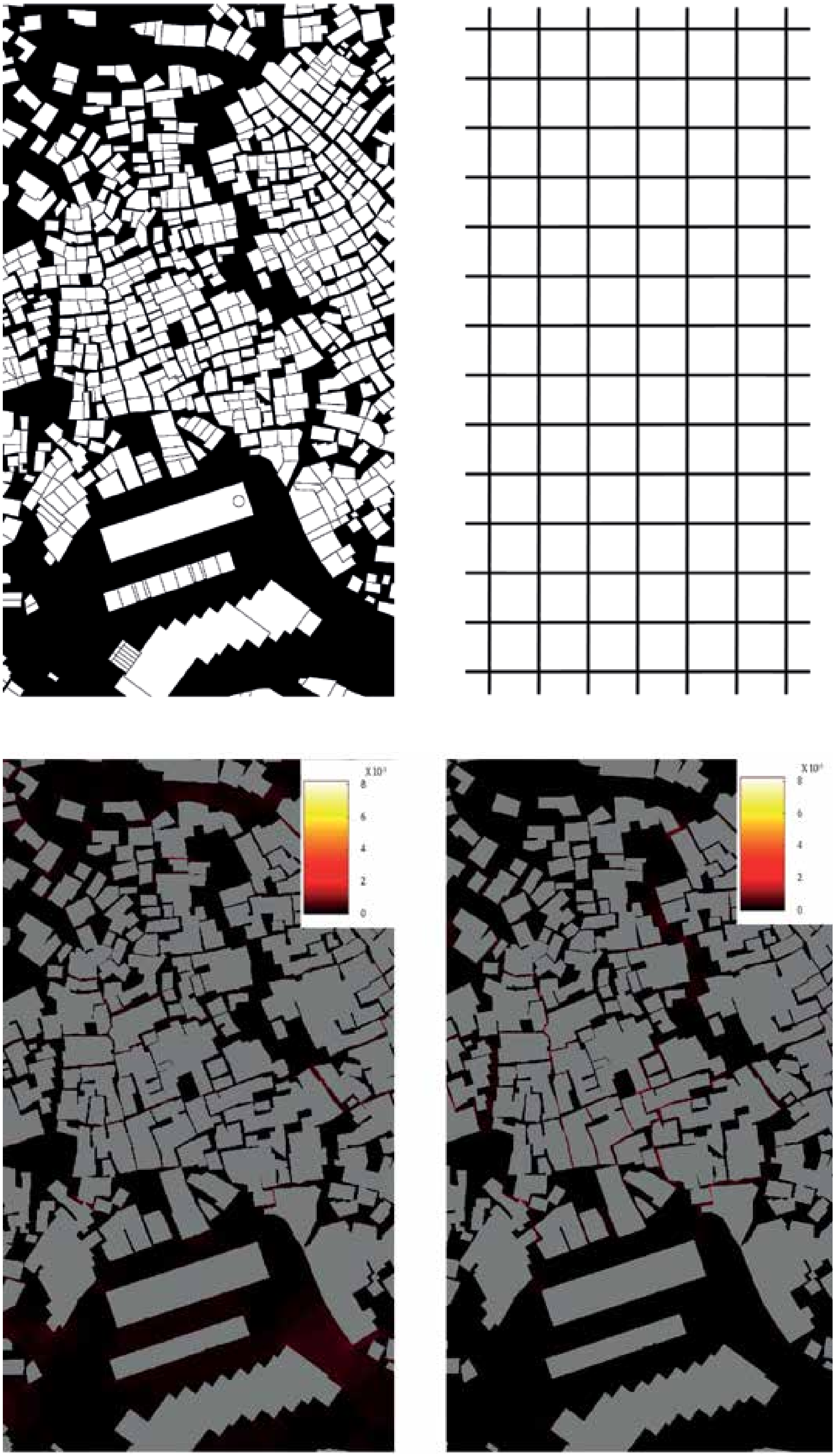


Figure 4.4.15 IMM Voids map, permeability Average Link Length illustration, IMM Permeability Tortuosity τx map, IMM Permeability Tortuosity τy map.

Figure 5.1 View of Area 1 after the intervention

5 ARCHITECTURAL DESIGN

As discussed in previous chapters, no single intervention or building can significantly impact the current living conditions of Rocinha. On that level, the architectural intervention presented in the next chapter shouldn't be debated on its own, but rather as a centrepiece of the projects described above.

The building designed in the following sections, a refurbishment of the Waldemar gas depot inside Villa Verde, will turn one of the most useless and potentially dangerous extant functions of Area 1 into a physical representation of the overall project for the betterment of the favela.

Brazilian contemporary residential architecture, expecially when related to favelas, has been analysed in order to determine appropriate living spaces for the apartments to be placed in the new building.

Moreover, a specific section will cover the structural design of the precast reinforced concrete frames which will bear the loads of the new addition to the existing edifice.

5. Architectural Design

5.1 Building design

5.1.1 Current situation and project overview

Figure 5.1.1 A view of Area 1; in the foreground, the UPA, with the Waldemar gas depot behind. Source: oglobo.globo.com

While the urban intervention outlined in the previous chapter focused on preserving most of the existing households, the rapid growth of Rocinha ensures an e demand of habitable space, a demand that the following section aims to answer, at least in part. As mentioned at various stages in this report, one of the most significant buildings present within Area 1 is the Waldemar gas depot, a relatively recent addition to the favela's urban landscape, completed by the end of 2018.

The depot presents an interesting conundrum: obviously such a potentially dangerous and socially useless function cannot be maintained in a project that aims at bettering Rocinha's urban landscape, already chaotic and rife with issues, as highlighted many times in previous chapters. On the other hand, however, it would be wasteful to completely demolish such a new construction, even to make room for a better alternative.

The proposed solution is thus twofold: first, it is reasonable to hypothesize that, should the right conditions be met, Waldemar would be willing to move the function of the depot to a building in a more acceptable position (most likely outside the favela), even factoring in the additional infrastructure needed to distribute the gas bottles through Rocinha. Having therefore emptied the building of its function, the building can be stripped of its outer layers, though the original materials can be re-used for the new construction, keeping only the existing cast reinforced concrete frame.

Further, the building will be expanded with three additional precast concrete frames, increasing its overall internal surfaces by more than a third, rivalling but not surpassing the adjacent school in mass. The completed building will contain 16 apartments of three different sizes, plus two canteens, supplied by the nearby biogas plant, one public and the other for the residents' use, and a space for shops at ground floor. The building will have green roof on which the same gardens provided for the school can be implemented and tended by the residents.

5.1.2 Housing in Brazil: a brief analysis through three examples

5.1.2.1 Introduction

By no means the analysis conducted at the beginning of this thesis is the first to highlight the manifolded issues inherent to the informal urban environment that is a favela, and in particular Rocinha. However, while said issues (overpopulation, sanitation, etc.) are widely recognized, the solutions proposed or implemented, either by the government or professionals, are often disjointed, brought about with little to no input from the population, and frequently worsen the situation.

While a comprehensive study of all the past interventions built or designed even exclusively for Rocinha is well outside the scope of this thesis, the following section will attempt to summarize Brazil's current outlook on the housing issue, though the analysis of the NBR 15575 (Performance of buildings housing of up to five floors to social housing) regulation of 2010, the *Minha Casa, Minha Vida* (My House, My Life) program and the book "Repensando as habitações de interesse social", detailing an urban intervention proposed for Rocinha by professor Luiz Carlos Toledo.

5.1.2.2 NBR 15575: *Desempenho de edifícios habitacionais de até cinco pavimentos à habitação de interesse social*

The NBR 15575, published in May of 2008 and in effect since May of 2010, details the performance of Brazilian housing of social interest. The norm is relatively recent, but has been implemented little in practice, especially when, in social housing, the cost limit is a determining factor in the quality and performance of the final product.

The NBR 15575 mandates that housing "must present adequate organization of the rooms and dimensions compatible with human needs ", thus defining the criteria for the availability of spaces for the use and operation of the household, setting the dimensions of the furniture and standard equipment and the spaces required for its use. It is also important to note that the NBR 15575 does not deal with accessibility, which can give rise to architectural solutions that undermine the functionality of the housing unit.

The Brazilian government has promulgated regulations detailing the surfaces' ranges for households, classified by number of bedrooms, as detailed in the table below:

Number of Bedrooms		1	2	3
Gross surface	Min.	52.00	72.00	91.00
	Max.	65.00	85.50	100.00
Habitable surface		30.50	43.50	54.50

Tab. 5.1.1 Dimensioning of habitable surface. Source: Ministérios do Equipamento Social e da Qualidade de Vida, Portaria 580/93.

In Brazil there are also some indicators of the general minimum area per dwelling in relation to the number of bedrooms and planned occupancy.

Criteria's Source	1 Bedroom / 2 Residents	2 Bedrooms / 4 Residents	3 Bedrooms / 6 Residents
IPT	35.00	43.00	51.00
PMSP	-	36.00	-

Tab. 5.1.2 Recommended minimum floor area for housing in m² (bedrooms + living rooms + kitchen + bathroom + service area). Source: IPT, 1987; PMSP Decreto 34049/94, altered with Decreto 35839/96 Art. 5º, alínea "h".

Room	Minimum Dimensions	
	Minimum Surface [m²]	**Shortest Side's Lenght [m]**
Kitchen / Living Room	14.00	2.40
Bedroom / Master Bedroom	9.00	2.50
2nd Bedroom	7.00	2.40
Bathroom	2.20	1.10
Hallway	1.40	1.20
Corridor or Internal Staircase	Minimum Width = 0.80	

Tab. 5.1.3 Minimum dimensions of the rooms. Source: NBR 15575, p. 31.

As detailed in the table above, the NBR 15575 does not establish guidelines regarding to the total area of the housing unit, mentioning the possibility of conflict with the municipal and state legislations. In addition, in the current version of NBR 15575 the requirement "minimum dimensions per room" has been deleted, which puts in the hands of the designer and the developer the question of dimensions, provided that the criterion of minimum furniture per room is met.

It is understood that there must be some design freedom and flexibility in terms of configuration space, but one should seek to determine minimum requirements that can guarantee minimum acceptable use of spaces.

5.1.2.3 *Minha Casa, Minha Vida*

Figure 5.1.2 A neighbourhood built by the *Minha Casa Minha Vida* programs. Source: diariodegoias.com.br

The program Minha Casa, Minha Vida began in 2009, as an integral part of the government-sponsored PAC program. The main goal of the program was to facilitate the purchase of first households for the poorest Brazilian families (whose income is between 0 and 10 minimum monthly salary), thereby reducing the housing deficit (-14%, building approximately 2.5 million households).

The first program run from 2009 to 2011, with the goal of building 1 million households, the second between 2011 and 2015, with 20 million units as a goal, while the third began in 2016, aiming to 3 million units. Though the numbers fluctuate between states, the households' surface vary between 32-40 m^2 (single homes) to 37-45 m^2 (apartments).

Below is a table summarising the building parameters outlined in the program:

Dimensions	Slopes & Context	Privacy
1. Number of units in a project: modules up to 500 units; fractional flats up to 250 units.	12. Excavations must be properly contained.	22. Terraced houses must be separated up to the roof.
2. Contaminated ground: the recovery plan should be approved by the national environment agency.	13. Terrain higher than the project area must be properly contained.	23. Waterproofing: the building's foundations mustn't be directly in contact with the terrain.
3. Protected areas and heritage sites: a special permission is necessary.	14. Slopes over 100%: containment or vegetal protection should be designed.	24. Roofing: roofs and open floors must be waterproofed.
4. Hydrogeological risks: the project must include a technical solution.	15. Slopes over 45° for excavations and 60° for sections: a stability test must be conducted.	25. Sustainability: timber must be from certified managed forest.
5. Marshlands and flood-risk areas: the project must include a technical solution with a return period over 50 years.	16. Slopes with a height difference over 3.00 m: a technical solution including embankments, drainage systems and other containment structures.	26. Parking: The sloping of parking areas must be under 8%.
6. Public services: they must include transportation, public lighting and waste management.	17. Slope proximity: there must be at least 1.50 m between the building and the foot of the slope.	27. Roads and streets for vehicles and pedestrians must be asphalted.
7. Utilities: they must include electricity, freshwater adduction, wastewater disposal and drainage.	18. Height differences over 1.50 m near transition zones: must include railings.	28. Soil coverage: use gravel for parking spaces and flat areas or other appropriate drainage solutions.
8. Maximum height.	19. Internal height: the minimum height for bathrooms, kitchens and corridors is 2.20 m, and 2.40 m for all other rooms.	29. Security: the property's boundary must be protected by a wall or fencing with minimum of 1.80 m in height.
9. The building must be in a favourable height compared to the street, drainage and sewerage networks.	20. Accessibility: the minimum width of external doors is 0.80 m.	30. Lighting: must be designed for common spaces.
10. Entrance: must be higher than the terrain level.	21. The rules for accessibility in common spaces, households and garages must be complied with.	
11. A drainage solution must be designed on the bottom for downhill sites.		

Tab. 5.1.4 *Minha Casa, Minha Vida* building provisions. Source: Caixa Economica Federal

On a purely quantity level, the program can be considered a success, however the quality of the finished products is mediocre at best, making it clear the priority of the federal government was to meet their own quota than provide a proper urban environment. Vast habitation blocks have been built throughout the country, many with unfinished roads with little to no buildings providing services for the newly constructed neighbourhoods. Overall, the Minha Casa, Minha Vida programs are the epitome of the "top-down" approach adopted in many instances by the Brazilian federal government.

5.1.2.4 *Repensando as habitações de interesse social*

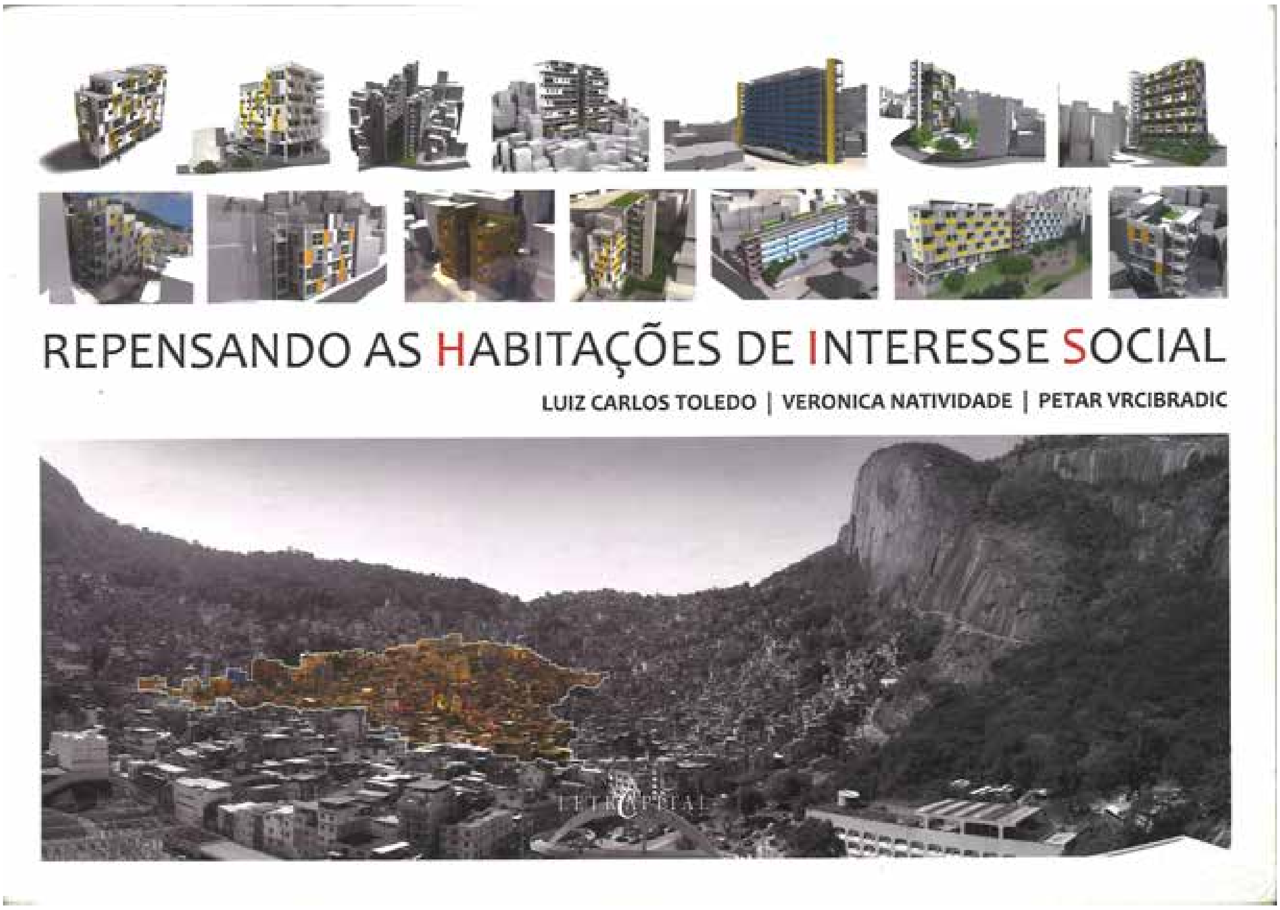


Figure 5.1.3 TOLEDO, Luiz C. et al. *Repensando as habitações de interesse social*, Letra Capital Editoria, 2nd Edition, Cover Page.

In his book, professor Toledo details the proposal for an urban intervention in Rocinha centred in an area cordoned by Estrada da Gávea in the north and Rua Nova in the south.

The book highlights the potential cascading beneficial effects of the so-called "Habitações de Interesse Social" (HIS), or social housing on an urban environment. Social housing is seen as the catalyst of a larger urban and social transformation, changing the traditional way to look at construction, both from the designers and builders point of view, by applying industrialization to building methods and materials, and the inhabitants, called to contribute to the design with their own ideas and the construction phase itself as workforce.

The design approach envisioned by professor Toledo starts with the "Plano Diretor da Rocinha" (2005-07). Recognizing that the most pressing issue within the favela is the excessive urban density, the urban plan mainly proposed a "verticalization" of the urban landscape, demolishing some households and replace them with new, multi-storey buildings, thereby ameliorating Rocinha's choked urban environment; this strategy is praised for solving the favela's accessibility and sanitary issues by employing very little expropriation.

Other provisions of the plan include the enhancement of the existing service networks. Great emphasis is placed on the completion of the sewerage network and the improvement of the drainage system, the latter accomplished mainly by clearing of waste the existing talvegues network; the quality of potable water is mentioned as well, with plans to improve the water supply system. The plan also includes the "Plano Director de Recolhimento e Reciclagem do Lixo", which deals with the strategies needed for a new waste collection system, and suggests employing community workers, with the aim to create new jobs in Rocinha.

Later urban renovation programs, such as Favela Bairro and PAC, would build upon the guidelines outlined by the Plano Diretor, always emphasising the need for new services' networks, the construction of new roads and public areas and buildings, as well as the necessity to remove households from risk areas (mainly floods and mudslides), moreover, the importance of minimal spaces in private houses is highlighted.

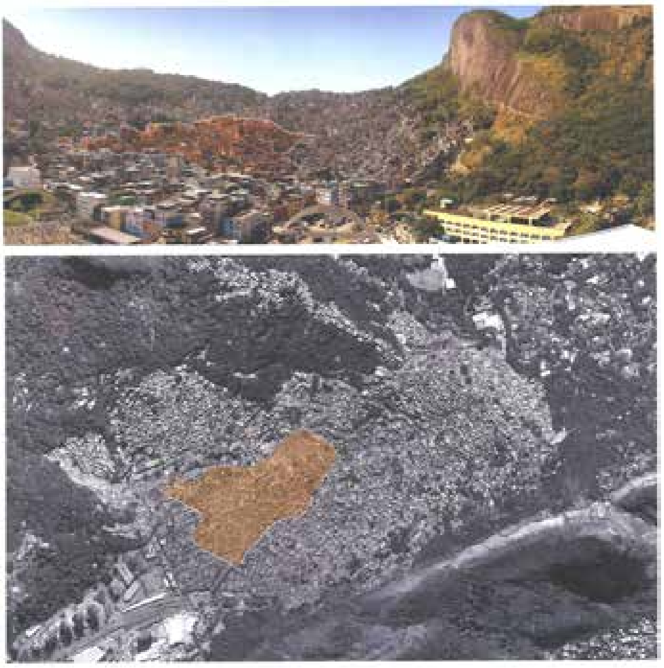


Figure 5.1.4 Ibidem, p. 37: AI2 Localization.

Figure 5.1.5 Ibidem, p. 54: Urban intervention view.

Perhaps the greatest paradigm shift introduced by professor Toledo is to have the inhabitants themselves participate in the design process. The architect is one of the first in Brazil to recognize the strong bonds between the favela and its people, which has caused uncounted “top-down” government intervention to fail, going ignored and unused by the population as they were not perceived as “theirs”.

“O sentiment de pertencimento próprio da maiora dos moradores de comunidades em relação aos poucos espaços públicos disponíveis explica-se pelo fato de que [...] são, muitas vezes, fruto de árduas lutas da população local.”

“The sense of belonging of the majority of the inhabitants of the communities relative to the few public spaces available is explained by the fact that [...] they are often the result of the arduous struggles of the local population.”

The people of Rocinha are extremely attached to their homes, that they often build themselves, therefore, every change has to pass the scrutiny of the inhabitants to have any hope of succeeding in the long-term. During the design phase, professor Toledo put much emphasis on the use of prefabrication and auto-construction; the first to reduce construction times as much as possible, the latter is seen as the extreme consequence of the inhabitants participation, to the point that the possibility of producing said prefabricated pieces inside the favela itself has been considered.

The design proposed by professor Toledo manifests itself in four architectural models over tow intervention scales (micro and macro); all buildings have a steel skeleton, with walls and partitions in prefabricated reinforced concrete panels. Furthermore, all buildings are designed on pilotis, the intention being to make as much public space as possible, using the undersides of the new construction as well.

Figure 5.1.6 Ibidem, p. 74: Flexible plans examples.

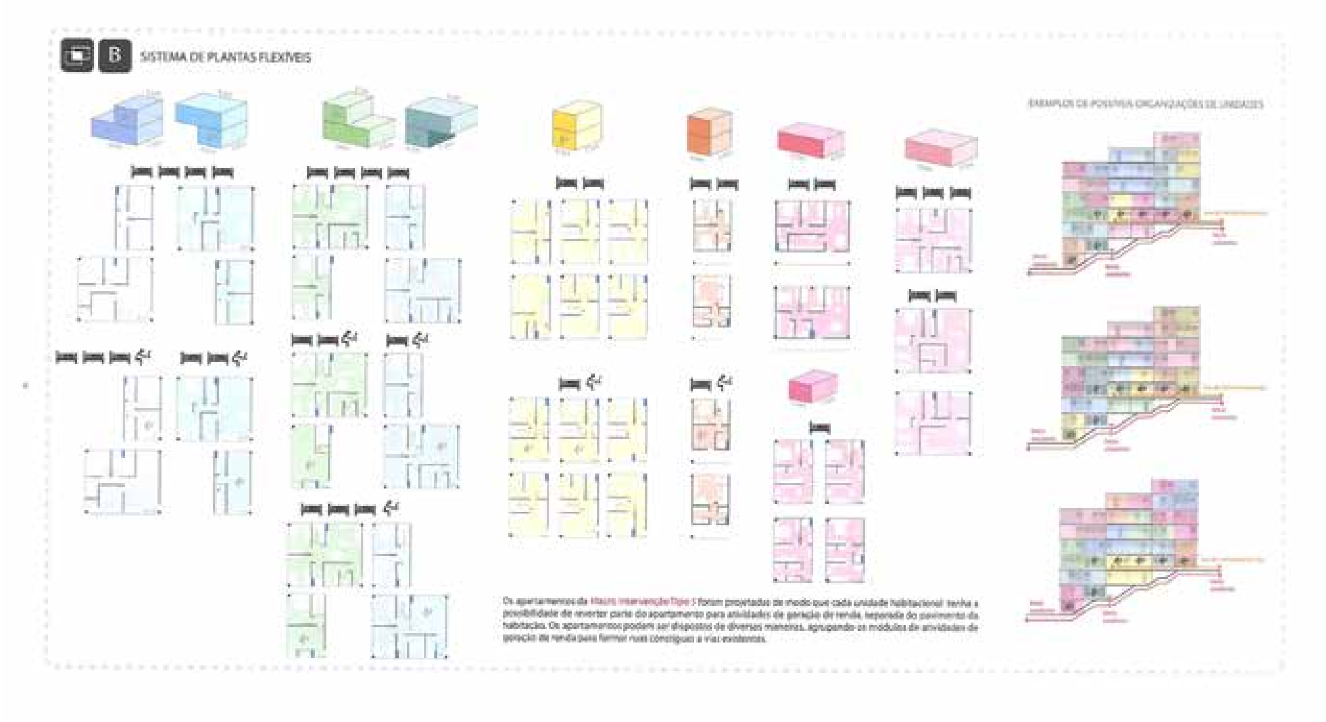


Figure 5.1.7 Ibidem, p. 81: Flexible plans examples and buildings' configurations.

Professor Toledo's intention was to create an architectural dictionary based on industrial components, to be compared and contrasted with the other urban environments of Rio de Janeiro (like Barra de Tijuca, Copacabana and Santa Teresa). At the end of the day, the intervention's ultimate goal is to mould the "informal" urban landscape of Rocinha into a more "formal" city, following similar guidelines to those of "Minha Casa, Minha Vida".

5.1.2.5 Analysis and Conclusions

Even a passing glance at Brazilian urban environments would reveal how wide the gap between written legislations and reality is. Putting aside NBR 15575 for a moment, the Minha Casa, Minha Vida programs are, at least on paper, a fairly good solution to the never-sufficiently-highlighted problem that is the housing deficit in Brazil, with ambitious but reachable goals (that, technically, have been, in fact, reached) and a well-structured funding program. However, as touched on briefly above, the programs resulted in endless expanses of single-story households, with very few services, with no regard to the context (natural or anthropized), low-quality materials and an architecture that can be generously called unremarkable.

Professor Toledo understands the limits (and issues) of the programs and takes noteworthy steps to address them, as mentioned in the previous section; especially important is his insistence in using participatory planning, taking into account the local populace's proposals. Despite his attention to the social framework of Rocinha, his proposed intervention is still rather heavy-handed, forcibly demolishing large swaths of existing buildings and relocating households into massive flats. The intention is to reduce soil coverage in the favela, however, due to the tremendous building density found in Rocinha, only small patches can be truly liberated, as the new buildings still occupy a non-negligible surface. Moreover, the intervention breaks the existing urban landscape like similar projects proposed and built throughout the world (most notably, the many interventions in the French banlieues) to "improve" informal or dilapidated neighbourhoods, most of which ended up as failures.

Therefore, the intervention proposed in this thesis will try and avoid the missteps outlined above. As highlighted many times in chapters past, one of the most important principles of the urban intervention is to proceed though small, localized projects that grow organically as a web, improving Rocinha's urban environment while readily proving their benefits. Similar principles guide the architectural design process, first by mostly reusing and expanding an existing building, thus reducing soil use; plus, the finished building will take chromatic and geometric cues from the surrounding urban landscape, inserting itself naturally into Area 1's built environment.

5.1.3 Apartment design

Using the provisions outlined in NBR 15575, while also taking Professor Toledo's analysis into account and filling the gaps with Italian and European apartment design principles, three kinds of apartments were designed: from one to three bedrooms, though each of them can add an additional one. The usage of Italian design principles was particularly useful, as the minimal spaces defined in NBR 15575 are often nigh-impossible to design properly, and have, in most instances, been enlarged to allow for a reasonable amount of living space.

The first constraint the design faced was the beams' span of the existing (and new) frames, each 7.00 metres in length. In other words, it was decided that all apartments will have a 7-metres-side, while the other side will increase depending on the internal surface requirements. Specific measurements and areas will be shown below.

Going through the various design option, the spans of the existing structure, combining with the need of keeping a clear path through the central corridor of the building, which connects the apartments to the staircases, it became clear that making the two-bedrooms apartments into duplexes with the same footprint as the one-bedroom apartment was the choice which allowed for the most configuration's options while designing the building.

As mentioned, favelas' have a rapidly expanding population, thus the design of both the apartments and the building allow for future expansions within the parameters set by the entire intervention, a "controlled growth" so to speak. As shown below, all the proposed designs have the possibility to add an additional bedroom with minimal adjustment of the internal disposition, should the family inhabiting it grow in size.

Figure 5.1.8 Three-bedroom apartment configuration options

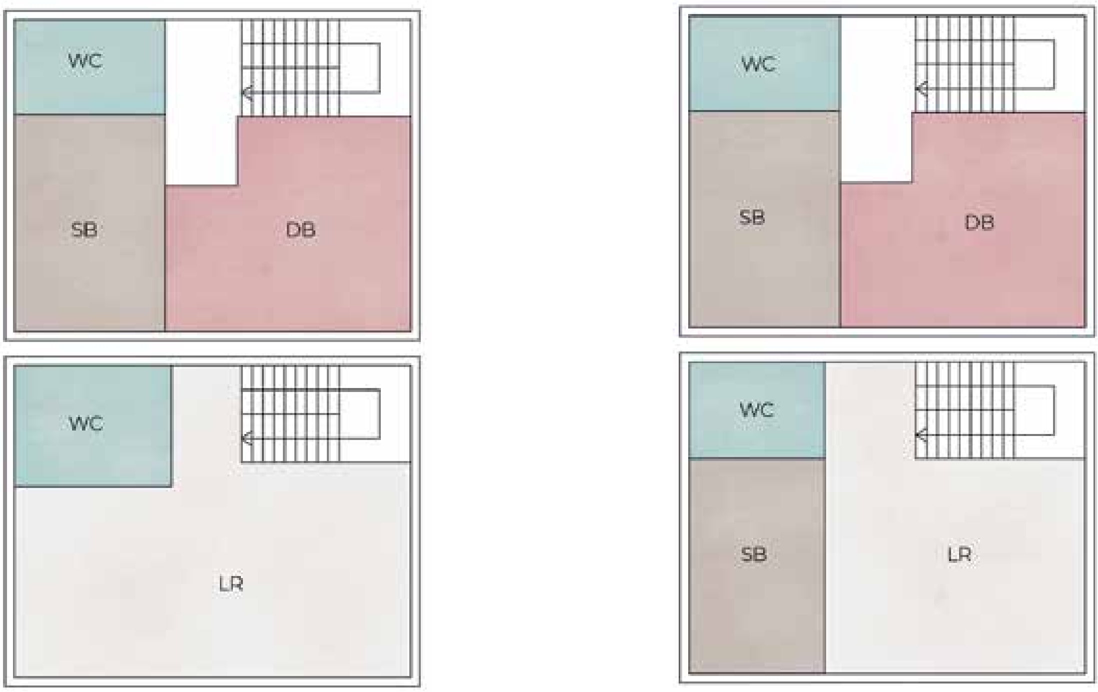


Figure 5.1.9 Duplex apartment configuration options

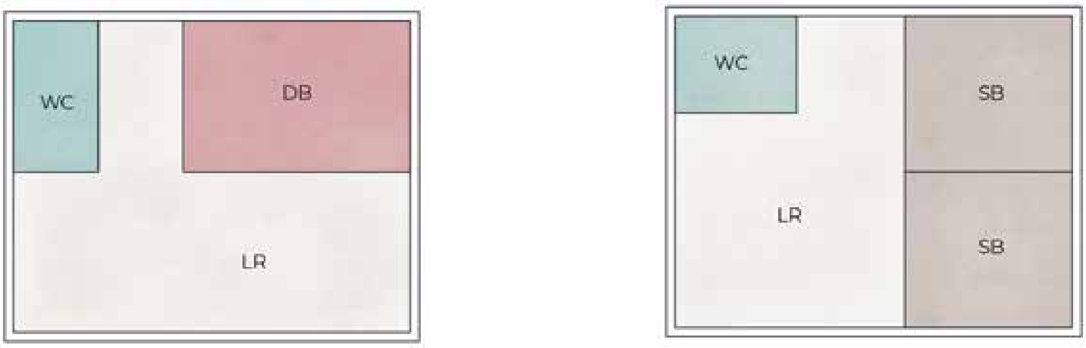


Figure 5.1.10 Single-bedroom apartment configuration options

Finally, shown below is a table summarizing the measurements chosen for each apartment, in relation to those proposed by NBR 15575 and the plans for said apartment.

Apartment	Room	Shorter Side (NBR 15575) [m]	Surface (NBR 15575) [m^2]	Shorter Side (Actual) [m]	Surface (Actual) [m^2]
Three-bedroom	**Kitchen / Living Room**	2.40	14.00	4.05	26.00
	Bedroom / Master Bedroom	2.50	9.00	3.25	14.00
	2nd Bedroom	2.40	7.00	2.40	7.00
	Bathroom	1.10	2.20	1.60	3.20
	TOTAL	-	54.50	-	61.40

Tab. 5.1.5 Minimum measurements and designed apartments comparison, part 1

Two-bedroom	**Kitchen / Living Room**	2.40	14.00	3.15	22.00
	Bedroom / Master Bedroom	2.50	9.00	3.45	12.50
	2nd Bedroom	2.40	7.00	2.50	8.60
	Bathroom	1.10	2.20	1.60	4.00
	TOTAL	-	43.50	-	51.85
Single-bedroom	**Kitchen / Living Room**	2.40	14.00	2.55	16.70
	Bedroom / Master Bedroom	2.50	9.00	2.50	9.40
	Bathroom	1.10	2.20	1.40	3.50
	TOTAL	-	30.50	-	31.50

Tab. 5.1.6 Minimum measurements and designed apartments comparison, part 2

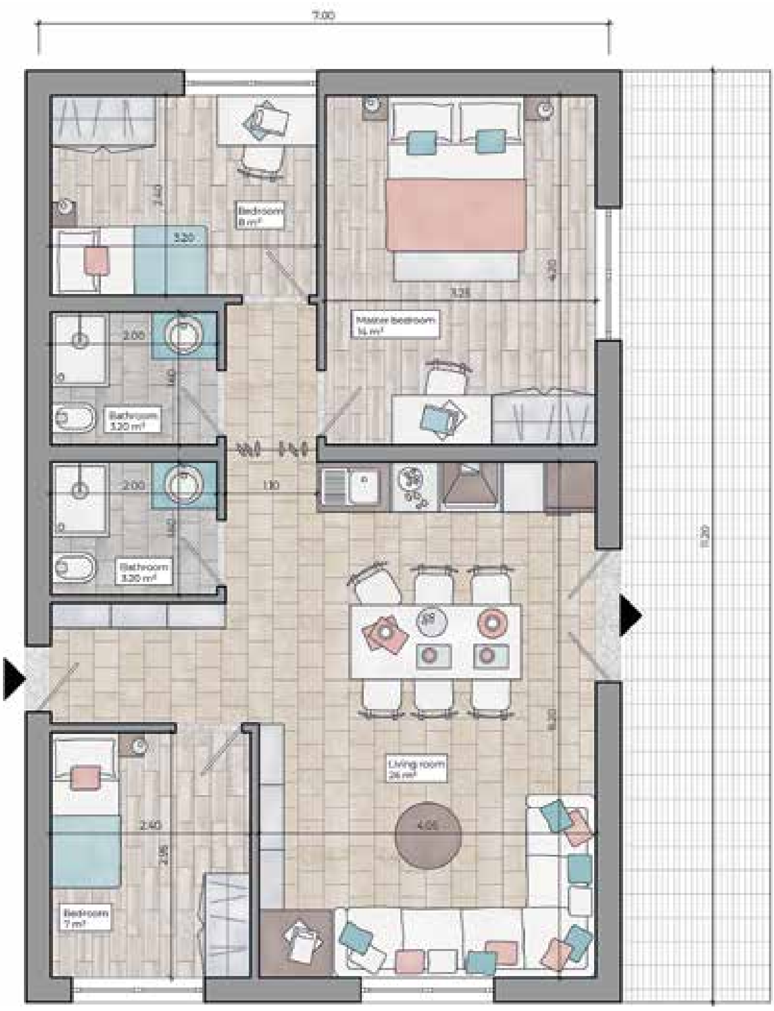


Figure 5.1.11 Three-bedroom apartment plan

Figure 5.1.12 Duplex apartment plan

Figure 5.1.13 Single-bedroom apartment plan

5.1.4 Plans and functions

5.1.4.1 Ground Floor

The internal disposition of the proposed building is fairly simple, built around the regular structural frame. The existing building already possessed a set of concrete stairs and elevator, which has been augmented by a second set at the connection between the extant and new structural frames, to allow for easier access and evacuation of the building's new and old areas; both also serves as entrances to the square between the school and the building.

The ground floor presents the biggest variety of functions. There're two canteens at both ends of the building, the one on the left for the exclusive use of the residents and their guests, as most apartment flats in Brazil have a space dedicated to social gatherings, which includes a cooking area. On the other hand, the one on the right is a public canteen, that everyone passing by Area 1 may use. Both are supplied by the nearby biogas plant, and dispose of their organic waste there, creating a virtuous circle.

The space between the two entrances is given to any activity or shop which may set up there in the future. It was decided not to provide a specific function in these spaces beyond that, though calculations and observations made on the ground suggests it could contain three to four stores, which will be in a prime position, at the very centre of the new intervention, directly overlooking the new square and passage.

The corridor's internal disposition and design will be analysed in a dedicated section below.

On the opposite long side, there are the bottom halves of four of the eight duplex apartments, partially in projection over and overlooking the UPA.

It should be noticed that the public and private parts of the ground floor are not directly linked to one another, meaning only the residents and those allowed by them can access their apartments, as is usual.

5.1.4.2 First Floor

Both the first and the second floors are entirely dedicated to habitation. In particular, there're two three-bedrooms apartment at the building's ends, both possessing a terrace; this arrangement is repeated on the second floor; the positioning of these was dictated by the necessity of keeping the central corridor clear to make through the entire building, on the other hand, it meant that the three-bedrooms apartments are open on three sides. On the first floor, they are adjacent to the top half of a duplex apartment and a single-bedroom apartment. In the centre, towards the school, from the left, there're the bottom halves of two duplex and a single-bedroom apartment, while on the opposite side are the top halves of the two duplex on the ground floor and the bottom half of yet another duplex in the very middle of the building.

5.1.4.3 Second Floor

Noticeably, there're four green roofs in place of apartments on the second floor, these are intended as vegetable gardens in the same vein as those on the school's roof described in previous chapters; however, recognizing the ever-changing and ever-growing nature of Rocinha, they could, potentially, be filled with more habitable space, should the need arise.

The second floor naturally also includes the top halves of the duplex beginning on the first floor, plus four single-bedroom apartments and the aforementioned three-bedroom apartments.

5.1.4.4 Roof

The roof is entirely accessible by the residents, and is entirely green, both to provide a drainage boost to the whole area, and to serve as vegetable gardens tended by the inhabitants of

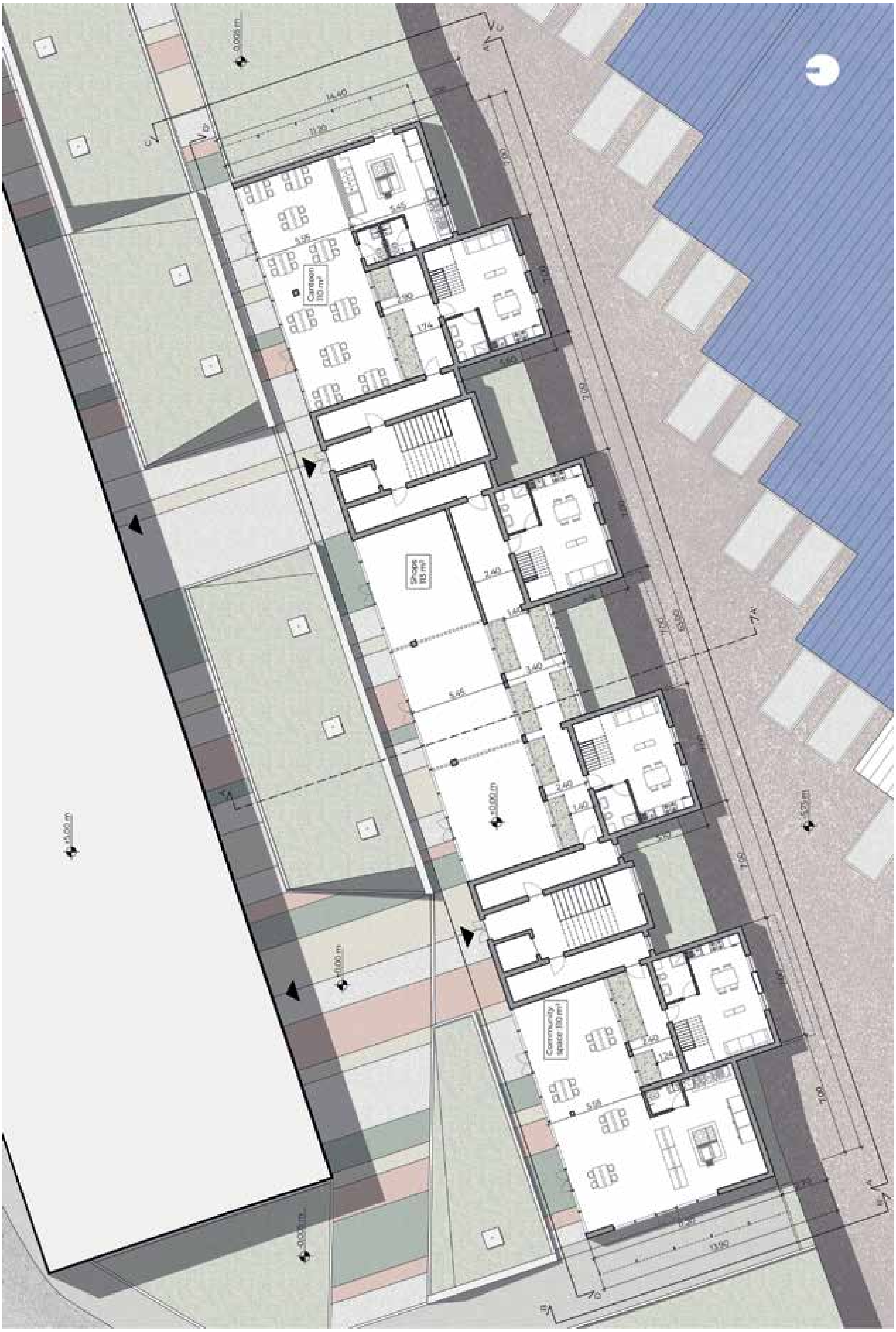


Figure 5.1.14 Ground Floor plan

Figure 5.1.15 First Floor plan

Figure 5.1.16 Second Floor plan

Figure 5.1.17 Roof plan

Figure 5.1.18 Allamanda Cathartica flowers. Source: gardensonline.com.au

the building. It also overlooks a large part of Rocinha, with Morro Dois Irmãos directly in South of it, as well as São Conrado to the South-West, and the Ocean behind it.

5.1.4.5 The corridor

As the centrepiece of the entire building, the central corridor hasn't been treated as a simple connecting element, but, enlarged though the apartments being in projection towards the front of the building, can also be a place for social gatherings between residents.

To further enhance said role, skylights, open to the sides, were placed on the roof, each projecting a hole going all the way to the ground floor, where a climbing plant (the Allamanda Cathartica) grows from concrete tanks all the way to the roof, supported by a steel cage (also functioning as railing at each floor), with nettings fixed on it. The combination of the above elements creates an aerated and luminous space, with plants going through and over the building.

Figure 5.1.19 Section AA'

5.1.5 Façades: geometry and colour

While the regular structural frame of the original gas depot and the fixed sizes of the apartments would lean themselves towards a regular geometry for the final design, even allowing for the substitution of some apartments with green roofs (which creates "voids" in the façades), a conscious design decision was taken to go a step further on the front façade, and have most of the apartments in projection, with different distances creating an "irregular" front.

This choice not only allowed for the peculiar arrangement of the corridor mentioned above but was also the result of the analysis of Rocinha's building landscape, with its irregular heights and geometries, an environment where the new interventions are often even more noticeable for their regular shapes. The building proposed in this thesis intends to pay homage to the chaotic asset of the favela with a non-standard geometry that still maintains its own internal order.

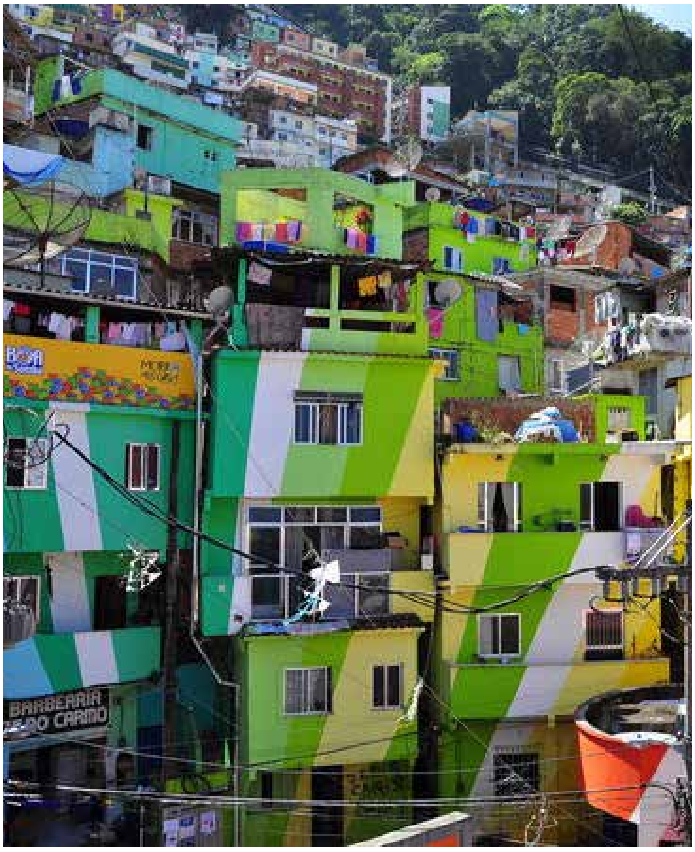


Figure 5.1.20 Façades refurbishment in the Santa Marta favela, RJ. Source: www.wiztours.com

On the other hand, the opposite façade has to confront itself with the massive and extremely regular front of the school "CIEP Bento Rubião", therefore it presents a surface just as regular, with glass façades on the ground floor to mark the common and social spaces, while the first and second floor are as massive as the concrete front of the school facing it.

The short sides of the building are also the ones more exposed to the morning and evening low sunrays, as such, terraces made of metal grids on a steel frames, on which concrete pots are mounted, where vegetables can be grown, shielding the windows behind them.

Beside its irregular geometry, the second important aspect of Rocinha's urban environment is its variety of materials and colours, as, while the majority of the buildings are made of bricks, both the type of bricks and the colour of the plaster which may or may not be applied on them can change wildly between each household. Therefore, the colour of the façades is the second important aspect which guides the design of the building's external layer.

The use of colour in a refurbishment project is an established practice, and has indeed been used already in various favelas around Rio de Janeiro, starting in 2006 with the project "Favela Painting", conceived by the Dutch artists Jeroen Koolhaas and Dre Urhahn in Villa Cruzeiro, and perhaps most notably with the intervention on 7,000 square metres of façades spread among 34 houses in the favela of Santa Marta, made by its inhabitants trained by TintasCoral.

It seemed therefore natural to paint the façades of each apartment to match further the surrounding urban environment, though again while the different façades of the favela are a visual representation of its chaotic nature, on the building designed in this thesis colour brings order to the façades, as shown in the following pages.

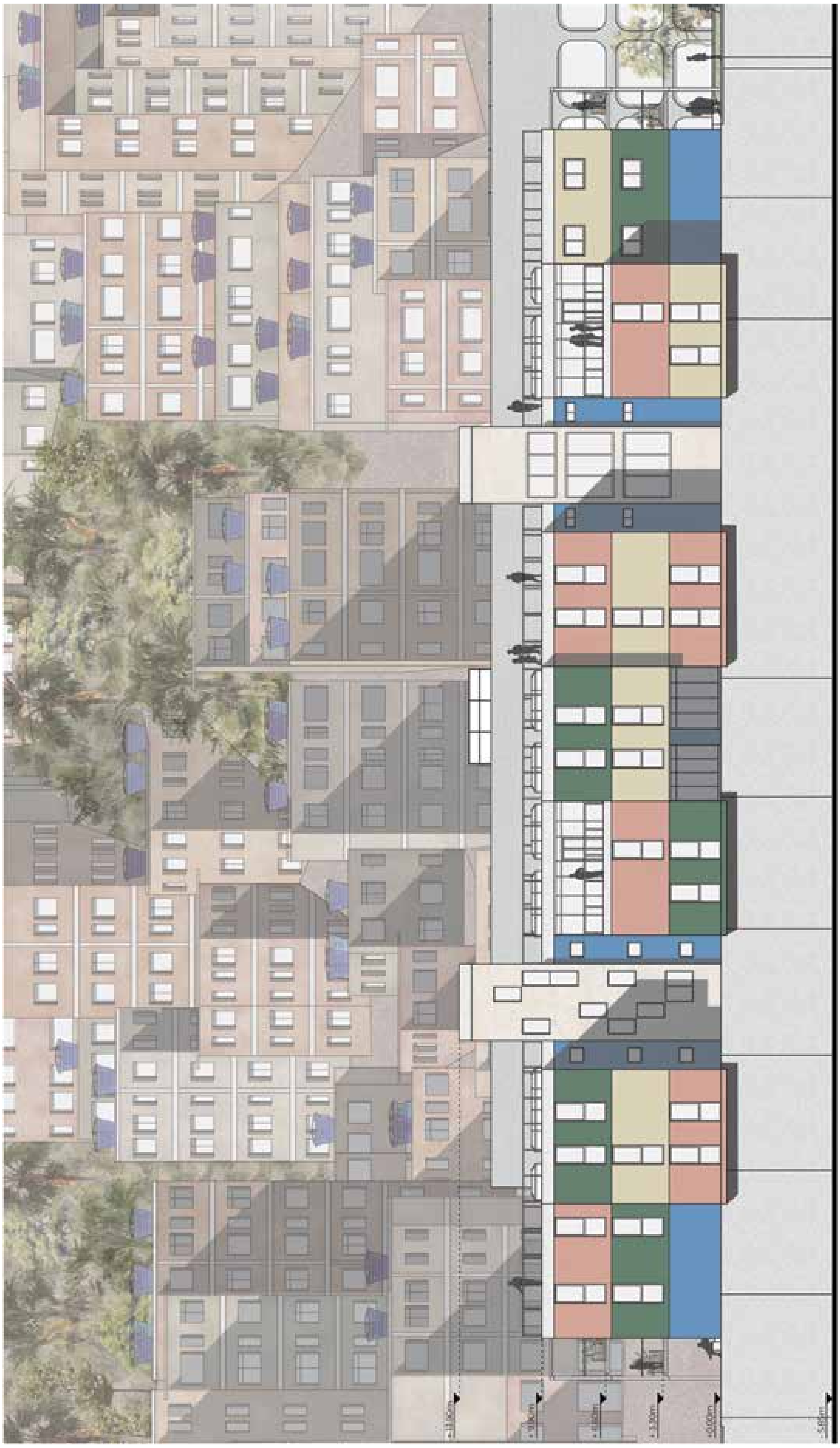


Figure 5.1.21 Elevation AA’

Figure 5.1.22 Elevation BB’

Figure 5.1.23 Elevation CC’

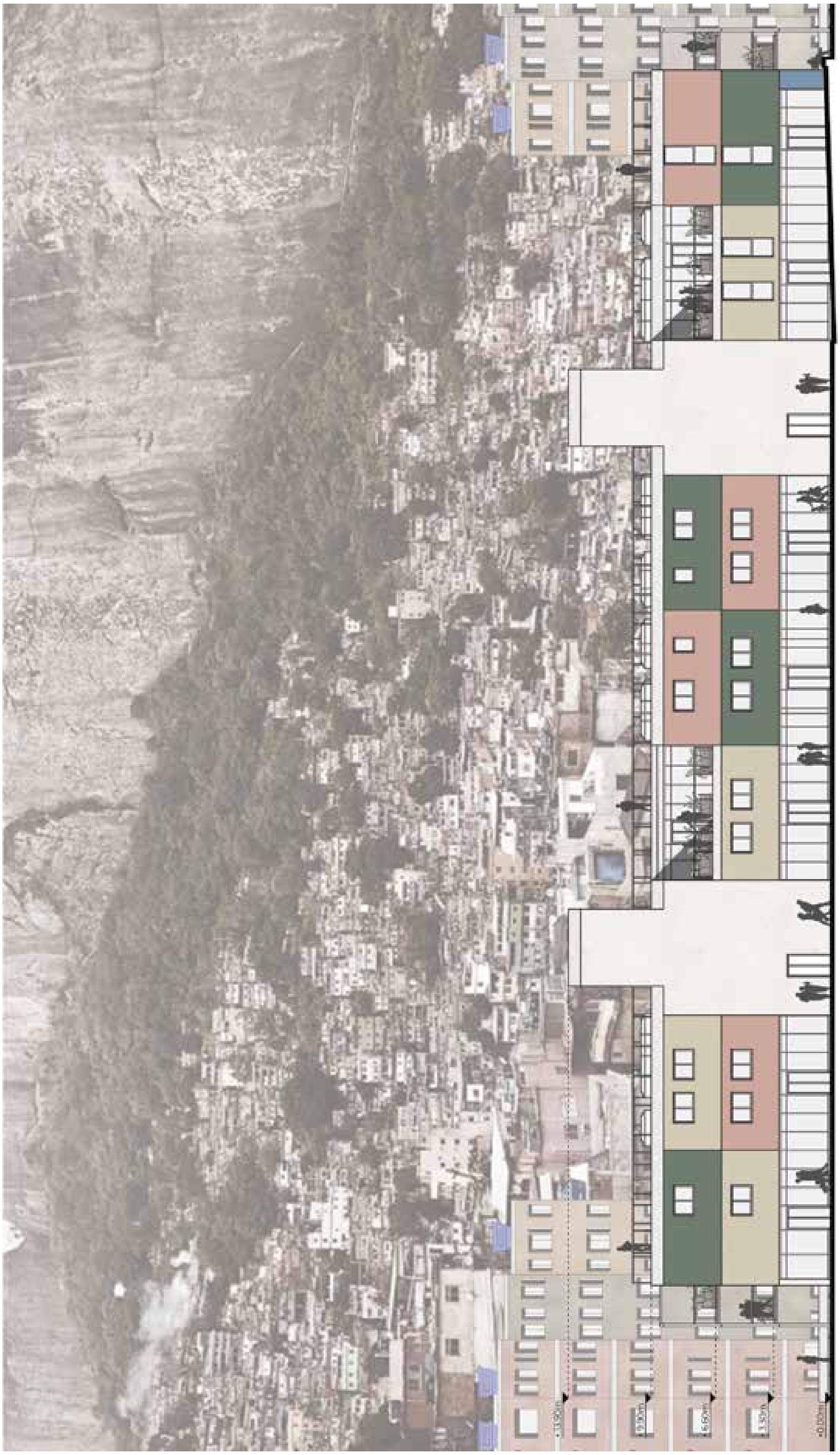


Figure 5.1.22 Elevation DD’

5.2 Structural design

5.2.1 Introduction

Analysis of the current urban layout and demographic situation of Rocinha, discussed at length in the previous chapters, show that the existing Waldemar gas depot, once refurbished into an apartment building, would be insufficient for Area 1's current and future necessities, despite its not inconsiderable size. Therefore, as detailed above, the project includes an expansion of the current edifice to almost double its current surface. Conversely, these new additions come with the design of additional structural elements to bear the building's new loads, which will be detailed in the next section of this report.

5.2.2 Design principles' overview

5.2.2.1 The existing structure

A detailed survey of the Waldemar gas depot, and therefore its structural elements, is unfortunately unavailable at this time; the data almost impossible to acquire due to both the unusual circumstances of Rocinha and its very nature as a privately-owned depot. Accordingly, it has been necessary to make a hypothesis on the nature of the existing structure, based for the most part on external observations and circumstantial evidence.

Both point to the depot having a conventional steel-reinforced concrete frame, as Brazil makes ample use of the material in its modern and contemporary architecture, while eschewing the comparatively expansive steel frames. Direct observation of the ground floor columns, visible from the outside, strongly supports this theory, to the point of certainty.

Moreover, since the depot is a very recent addition to the favela's urban landscape (built sometimes in the late 2018), it is even possible to correctly discern the dimensions of the existing structure using the latest Brazilian technical standards: ABNT – NBR (Associação Brasiliera de Normas Técnicas – Norma Brasiliera), numbers 6118, 6120, 6123, 8681 and 15421.

These documents provided a solid bedrock of information to make the reasonable hypothesis that, as the building's function changes from a gas depot to an apartment complex, the existing structure, designed to bear much greater loads, will suffice for the new function, and therefore not only it becomes extremely convenient to keep the current reinforced concrete frame, both from an economical and design standpoint, but it will be unnecessary to redesign it, as the new structure is designed not to interact with the existing one, as detailed below.

In conclusion, this section will not analyse the extant frame any further, both because of the impossibility of obtaining precise information and because every reasonable assumption point to a more than adequate, almost oversized, existing structure.

5.2.2.2 The new structure

As mentioned above, the new structure will be independent from the old one, bar a single connection that will be discussed at the end of this section. This choice allows for a simpler design process, as the new structural elements and frames can be dimensioned independently from the existing ones, with no interactions between them.

While designing the new structure, the aforementioned separation allowed for further simplification during the calculation process, as the proposed frames could effectively be split into three separate and independent structures (four when factoring in the current one). Each frame, designated Frame 1, Frame 2 and Frame 3, respectively, has thus been designed on its own, as shown below.

Another important step is the choice of material for the frames. Climate and availability exclude almost immediately any type of wooden structure, conversely, steel has been

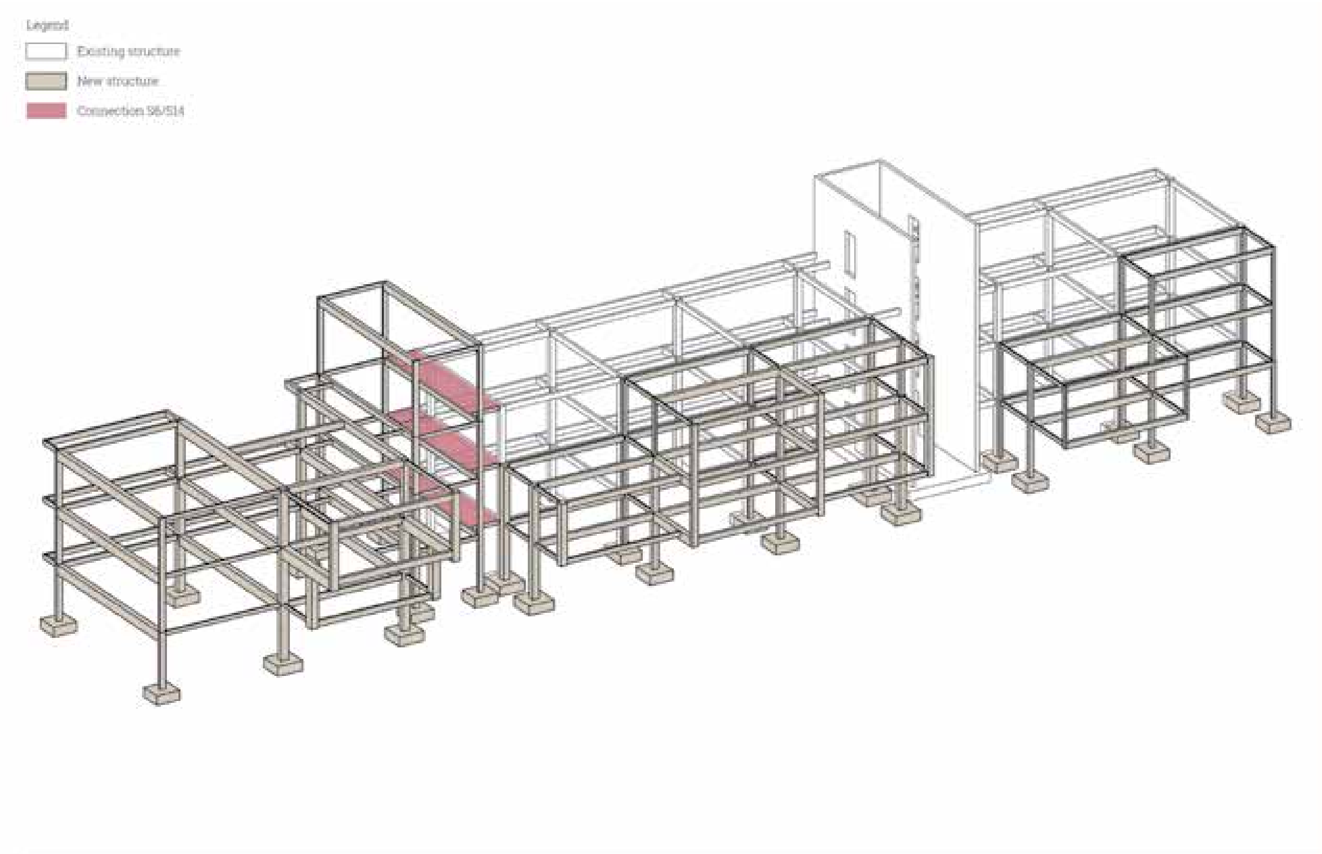


Figure 5.2.1 3D overview of the structure

excluded as it is very uncommon in Brazilian architecture due to its higher prices, and the project emphasis on “cheaper” materials throughout every step.

Reinforced concrete is, therefore, the natural choice for this kind of building. Going one step further, it was decided that a precast reinforced concrete frame would be employed, which provides three key advantages to the designer and builders: first and foremost, quality control; in an urban landscape as informal as Rocinha, and Brazil in general besides, precast concrete, made in a factory and shipped on location, guarantees that the standards enforced by the designer is met.

Secondly, speed of assembly; as mentioned many times, urban changes inside a favela are fast and continuous, therefore precast concrete, whose elements need only to be stacked atop one another, with minimal usage of liquid concrete for floors, speeds up the process considerably, and allows for the building to become functional sooner than employing a traditional cast reinforced concrete structure.

Thirdly, the use of precast reinforced concrete elements further simplifies the calculation process, as the beams are simply in support of the columns, while in a traditional concrete structure they would be built-in support, which ironically makes the precast structure closer to a steel frame than a concrete one.

A final note on the usage of precast reinforced concrete elements: as the beam and floor spans of the new frames are relatively short (with the longest beams spanning 9.60 metres) and do not bear exceptional loads, it has been deemed unnecessary to pretension neither, a choice supported by the following calculations. Moreover, Area 1, uniquely among the intervention areas, is directly adjacent to Estrada da Gávea, allowing the trucks transporting the precast elements from the factory to access the construction site with relative ease, especially compared to Rocinha as a whole, furthermore, Villa Verde forms a roundabout around the chosen site, adding convenient manoeuvre space for any vehicles.

On the matter of foundations, as Rocinha's soil is, as mentioned multiple times in the past, a solid bedrock just under the surface, traditional cast reinforced concrete plinths have been chosen rather than a mat foundation or ground beams. Moreover, as the favela does not lay in a seismic area, the frame needs not to be braced.

The dimensioning and verifications presented below have all been conducted using the principles outlined in the NTC 2018, of easier access and consultation compared to the Brazilian NBR, not to mention more restrictive and precise, thus guaranteeing superior standards to those required by the former.

5.2.3 Precast reinforced concrete overview

5.2.3.1 Production, transportation and assembly

Precast reinforced concrete is produced in dedicated factories, under controlled conditions. The first step is the production and assembly of the reinforced steel cages and the main connections of the element; the precast factory often has specialist workshops for the manufacture and maintenance of moulds, and for the production of jig-built reinforcing cages and connections. The finished reinforced cage is positioned in the partly assembled mould, then the remaining mould section is completed. Carefully specified concrete is placed into the mould, and many precast works now employ computer controlled batching plants. To ensure that optimum density is obtained and that specified strengths are achieved, concrete is placed and compacted using high frequency external vibrators or pokers.

Once the appropriate strength has been reached, the precast units are moved to the storage area; units are usually handled within hours of casting as part of the rapid production cycle. The product exhibits a high degree of dimensional accuracy and quality finish; economies of production are achieved through repetitive and automated process. The finished precast components are stacked on clean battens or plastic pads positioned to suit the design of the component. Care is taken to keep the stacks vertical and to ensure that battens are placed directly above one another within the stack.

The components are delivered from the factory to the construction site using appropriately sized trucks or other vehicles in a pre-determined sequence

Figure 5.2.2 Vibratory finishing machine for the production of precast reinforced concrete. Source: ASSAP

Figure 5.2.3 Transportation of hollow core precast slabs. Source: bgcprecast.com.au

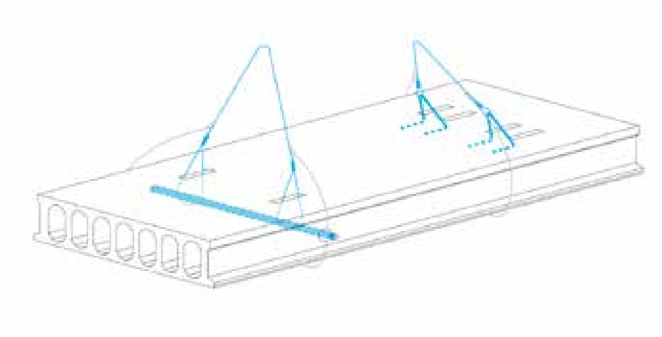


Figure 5.2.4 Handling of hollow core precast slabs. Source: ASSAP

to ensure that hardened concrete are ready for instant erection. In many instances, this phase is the main limiting factor, as precast concrete elements can reach unwieldy sizes. Thus, during the design phase, it is important to analyse the construction site and the surrounding areas, in order to understand the maximum size of the pieces that can be transported there, breaking down the biggest elements into smaller ones then reassembling them on site when necessary. On the plus side, the speed of construction of a prefabricated structure is such that, at times, stockpiling materials on site becomes unnecessary, though a stockpile area should still be taken into account.

Once the elements of the structure have been delivered, they can be quickly assembled ("tilt up") with a comparatively small number of workers straight from the lorry, as the pieces have been cast to fit into one another (for example, L or inverted T-shaped beams), the entire frame can, and at times is, be built with elements entirely in support of one another, with some neoprene membranes between them. However, in most cases it is recommended, especially for floor slabs, to add a thin concrete screed to improve the frame's flexural rigidity. Even with that, the construction process is far "cleaner" and faster than any cast reinforced concrete structure. The elements can be moved around the construction site using a crane, as most pieces can be fitted with holes or nooks to be slung from with cables (https://theconstructor.org/concrete/precast-concrete-process/6272/).

5.2.3.2 Precast reinforced concrete in Brazil

Figure 5.2.5 The interior of LCI plant in Atibaia. Source: www.leonardi.com.br

Brazilian building sector has known and used precast reinforced concrete for decades, though always in modest quantities when compared to traditional cast reinforced concrete, due in no small part to the wildly fluctuating economy of the country, plagued by inflation. Still, a number of industrialists over the years have invested in the construction of precast concrete factories, especially in the more densely built and industrialized urban centres, such as São Paulo, including one of the oldest and largest plants in Brazil, the Leonardi Construção Industrializada Ltda in Atibaia, founded in 1989. While as of 2012 precast reinforced concrete represents 5% of the cement consumption in Brazil, a percentage not too far from worldwide data (https://www.cpi-worldwide.com/journals/artikel/816).

5.2.4 Materials' properties

Following the definitions Eurocodes 2 ENV 1992-1-1 and pr EN 1992-1, as well as NTC 2018, the properties of concrete C45/55 and steel employed in precast structures are as reported below:

N/mm²	
Strength Class	**C 45/55**
$f_{ck\ cube}$	55
f_{ck}	46
f_{ctm}	4.34
$f_{ctk\ 0.05}$	3.04
$f_{ctk\ 0.95}$	5.64
f_{cfm}	5.21
f_{cd}	31.17
f'_{cd}	15.58
f_{ctd}	2.17
f_{cfd}	3.72
τ_{Rd}	0.54
E_{cm}	35830
E_{cd}	29858

Tab. 5.2.1 C45/55 concrete properties

N/mm²	Bars	Wires	Strands and Braids	Compacted Strands
f_{tk}	1000	1570	1860	1820
f_{yk}	800	800	800	800
E_s	200000	200000	200000	200000
γ_s	1.15	1.15	1.15	1.15
f_{yd}	695.65	695.65	695.65	695.65
f_{bk}	2250.0	3532.5	4185.0	4095.0
f_{bd}	1500	2355	2790	2730

Tab. 5.2.2 Steel properties

Where, in 5.2.1:

- $f_{ck\ cube}$ is the cubic characteristic compressive strength [N/mm²];
- $f_{ck} = 0.83\ f_{ck\ cube}$ is the cylindrical characteristic compressive strength [N/mm²];
- $f_{ctm} = 0.3\ f_{ck}^{2/3}$ is the mean value of the tensile strength [N/mm²];
- $f_{ctk\ 0.05} = 0.7\ f_{ctm}$ is the characteristic value inferior to the axial tensile strength (fractile 5%) [N/mm²];
- $f_{ctk\ 0.95} = 1.3\ f_{ctm}$ is the characteristic value superior to the axial tensile strength (fractile 95%) [N/mm²];
- $f_{cfm} = 1.2\ f_{ctm}$ is the mean value of the bending tensile strength [N/mm²];
- $f_{cd} = 0.83\ f_{ck\ cube} / \gamma_c$ is the cylindrical design compressive strength [N/mm²];
- $\gamma_c = 1.4$ is a safety factor for precast concrete;
- $f'_{cd} = 0{,}5\ f_{cd}$ is the reduced cylindrical design compressive strength [N/mm²];
- $f_{ctd} = f_{ctk}\ 0.05 / \gamma_c$ is the design axial tensile strength [N/mm²];
- $f_{cfd} = f_{cfm} / \gamma_c$ is the design bending tensile strength [N/mm²];
- $\tau_{Rd} = 0.25\ f_{ctk} / \gamma_c$ is the unitary design shear strength [N/mm²];
- $E_{cm} = 9500\ (f_{ck} + 8)^{1/3}$ is the secant Young modulus [N/mm²];
- $E_{cd} = E_{cm} / \gamma_{CE}$ is the design Young modulus [N/mm²].

And, in 5.2.2:

- f_{tk} is the characteristic failure stress [N/mm²];
- f_{yk} is the characteristic yielding stress [N/mm²];
- E_s is the Young modulus [N/mm²];
- $f_{yd} = f_{yk} / \gamma_s$ is the design yielding stress [N/mm²];
- γ_s =1.15 is a safety factor for steel;
- $f_{bk} = 2.25\ f_{tk}$ is the characteristic tangential bond strength [N/mm²];
- $f_{bd} = f_{bk} / \gamma_c$ is the design tangential bond strength [N/mm²].

5.2.5 Loads and load combinations

The first step in dimensioning the new structural frames is to calculate the loads bore by the new structure. Following the provisions of NTC 2018, loads are split into two categories:

- G_k are the permanent loads, themselves split between permanent structural loads (the structural element own weight; G_1) and permanent non-structural loads (the weight of the floors, G_2);
- Q_k are variable loads, those loads derived from the function of the building.

The calculation of the G_k loads for the project is shown in the tables below:

Layer	Material	Thk. [m]	Weigth [kN/m³]	Weigth [kN/m²]
1	Plaster	0.008	16.67	0.13
2	Precast Slab	-	-	2.45
3	Cement	0.100	19.61	1.96
4	Cement	0.040	19.61	0.78
5	Porcelain Tiles	-	-	0.20
			TOTAL	5.52

Tab. 5.2.3 Horizontal Partition 01B permanent loads

Layer	Material	Thk. [m]	Weigth [kN/m³]	Weigth [kN/m²]
1	Plaster	0.008	16.67	0.13
2	Precast Slab	-	-	3.00
3	Cement	0.100	19.61	1.96
4	Cement	0.040	19.61	0.78
5	Porcelain Tiles	-	-	0.20
			TOTAL	6.07

Tab. 5.2.4 Horizontal Partition 01C permanent loads

Layer	Material	Thk. [m]	Weigth [kN/m³]	Weigth [kN/m²]
1	Plaster	0.008	16.67	0.13
2	Rock Wool	0.050	0.78	0.04
3	Precast Slab	-	-	2.45
4	Cement	0.100	19.61	1.96
5	Soil	0.080	19.61	1.57
			TOTAL	6.15

Tab. 5.2.5 Horizontal Floor 02B permanent loads

Layer	Material	Thk. [m]	Weigth [kN/m³]	Weigth [kN/m²]
1	Plaster	0.008	16.67	0.13
2	Rock Wool	0.050	0.78	0.04
3	Precast Slab	-	-	3.00
4	Cement	0.100	19.61	1.96
5	Soil	0.080	19.61	1.57
			TOTAL	6.70

Tab. 5.2.6 Horizontal Floor 02C permanent loads

Layer	Material	Thk. [m]	Weigth [kN/m³]	Weigth [kN/m²]
1	Plaster	0.015	16.67	0.25
2	Rock Wool	0.050	0.78	0.04
3	Precast Slab	-	-	2.45
4	Cement	0.100	19.61	1.96
5	Cement	0.040	19.61	0.78
6	Porcelain Tiles	-	-	0.20
			TOTAL	5.68

Tab. 5.2.7 Horizontal Floor 03 permanent loads

On the other hand, the Q_k loads are provided by NTC 2018 in Tab. 3.1.II.

For the purpose of this analysis, the categories that needs to be selected are A (Residential spaces) and I (Accessible roofs), though the latter will still use the A category values, as stated in the table.

Depending on the type of verification put forward by NTC 2018, the loads needs to be added together into two kind of combinations: the ultimate limit state (SLU) and the serviceability limit state (SLE), the latter further split into the rare (SLEr), frequent (SLEf) and quasi permanent (SLEqp), as shown in § 2.5.3:

SLU combination:

$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \psi_{03} \cdot Q_{k3} \ldots$$

SLE rare combination:

$$G_1 + G_2 + P + Q_{k1} + \psi_{02} \cdot Q_{k2} + \psi_{03} \cdot Q_{k3} \dots$$

SLE frequent combination:

$$G_1 + G_2 + P + \psi_{11} \cdot Q_{k1} + \psi_{12} \cdot Q_{k2} + \psi_{13} \cdot Q_{k3} \dots$$

SLE quasi permanent combination:

$$G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \psi_{23} \cdot Q_{k3} \dots$$

Seismic combination:

$$E + G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} \dots$$

Exceptional combination:

$$G_1 + G_2 + P + A_d + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} \dots$$

Where:

- γ_{G1} is the coefficient for permanent structural loads for SLU verifications;
- γ_{G2} is the coefficient for permanent non-structural loads for SLU verifications;
- γ_P =1.0 is the precompression coefficient;
- γ_{Qk} are the coefficients for variable loads for SLU verifications;
- ψ_{ij} are the combinations' coefficients;
- P is the precompression value;
- E is the seismic force value;
- A is the exceptional force value.

P, E and A won't be used in the following analysis, as precompression has been judged unnecessary for the spans found in the new frames, Rocinha does not lay in a seismic area, and there aren't any exceptional forces of note. The value for the coefficients γ_{G1}, γ_{G2} and γ_{Qk} can be found in Tab. 2.6.I, while those for ψ_{ij} in Tab. 2.5.I.

5.2.6 Floor slabs

5.2.6.1 Overview

One of the most common kind of precast reinforced concrete floor slabs, the concrete hollow core slabs, has been selected to serve as load-bearing floors for its ease of production, transportation and laying. The basic slab is 1.20 metres wide, while its height and length vary according to the designer's choice; moreover, it is fairly easy to cut holes into the finished slabs, when the need arise (such as the stairs connecting the two floors of the duplex apartments and the central corridors).

As mentioned above, while the floor slabs could be laid in simple support of the beams, it has been decided, to improve the new frames flexural rigidity and the transversal distribution of concentrated loads, to cast a thin concrete screed above the slabs. In Italy, the DM 09.01.1996 (par. 7.3.4) specify that the concrete screed to make a statically composite slab must be at least 4 cm in thickness and reinforced by a welded mesh.

Furthermore, each precast floor slabs comes with its own technical documentation and calibration curve, the latter gives the designer its performances and maximum reinforcements following regulatory limits. Notice that the calibration curve doesn't take into account the slenderness limit and the limits coming from the connections with the beams, both of which will be analysed further into this section. Below is the calibration curve employed in this project and the hollow core slab properties depending on its height:

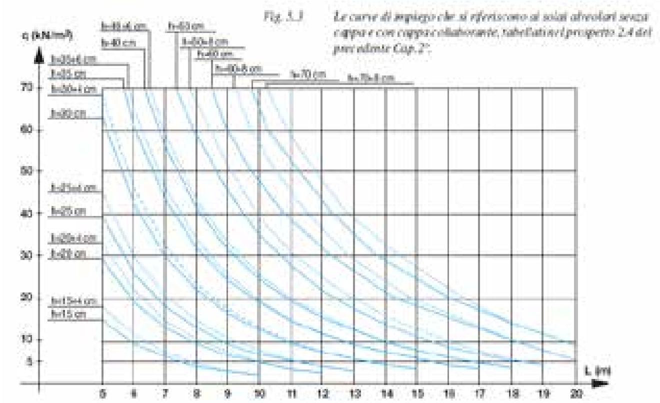


Figure 5.2.6 Hollow core slabs calibration curve. Source: ASSAP

h [mm]	W [kN/m^2]	W_l [kN/m^2]	$A_{s, max}$ [mm^2]	I [cm^4]	M_{max} [kNm]	V_{max} [kN]	s [cm]	I_{cs} [cm^4]	$M_{max, cs}$ [kNm]	$V_{max,cs}$ [kN]
150	2.3	2.45	900	27400	60	40	4	52000	80	45
200	2.8	3.00	1130	66000	115	50	4	110000	140	60
250	3.3	3.50	1180	120000	160	70	4	190000	185	80
300	3.6	4.00	1450	205000	230	80	4	310000	275	90
350	4.0	4.40	1600	315000	320	90	6	520000	380	100
400	4.7	5.30	1900	465000	420	105	6	700000	480	120
500	5.7	6.50	2300	900000	630	135	8	1400000	720	155
600	6.4	7.40	2500	1450000	760	140	8	2200000	870	170
700	7.3	8.40	2650	2200000	980	170	8	3200000	1080	205

Tab. 5.2.8 Hollow core slabs properties. Source: ASSAP

Where:

- h is the thickness of the floor slab [mm];
- W is the floor slab's own weight [kN/m^2];
- W_l is the floor slab's own weight once laid down [kN/m^2];
- $A_{s, max}$ is the reinforcement maximum area [mm^2]
- I is the floor slab's moment of inertia [cm^4];
- M_{max} is the floor slab's maximum bending strength [kNm];
- V_{max} is the floor slab maximum shear strength [kN];
- s is the cement screed's thickness [cm];

- I_{cs} is the floor slab's moment of inertia, with cement screed [cm^4];
- $M_{max, cs}$ is the floor slab's maximum bending strength, with cement screed [kNm];
- $V_{max, cs}$ is the floor slab maximum shear strength, with cement screed [kN].

Since the floor slabs' width is fixed and its thickness is the value that needs to be determined, the two factors regulating the loads on each slab are the span between beams and the type of floor. Analysing the frames of the new structure, 18 different load types have been identified, meaning 18 floor slabs (named S1 through S18) will need to be dimensioned in the following sections, as shown in the plans below:

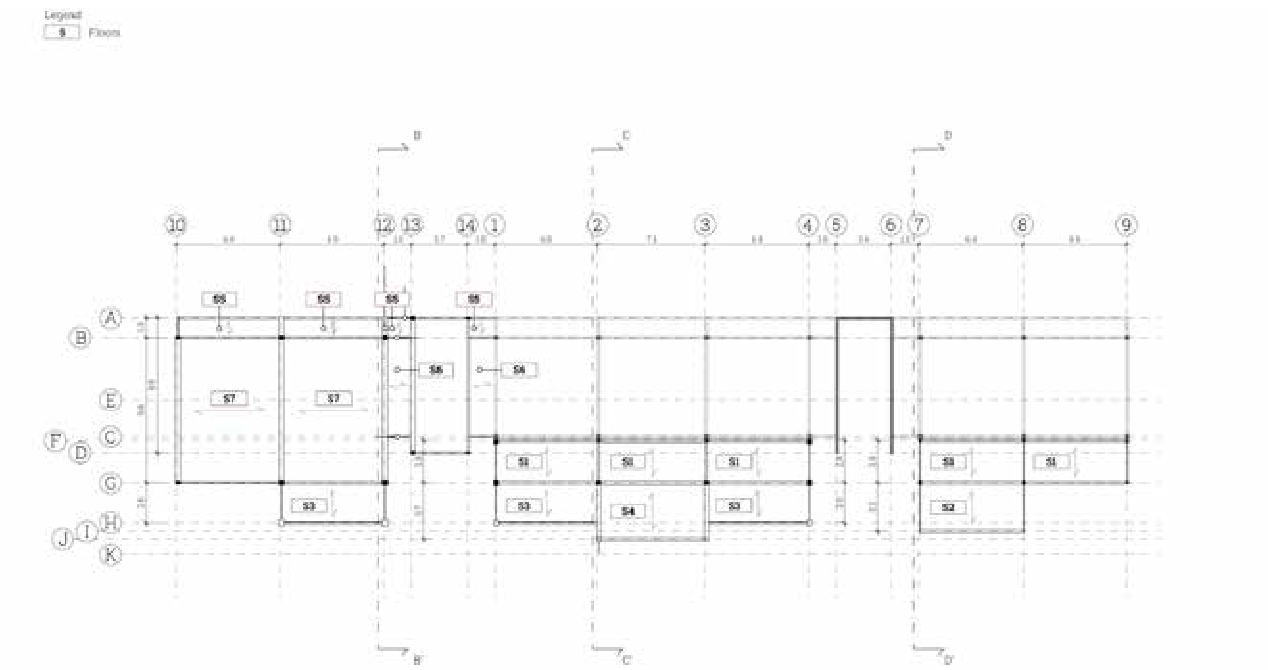


Figure 5.2.7 First Floor slabs plan

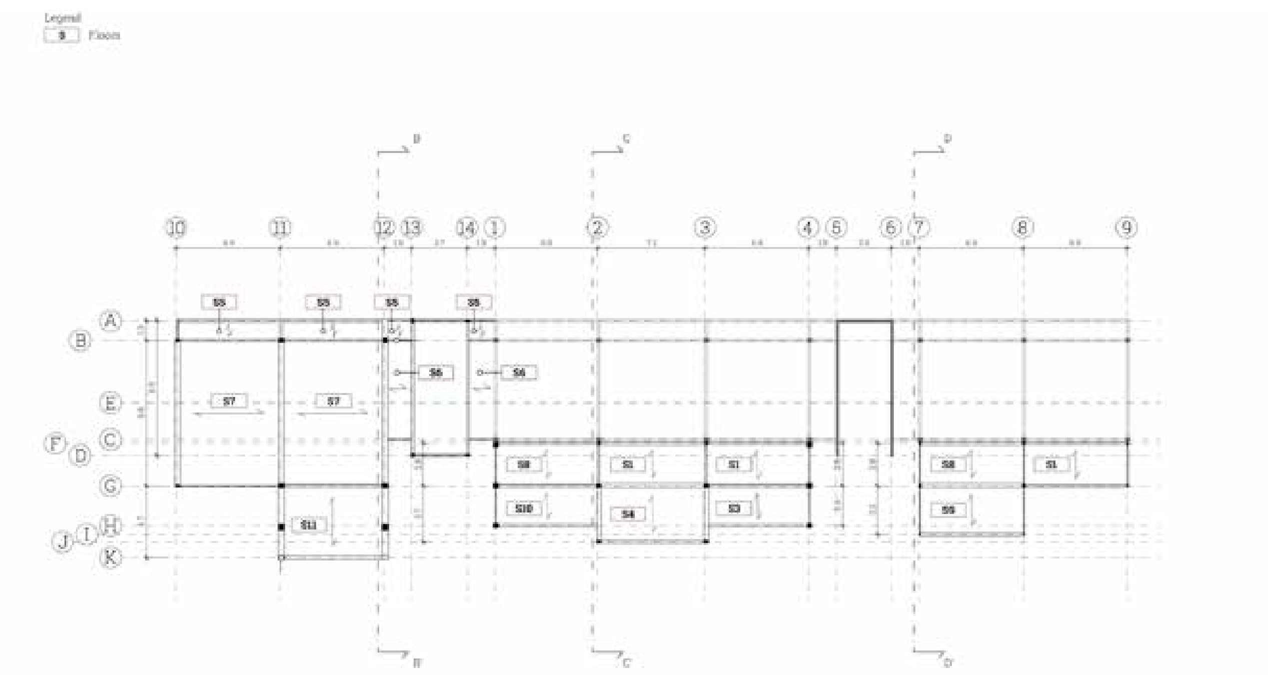


Figure 5.2.8 Second Floor slabs plan

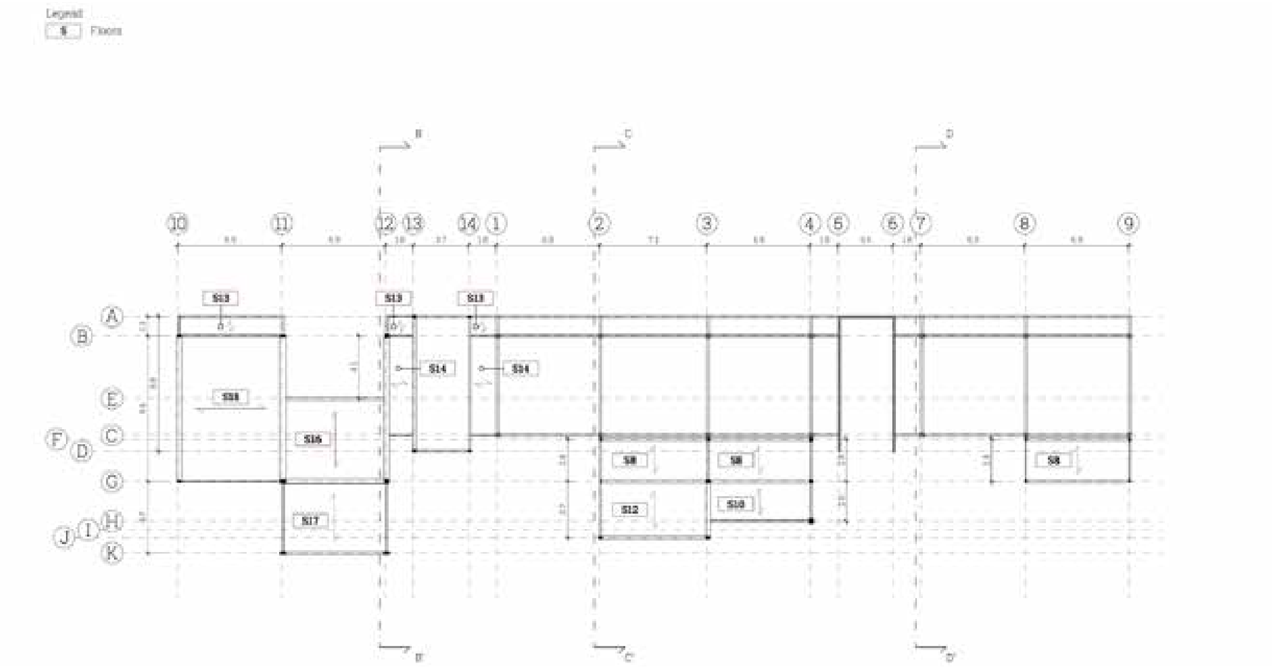


Figure 5.2.9 Roof slabs plan

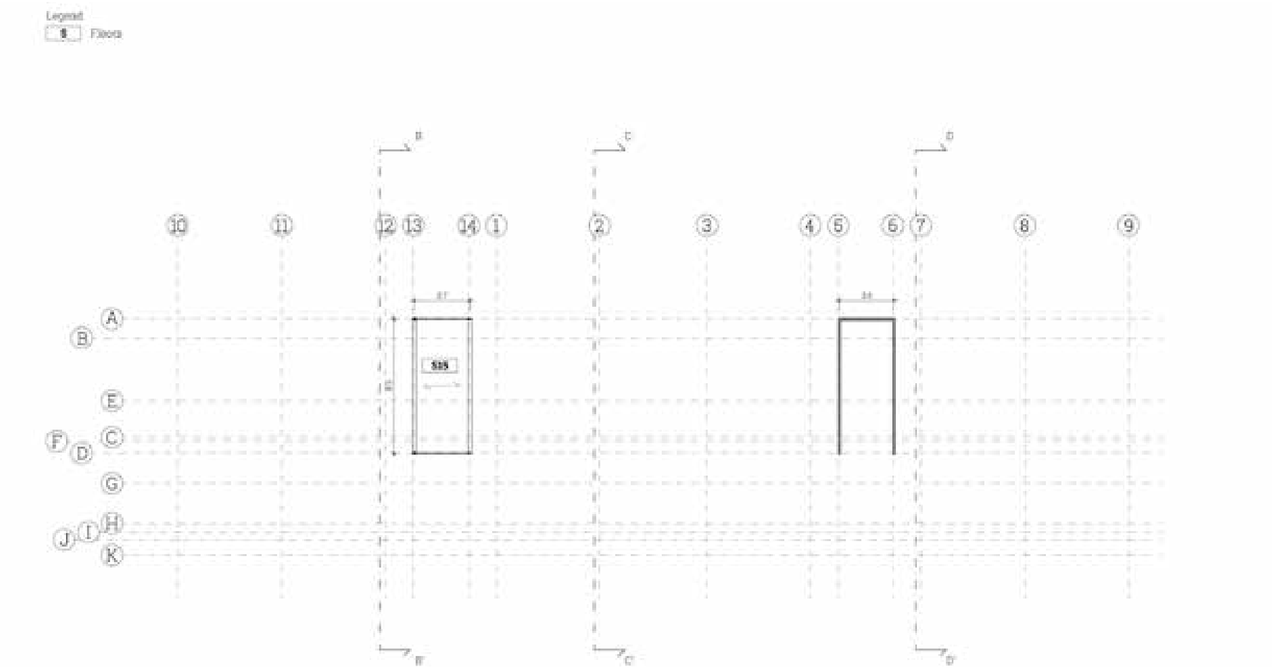


Figure 5.2.10 Roof slabs plan

5.2.6.2 Slenderness limit

Following the Norma Italiana D.M. 09.01.96 Art. 7.3.2 and the Istruzioni CNR 10025/98 par. 2.2.1, the criteria for the determination of the minimum height of hollow core slabs, specifically those in support of the beams with concrete screed is:

$$\frac{L_c}{h + \frac{s}{2}} \leq 35$$

Where:

- L_c is the span of the floor slab [m];
- h is the thickness of the floor slab [m];
- s is the thickness of the screed [m].

As h is the sole unknown, it can be easily determined, then compared to the produced floor slab thickness to choose the hollow core slab to be employed. The results for the new structure frames are shown in the tables below:

Slab	L_c [m]	h [m]	s [m]	λ
S01	2.90	0.15	0.04	17.06
S02	3.20	0.15	0.04	18.82
S03	2.70	0.15	0.04	15.88
S04	3.70	0.15	0.04	21.76
S05	1.35	0.15	0.04	7.94
S06	1.85	0.15	0.04	10.88
S07	6.85	0.20	0.04	31.14
S08	2.90	0.15	0.04	17.06
S09	3.20	0.15	0.04	18.82
S10	2.70	0.15	0.04	15.88
S11	4.75	0.15	0.04	27.94
S12	3.70	0.15	0.04	21.76
S13	1.35	0.15	0.04	7.94
S14	1.85	0.15	0.04	10.88
S15	3.60	0.15	0.04	21.18
S16	5.30	0.15	0.04	31.18
S17	4.75	0.15	0.04	27.94
S18	6.85	0.20	0.04	31.14

Tab. 5.2.9 Hollow core slabs slenderness limit

5.2.6.3 Instantaneous elastic deflection

The same paragraph of the D.M. 09.01.96 Art. 7.3.2 suggests also to verify the instantaneous elastic deflection of the slabs under both the permanent and variable loads. In particular:

Where:

$$\upsilon_{is,min} \leq \frac{L_c}{1000}$$

- $\upsilon_{is,\,min}$ is the minimum instantaneous elastic deflection [m].

This value should be compared with the general equations for the instantaneous elastic deflection:

$$\upsilon_{is} = K \cdot \frac{(G_k + Q_{ik}) \cdot L_c^4}{EI}$$

Where:

- υ_{is} is the instantaneous elastic deflection [m];
- K = 0.013 is a coefficient representing the slab restraints;
- G_k is the floor permanent load [kN/m^2];
- Q_{ik} is the floor variable load [kN/m^2];
- E is the hollow core slab Young modulus [kN/m^2];
- I is the hollow core slab moment of inertia [m^4].

Assuming the value from the first equation as the instantaneous elastic deflection limit, we can verify that the sections dimensioned previously with the slenderness are correct. The results are shown in the tables below:

Slab	K	G_k [kN/m^2]	Q_{ik} [kN/m^2]	L_c [m]	E_{cm} [kN/m^2]	I [m^4]	υ_{is} [m]	$\upsilon_{is, min}$ [m]
S01	0.013	5.52	2.00	2.90	3.35E+07	5.20E-04	3.98E-04	0.00290
S02	0.013	5.52	2.00	3.20	3.35E+07	5.20E-04	5.90E-04	0.00320
S03	0.013	5.52	2.00	2.70	3.35E+07	5.20E-04	2.99E-04	0.00270
S04	0.013	5.52	2.00	3.70	3.35E+07	5.20E-04	1.05E-03	0.00370
S05	0.013	5.52	2.00	1.35	3.35E+07	5.20E-04	1.87E-05	0.00135
S06	0.013	5.52	2.00	1.85	3.35E+07	5.20E-04	6.59E-05	0.00185
S07	0.013	6.07	2.00	6.85	3.35E+07	1.10E-03	6.28E-03	0.00685
S08	0.013	6.15	2.00	2.90	3.35E+07	5.20E-04	4.31E-04	0.00290
S09	0.013	6.15	2.00	3.20	3.35E+07	5.20E-04	6.39E-04	0.00320
S10	0.013	6.15	2.00	2.70	3.35E+07	5.20E-04	3.24E-04	0.00270
S11	0.013	5.52	2.00	4.75	3.35E+07	5.20E-04	2.86E-03	0.00475
S12	0.013	6.15	2.00	3.70	3.35E+07	5.20E-04	1.14E-03	0.00370
S13	0.013	6.15	2.00	1.35	3.35E+07	5.20E-04	2.02E-05	0.00135
S14	0.013	6.15	2.00	1.85	3.35E+07	5.20E-04	7.13E-05	0.00185
S15	0.013	6.15	2.00	3.60	3.35E+07	5.20E-04	1.02E-03	0.00360
S16	0.013	6.15	2.00	5.30	3.35E+07	5.20E-04	1.18E-03	0.00530
S17	0.013	6.15	2.00	4.75	3.35E+07	5.20E-04	3.10E-03	0.00475
S18	0.013	6.70	2.00	6.85	3.35E+07	1.10E-03	6.77E-03	0.00685

Tab. 5.2.10 Hollow core slabs instantaneous elastic deflection

5.2.6.4 Minimum support length

Before dimensioning the other elements of the frames, it is necessary to calculate the minimum support length of the wings of the inverted-T and L shaped beams the slabs are built-in support of. The nominal minimum support length is detailed in Part 1.3 "Elementi e strutture prefabricate in calcestruzzo", of the EC2 ENV 1992, Art. 4.5.5.2, in particular:

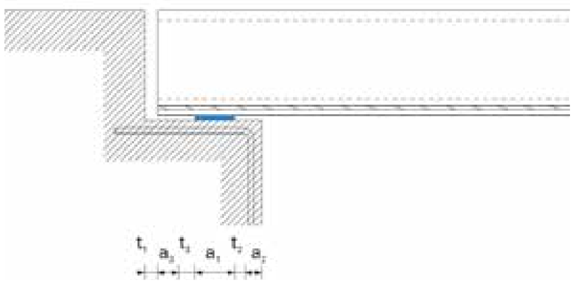


Figure 5.2.11 Minimum support lenght calculation scheme. Source: ASSAP

$$a = a_1 + (a_2^2 + a_3^2 + t_2^2 + t_3^2)^{\frac{1}{2}}$$

Where:

- a is the minimum support length [mm].

The other terms are detailed in the scheme above.

Where:

- $a_1 = \frac{V_{max}}{b_n \cdot \sigma_{Rd}}$ [m];
- V_{max} is the maximum shear force on the support point [kN];
- b_n is the effective support width, assumed at its maximum value b_n = 600 mm [mm];
- $\sigma_{Rd} = 0.6\ f_{cd}$ is the design value of pressure strength [N/mm2];
- a_2 = 25 mm is length of the possible subsidence of the load-bearing structure edge, equal to the concrete cover [mm];
- a_3 = 25 mm is the length of the possible subsidence at the edge of the element's head, equal to the concrete cover [mm];
- t_2 = 15 mm for precast concrete structures;
- $t_3 = L_c/2500$ [mm].

The results are shown in the table below and must be taken into account when designing the beams in the next section.

Slab	V_{max} [kN]	b_n [mm]	σ_{Rd} [N/mm²]	a_1 [mm]	a_2 [mm]	a_3 [mm]	t_2 [mm]	t_3 [mm]	a_{min} [mm]
S01	13.09	600	18.7	1.17E-03	25	25	15	1.16	38.42
S02	14.45	600	18.7	1.29E-03	25	25	15	1.28	38.43
S03	12.19	600	18.7	1.09E-03	25	25	15	1.08	38.44
S04	16.71	600	18.7	1.49E-03	25	25	15	1.48	38.41
S05	6.10	600	18.7	5.43E-04	25	25	15	0.54	38.41
S06	8.35	600	18.7	7.44E-04	25	25	15	0.74	38.41
S07	33.19	600	18.7	2.96E-03	25	25	15	2.74	38.51
S08	14.18	600	18.7	1.26E-03	25	25	15	1.16	38.42
S09	15.65	600	18.7	1.40E-03	25	25	15	1.28	38.43
S10	13.21	600	18.7	1.18E-03	25	25	15	1.08	38.42
S11	21.45	600	18.7	1.91E-03	25	25	15	1.90	38.45
S12	18.10	600	18.7	1.61E-03	25	25	15	1.48	38.44
S13	6.60	600	18.7	5.89E-04	25	25	15	0.54	38.41
S14	9.05	600	18.7	8.06E-04	25	25	15	0.74	38.42
S15	17.61	600	18.7	1.57E-03	25	25	15	1.44	38.43
S16	6.38	600	18.7	5.69E-04	25	25	15	2.12	38.46
S17	23.23	600	18.7	2.07E-03	25	25	15	1.90	38.45
S18	35.77	600	18.7	3.19E-03	25	25	15	2.74	38.51

Tab. 5.2.11 Hollow core slabs minimum support length

5.2.7 New structure frames' forces

As mentioned above, the three new structure frames are independent from the old one, meaning that, in order to calculate the frames' internal forces, each independent portion of the new frames (Frame 1, 2 and 3), can be analysed separately, simplifying the calculation process. Further, each beam and column has been named depending on which frame it belongs to, as shown in the plans below:

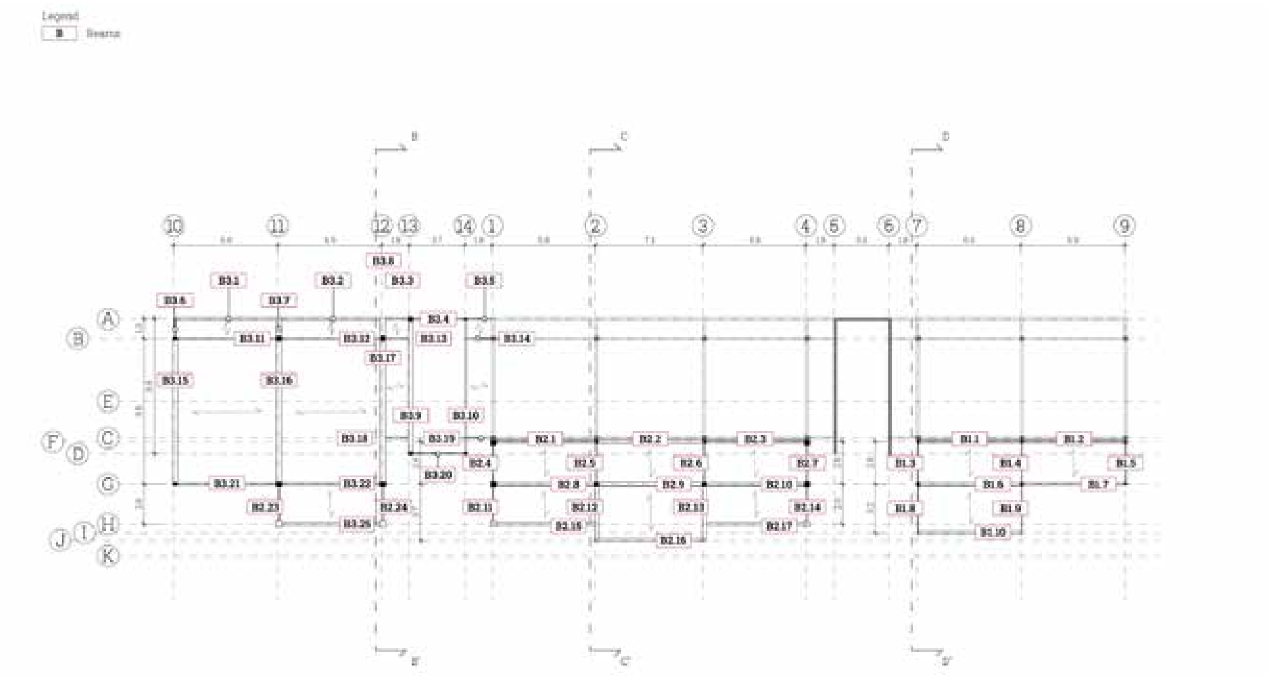


Figure 5.2.12 First Floor beams plan

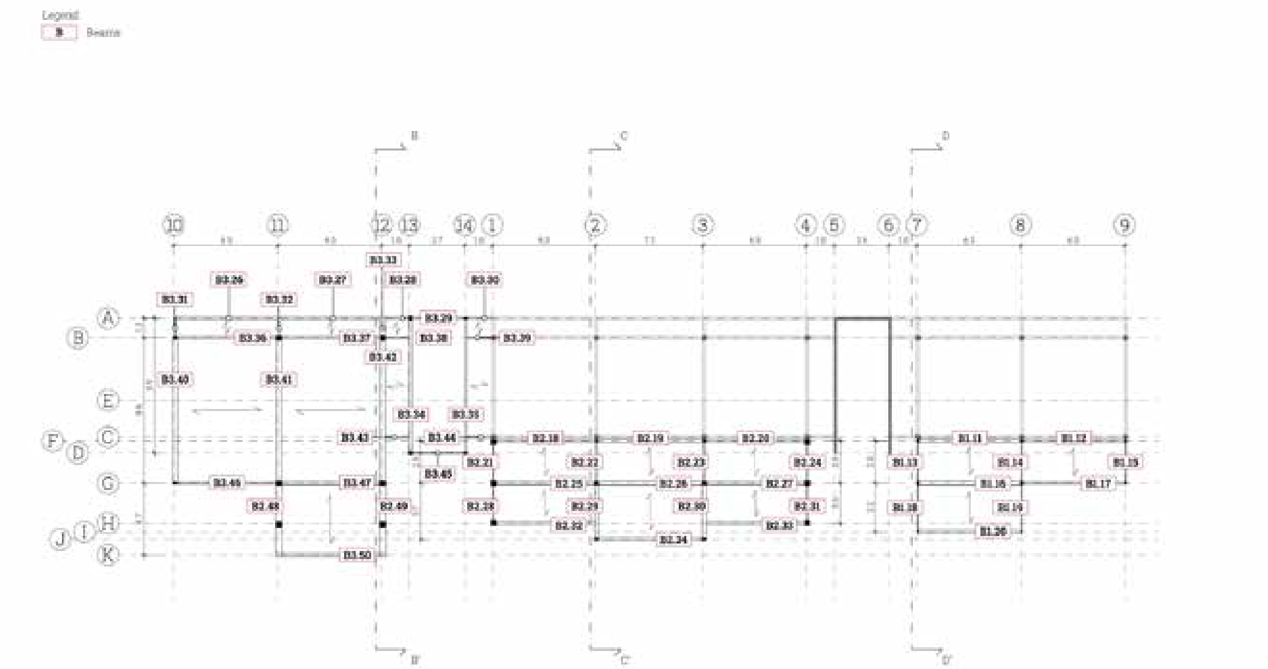


Figure 5.2.13 Second Floor beams plan

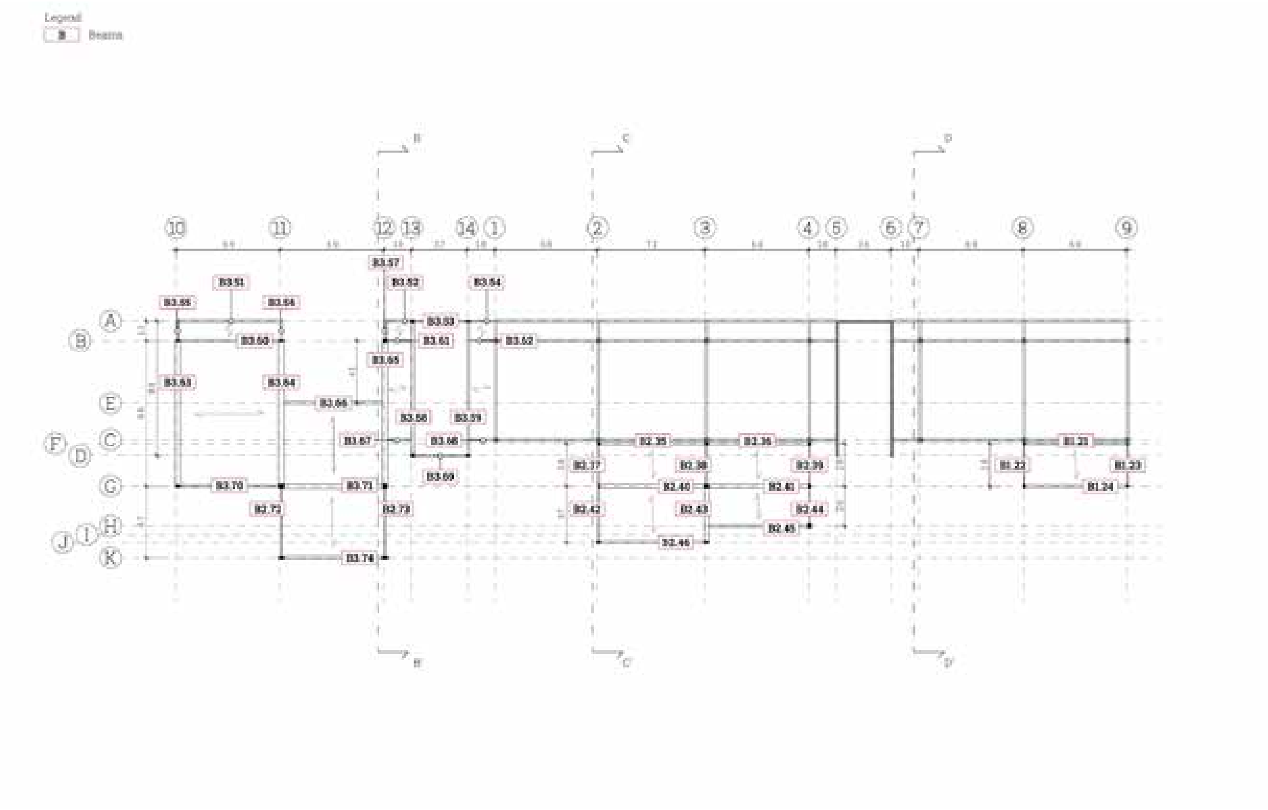


Figure 5.2.14 Roof beams plan

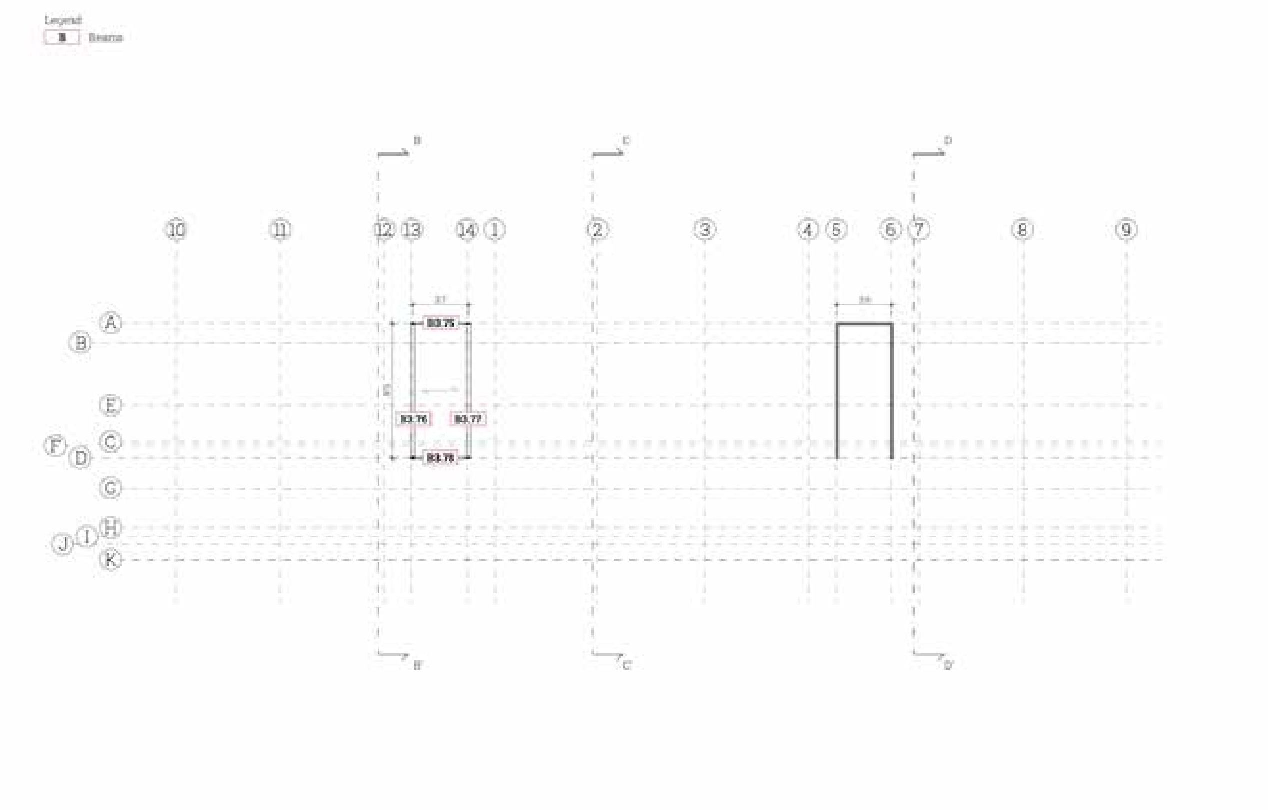


Figure 5.2.15 Roof beams plan

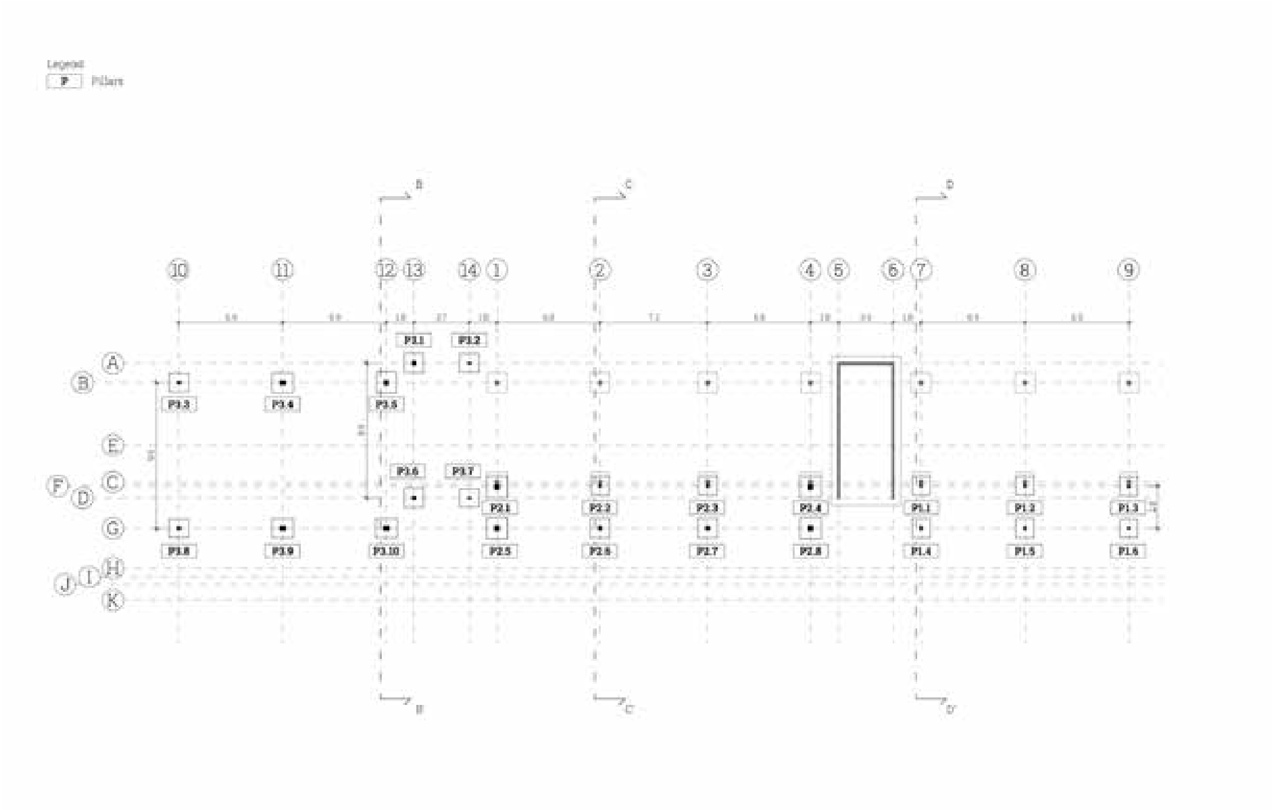


Figure 5.2.16 Foundation plinths and columns plan

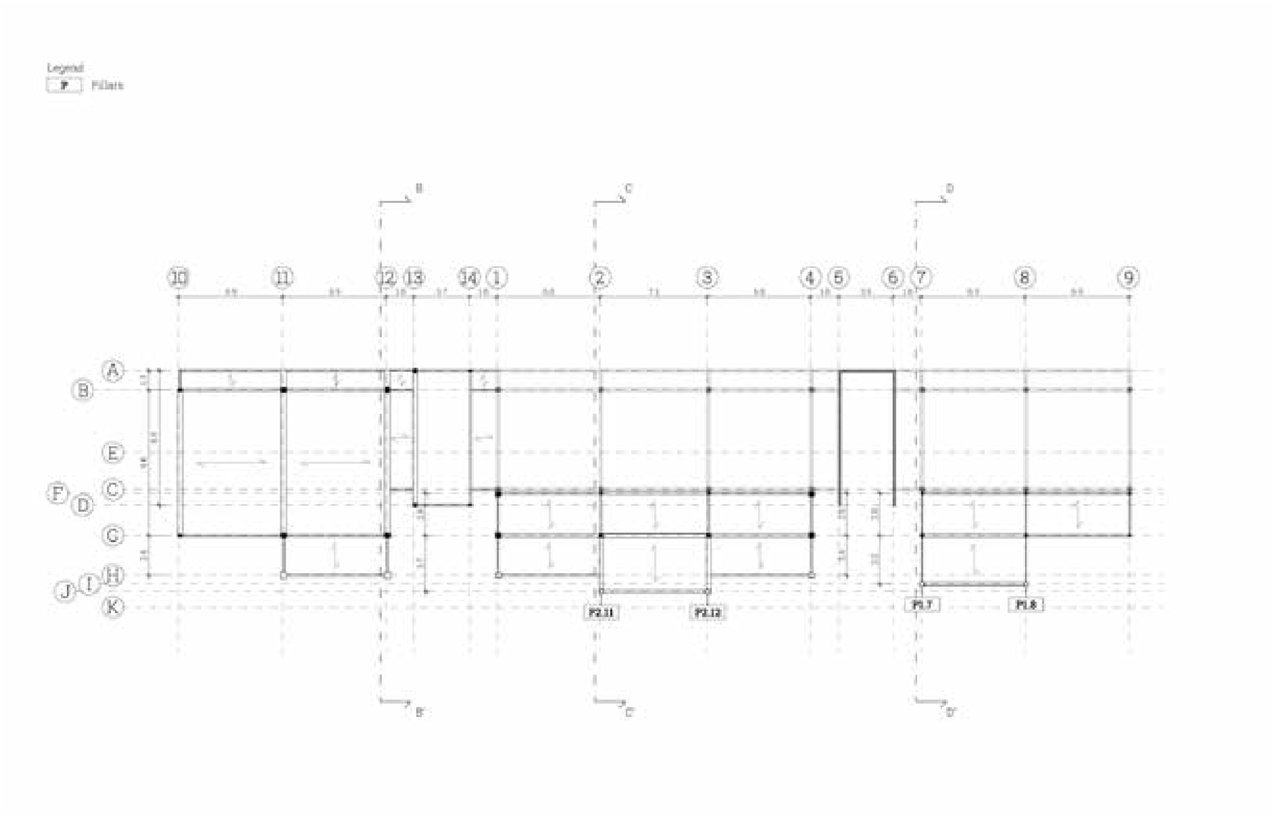


Figure 5.2.17 First Floor columns plan

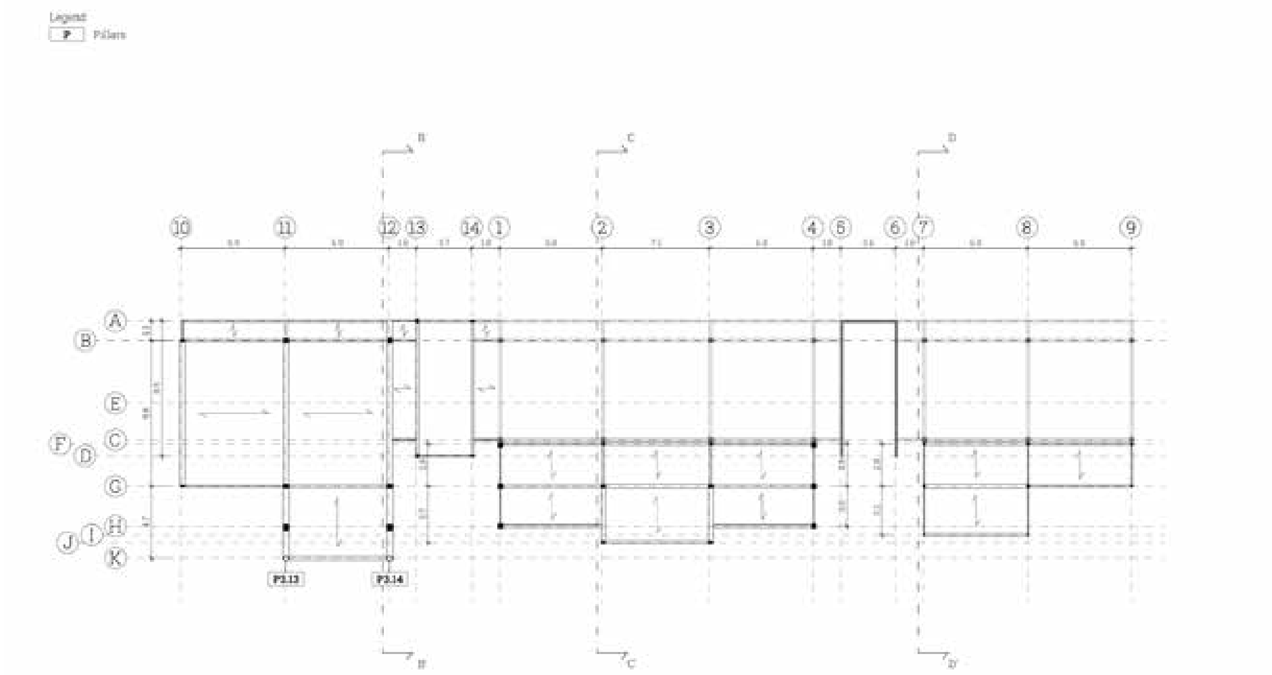


Figure 5.2.18 Second Floor columns plan

Using the finite elements software SAP2000, the three frames have been modelled separately, and the loads calculated in the previous sections assigned as uniformly distributed loads on beams, in the loads' combination provided by NTC 2018 (SLU, SLE rare, frequent and quasi permanent). After the three simulations were complete, all the internal and nodal forces of the frames have been obtained, along with the rods' deformations, as shown in the following images:

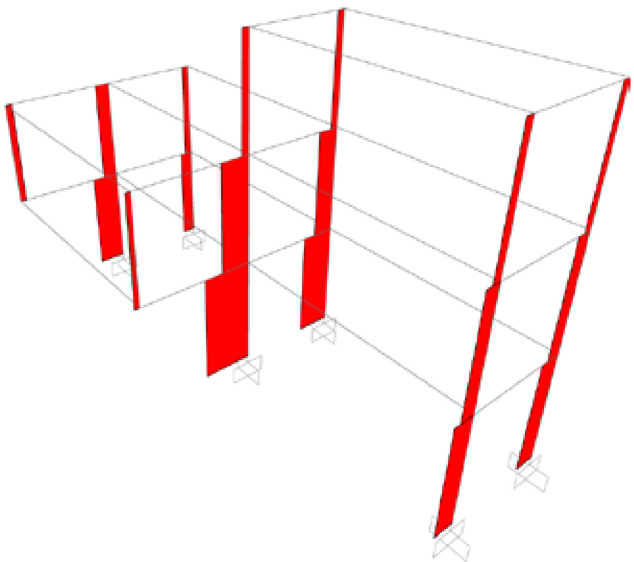


Figure 5.2.19 Frame 1: Axial force diagram

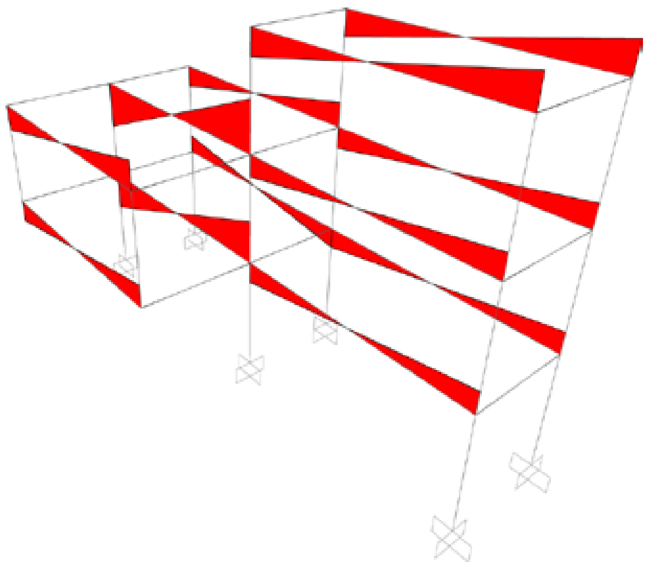


Figure 5.2.20 Frame 1: Shear force diagram

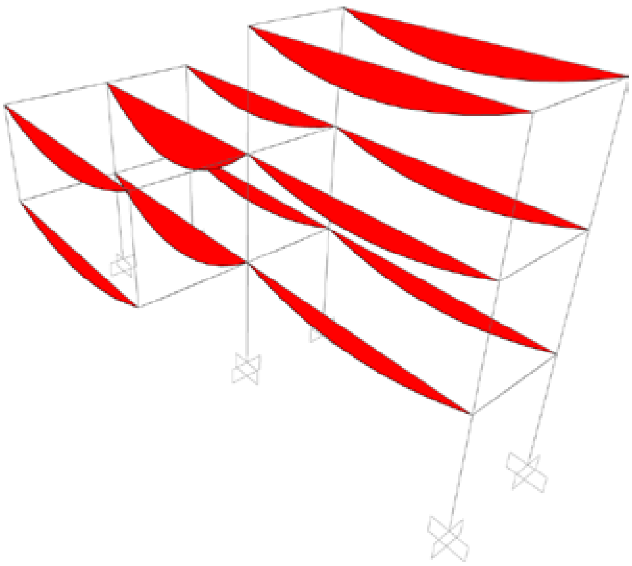


Figure 5.2.21 Frame 1: Moment diagram

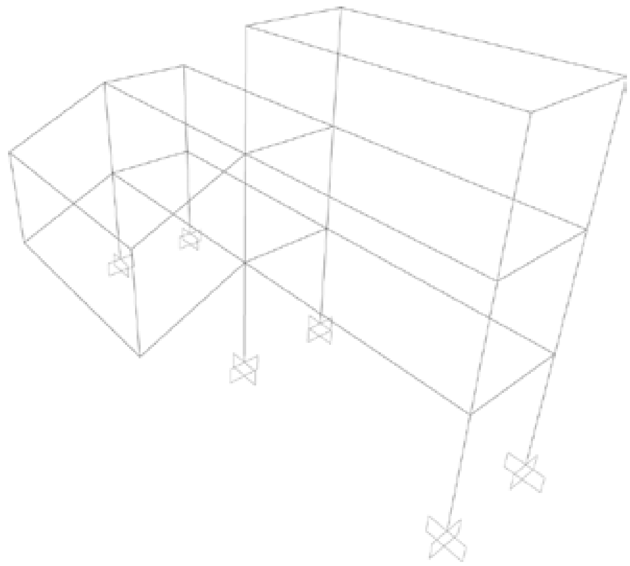


Figure 5.2.22 Frame 1: Deformation diagram

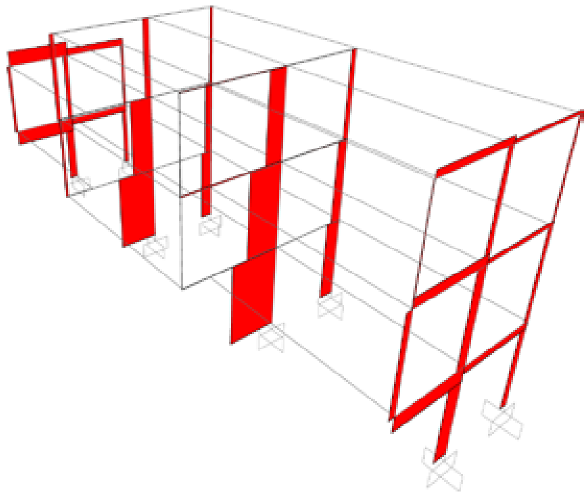


Figure 5.2.23 Frame 2: Axial force diagram

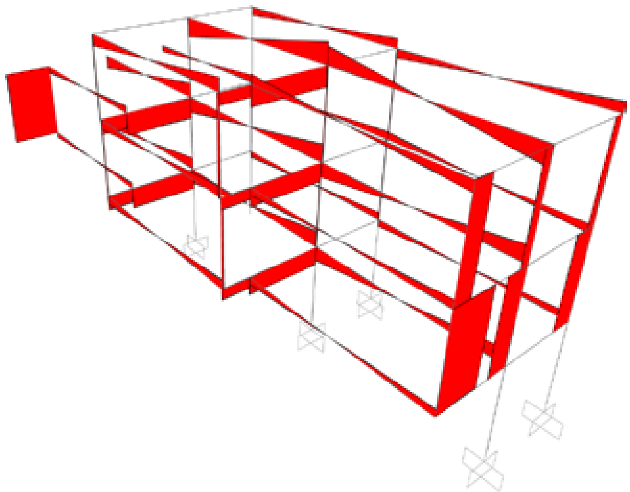


Figure 5.2.24 Frame 2: Shear force diagram

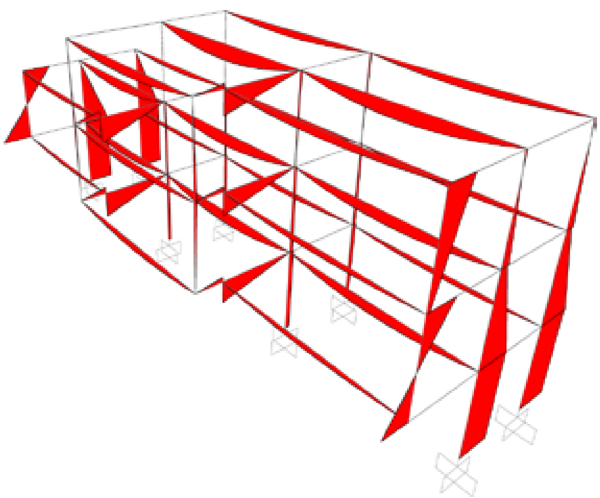


Figure 5.2.25 Frame 2: Moment diagram

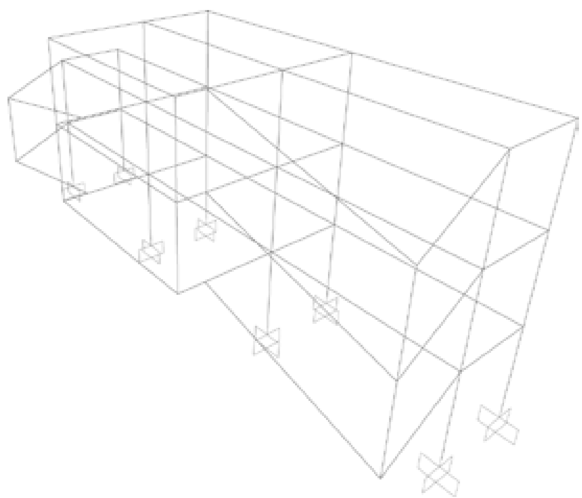


Figure 5.2.26 Frame 2: Deformation diagram

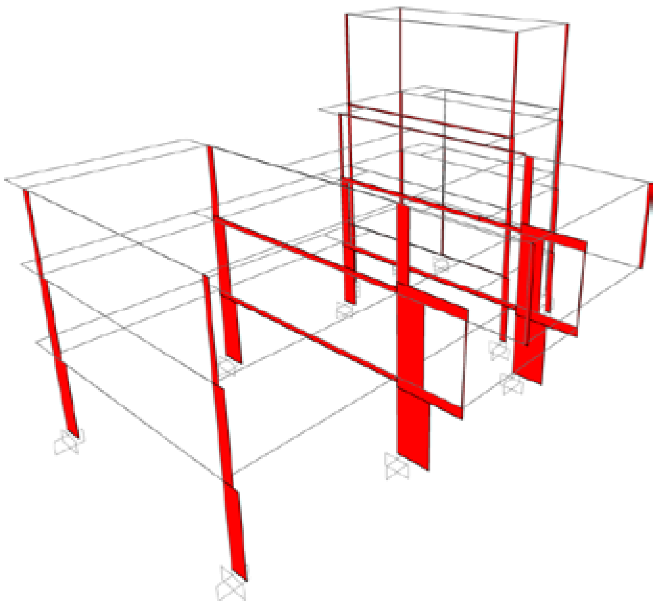


Figure 5.2.27 Frame 3: Axial force diagram

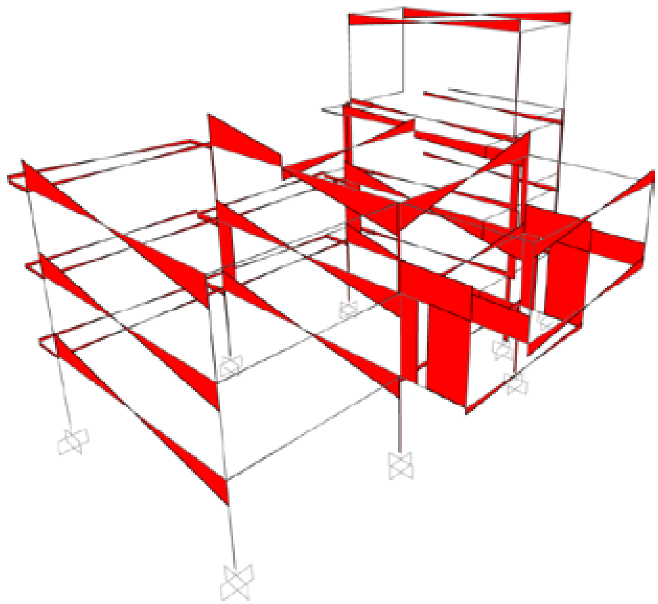


Figure 5.2.28 Frame 3: Shear force diagram

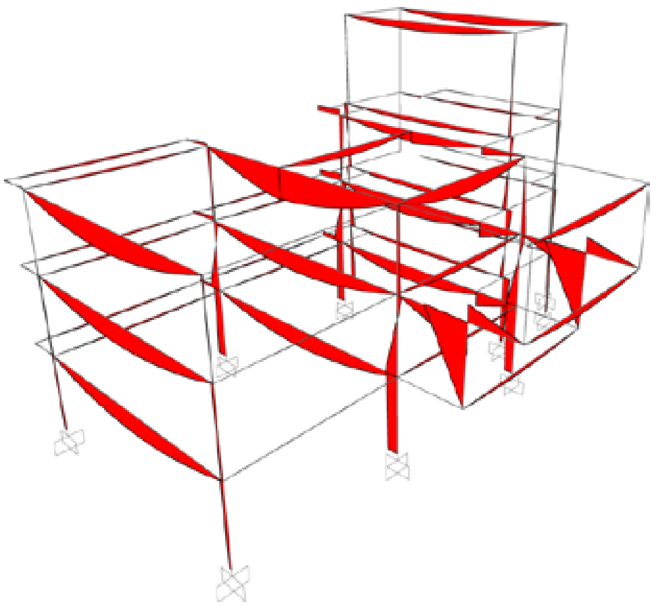


Figure 5.2.29 Frame 2: Moment diagram

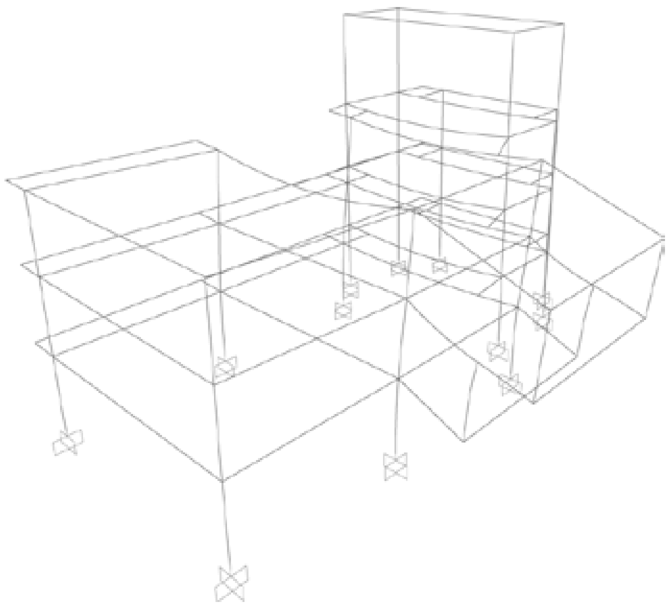


Figure 5.2.30 Frame 2: Deformation diagram

5.2.8 Beams

5.2.8.1 Overview

While there exist a number of precast reinforced concrete beam sections, for the frames designed in this project, it has been decided, as alluded briefly above, to use inverted-T and L shaped beams, which can easily house the floor slabs designed above within their height. It should be noticed that the stalks of any given beam, on its own, should be calculated to hold the loads encumbering it, while the wings have been designed using the calculations already shown above.

The specific provisions for dimensioning precast elements (be they beams or columns) are contained in NTC 2018 § 4.1.10, though the verifications needed are, for the most part, the very same used for standard cast concrete, contained in § 4.1.2 and § 11.2. In particular, reinforced concrete beams needs to be designed to resist bending moment and transverse shear.

Detailed drawings and data on beam sections are found in the appendix.

5.2.8.2 Steel Bars

NTC 2018 § 4.1.6.1.1 provides the equations in order to find the minimum area of steel bars necessary in relation to the concrete area of a beam, using the loads in SLU combination:

$$A_{s,d,min} = MAX[A_{s,req}; A_{s,min,1}; A_{s,min,2}]$$

Where:

- $A_{s,\,d,\,min}$ is the minimum design steel area [mm²];
- $A_{s,\,req}$ is the requested steel bars area [mm²]: $A_{s,req} = \frac{0.8 \cdot b \cdot x \cdot f_{cd}}{f_{yd}}$
- b is the beam's stalk base [mm];
- x is the neutral axis' position [mm];
- $A_{s,\,min,\,1}$ is the minimum steel bars area [mm²]: $A_{s,min,1} = 0.26 \cdot \frac{f_{ctm}}{f_{yk}} \cdot d \cdot b$
- d=h - c is the useful height of the beam's stalk [mm];
- h is the beam's stalk height [mm];
- c is the concrete cover [mm];
- $A_{s,\,min,\,2}$ is the minimum steel bars area [mm²]: $A_{s,min,2} = 0.0013 \cdot b \cdot d$

Having found the minimum steel bars design area, the number and the diameter of the bars will be chosen so that the resulting area As, d is greater than the former. Below is an example of the calculations for beam B1.1:

X [m]	h [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$A_{s,\,d,\,min}$ [mm²]	n	n'	Φ	Φ'	$A_{s,\,d}$ [mm²]	$A'_{s,\,d}$ [mm²]
0.00	300	150	25	275	0.00	58.17	2	2	8	8	100.48	100.48
0.57	300	150	25	275	26.92	144.71	2	2	10	8	157.00	100.48
1.14	300	150	25	275	50.77	272.97	4	2	10	8	314.00	100.48
1.71	300	150	25	275	70.77	380.46	4	2	12	8	452.16	100.48
2.28	300	150	25	275	86.00	462.33	4	2	14	8	615.44	100.48
2.85	300	150	25	275	95.58	513.87	4	2	14	8	615.44	100.48
3.43	300	150	25	275	98.86	531.49	4	2	14	8	615.44	100.48
4.00	300	150	25	275	98.58	513.87	4	2	14	8	615.44	100.48
4.57	300	150	25	275	86.00	462.33	4	2	14	8	615.44	100.48
5.14	300	150	25	275	70.77	380.46	4	2	12	8	452.16	100.48
5.71	300	150	25	275	50.77	272.97	4	2	10	8	314.00	100.48
6.28	300	150	25	275	26.92	144.71	2	2	10	8	157.00	100.48
6.85	300	150	25	275	0.00	58.17	2	2	8	8	100.48	100.48

Tab. 5.2.12 Beam B1.1: Steel bars dimensioning

5.2.8.3 Bending strength

NTC 2018 § 4.1.2.3.4 provides the equations in order to find the resisting design moment to be compared to the design bending moment bore by the beam (both with and without axial force), using the loads in SLU combination:

$$M_{Rd} = A_{s,d} \cdot f_{yd} \cdot (d - 0.4x) \leq M_{Ed}$$

Where:

- M_{Rd} is the resisting design moment [kNm];
- M_{Ed} is the design bending moment [kNm].

Below is an example of the calculations for beam B1.1:

X [m]	M_{Ed} [kNm]	n	n'	Φ	Φ'	$A_{s,d}$ [mm²]	$A'_{s,d}$ [mm²]	x [mm]	M_{Rd} [kNm]
0.00	0.00	2	2	8	8	100.48	100.48	18.69	18.70
0.57	26.60	2	2	10	8	157.00	100.48	29.20	28.76
1.14	48.36	4	2	10	8	314.00	100.48	58.41	54.97
1.71	65.29	4	2	12	8	452.16	100.48	84.10	75.92
2.28	77.38	4	2	14	8	615.44	100.48	114.47	98.13
2.85	84.64	4	2	14	8	615.44	100.48	114.47	98.13
3.43	87.06	4	2	14	8	615.44	100.48	114.47	98.13
4.00	84.64	4	2	14	8	615.44	100.48	114.47	98.13
4.57	77.38	4	2	14	8	615.44	100.48	114.47	98.13
5.14	65.29	4	2	12	8	452.16	100.48	84.10	75.92
5.71	48.36	4	2	10	8	314.00	100.48	58.41	54.97
6.28	26.60	2	2	10	8	157.00	100.48	29.20	28.76
6.85	0.00	2	2	8	8	100.48	100.48	18.69	18.70

Tab. 5.2.13 Beam B1.1: Bending stength

5.2.8.4 Materials stress

NTC 2018 § 4.1.2.2.5 provides the equations in order to find the maximum stress for concrete and steel bars, using the SLE combinations:

$$\sigma_{c,max} \leq 0.6\ f_{ck}$$

Where:

- $\sigma_{c,max}$ is the maximum tension in the concrete, in SLE rare combination [N/mm²].

$$\sigma_{c,max} \leq 0.45\ f_{ck}$$

Where:

- $\sigma_{c,max}$ is the maximum tension in the concrete, in SLE quasi permanent combination [N/mm²].

$$\sigma_{s,max} = 0.8\ f_{yk}$$

Where:

- $\sigma_{s, max}$ is the maximum tension in the concrete, in SLE rare combination [N/mm²].

Below is an example of the calculations for beam B1.1:

X [m]	M_{Ed} [kNm]	h [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$\sigma_{c,r}$ [N/mm²]	$\sigma_{s,r}$ [N/mm²]
0.00	0.00	300	150	25	275	60.11	0.00	0.00
0.57	17.82	300	150	25	275	73.25	12.95	276.24
1.14	32.41	300	150	25	275	98.16	18.17	322.70
1.71	43.75	300	150	25	275	113.33	21.70	333.70
2.28	51.85	300	150	25	275	127.10	23.38	311.32
2.85	56.71	300	150	25	275	127.10	25.57	340.50
3.43	58.33	300	150	25	275	127.10	26.30	350.23
4.00	56.71	300	150	25	275	127.10	25.57	340.50
4.57	51.85	300	150	25	275	127.10	23.38	311.32
5.14	43.75	300	150	25	275	113.33	21.70	333.70
5.71	32.41	300	150	25	275	98.16	18.17	322.70
6.28	17.82	300	150	25	275	73.25	12.95	276.24
6.85	0.00	300	150	25	275	60.11	0.00	0.00

Tab. 5.2.14 Beam B1.1: Material stress, SLE rare

X [m]	M_{Ed} [kNm]	h [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$\sigma_{c,r}$ [N/mm²]
0.00	0.00	300	150	25	275	60.11	0.00
0.57	16.78	300	150	25	275	73.25	12.19
1.14	30.52	300	150	25	275	98.16	17.11
1.71	41.20	300	150	25	275	113.33	20.43
2.28	48.83	300	150	25	275	127.10	22.02
2.85	53.40	300	150	25	275	127.10	24.08
3.43	54.93	300	150	25	275	127.10	24.77
4.00	53.40	300	150	25	275	127.10	24.08
4.57	48.83	300	150	25	275	127.10	22.02
5.14	41.20	300	150	25	275	113.33	20.43
5.71	30.52	300	150	25	275	98.16	17.11
6.28	16.78	300	150	25	275	73.25	12.19
6.85	0.00	300	150	25	275	60.11	0.00

Tab. 5.2.15 Beam B1.1: Material stress, SLE quasi permanent

5.2.8.5 Steel stirrups

NTC 2018 § 4.1.2.3.5.2 provides the equations in order to find the resisting design transverse shear to be compared to the design transverse shear bore by the beam, using loads in SLU combination:

$$V_{Rd} = MIN[V_{Rsd}; V_{Rcd}] \leq V_{Ed}$$

Where:

- V_{Rd} is the resisting transverse shear [kN];
- V_{Rsd} is the resisting transverse shear for the steel tie [kN]:

  $$V_{Rsd} = 0.9 \cdot d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot \cot(\alpha + 2) \cdot \sin\alpha$$

- A_{sw} is the steel stirrups area [mm^2];
- s is the distance between stirrups [mm]
- α is the angle of the stirrups [°];
- V_{Rcd} is the resisting transverse shear for the concrete strut [kN]: $V_{Rcd} = \frac{0.9 \cdot b \cdot d \cdot \nu \cdot f_{cd}}{2 + \tan 26.5}$
- v is a coefficient: $\nu = 0.6 \cdot (1 - \frac{f_{ck}}{250})$
- V_{Ed} is the design transverse shear [kN].

Below is an example of the calculations for beam B1.1:

X [m]	V_{Ed} [kN]	n	Φ	A_{sw} [mm^2]	s [mm]	α	v	V_{Rsd} [kN]	V_{Rcd} [kN]	V_{Rd} [kN]
0.00	-50.84	2	8	100.48	110	90	0.49	314.55	227.12	227.12
0.57	-42.36	2	8	100.48	200	90	0.49	173.00	227.12	173.00
1.14	-33.89	2	8	100.48	100	90	0.49	346.00	227.12	227.12
1.71	-25.42	2	8	100.48	200	90	0.49	173.00	227.12	173.00
2.28	-16.95	2	8	100.48	100	90	0.49	346.00	227.12	227.12
2.85	-8.47	2	8	100.48	200	90	0.49	173.00	227.12	173.00
3.43	0.00	2	8	100.48	100	90	0.49	346.00	227.12	227.12
4.00	8.47	2	8	100.48	200	90	0.49	173.00	227.12	173.00
4.57	16.95	2	8	100.48	100	90	0.49	346.00	227.12	227.12
5.14	25.42	2	8	100.48	200	90	0.49	173.00	227.12	173.00
5.71	33.89	2	8	100.48	100	90	0.49	346.00	227.12	227.12
6.28	42.36	2	8	100.48	200	90	0.49	173.00	227.12	173.00
6.85	50.84	2	8	100.48	110	90	0.49	314.55	227.12	227.12

Tab. 5.2.16 Beam B1.1: Steel stirrups dimensioning

5.2.9 Columns

5.2.9.1 Overview

Precast reinforced concrete columns differ little from their cast concrete counterparts. The key difference lays in the presence of corbel upon which the beam lay in support, over sheets of neoprene. The corberl won't be dimensioned in the following section, though they follow the same provisions of the beams' wings.

The specific provisions for dimensioning precast elements (be they beams or columns) are contained in NTC 2018 § 4.1.10, though the verifications needed are, for the most part, the very same used for standard cast concrete, contained in § 4.1.2 and § 11.2. In particular, reinforced concrete beams needs to be designed to resist axial force or eccentric axial force.

Detailed drawings and data on column sections are found in the appendix.

5.2.9.2 Steel bars

NTC 2018 § 4.1.6.1.2 provides the equations in order to find the minimum area of steel bars necessary in relation to the concrete area of a column, that is subjected mostly to axial force, using the loads in SLU combination:

$$A_{s,min} = 0.10 \cdot \frac{N_{Ed}}{f_{yd}}$$

Or, at least:

$$A_{s,d} = 0.003 \cdot A_c$$

Where:

- $A_{s,min}$ is the minimum steel bars area [mm^2];
- N_{Ed} is the axial force on the column [kN];
- $A_{s,d}$ is the design steel bars area [mm^2]
- A_c is the concrete area [mm^2].

Having found the minimum steel bars design area, the number and the diameter of the bars will be chosen so that the resulting area As, d is greater than the former. Below is an example of the calculations for column P1.1:

h [m]	N_{Ed} [kN]	a [mm]	b [mm]	A_c [mm^2]	$A_{s,min}$ [mm^2]	$A_{s,d}$ [mm^2]	n	Φ	A_s [mm^2]
0.00	-117.97	150	200	30000	16.96	90.00	8	16	160.77
3.00	-114.07	150	200	30000	16.40	90.00	8	14	123.09
3.00	-62.53	150	200	30000	8.99	90.00	8	14	123.09
6.00	-58.63	150	200	30000	8.43	90.00	8	14	123.09

Tab. 5.2.17 Column P1.1: Steel bars dimensioning

For columns subjected to eccentric axial force, the equations presented above for beams can be reused, as shown in the example below for column P2.1:

h [m]	a [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$A_{s, d, min}$ [mm²]	n	n'	Φ	Φ'	$A_{s, d}$ [mm²]	$A'_{s, d}$ [mm²]
0.00	350	350	25	325	258.44	3241.97	2	6	12	28	226.08	3692.64
3.00	350	350	25	325	255.50	3205.08	2	6	12	28	226.08	3692.64
3.00	350	350	25	325	273.77	3434.35	2	6	12	28	226.08	3692.64
6.00	350	350	25	325	9.56	119.99	4	2	12	12	452.16	226.08

Tab. 5.2.18 Column P2.1: Steel bars dimensioning

h [m]	M_{Ed} [kNm]	n	n'	Φ	Φ'	$A_{s, d}$ [mm²]	$A'_{s, d}$ [mm²]	x [mm]	M_{Rd} [kNm]
0.00	-499.83	2	6	12	28	226.08	3692.64	294.36	532.40
3.00	-496.76	2	6	12	28	226.08	3692.64	294.36	532.40
3.00	-514.83	2	6	12	28	226.08	3692.64	294.36	532.40
6.00	26.81	4	2	12	12	452.16	226.08	36.04	97.69

Tab. 5.2.19 Column P2.1: Bending strenght

5.2.9.3 Materials stress

The same provisions listed above for beams apply to columns, both subjected to eccentric and non-eccentric axial force. Results for both cases are shown below for columns P1.1 and P2.1, respectively:

h [m]	N_{Ed} [kN]	A_c [mm²]	A_s [mm²]	$\sigma_{c,r}$ [N/mm²]	$\sigma_{s,r}$ [N/mm²]
0.00	-79.93	30000	160.77	2.66	497.20
3.00	-76.93	30000	123.09	2.56	625.03
3.00	-42.33	30000	123.09	1.41	343.90
6.00	-39.33	30000	123.09	1.31	319.53

Tab. 5.2.20 Column P1.1: Material stress, SLE rare

h [m]	N_{Ed} [kN]	A_c [mm²]	$\sigma_{c,r}$ [N/mm²]
0.00	-75.96	30000	2.53
3.00	-72.96	30000	2.43
3.00	-40.34	30000	1.34
6.00	-37.34	30000	1.24

Tab. 5.2.21 Column P1.1: Material stress, SLE quasi permanent

h [m]	N_{Ed} [kN]	M_{Ed} [kNm]	a [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$\sigma_{c,r}$ [N/mm²]	$\sigma_{s,r}$ [N/mm²]
0.00	-79.40	-336.38	350	350	25	325	38.01	5.97	30.39
3.00	-76.40	-334.32	350	350	25	325	38.01	5.74	29.25
3.00	-42.05	-346.48	350	350	25	325	38.01	3.16	16.09
6.00	-39.05	18.04	350	350	25	325	88.94	1.25	86.36

Tab. 5.2.22 Column P2.1: Material stress, SLE rare

h [m]	N_{Ed} [kN]	M_{Ed} [kNm]	a [mm]	b [mm]	c [mm]	d [mm]	x [mm]	$\sigma_{c,r}$ [N/mm²]
0.00	-75.46	-318.40	350	350	25	325	38.01	5.67
3.00	-72.46	-316.45	350	350	25	325	38.01	5.45
3.00	-40.08	-327.96	350	350	25	325	38.01	3.01
6.00	-37.08	17.08	350	350	25	325	88.94	1.19

Tab. 5.2.23 Column P2.1: Material stress, SLE quasi permanent

5.2.10 Plinths

5.2.10.1 Overview

As mentioned at various stages in this report, Rocinha's terrain is for the most part rocky just under the surface. Therefore it makes the most sense to use superficial foundations in this design, moreover, to maximise the adaptability of the new foundation elements both to the terrain and the existing structure which they need to be connected to, it has been decided to use standard cast reinforced concrete plinths instead of precast concrete ones.

The specific provisions for dimensioning superficial foundations are contained in NTC 2018 § 6.4.2. The plinths are simplified as double reversed bending bracket, shown below:

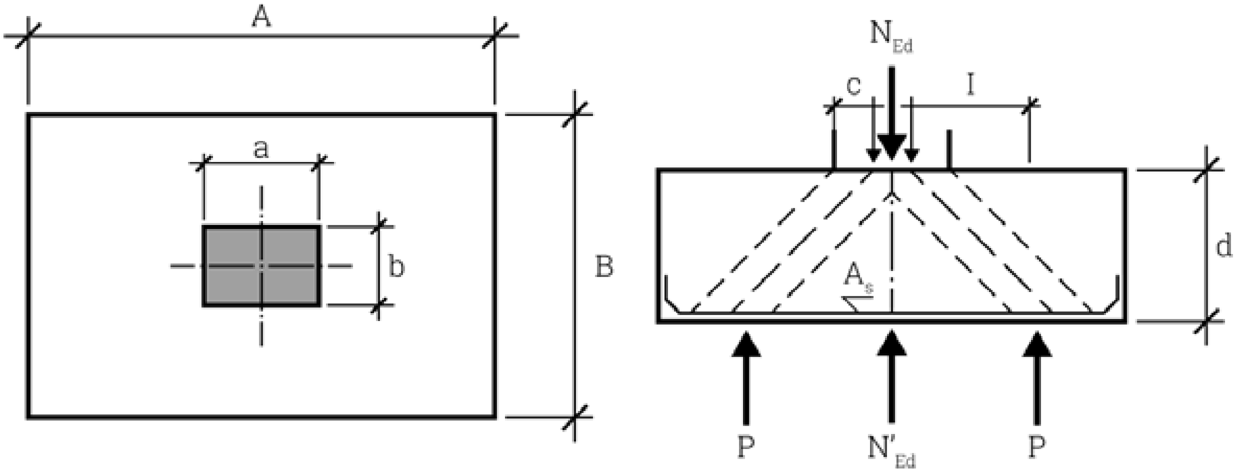


Figure 5.2.31 Plinth diagram

Detailed drawings and data on plinth sections are found in the appendix.

5.2.10.2 Steel bars

As shown in the image above, plinths have two sides (a and b), and doubly symmetrical; as such, the formulas below must be repeated for both sides:

$$A_{s,min} = \frac{N_{Ed} - N'_{Ed}}{2 \cdot f_{yd}} \lambda$$

Where:

- $A_{s,\,min}$ is the minimum steel bars area [mm²];
- N'_{Ed} is the terrain reaction force [kN]: $N'_{Ed} = \frac{l}{L \cdot N_{Ed}}$

- l is the measure of the column's side [mm];
- L is the measure of the plinth's side [mm];
- λ=d / I is the slenderness of the strut;
- d=H - c is the useful height of the plinth [mm];
- H is the height of the plinth [mm];
- I is the internal lever arm of the strut [mm]: $I = \frac{L-l}{4} + c_a$
- c_a is the concrete cover on the designed side [mm]: $c_a = MIN[0.2 \cdot l; \frac{d}{4}]$

Having found the minimum steel bars design area, the number and the diameter of the bars will be chosen and verified via the equation:

$$N_{Rsd} = N'_{Ed} + \frac{2 \cdot A_{s,d} \cdot f_{yd}}{\lambda} \leq N_{Ed}$$

Where:

- N_{Rsd} is the design resisting axial force for steel reinforcements [kN];
- $A_{s,d}$ is the design steel bars area [mm^2].

Below is an example of the calculations for plinth P1.1:

a [mm]	b [mm]	A [mm]	B [mm]	H [mm]	c [mm]	N_{Ed} [kN]	N'_{Ed} [kN]	d [mm]	l [mm]	λ	n	Φ	$A_{s,d}$ [mm^2]	N_{Rsd} [kN]
150	200	1200	1200	500	50	117.97	14.75	450	292.5	1.54	4	8	200.96	196.48
					58		19.66	442	290.0	1.52	4	8	200.96	203.11

Tab. 5.2.24 Plinth P1.1: Steel bars dimensioning

5.2.10.3 Concrete

After dimensioning the steel bars, it is necessary to verify the strength of the cast concrete section, using the formulas:

$$N_{Rcd} = N_0 + 2 \cdot 0.4 \left[\frac{d_a \cdot b \cdot f_{cd}}{1 + \lambda_a^2} + \frac{d_b \cdot a \cdot f_{cd}}{1 + \lambda_b^2} \right]$$

$$N_0 = \frac{a \cdot b}{A \cdot B} N_{Ed}$$

Where:

- N_{Rcd} is the design resisting axial force for concrete [kN];
- b is the column's b side length [mm];
- a is the column's a side length [mm].
- B is the plinth's B side length [mm];
- A is the plinth's A side length [mm].

Below is an example of the calculations for plinth P1.1:

a [mm]	b [mm]	A [mm]	B [mm]	H [mm]	c [mm]	N_{Ed} [kN]	d [mm]	λ	n	Φ	N_0 [kN]	N_{Rcd} [kN]
150	200	1200	1200	500	50	117.97	450	1.54	4	8	2.46	1166.42
					58		442	1.52	4	8		

Tab. 5.2.25 Plinth P1.1: Concrete

5.2.10.4 Punching

As per NTC 2018 § 4.1.2.3.5.4, foundation elements strength to punching must be verified using the equations:

$$MIN[N'_R; N''_R] \leq N_{Ed}$$

$$N'_R = 0.25 \cdot u \cdot H \cdot f_{ctd} \cdot k \cdot (1 + 50 \cdot \rho_s)$$

$$N''_R = \frac{0.8 \cdot u_0 \cdot H \cdot f_{cd}}{1 + \lambda^2}$$

Where:

- N'_R is the strength calculated on the critical perimeter [kN];
- u is the critical perimeter [mm];
- k is a coefficient proportional to the plinth's height;
- ρ_s is the geometric reinforcement ratio;
- N''_R is the strength calculated at the column's perimeter [kN];
- u_0 is the column's perimeter [mm];
- λ is the ratio between the height of the plinth and the I-projection of the strut on the plinth's base.

Below is an example of the calculations for plinth P1.1:

a [mm]	b [mm]	A [mm]	B [mm]	H [mm]	u [mm]	k	ρ_s	N'_R [kN]	u_0 [mm]	λ	N''_R [kN]
150	200	1200	1200	500	7627.43	1.00	3.49E-05	2071.95	700	1.5	2685.13

Tab. 5.2.26 Plinth P1.1: Punching

5.2.11 Connection with the existing structure

As mentioned at the beginning of this section, the new precast reinforced concrete frames and the existing cast concrete structure are independent from each other, with only a neoprene joint separating them, with a single exception, namely the connection between the hollow core slabs S6 and S17, and the existing beams at the far left of the cast concrete frame.

To properly have the new slabs in support of the existing beam, it is necessary to add an element functioning as a bracket, which will have the same purpose of the precast inverted-T and L shaped beams wings. While the connection won't be dimensioned in this section, a schematic design of the proposed solution will be provided upon which in-depth calculations can be done at a later date.

The proposed solution is a hybrid steel-concrete structure, whereupon, for every 1200 mm slab section, two L shaped steel plates are bolted to the existing beam with chemical anchor bolts. Meanwhile, the hollow core slab has been milled along longitudinally through two of its hollow section; two steel stirrups are inserted through the mills and into the hollow sections and sealed in concrete. Finally, the stirrups near the perimeter of the slab is welded to the steel plates. The resulting structure is a hybrid steel-concrete bracket able to bear the weight of the hollow core precast slab in support of the cast concrete beam.

Below is a detailed schematic design of the proposed solution:

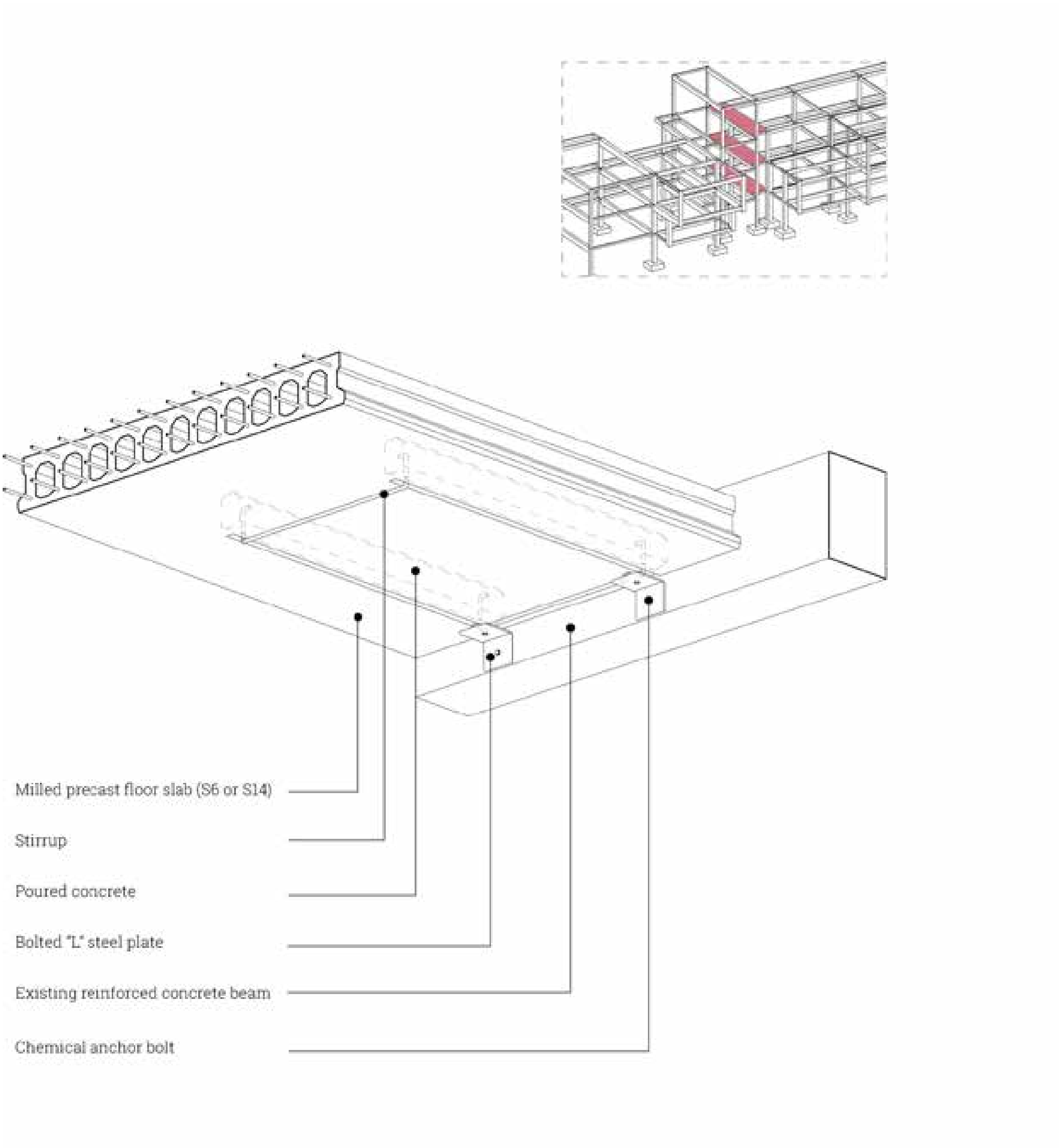


Figure 5.2.32 Hollow core slabs S6 and S14 connection detail schematic design

5.2.12 Appendix: structural elements schedule

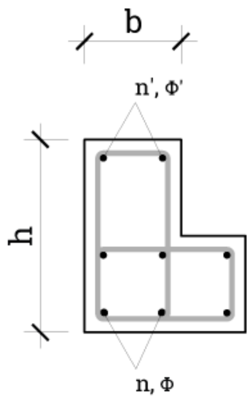
1. Beams: B1.1; B1.2; B1.7; B1.12; B1.17 / B1.3; B1.4; B1.5; B1.13; B1.14; B1.15; B1.22; B1.23 / B1.6 / B1.8; B1.9; B1.18; B1.19.
2. Beams: B1.10; B1.11 / B1.16 / B1.20 / B1.21; B1.24.
3. Beams: B2.1; B2.3 / B2.2 / B2.4; B2.5; B2.6; B2.7; B2.21; B2.22; B2.23; B2.24; B2.37; B2.38; B2.39 / B2.8; B2.10.
4. Beams: B2.9 / B2.11; B2.14; B2.28; B2.31; B2.44 / B2.12 / B2.13; B2.30; B2.43.
5. Beams: B2.15; B2.17 / B2.16 / B2.18; B2.20 / B2.19.
6. Beams: B2.25; B2.27 / B2.26 / B2.29 / B2.32; B2.33.
7. Beams: B2.34; B2.35 / B2.36 / B2.40 / B2.41.
8. Beams: B2.42 / B2.45 / B2.46.
9. Beams: B3.1 / B3.2 / B3.3; B3.13; B3.18; B3.28; B3.38; B3.43; B3.52; B3.61; B3.67 / B3.4; B3.20; B3.29; B3.45; B3.53; B3.69; B3.75; B3.78.
10. Beams: B3.5; B3.14; B3.19; B3.30; B3.39; B3.44; B3.54; B3.62; B3.68 / B3.6; B3.31 / B3.7 / B3.8.
11. Beams: B3.9 / B3.10 / B3.11; B3.12.
12. Beams: B3.15; B3.16; B3.40 / B3.17 / B3.21; B3.46; B3.70.
13. Beams: B3.22; B3.25 / B3.23; B3.24 / B3.26; B3.27; B3.36; B3.37 / B3.32.
14. Beams: B3.33 / B3.34; B3.58 / B3.35.
15. Beams: B3.41; B3.63 / B3.42 / B3.47; B3.50.
16. Beams: B3.48; B3.49 / B3.51 / B3.55 / B3.56.
17. Beams: B3.57 / B3.59 / B3.60.
18. Beams: B3.64 / B3.65 / B3.66.
19. Beams: B3.71 / B3.72; B3.73 / B3.74 / B3.76; B3.77.
20. Columns: P1.1 / P1.2 / P1.3 / P1.4.
21. Columns: P1.5 / P1.6 / P1.7; P1.8.
22. Columns: P2.1; P2.5 / P2.2 / P2.3 / P2.4; P2.8.
23. Columns: P2.6 / P2.7 / P2.9 / P2.10.
24. Columns: P2.11 / P2.12.
25. Columns: P3.1 / P3.2 / P3.3 / P3.4.
26. Columns: P3.5 / P3.6 / P3.7 / P3.8.
27. Columns: P3.9 / P3.10 / P3.11; P3.12 / P3.13; P3.14.
28. Plinths: P1.1.
29. Plinths: P1.2.
30. Plinths: P1.3.
31. Plinths: P1.4.
32. Plinths: P1.5.

33. Plinths: P1.6.
34. Plinths: P2.1; P2.5.
35. Plinths: P2.2.
36. Plinths: P2.3.
37. Plinths: P2.4; P2.8.
38. Plinths: P2.6.
39. Plinths: P2.7.
40. Plinths: P3.1.
41. Plinths: P3.2.
42. Plinths: P3.3.
43. Plinths: P3.4.
44. Plinths: P3.5.
45. Plinths: P3.6.
46. Plinths: P3.7.
47. Plinths: P3.8.
48. Plinths: P3.9
49. Plinths: P3.10.

STRUCTURAL SCHEDULE

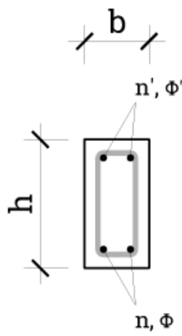
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B1.1; B1.2; B1.7;
B1.12; B1.17



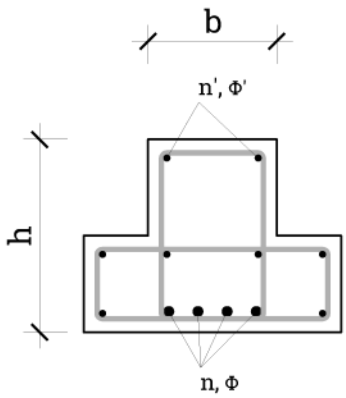
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	10	8	2	8
1,14	300	150	4	2	10	8	2	8
1,71	300	150	4	2	12	8	2	8
2,28	300	150	4	2	14	8	2	8
2,85	300	150	4	2	14	8	2	8
3,43	300	150	4	2	14	8	2	8
4,00	300	150	4	2	14	8	2	8
4,57	300	150	4	2	14	8	2	8
5,14	300	150	4	2	12	8	2	8
5,71	300	150	4	2	10	8	2	8
6,28	300	150	2	2	10	8	2	8
6,85	300	150	2	2	8	8	2	8

Beam:
B1.3; B1.4; B1.5;
B1.13; B1.14; B1.15;
B1.22; B1.23



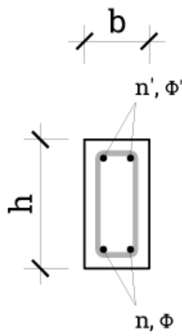
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,58	200	100	2	2	8	8	2	8
1,16	200	100	2	2	8	8	2	8
1,73	200	100	2	2	8	8	2	8
2,31	200	100	2	2	8	8	2	8
2,89	200	100	2	2	8	8	2	8

Beam:
B1.6



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,57	300	200	4	2	10	8	2	8
1,14	300	200	4	2	14	8	2	8
1,71	300	200	5	2	16	8	2	8
2,28	300	200	5	2	18	8	2	8
2,85	300	200	5	2	18	8	2	8
3,43	300	200	5	2	18	8	2	8
4,00	300	200	5	2	18	8	2	8
4,57	300	200	5	2	18	8	2	8
5,14	300	200	5	2	16	8	2	8
5,71	300	200	4	2	14	8	2	8
6,28	300	200	4	2	10	8	2	8
6,85	300	200	2	2	8	8	2	8

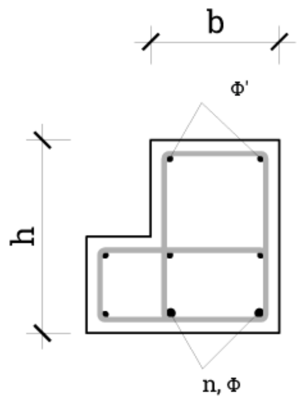
Beam:
B1.8; B1.9; B1.18;
B1.19



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,53	200	100	2	2	8	8	2	8
1,07	200	100	2	2	8	8	2	8
1,60	200	100	2	2	8	8	2	8
2,13	200	100	2	2	8	8	2	8
2,67	200	100	2	2	8	8	2	8
3,20	200	100	2	2	8	8	2	8

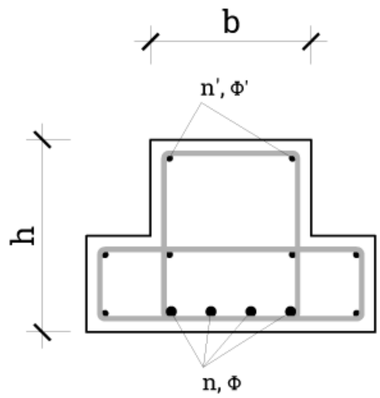
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B1.10; B1.11



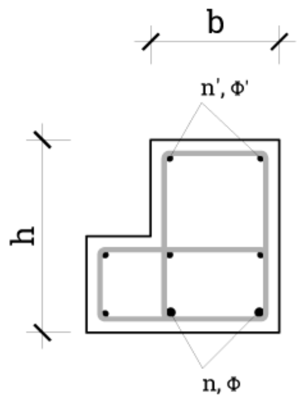
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,57	300	200	2	2	12	8	2	8
1,14	300	200	4	2	10	8	2	8
1,71	300	200	4	2	12	8	2	8
2,28	300	200	4	2	14	8	2	8
2,85	300	200	4	2	14	8	2	8
3,43	300	200	4	2	14	8	2	8
4,00	300	200	4	2	14	8	2	8
4,57	300	200	4	2	14	8	2	8
5,14	300	200	4	2	12	8	2	8
5,71	300	200	4	2	10	8	2	8
6,28	300	200	2	2	12	8	2	8
6,85	300	200	2	2	8	8	2	8

Beam:
B1.16



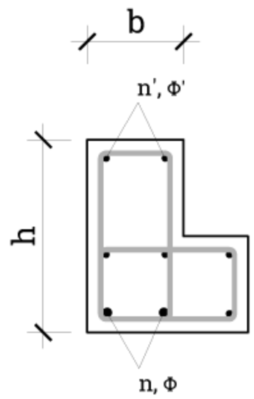
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	250	4	2	8	8	2	8
0,57	300	250	4	2	12	8	2	8
1,14	300	250	5	2	14	8	2	8
1,71	300	250	5	2	16	8	2	8
2,28	300	250	5	2	18	8	2	8
2,85	300	250	5	2	20	8	2	8
3,43	300	250	5	2	20	8	2	8
4,00	300	250	5	2	20	8	2	8
4,57	300	250	5	2	18	8	2	8
5,14	300	250	5	2	16	8	2	8
5,71	300	250	5	2	14	8	2	8
6,28	300	250	4	2	12	8	2	8
6,85	300	250	4	2	8	8	2	8

Beam:
B1.20



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,57	300	200	2	2	12	8	2	8
1,14	300	200	4	2	12	8	2	8
1,71	300	200	4	2	14	8	2	8
2,28	300	200	4	2	14	8	2	8
2,85	300	200	4	2	16	8	2	8
3,43	300	200	4	2	16	8	2	8
4,00	300	200	4	2	16	8	2	8
4,57	300	200	4	2	14	8	2	8
5,14	300	200	4	2	14	8	2	8
5,71	300	200	4	2	12	8	2	8
6,28	300	200	2	2	12	8	2	8
6,85	300	200	2	2	8	8	2	8

Beam:
B1.21; B1.24

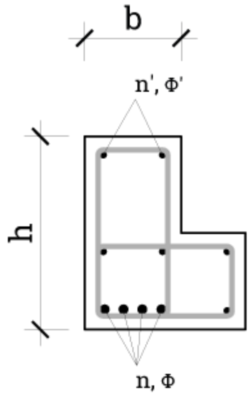


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	12	8	2	8
1,14	300	150	4	2	12	8	2	8
1,71	300	150	4	2	12	8	2	8
2,28	300	150	4	2	14	8	2	8
2,85	300	150	4	2	16	8	2	8
3,43	300	150	4	2	16	8	2	8
4,00	300	150	4	2	16	8	2	8
4,57	300	150	4	2	14	8	2	8
5,14	300	150	4	2	12	8	2	8
5,71	300	150	4	2	12	8	2	8
6,28	300	150	2	2	12	8	2	8
6,85	300	150	2	2	8	8	2	8

STRUCTURAL SCHEDULE

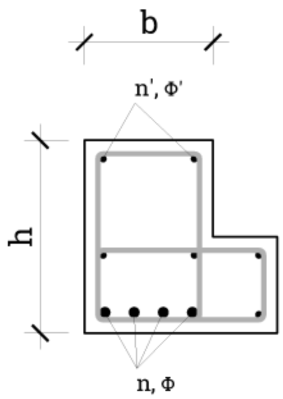
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.1; B2.3



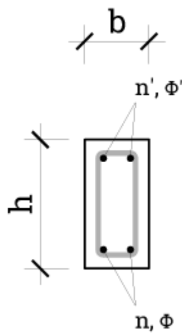
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	10	8	2	8
1,13	300	150	4	2	10	8	2	8
1,70	300	150	4	2	12	8	2	8
2,27	300	150	4	2	14	8	2	8
2,83	300	150	4	2	14	8	2	8
3,40	300	150	4	2	14	8	2	8
3,97	300	150	4	2	14	8	2	8
4,53	300	150	4	2	14	8	2	8
5,10	300	150	4	2	12	8	2	8
5,67	300	150	4	2	10	8	2	8
6,23	300	150	2	2	10	8	2	8
6,80	300	150	2	2	8	8	2	8

Beam:
B2.2



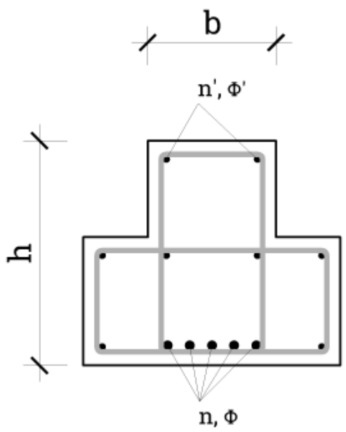
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,59	300	200	2	2	10	8	2	8
1,18	300	200	4	2	10	8	2	8
1,78	300	200	4	2	12	8	2	8
2,37	300	200	4	2	14	8	2	8
2,96	300	200	4	2	14	8	2	8
3,55	300	200	4	2	14	8	2	8
4,14	300	200	4	2	14	8	2	8
4,73	300	200	4	2	14	8	2	8
5,33	300	200	4	2	12	8	2	8
5,92	300	200	4	2	10	8	2	8
6,51	300	200	2	2	10	8	2	8
7,10	300	200	2	2	8	8	2	8

Beam:
B2.4; B2.5: B2.6;
B2.7; B2.21; B2.22;
B2.23; B2.24; B2.37;
B2.38; B2.39



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,58	200	100	2	2	8	8	2	8
1,16	200	100	2	2	8	8	2	8
1,73	200	100	2	2	8	8	2	8
2,31	200	100	2	2	8	8	2	8
2,89	200	100	2	2	8	8	2	8

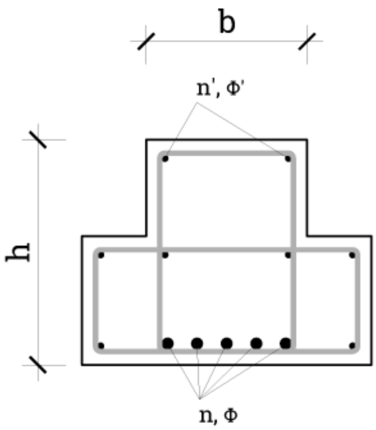
Beam:
B2.8; B2.10



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	2	2	8	8	2	8
0,57	350	200	4	2	10	8	2	8
1,13	350	200	5	2	12	8	2	8
1,70	350	200	5	2	14	8	2	8
2,27	350	200	5	2	16	8	2	8
2,83	350	200	6	2	16	8	2	8
3,40	350	200	6	2	16	8	2	8
3,97	350	200	6	2	16	8	2	8
4,53	350	200	5	2	16	8	2	8
5,10	350	200	5	2	14	8	2	8
5,67	350	200	5	2	12	8	2	8
6,23	350	200	4	2	10	8	2	8
6,80	350	200	2	2	8	8	2	8

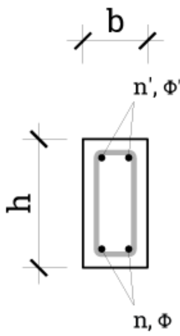
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.9



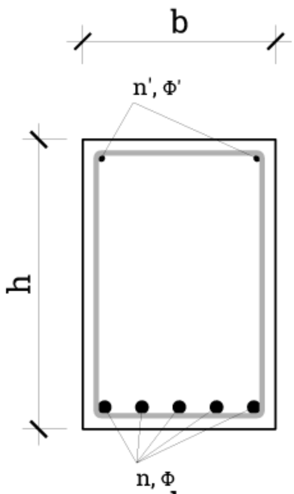
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	250	2	2	10	8	2	8
0,59	350	250	4	2	12	8	2	8
1,18	350	250	5	2	14	8	2	8
1,78	350	250	5	2	16	8	2	8
2,37	350	250	5	2	18	8	2	8
2,96	350	250	6	2	18	8	2	8
3,55	350	250	6	2	18	8	2	8
4,14	350	250	6	2	18	8	2	8
4,73	350	250	5	2	18	8	2	8
5,33	350	250	5	2	16	8	2	8
5,92	350	250	5	2	14	8	2	8
6,51	350	250	4	2	12	8	2	8
7,10	350	250	2	2	10	8	2	8

Beam:
B2.11; B2.14; B2.28;
B2.31; B2.44



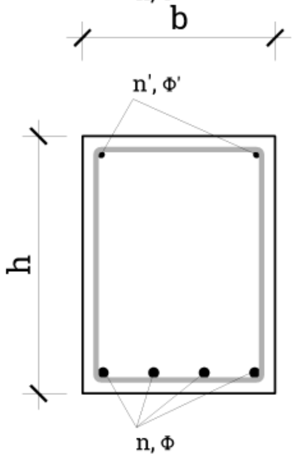
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,54	200	100	2	2	8	8	2	8
1,08	200	100	2	2	8	8	2	8
1,62	200	100	2	2	8	8	2	8
2,16	200	100	2	2	8	8	2	8
2,70	200	100	2	2	8	8	2	8

Beam:
B2.12



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	450	300	2	2	12	8	2	8
0,54	450	300	4	2	14	8	2	8
1,08	450	300	5	2	18	8	2	8
1,62	450	300	6	2	20	8	2	8
2,16	450	300	6	2	20	8	2	8
2,70	450	300	6	2	20	12	2	8
2,70	450	300	2	6	12	20	2	8
3,20	450	300	2	6	8	20	2	8
3,70	450	300	4	2	12	8	2	8

Beam:
B2.13; B2.30; B2.43

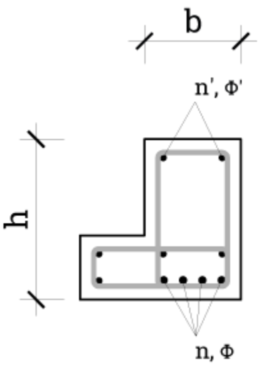


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	2	2	12	8	2	8
0,54	400	300	3	2	12	8	2	8
1,08	400	300	4	2	14	8	2	8
1,62	400	300	6	2	14	8	2	8
2,16	400	300	5	2	18	8	2	8
2,70	400	300	5	2	20	8	2	8
2,70	400	300	2	4	8	10	2	8
3,20	400	300	2	3	8	10	2	8
3,70	400	300	2	2	12	8	2	8

STRUCTURAL SCHEDULE

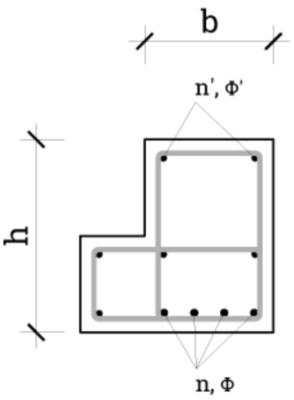
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.15; B2.17



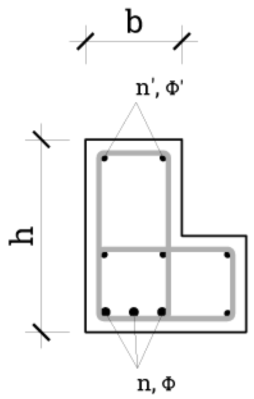
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	150	2	2	8	8	2	8
0,57	250	150	4	2	10	8	2	8
1,13	250	150	5	2	12	8	2	8
1,70	250	150	5	2	14	8	2	8
2,27	250	150	5	2	16	8	2	8
2,83	250	150	6	2	18	8	2	8
3,40	250	150	6	2	20	8	2	8
3,97	250	150	6	2	18	8	2	8
4,53	250	150	5	2	16	8	2	8
5,10	250	150	5	2	14	8	2	8
5,67	250	150	5	2	12	8	2	8
6,23	250	150	4	2	10	8	2	8
6,80	250	150	2	2	8	8	2	8

Beam:
B2.16



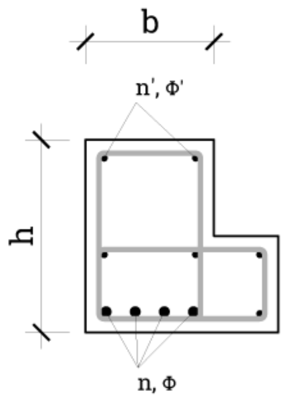
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,59	300	200	4	2	10	8	2	8
1,18	300	200	4	2	12	8	2	8
1,78	300	200	4	2	14	8	2	8
2,37	300	200	4	2	16	8	2	8
2,96	300	200	4	2	16	8	2	8
3,55	300	200	4	2	16	8	2	8
4,14	300	200	4	2	16	8	2	8
4,73	300	200	4	2	16	8	2	8
5,33	300	200	4	2	14	8	2	8
5,92	300	200	4	2	12	8	2	8
6,51	300	200	4	2	10	8	2	8
7,10	300	200	2	2	8	8	2	8

Beam:
B2.18; B2.20



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	3	2	10	8	2	8
1,13	300	150	3	2	12	8	2	8
1,70	300	150	4	2	12	8	2	8
2,27	300	150	4	2	14	8	2	8
2,83	300	150	4	2	16	8	2	8
3,40	300	150	4	2	16	8	2	8
3,97	300	150	4	2	16	8	2	8
4,53	300	150	4	2	14	8	2	8
5,10	300	150	4	2	12	8	2	8
5,67	300	150	3	2	12	8	2	8
6,23	300	150	3	2	10	8	2	8
6,80	300	150	2	2	8	8	2	8

Beam:
B2.19

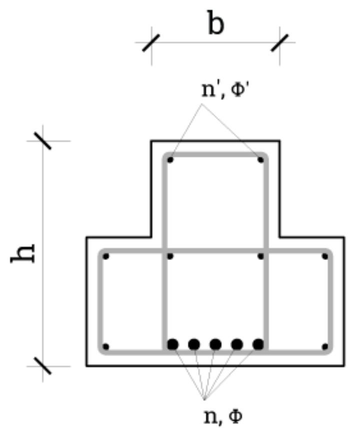


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,59	300	200	2	2	10	8	2	8
1,18	300	200	3	2	12	8	2	8
1,78	300	200	4	2	12	8	2	8
2,37	300	200	4	2	14	8	2	8
2,96	300	200	4	2	14	8	2	8
3,55	300	200	4	2	14	8	2	8
4,14	300	200	4	2	14	8	2	8
4,73	300	200	4	2	14	8	2	8
5,33	300	200	4	2	12	8	2	8
5,92	300	200	3	2	12	8	2	8
6,51	300	200	2	2	10	8	2	8
7,10	300	200	2	2	8	8	2	8

STRUCTURAL SCHEDULE

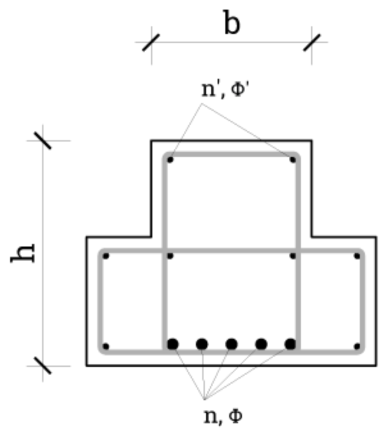
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.25; B2.27



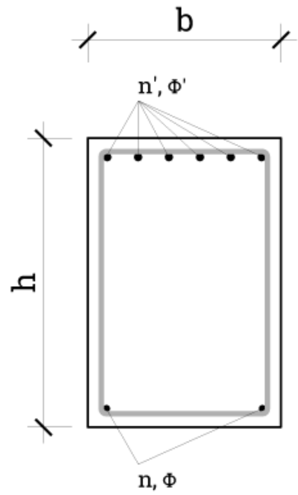
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	2	2	8	8	2	8
0,57	350	200	3	2	12	8	2	8
1,13	350	200	4	2	14	8	2	8
1,70	350	200	5	2	14	8	2	8
2,27	350	200	5	2	16	8	2	8
2,83	350	200	6	2	16	8	2	8
3,40	350	200	6	2	18	8	2	8
3,97	350	200	6	2	16	8	2	8
4,53	350	200	5	2	16	8	2	8
5,10	350	200	5	2	14	8	2	8
5,67	350	200	4	2	14	8	2	8
6,23	350	200	3	2	12	8	2	8
6,80	350	200	2	2	8	8	2	8

Beam:
B2.26



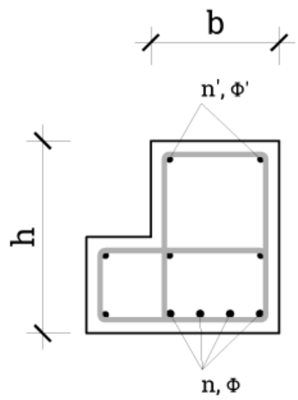
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	250	2	2	10	8	2	8
0,59	350	250	3	2	12	8	2	8
1,18	350	250	4	2	14	8	2	8
1,78	350	250	6	2	14	8	2	8
2,37	350	250	5	2	16	8	2	8
2,96	350	250	6	2	16	8	2	8
3,55	350	250	5	2	18	8	2	8
4,14	350	250	6	2	16	8	2	8
4,73	350	250	5	2	16	8	2	8
5,33	350	250	6	2	14	8	2	8
5,92	350	250	4	2	14	8	2	8
6,51	350	250	3	2	12	8	2	8
7,10	350	250	2	2	10	8	2	8

Beam:
B2.29



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	450	300	2	2	12	8	2	8
0,54	450	300	4	2	12	8	2	8
1,08	450	300	4	2	16	8	2	8
1,62	450	300	5	2	16	8	2	8
2,16	450	300	5	2	20	8	2	8
2,70	450	300	6	2	20	8	2	8
2,70	450	300	2	6	8	10	2	8
3,20	450	300	2	3	8	10	2	8
3,70	450	300	2	2	12	8	2	8

Beam:
B2.32; B2.33

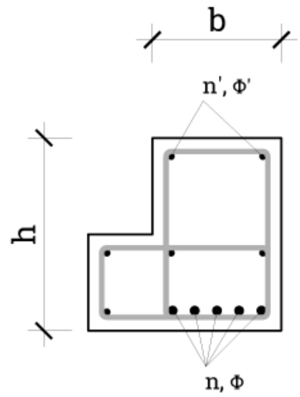


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,57	300	200	2	2	10	8	2	8
1,13	300	200	4	2	10	8	2	8
1,70	300	200	5	2	10	8	2	8
2,27	300	200	6	2	10	8	2	8
2,83	300	200	5	2	12	8	2	8
3,40	300	200	4	2	14	8	2	8
3,97	300	200	5	2	12	8	2	8
4,53	300	200	6	2	10	8	2	8
5,10	300	200	5	2	10	8	2	8
5,67	300	200	4	2	10	8	2	8
6,23	300	200	2	2	10	8	2	8
6,80	300	200	2	2	8	8	2	8

STRUCTURAL SCHEDULE

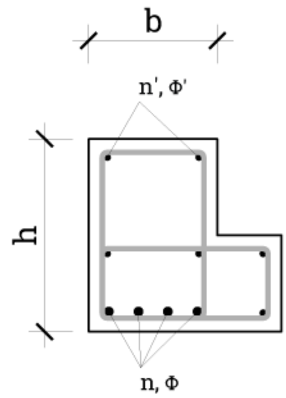
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.34; B2.35



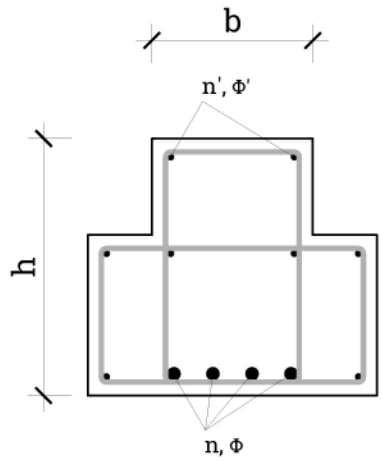
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,59	300	200	4	2	8	8	2	8
1,18	300	200	5	2	10	8	2	8
1,78	300	200	5	2	12	8	2	8
2,37	300	200	5	2	14	8	2	8
2,96	300	200	4	2	16	8	2	8
3,55	300	200	4	2	16	8	2	8
4,14	300	200	4	2	16	8	2	8
4,73	300	200	5	2	14	8	2	8
5,33	300	200	5	2	12	8	2	8
5,92	300	200	5	2	10	8	2	8
6,51	300	200	4	2	8	8	2	8
7,10	300	200	2	2	8	8	2	8

Beam:
B2.36



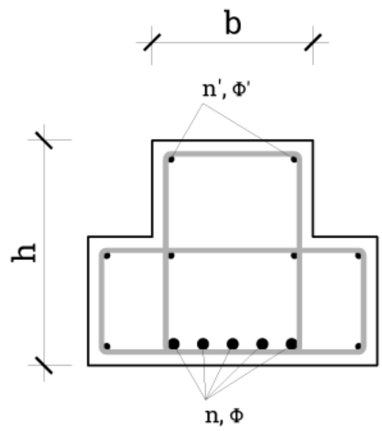
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,57	300	200	4	2	10	8	2	8
1,13	300	200	4	2	10	8	2	8
1,70	300	200	4	2	12	8	2	8
2,27	300	200	5	2	12	8	2	8
2,83	300	200	4	2	14	8	2	8
3,40	300	200	4	2	14	8	2	8
3,97	300	200	4	2	14	8	2	8
4,53	300	200	5	2	12	8	2	8
5,10	300	200	4	2	12	8	2	8
5,67	300	200	4	2	10	8	2	8
6,23	300	200	4	2	10	8	2	8
6,80	300	200	2	2	8	8	2	8

Beam:
B2.40



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	250	2	2	10	8	2	8
0,59	400	250	4	2	10	8	2	8
1,18	400	250	5	2	12	8	2	8
1,78	400	250	5	2	14	8	2	8
2,37	400	250	5	2	16	8	2	8
2,96	400	250	4	2	18	8	2	8
3,55	400	250	5	2	18	8	2	8
4,14	400	250	4	2	18	8	2	8
4,73	400	250	5	2	16	8	2	8
5,33	400	250	5	2	14	8	2	8
5,92	400	250	5	2	12	8	2	8
6,51	400	250	4	2	10	8	2	8
7,10	400	250	2	2	10	8	2	8

Beam:
B2.41

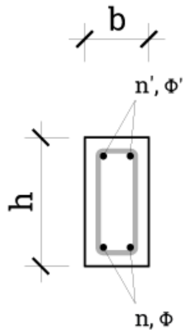


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	250	2	2	10	8	2	8
0,57	350	250	4	2	10	8	2	8
1,13	350	250	5	2	12	8	2	8
1,70	350	250	5	2	14	8	2	8
2,27	350	250	5	2	16	8	2	8
2,83	350	250	6	2	16	8	2	8
3,40	350	250	6	2	16	8	2	8
3,97	350	250	6	2	16	8	2	8
4,53	350	250	5	2	16	8	2	8
5,10	350	250	5	2	14	8	2	8
5,67	350	250	5	2	12	8	2	8
6,23	350	250	4	2	10	8	2	8
6,80	350	250	2	2	10	8	2	8

STRUCTURAL SCHEDULE

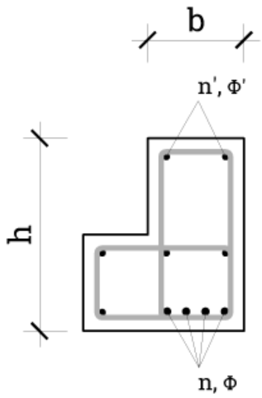
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B2.42



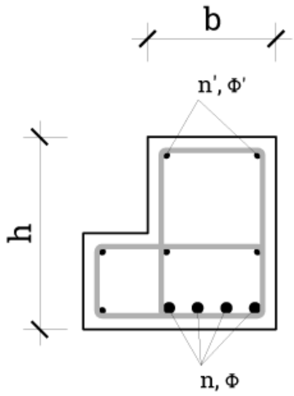
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,54	200	100	2	2	8	8	2	8
1,08	200	100	2	2	8	8	2	8
1,62	200	100	2	2	8	8	2	8
2,16	200	100	2	2	8	8	2	8
2,70	200	100	2	2	8	8	2	8
2,70	200	100	2	2	8	8	2	8
3,20	200	100	2	2	8	8	2	8

Beam:
B2.45



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	10	8	2	8
1,13	300	150	4	2	10	8	2	8
1,70	300	150	6	2	10	8	2	8
2,27	300	150	5	2	12	8	2	8
2,83	300	150	4	2	14	8	2	8
3,40	300	150	5	2	14	8	2	8
3,97	300	150	4	2	14	8	2	8
4,53	300	150	5	2	12	8	2	8
5,10	300	150	6	2	10	8	2	8
5,67	300	150	4	2	10	8	2	8
6,23	300	150	2	2	10	8	2	8
6,80	300	150	2	2	8	8	2	8

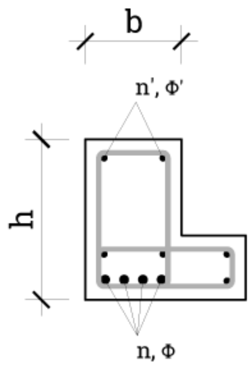
Beam:
B2.46



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	2	8	8	2	8
0,59	300	200	3	2	10	8	2	8
1,18	300	200	6	2	10	8	2	8
1,78	300	200	6	2	12	8	2	8
2,37	300	200	4	2	16	8	2	8
2,96	300	200	5	2	18	8	2	8
3,55	300	200	5	2	18	8	2	8
4,14	300	200	5	2	18	8	2	8
4,73	300	200	4	2	16	8	2	8
5,33	300	200	6	2	12	8	2	8
5,92	300	200	6	2	10	8	2	8
6,51	300	200	3	2	10	8	2	8
7,10	300	200	2	2	8	8	2	8

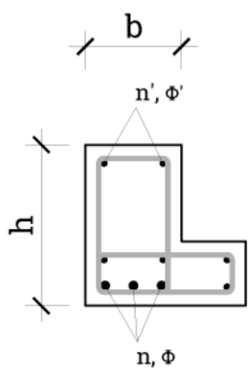
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.1



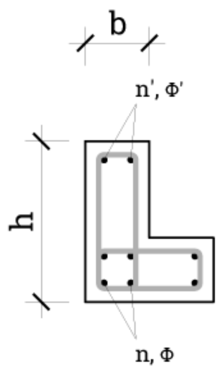
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	150	2	2	8	8	2	8
0,57	250	150	2	2	10	8	2	8
1,14	250	150	4	2	10	8	2	8
1,71	250	150	4	2	12	8	2	8
2,28	250	150	4	2	14	8	2	8
2,85	250	150	4	2	14	8	2	8
3,43	250	150	4	2	14	8	2	8
4,00	250	150	4	2	14	8	2	8
4,57	250	150	4	2	14	8	2	8
5,14	250	150	4	2	12	8	2	8
5,71	250	150	4	2	10	8	2	8
6,28	250	150	2	2	10	8	2	8
6,85	250	150	2	2	8	8	2	8

Beam:
B3.2



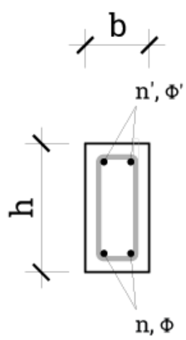
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	150	2	2	8	8	2	8
0,57	250	150	2	2	8	8	2	8
1,14	250	150	3	2	10	8	2	8
1,71	250	150	4	2	10	8	2	8
2,28	250	150	3	2	12	8	2	8
2,85	250	150	3	2	12	8	2	8
3,43	250	150	3	2	12	8	2	8
4,00	250	150	3	2	12	8	2	8
4,57	250	150	3	2	12	8	2	8
5,14	250	150	4	2	10	8	2	8
5,71	250	150	3	2	10	8	2	8
6,28	250	150	2	2	8	8	2	8
6,85	250	150	2	2	8	8	2	8

Beam:
B3.3; B3.13; B3.18;
B3.28; B3.38; B3.43;
B3.52; B3.61; B3.67



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	100	2	2	8	8	2	8
0,61	250	100	2	2	8	8	2	8
1,22	250	100	2	2	8	8	2	8
1,83	250	100	2	2	8	8	2	8

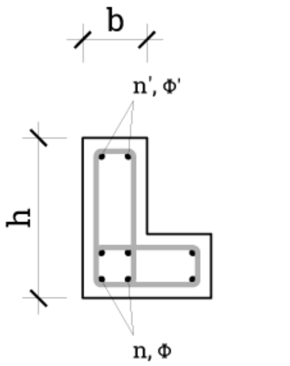
Beam:
B3.4; B3.20; B3.29;
B3.45; B3.53; B3.69;
B3.75; B3.78



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,60	200	100	2	2	8	8	2	8
1,20	200	100	2	2	8	8	2	8
1,80	200	100	2	2	8	8	2	8
2,40	200	100	2	2	8	8	2	8
3,00	200	100	2	2	8	8	2	8
3,60	200	100	2	2	8	8	2	8

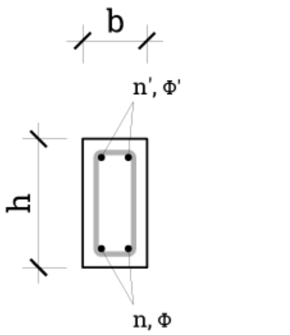
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.5; B3.14; B3.19;
B3.30; B3.39; B3.44;
B3.54; B3.62; B3.68



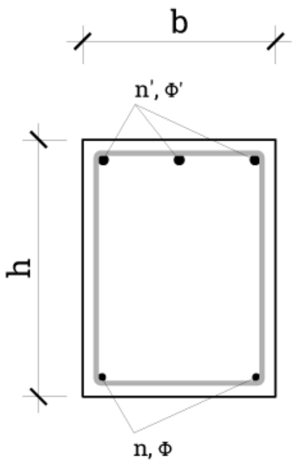
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	100	2	2	8	8	2	8
0,46	250	100	2	2	8	8	2	8
0,93	250	100	2	2	8	8	2	8
1,39	250	100	2	2	8	8	2	8
1,85	250	100	2	2	8	8	2	8

Beam:
B3.6; B3.31



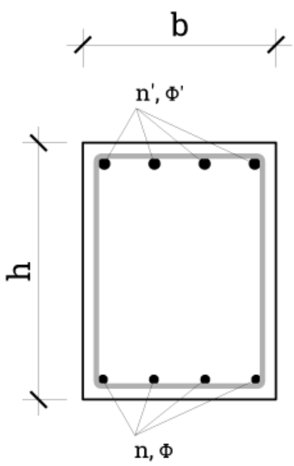
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,45	200	100	2	2	8	8	2	8
0,90	200	100	2	2	8	8	2	8
1,35	200	100	2	2	8	8	2	8

Beam:
B3.7



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	2	3	10	14	2	8
0,45	400	300	2	3	8	12	2	8
0,90	400	300	2	3	8	10	2	8
1,35	400	300	2	3	8	10	2	8

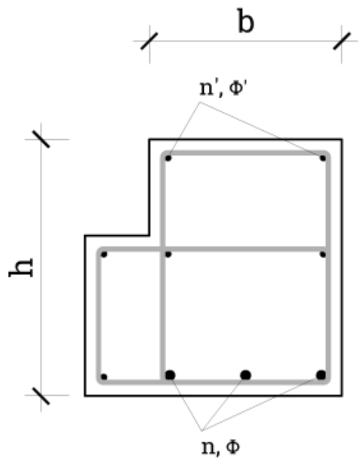
Beam:
B3.8



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	4	4	12	16	2	8
0,45	400	300	2	4	12	14	2	8
0,90	400	300	2	4	12	14	2	8
1,35	400	300	2	4	10	12	2	8

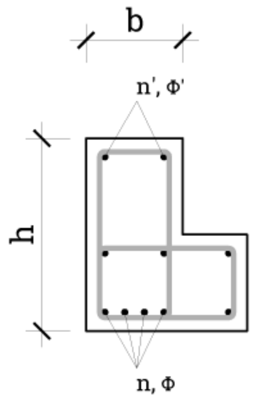
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.9



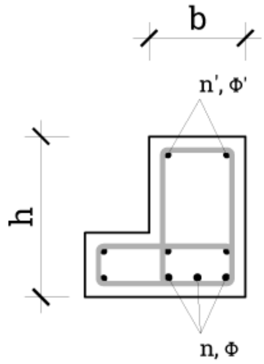
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	4	2	10	8	2	8
0,59	400	300	3	2	12	8	2	8
1,18	400	300	4	2	12	8	2	8
1,78	400	300	3	2	14	8	2	8
2,37	400	300	3	2	14	8	2	8
2,96	400	300	3	2	14	8	2	8
3,55	400	300	3	2	14	8	2	8
4,15	400	300	3	2	14	8	2	8
4,74	400	300	4	2	12	8	2	8
5,33	400	300	3	2	12	8	2	8
5,92	400	300	4	2	10	8	2	8
6,52	400	300	3	2	10	8	2	8
7,11	400	300	4	2	8	8	2	8
7,70	400	300	4	2	8	8	2	8
7,70	400	300	4	2	8	8	2	8
8,15	400	300	4	2	8	8	2	8
8,60	400	300	4	2	8	8	2	8
9,05	400	300	3	2	10	8	2	8

Beam:
B3.10



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	4	2	8	8	2	8
0,58	300	150	4	2	8	8	2	8
1,15	300	150	3	2	10	8	2	8
1,15	300	150	2	4	8	8	2	8
1,75	300	150	4	2	8	8	2	8
2,34	300	150	4	2	8	8	2	8
2,94	300	150	3	2	10	8	2	8
3,53	300	150	4	2	10	8	2	8
4,13	300	150	4	2	10	8	2	8
4,72	300	150	4	2	10	8	2	8
5,32	300	150	4	2	10	8	2	8
5,91	300	150	3	2	10	8	2	8
6,51	300	150	4	2	8	8	2	8
7,10	300	150	4	2	8	8	2	8
7,70	300	150	4	2	8	8	2	8
7,70	300	150	4	2	10	8	2	8
8,15	300	150	4	2	8	8	2	8
8,60	300	150	4	2	8	8	2	8
9,05	300	150	4	2	8	8	2	8

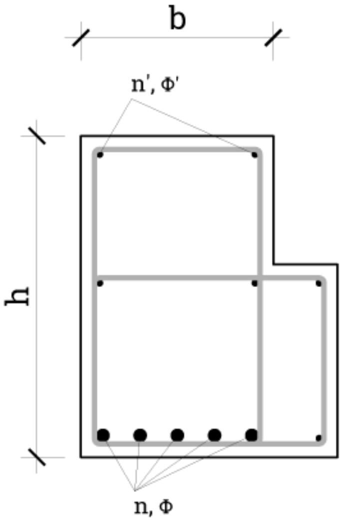
Beam:
B3.11; B3.12



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	150	2	2	8	8	2	8
0,57	250	150	2	2	8	8	2	8
1,14	250	150	3	2	10	8	2	8
1,71	250	150	3	2	10	8	2	8
2,28	250	150	3	2	12	8	2	8
2,85	250	150	3	2	12	8	2	8
3,43	250	150	3	2	12	8	2	8
4,00	250	150	3	2	12	8	2	8
4,57	250	150	3	2	12	8	2	8
5,14	250	150	3	2	10	8	2	8
5,71	250	150	3	2	10	8	2	8
6,28	250	150	2	2	8	8	2	8
6,85	250	150	2	2	8	8	2	8

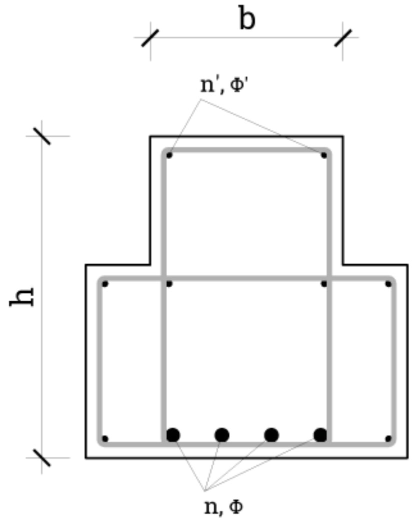
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.15; B3.16; B3.40



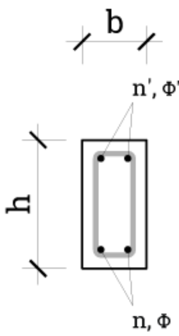
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	500	300	3	2	12	8	2	8
0,60	500	300	3	2	12	8	2	8
1,20	500	300	5	2	14	8	2	8
1,80	500	300	5	2	16	8	2	8
2,40	500	300	5	2	18	8	2	8
3,00	500	300	6	2	18	8	2	8
3,60	500	300	6	2	18	8	2	8
4,20	500	300	5	2	20	8	2	8
4,80	500	300	5	2	20	8	2	8
5,40	500	300	5	2	20	8	2	8
6,00	500	300	6	2	18	8	2	8
6,60	500	300	6	2	18	8	2	8
7,20	500	300	5	2	18	8	2	8
7,80	500	300	5	2	16	8	2	8
8,40	500	300	5	2	14	8	2	8
9,00	500	300	3	2	12	8	2	8
9,60	500	300	3	2	12	8	2	8

Beam:
B3.17



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	500	300	3	2	10	8	2	8
0,48	500	300	3	2	12	8	2	8
0,95	500	300	4	2	16	8	2	8
1,43	500	300	4	2	20	8	2	8
1,90	500	300	5	2	20	8	2	8
1,90	500	300	4	2	10	8	2	8
2,49	500	300	4	2	14	8	2	8
3,08	500	300	5	2	16	8	2	8
3,68	500	300	5	2	18	8	2	8
4,27	500	300	5	2	18	8	2	8
4,86	500	300	5	2	20	8	2	8
5,45	500	300	5	2	20	8	2	8
6,05	500	300	5	2	20	8	2	8
6,64	500	300	5	2	18	8	2	8
7,23	500	300	5	2	18	8	2	8
7,82	500	300	5	2	16	8	2	8
8,42	500	300	4	2	16	8	2	8
9,01	500	300	3	2	12	8	2	8
9,60	500	300	3	2	10	8	2	8

Beam:
B3.21; B3.46; B3.70

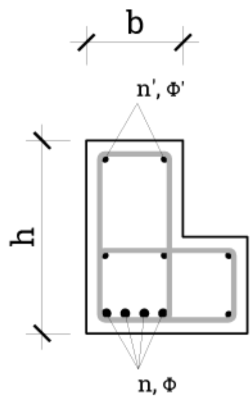


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,57	200	100	2	2	8	8	2	8
1,14	200	100	2	2	8	8	2	8
1,71	200	100	2	2	8	8	2	8
2,28	200	100	2	2	8	8	2	8
2,85	200	100	2	2	8	8	2	8
3,43	200	100	2	2	8	8	2	8
4,00	200	100	2	2	8	8	2	8
4,57	200	100	2	2	8	8	2	8
5,14	200	100	2	2	8	8	2	8
5,71	200	100	2	2	8	8	2	8
6,28	200	100	2	2	8	8	2	8
6,85	200	100	2	2	8	8	2	8

STRUCTURAL SCHEDULE

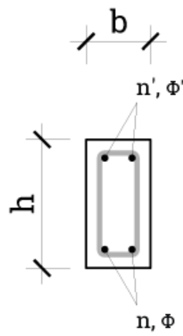
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.22; B3.25



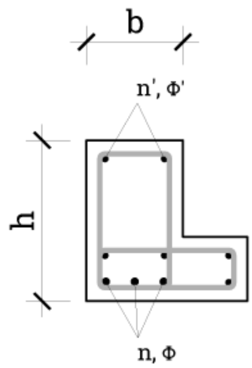
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	10	8	2	8
1,14	300	150	4	2	10	8	2	8
1,71	300	150	4	2	12	8	2	8
2,28	300	150	4	2	12	8	2	8
2,85	300	150	4	2	14	8	2	8
3,43	300	150	3	2	16	8	2	8
4,00	300	150	4	2	14	8	2	8
4,57	300	150	4	2	12	8	2	8
5,14	300	150	4	2	12	8	2	8
5,71	300	150	4	2	10	8	2	8
6,28	300	150	2	2	10	8	2	8
6,85	300	150	2	2	8	8	2	8

Beam:
B3.23; B3.24



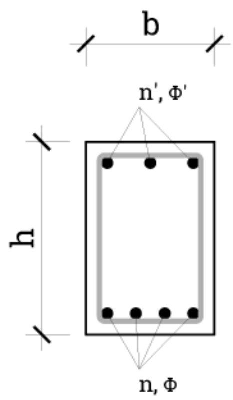
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,54	200	100	2	2	8	8	2	8
1,08	200	100	2	2	8	8	2	8
1,62	200	100	2	2	8	8	2	8
2,16	200	100	2	2	8	8	2	8
2,70	200	100	2	2	8	8	2	8

Beam:
B3.26; B3.27; B3.36; B3.37



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	150	2	2	8	8	2	8
0,57	250	150	2	2	8	8	2	8
1,14	250	150	3	2	10	8	2	8
1,71	250	150	3	2	10	8	2	8
2,28	250	150	4	2	10	8	2	8
2,85	250	150	4	2	10	8	2	8
3,43	250	150	3	2	12	8	2	8
4,00	250	150	4	2	10	8	2	8
4,57	250	150	4	2	10	8	2	8
5,14	250	150	3	2	10	8	2	8
5,71	250	150	3	2	10	8	2	8
6,28	250	150	2	2	8	8	2	8
6,85	250	150	2	2	8	8	2	8

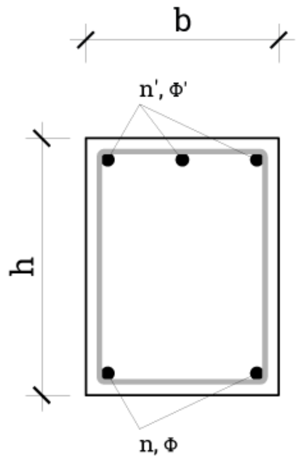
Beam:
B3.32



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	5	3	18	18	2	8
0,45	300	200	4	3	16	16	2	8
0,90	300	200	2	3	14	14	2	8
1,35	300	200	2	3	8	12	2	8

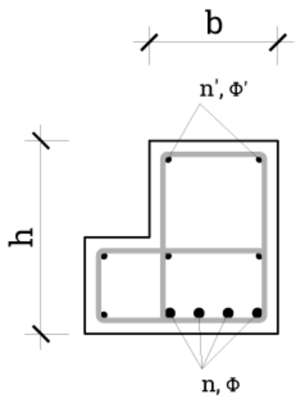
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.33



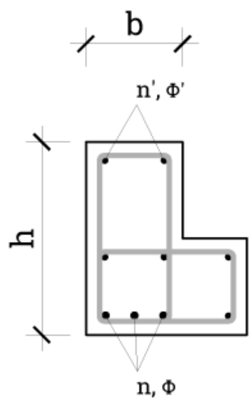
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	3	4	18	18	2	8
0,45	400	300	2	3	18	18	2	8
0,90	400	300	2	3	18	18	2	8
1,35	400	300	2	3	18	18	2	8

Beam:
B3.34; B3.58



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	4	2	14	8	2	8
0,59	300	200	4	2	14	8	2	8
1,18	300	200	4	2	16	8	2	8
1,78	300	200	4	2	16	8	2	8
2,37	300	200	5	2	16	8	2	8
2,96	300	200	5	2	16	8	2	8
3,55	300	200	5	2	16	8	2	8
4,15	300	200	4	2	16	8	2	8
4,74	300	200	5	2	14	8	2	8
5,33	300	200	4	2	14	8	2	8
5,92	300	200	3	2	14	8	2	8
6,52	300	200	3	2	12	8	2	8
7,11	300	200	2	2	10	8	2	8
7,70	300	200	2	2	8	8	2	8
7,70	300	200	2	2	8	8	2	8
8,15	300	200	2	2	8	8	2	8
8,60	300	200	3	2	10	8	2	8
9,05	300	200	3	2	12	8	2	8

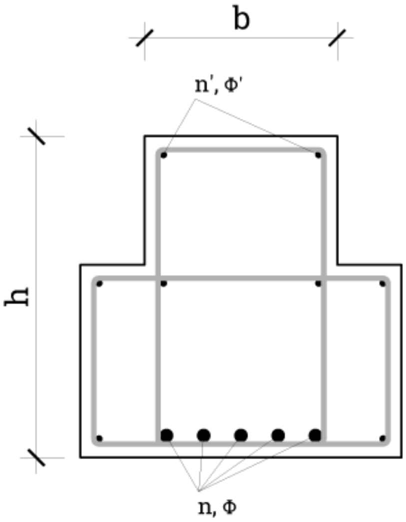
Beam:
B3.35



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,58	300	150	4	2	8	8	2	8
1,15	300	150	3	2	10	8	2	8
1,15	300	150	2	2	8	8	2	8
1,75	300	150	2	2	8	8	2	8
2,34	300	150	4	2	8	8	2	8
2,94	300	150	3	2	10	8	2	8
3,53	300	150	4	2	10	8	2	8
4,13	300	150	4	2	10	8	2	8
4,72	300	150	4	2	10	8	2	8
5,32	300	150	4	2	10	8	2	8
5,91	300	150	3	2	10	8	2	8
6,51	300	150	4	2	8	8	2	8
7,10	300	150	2	2	8	8	2	8
7,70	300	150	2	2	8	8	2	8
7,70	300	150	4	2	10	8	2	8
8,15	300	150	4	2	8	8	2	8
8,60	300	150	2	2	8	8	2	8
9,05	300	150	2	2	8	8	2	8

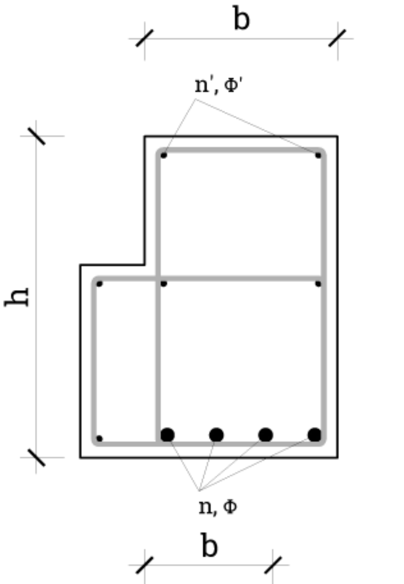
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.41; B3.63



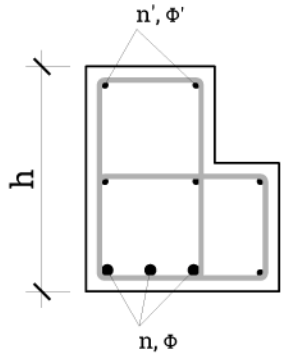
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	500	300	3	2	12	8	2	8
0,60	500	300	3	2	12	8	2	8
1,20	500	300	5	2	14	8	2	8
1,80	500	300	5	2	16	8	2	8
2,40	500	300	5	2	18	8	2	8
3,00	500	300	6	2	18	8	2	8
3,60	500	300	6	2	18	8	2	8
4,20	500	300	5	2	20	8	2	8
4,80	500	300	5	2	20	8	2	8
5,40	500	300	5	2	20	8	2	8
6,00	500	300	6	2	18	8	2	8
6,60	500	300	6	2	18	8	2	8
7,20	500	300	5	2	18	8	2	8
7,80	500	300	5	2	16	8	2	8
8,40	500	300	5	2	14	8	2	8
9,00	500	300	3	2	12	8	2	8
9,60	500	300	3	2	12	8	2	8

Beam:
B3.42



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	500	300	2	2	12	8	2	8
0,48	500	300	4	2	12	8	2	8
0,95	500	300	4	2	16	8	2	8
1,43	500	300	4	2	20	8	2	8
1,90	500	300	5	2	20	8	2	8
1,90	500	300	3	2	12	8	2	8
2,49	500	300	4	2	14	8	2	8
3,08	500	300	4	2	18	8	2	8
3,68	500	300	4	2	20	8	2	8
4,27	500	300	4	2	20	8	2	8
4,86	500	300	5	2	20	8	2	8
5,45	500	300	5	2	20	8	2	8
6,05	500	300	5	2	20	8	2	8
6,64	500	300	4	2	20	8	2	8
7,23	500	300	4	2	20	8	2	8
7,82	500	300	4	2	18	8	2	8
8,42	500	300	4	2	16	8	2	8
9,01	500	300	3	2	12	8	2	8
9,60	500	300	3	2	10	8	2	8

Beam:
B3.47; B3.50

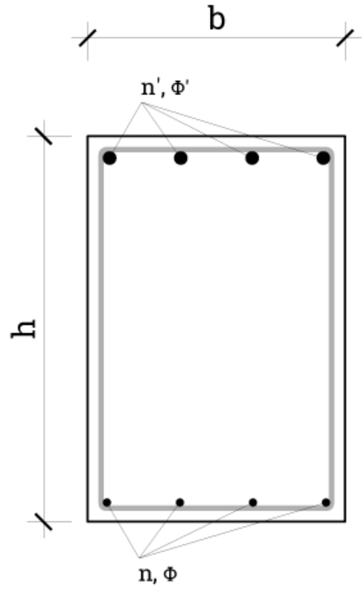


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	2	2	8	8	2	8
0,57	350	200	3	2	10	8	2	8
1,14	350	200	4	2	12	8	2	8
1,71	350	200	3	2	16	8	2	8
2,28	350	200	4	2	16	8	2	8
2,85	350	200	4	2	16	8	2	8
3,43	350	200	4	2	16	8	2	8
4,00	350	200	4	2	16	8	2	8
4,57	350	200	4	2	16	8	2	8
5,14	350	200	3	2	16	8	2	8
5,71	350	200	4	2	12	8	2	8
6,28	350	200	3	2	10	8	2	8
6,85	350	200	2	2	8	8	2	8

STRUCTURAL SCHEDULE

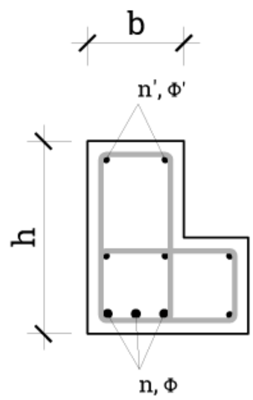
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.48; B3.49



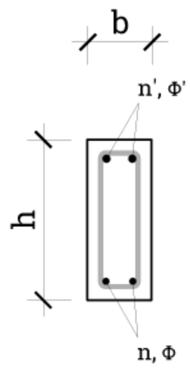
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	600	400	2	3	8	12	2	8
0,50	600	400	2	3	8	12	2	8
1,00	600	400	2	3	8	16	2	8
1,50	600	400	4	5	8	16	2	8
1,99	600	400	4	4	10	18	2	8
1,99	600	400	6	2	20	8	2	8
2,54	600	400	5	2	20	8	2	8
3,09	600	400	4	2	20	8	2	8
3,63	600	400	5	2	16	8	2	8
4,18	600	400	4	2	12	8	2	8
4,73	600	400	3	2	12	8	2	8

Beam:
B3.51



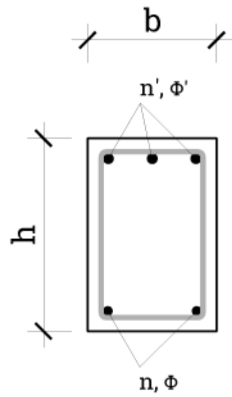
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	8	8	2	8
1,14	300	150	3	2	10	8	2	8
1,71	300	150	3	2	10	8	2	8
2,28	300	150	3	2	12	8	2	8
2,85	300	150	3	2	12	8	2	8
3,43	300	150	3	2	12	8	2	8
4,00	300	150	3	2	12	8	2	8
4,57	300	150	3	2	12	8	2	8
5,14	300	150	3	2	10	8	2	8
5,71	300	150	3	2	10	8	2	8
6,28	300	150	2	2	8	8	2	8
6,85	300	150	2	2	8	8	2	8

Beam:
B3.55



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	250	100	2	2	8	10	2	8
0,45	250	100	2	2	8	8	2	8
0,90	250	100	2	2	8	8	2	8
1,35	250	100	2	2	10	8	2	8

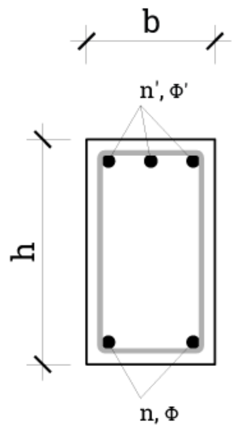
Beam:
B3.56



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	200	2	3	12	14	2	8
0,45	300	200	2	4	8	10	2	8
0,90	300	200	2	3	8	10	2	8
1,35	300	200	2	2	8	10	2	8

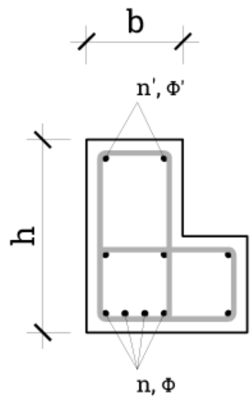
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.57



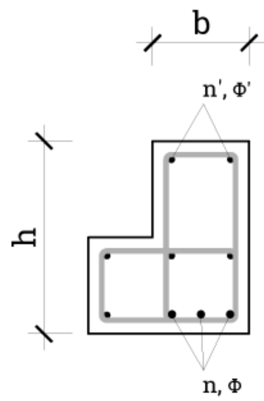
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	5	3	18	18	2	8
0,45	350	200	4	3	18	18	2	8
0,90	350	200	4	3	18	18	2	8
1,35	350	200	4	3	18	18	2	8

Beam:
B3.59



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,58	300	150	4	2	8	8	2	8
1,15	300	150	4	2	10	8	2	8
1,15	300	150	2	2	8	8	2	8
1,75	300	150	2	2	8	8	2	8
2,34	300	150	2	3	8	10	2	8
2,94	300	150	4	2	10	8	2	8
3,53	300	150	4	2	10	8	2	8
4,13	300	150	3	2	12	8	2	8
4,72	300	150	3	2	12	8	2	8
5,32	300	150	3	2	12	8	2	8
5,91	300	150	4	2	10	8	2	8
6,51	300	150	4	2	8	8	2	8
7,10	300	150	3	2	8	8	2	8
7,70	300	150	2	2	8	8	2	8
7,70	300	150	4	2	12	8	2	8
8,15	300	150	4	2	10	8	2	8
8,60	300	150	3	2	8	8	2	8
9,05	300	150	2	2	8	8	2	8

Beam:
B3.60

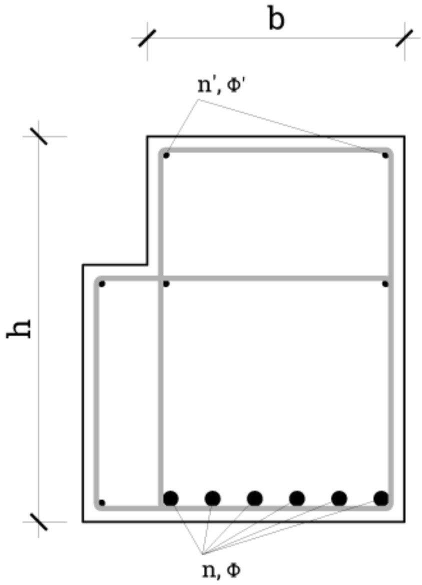


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	300	150	2	2	8	8	2	8
0,57	300	150	2	2	8	8	2	8
1,14	300	150	2	2	10	8	2	8
1,71	300	150	3	2	10	8	2	8
2,28	300	150	3	2	12	8	2	8
2,85	300	150	3	2	12	8	2	8
3,43	300	150	3	2	12	8	2	8
4,00	300	150	3	2	12	8	2	8
4,57	300	150	3	2	12	8	2	8
5,14	300	150	3	2	10	8	2	8
5,71	300	150	2	2	10	8	2	8
6,28	300	150	2	2	8	8	2	8
6,85	300	150	2	2	8	8	2	8

STRUCTURAL SCHEDULE

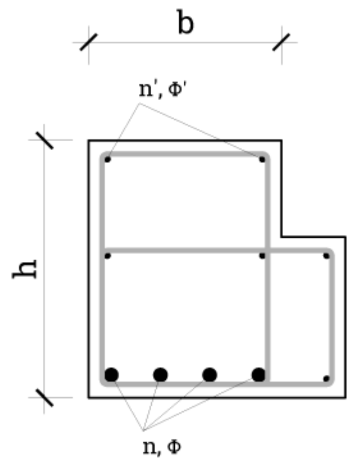
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.64



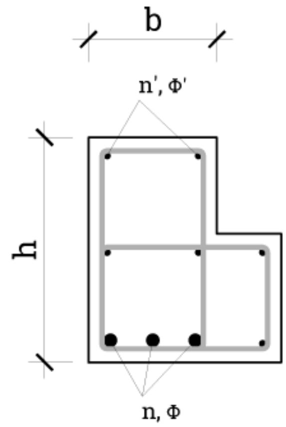
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	600	400	3	2	12	8	2	8
0,61	600	400	4	2	12	8	2	8
1,21	600	400	4	2	16	8	2	8
1,82	600	400	4	2	18	8	2	8
2,42	600	400	5	2	18	8	2	8
3,03	600	400	5	2	20	8	2	8
3,63	600	400	6	2	20	8	2	8
4,24	600	400	6	2	20	8	2	8
4,84	600	400	6	2	22	8	2	8
5,45	600	400	6	2	22	8	2	8
5,45	600	400	6	2	22	8	2	8
6,04	600	400	5	2	22	8	2	8
6,64	600	400	6	2	20	8	2	8
7,23	600	400	5	2	20	8	2	8
7,82	600	400	4	2	20	8	2	8
8,41	600	400	4	2	16	8	2	8
9,01	600	400	4	2	12	8	2	8
9,60	600	400	3	2	12	8	2	8

Beam:
B3.65



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	300	3	2	10	8	2	8
0,48	400	300	3	2	10	8	2	8
0,95	400	300	4	2	12	8	2	8
1,43	400	300	4	2	14	8	2	8
1,90	400	300	4	2	18	8	2	8
1,90	400	300	3	2	10	8	2	8
2,49	400	300	4	2	12	8	2	8
3,08	400	300	4	2	14	8	2	8
3,68	400	300	4	2	16	8	2	8
4,27	400	300	4	2	20	8	2	8
4,86	400	300	5	2	20	8	2	8
5,45	400	300	5	2	20	8	2	8
5,45	400	300	4	2	20	8	2	8
6,04	400	300	4	2	20	8	2	8
6,64	400	300	4	2	18	8	2	8
7,23	400	300	4	2	16	8	2	8
7,82	400	300	4	2	14	8	2	8
8,41	400	300	4	2	12	8	2	8
9,01	400	300	3	2	10	8	2	8
9,60	400	300	3	2	10	8	2	8

Beam:
B3.66

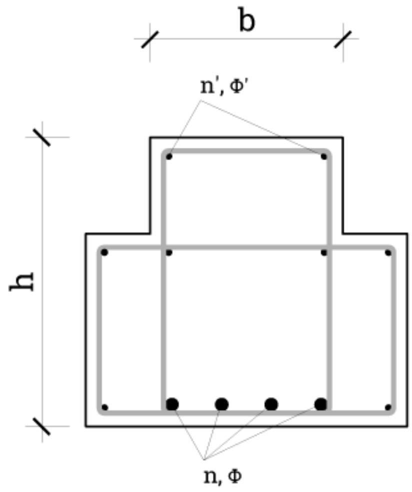


			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	2	2	8	8	2	8
0,57	350	200	4	2	10	8	2	8
1,14	350	200	4	2	14	8	2	8
1,71	350	200	3	2	18	8	2	8
2,28	350	200	3	2	20	8	2	8
2,85	350	200	4	2	20	8	2	8
3,43	350	200	4	2	20	8	2	8
4,00	350	200	4	2	20	8	2	8
4,57	350	200	3	2	20	8	2	8
5,14	350	200	3	2	18	8	2	8
5,71	350	200	4	2	14	8	2	8
6,28	350	200	4	2	10	8	2	8
6,85	350	200	2	2	8	8	2	8

STRUCTURAL SCHEDULE

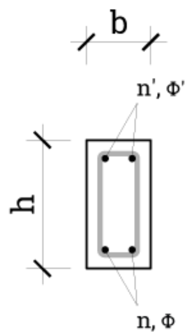
PRECAST REINFORCED CONCRETE BEAMS

Beam:
B3.71



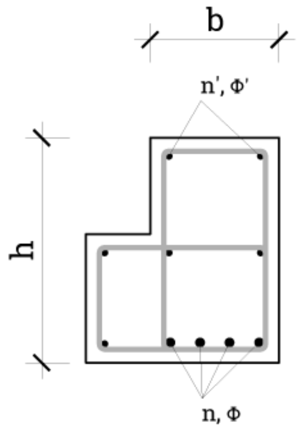
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	450	300	3	2	10	8	2	8
0,57	450	300	4	2	12	8	2	8
1,14	450	300	4	2	16	8	2	8
1,71	450	300	4	2	18	8	2	8
2,28	450	300	5	2	18	8	2	8
2,85	450	300	4	2	20	8	2	8
3,43	450	300	5	2	20	8	2	8
4,00	450	300	4	2	20	8	2	8
4,57	450	300	5	2	18	8	2	8
5,14	450	300	4	2	18	8	2	8
5,71	450	300	4	2	16	8	2	8
6,28	450	300	4	2	12	8	2	8
6,85	450	300	3	2	10	8	2	8

Beam:
B3.72; B3.73



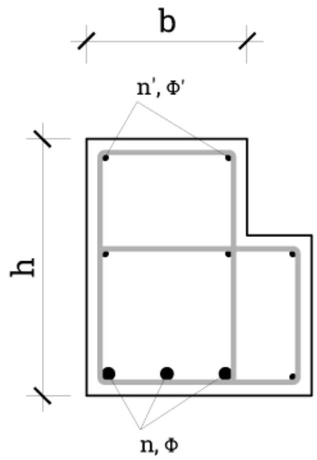
			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	200	100	2	2	8	8	2	8
0,59	200	100	2	2	8	8	2	8
1,18	200	100	2	2	8	8	2	8
1,77	200	100	2	2	8	8	2	8
2,36	200	100	2	2	8	8	2	8
2,95	200	100	2	2	8	8	2	8
3,54	200	100	2	2	8	8	2	8
4,13	200	100	2	2	8	8	2	8
4,73	200	100	2	2	8	8	2	8

Beam:
B3.74



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	350	200	2	2	8	8	2	8
0,57	350	200	3	2	10	8	2	8
1,14	350	200	4	2	12	8	2	8
1,71	350	200	4	2	16	8	2	8
2,28	350	200	4	2	16	8	2	8
2,85	350	200	4	2	18	8	2	8
3,43	350	200	4	2	18	8	2	8
4,00	350	200	4	2	18	8	2	8
4,57	350	200	4	2	16	8	2	8
5,14	350	200	4	2	16	8	2	8
5,71	350	200	4	2	12	8	2	8
6,28	350	200	3	2	10	8	2	8
6,85	350	200	2	2	8	8	2	8

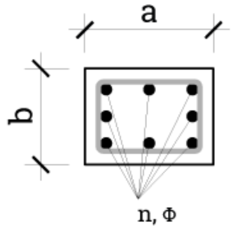
Beam:
B3.76; B3.77



			Rebar				Stirrup	
l [m]	h [mm]	b [mm]	n	n'	ϕ	ϕ'	n	ϕ
0,00	400	250	2	2	10	8	2	8
0,60	400	250	2	2	12	8	2	8
1,21	400	250	3	2	14	8	2	8
1,81	400	250	3	2	16	8	2	8
2,41	400	250	3	2	18	8	2	8
3,02	400	250	4	2	18	8	2	8
3,62	400	250	4	2	18	8	2	8
4,22	400	250	4	2	18	8	2	8
4,83	400	250	4	2	18	8	2	8
5,43	400	250	4	2	18	8	2	8
6,03	400	250	4	2	18	8	2	8
6,64	400	250	3	2	18	8	2	8
7,24	400	250	3	2	16	8	2	8
7,84	400	250	3	2	14	8	2	8
8,45	400	250	2	2	12	8	2	8
9,05	400	250	2	2	10	8	2	8

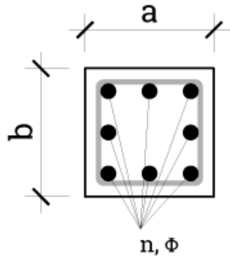
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P1.1



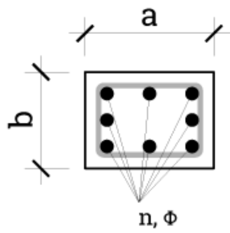
			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	150	200	8	16
3,00	150	200	8	14
3,00	150	200	8	14
6,00	150	200	4	14

Column:
P1.2



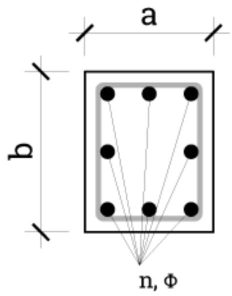
			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	200	200	8	22
3,00	200	200	8	22
3,00	200	200	8	18
4,50	200	200	8	18
6,00	200	200	8	18
6,00	150	200	8	12
9,00	150	200	8	12

Column:
P1.3



			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	200	150	8	18
3,00	200	150	8	18
3,00	150	150	8	16
4,50	150	150	8	14
6,00	150	150	8	14
6,00	150	150	8	12
9,00	150	150	8	12

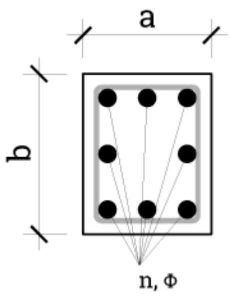
Column:
P1.4



			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	200	250	8	20
3,00	200	250	8	20
3,00	150	250	8	16
6,00	150	250	8	16

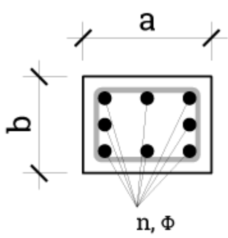
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P1.5



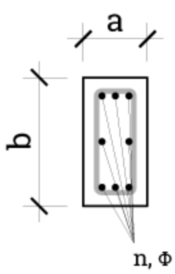
			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	200	250	8	26
3,00	200	250	8	26
3,00	200	250	8	20
4,50	200	250	8	20
6,00	200	250	8	20
6,00	150	250	8	12
9,00	150	250	8	12

Column:
P1.6



			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	200	150	8	18
3,00	200	150	8	18
3,00	150	150	8	16
4,50	150	150	8	14
6,00	150	150	8	14
6,00	150	150	8	12
9,00	150	150	8	12

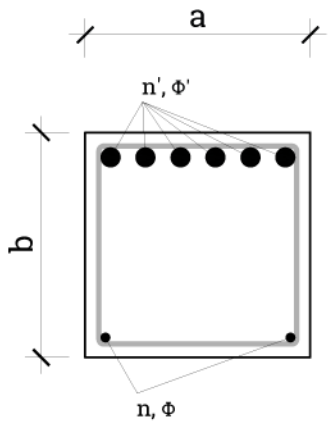
Column:
P1.7; P1.8



			Rebar	
h [m]	a [mm]	b [mm]	n	ϕ
0,00	100	200	8	12
1,50	100	200	8	12
3,00	100	200	8	12

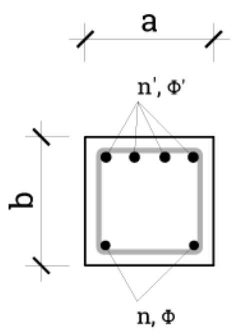
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P2.1; P2.5



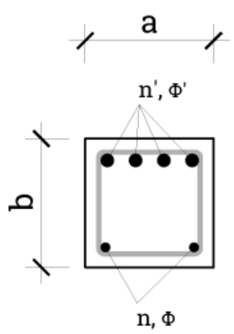
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	350	350	2	6	12	28
3,00	350	350	2	6	12	28
3,00	350	350	2	6	12	28
6,00	350	350	4	2	12	12

Column:
P2.2



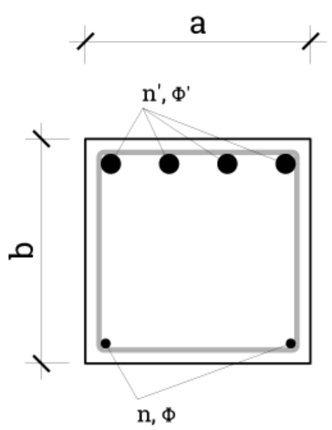
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	200	200	2	4	12	14
3,00	200	200	2	4	12	14
3,00	200	200	2	4	12	10
4,50	200	200	2	4	12	10
6,00	200	200	2	4	12	10
6,00	200	200	2	2	12	12
9,00	200	200	2	2	12	12

Column:
P2.3



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	200	200	2	4	12	18
3,00	200	200	2	4	12	16
3,00	200	200	2	4	12	14
4,50	200	200	2	4	12	12
6,00	200	200	2	4	12	12
6,00	200	200	2	2	12	12
9,00	200	200	2	4	12	12

Column:
P2.4; P2.8

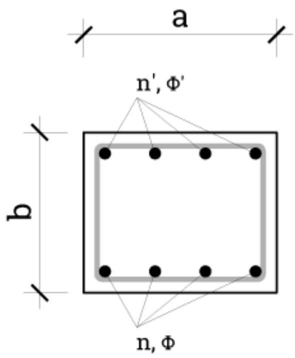


			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	350	350	2	6	12	28
3,00	350	350	2	6	12	28
3,00	350	350	2	6	12	30
4,50	350	350	2	6	12	20
6,00	350	350	2	4	12	14
6,00	200	250	2	4	12	22
9,00	200	250	2	2	12	12

STRUCTURAL SCHEDULE

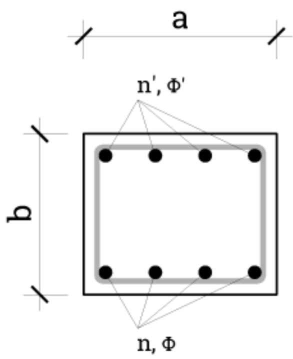
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P2.6



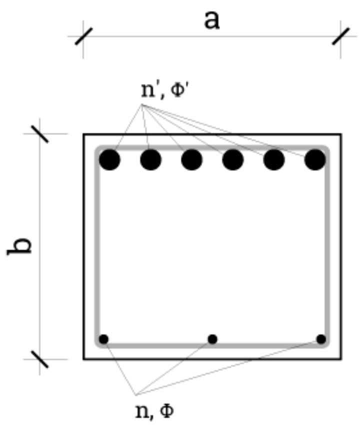
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	250	4	4	16	16
3,00	300	250	4	4	16	16
3,00	300	250	4	4	12	12
4,50	300	250	4	4	12	12
6,00	300	250	4	4	12	12
6,00	100	250	2	2	12	12
9,00	100	250	2	2	12	12

Column:
P2.7



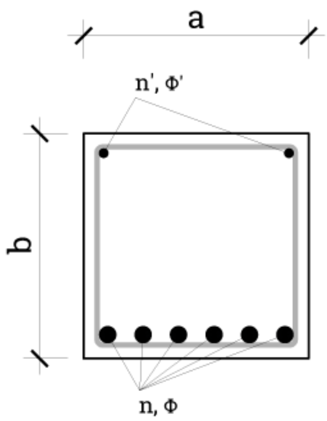
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	250	4	4	18	18
3,00	300	250	4	4	18	18
3,00	300	250	4	4	12	14
4,50	300	250	4	4	12	14
6,00	300	250	4	4	12	14
6,00	300	250	2	3	12	12
9,00	300	250	2	3	12	12

Column:
P2.9



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	350	3	6	12	30
1,50	400	350	3	3	12	12
3,00	400	350	6	3	30	12

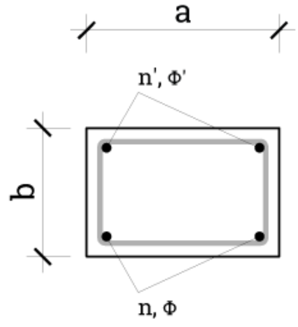
Column:
P2.10



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	350	350	6	2	24	12
3,00	350	350	2	6	12	28
3,00	350	350	2	4	12	10
6,00	350	350	2	6	12	24

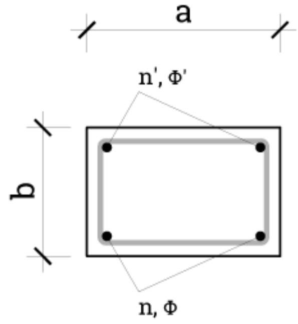
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P2.11



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	200	2	2	12	12
3,00	300	200	2	2	12	12
3,00	300	200	2	2	12	12
6,00	300	200	2	2	12	12

Column:
P2.12

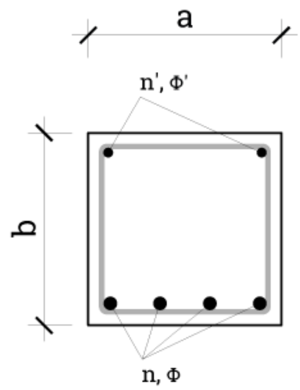


			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	200	2	2	12	12
3,00	300	200	2	4	12	12
3,00	300	200	2	4	12	12
6,00	300	200	2	2	12	12

STRUCTURAL SCHEDULE

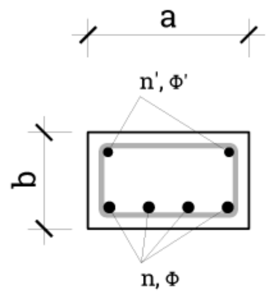
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P3.1



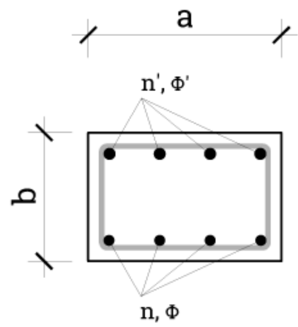
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	300	4	2	18	12
3,00	300	300	2	2	12	12
3,00	250	300	4	2	20	12
6,00	250	300	2	4	12	14
6,00	250	250	4	2	16	12
6,50	250	250	4	2	14	12
9,00	250	250	2	4	12	18
9,00	250	150	4	2	12	12
13,00	250	150	2	2	12	12

Column:
P3.2



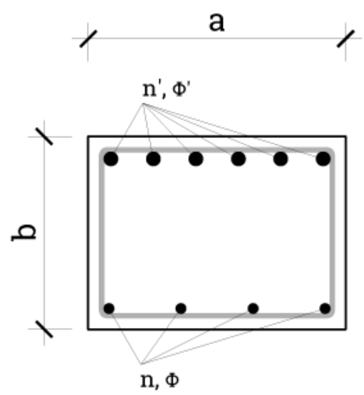
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	250	150	4	2	16	12
3,00	250	150	4	2	14	12
3,00	250	150	4	2	14	12
6,00	250	150	3	2	12	12
6,00	250	150	3	2	12	12
6,50	250	150	3	2	12	12
9,00	250	150	2	2	12	12
9,00	250	100	4	2	12	12
13,00	250	100	3	2	12	12

Column:
P3.3



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	200	4	4	14	16
3,00	300	200	4	4	14	16
3,00	300	150	4	4	12	18
4,50	300	150	4	4	12	16
6,00	300	150	4	4	12	16
6,00	300	150	2	3	12	12
9,00	300	150	2	2	12	12

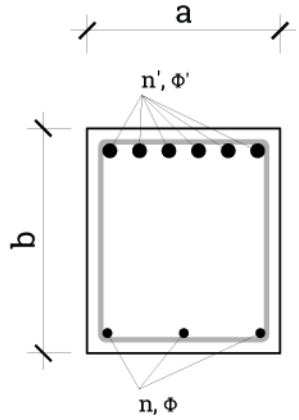
Column:
P3.4



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	300	4	6	14	20
3,00	400	300	4	6	14	20
3,00	400	300	3	6	12	26
4,50	400	300	4	4	12	14
6,00	400	300	4	4	20	12
6,00	400	150	4	4	12	12
9,00	400	150	4	4	24	12

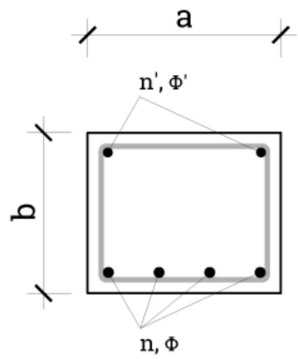
STRUCTURAL SCHEDULE
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P3.5



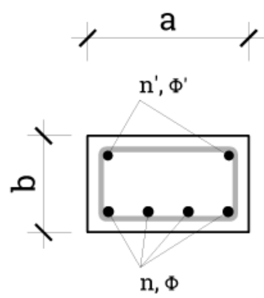
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	350	3	6	12	20
3,00	300	350	3	4	12	20
3,00	300	350	2	6	12	24
4,50	300	350	2	4	12	12
6,00	300	350	4	2	20	12
6,00	300	250	2	2	12	12
9,00	300	250	4	2	20	12

Column:
P3.6



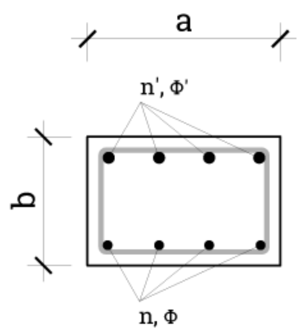
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	250	4	2	14	12
3,00	300	250	6	2	22	12
3,00	300	250	2	4	12	16
6,00	300	250	6	2	18	12
6,00	300	200	2	6	12	20
6,50	300	200	2	4	12	18
9,00	300	200	4	2	18	12
9,00	300	150	2	4	12	16
13,00	300	150	2	2	12	12

Column:
P3.7



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	250	150	4	2	14	12
3,00	250	150	4	2	16	12
3,00	250	150	3	2	12	12
6,00	250	150	4	2	16	12
6,00	250	150	2	2	12	12
6,50	250	150	2	2	12	12
9,00	250	150	4	2	12	12
9,00	250	100	2	2	12	12
13,00	250	100	2	2	12	12

Column:
P3.8

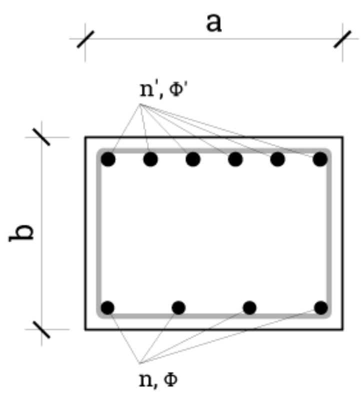


			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	300	200	4	4	12	16
3,00	300	200	4	4	12	16
3,00	300	150	2	4	12	16
4,50	300	150	2	4	12	16
6,00	300	150	2	4	12	16
6,00	300	150	2	2	12	12
9,00	300	150	2	2	12	12

STRUCTURAL SCHEDULE

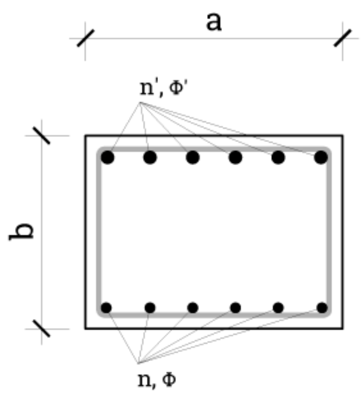
PRECAST REINFORCED CONCRETE COLUMNS

Column:
P3.9



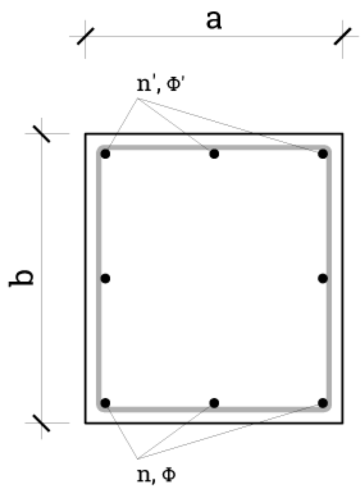
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	300	4	6	18	20
3,00	400	300	4	6	18	22
3,00	400	300	4	6	14	22
4,50	400	300	4	4	16	16
6,00	400	300	4	4	16	16
6,00	400	300	4	2	14	12
9,00	400	300	4	2	12	12

Column:
P3.10



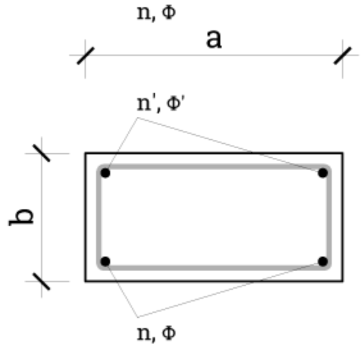
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	300	6	6	14	18
3,00	400	300	6	6	14	22
3,00	400	300	6	6	12	22
4,50	400	300	4	4	14	16
6,00	400	300	4	4	16	14
6,00	300	300	4	2	18	12
9,00	300	300	2	3	12	12

Column:
P3.11; P3.12



			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	450	3	3	12	12
1,50	400	450	3	6	12	22
3,00	400	450	3	8	12	32

Column:
P3.13; P3.14

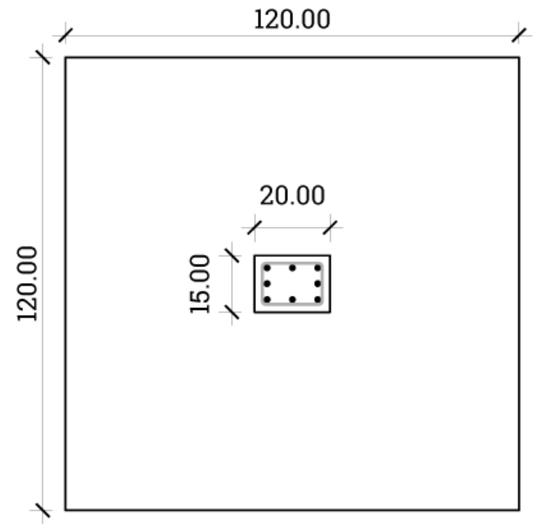


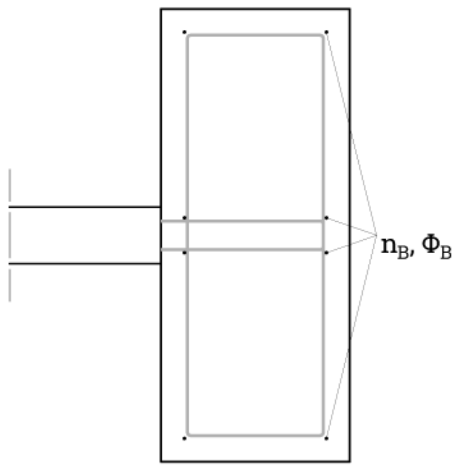
			Rebar			
h [m]	a [mm]	b [mm]	n	n'	ϕ	ϕ'
0,00	400	200	2	2	12	12
1,50	400	200	2	2	12	12
3,00	400	200	2	2	12	12

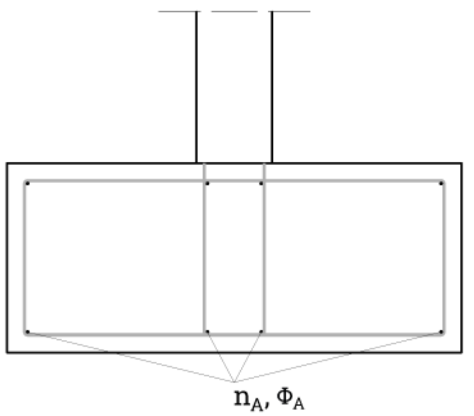
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P1.1

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	8	4	8

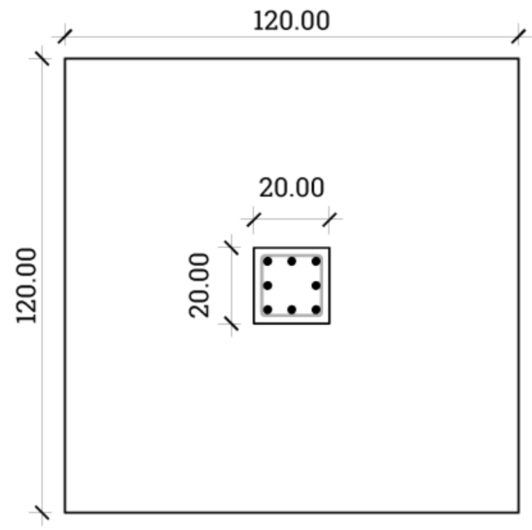


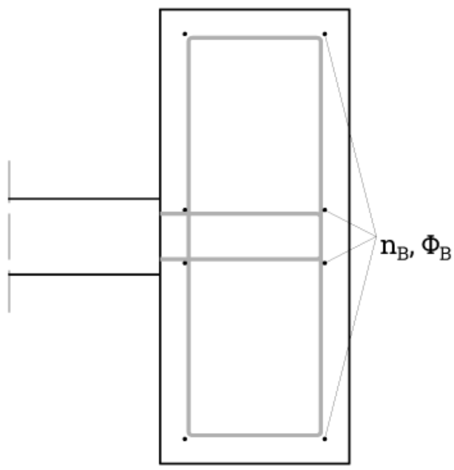


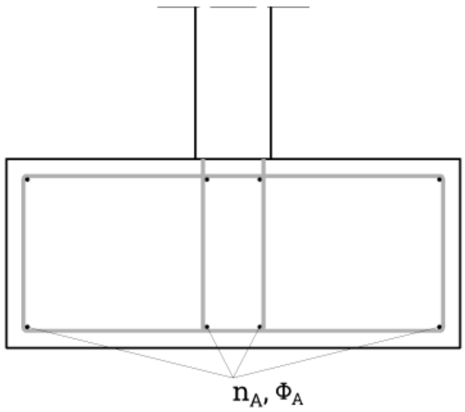


Plinth:
P1.2

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	10	4	10



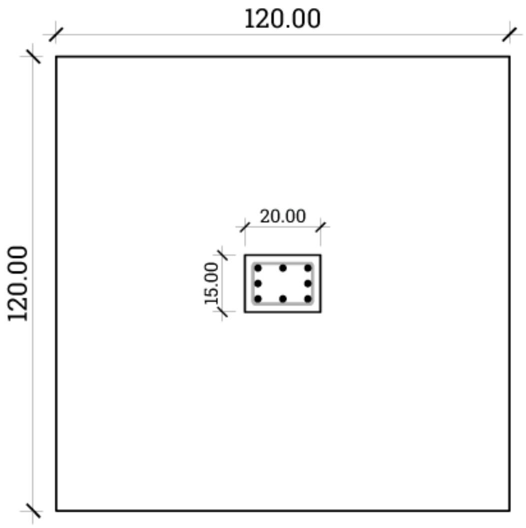


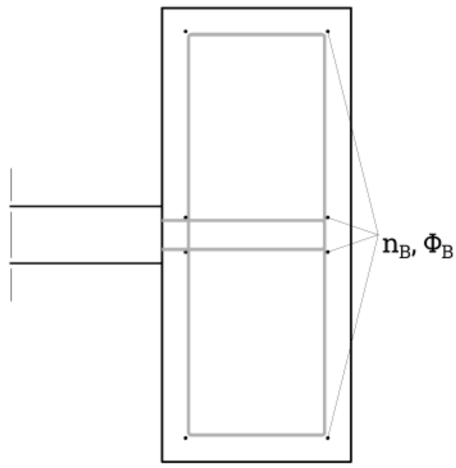


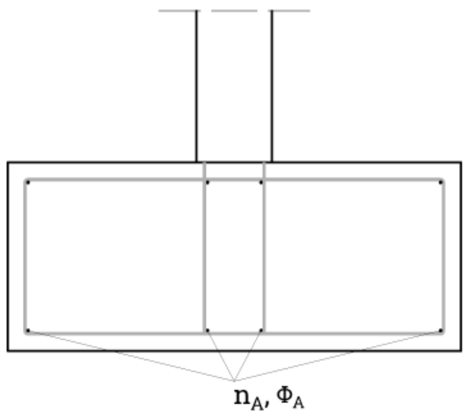
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P1.3

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	8	4	8



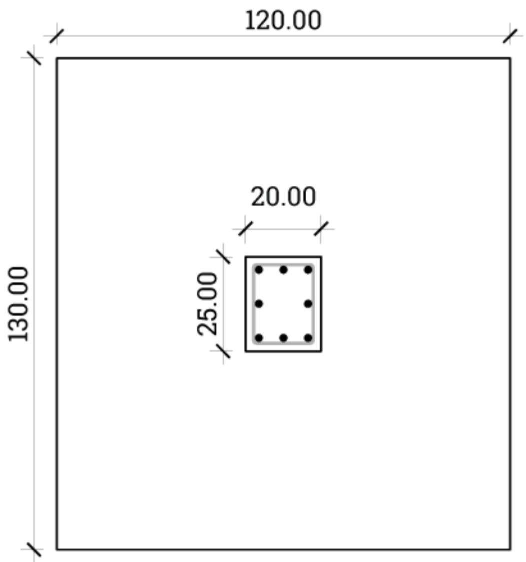


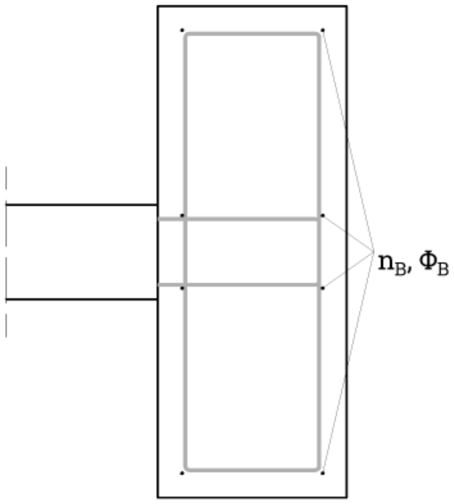


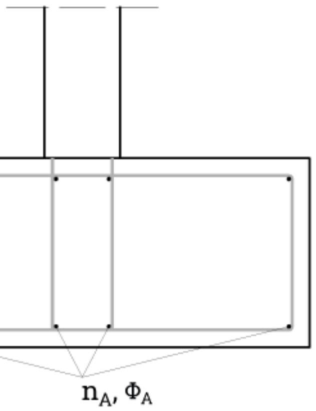
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P1.4

A [mm]	B [mm]	H [mm]	n_A	Φ_A	n_B	Φ_B
1200	1300	500	4	10	4	8



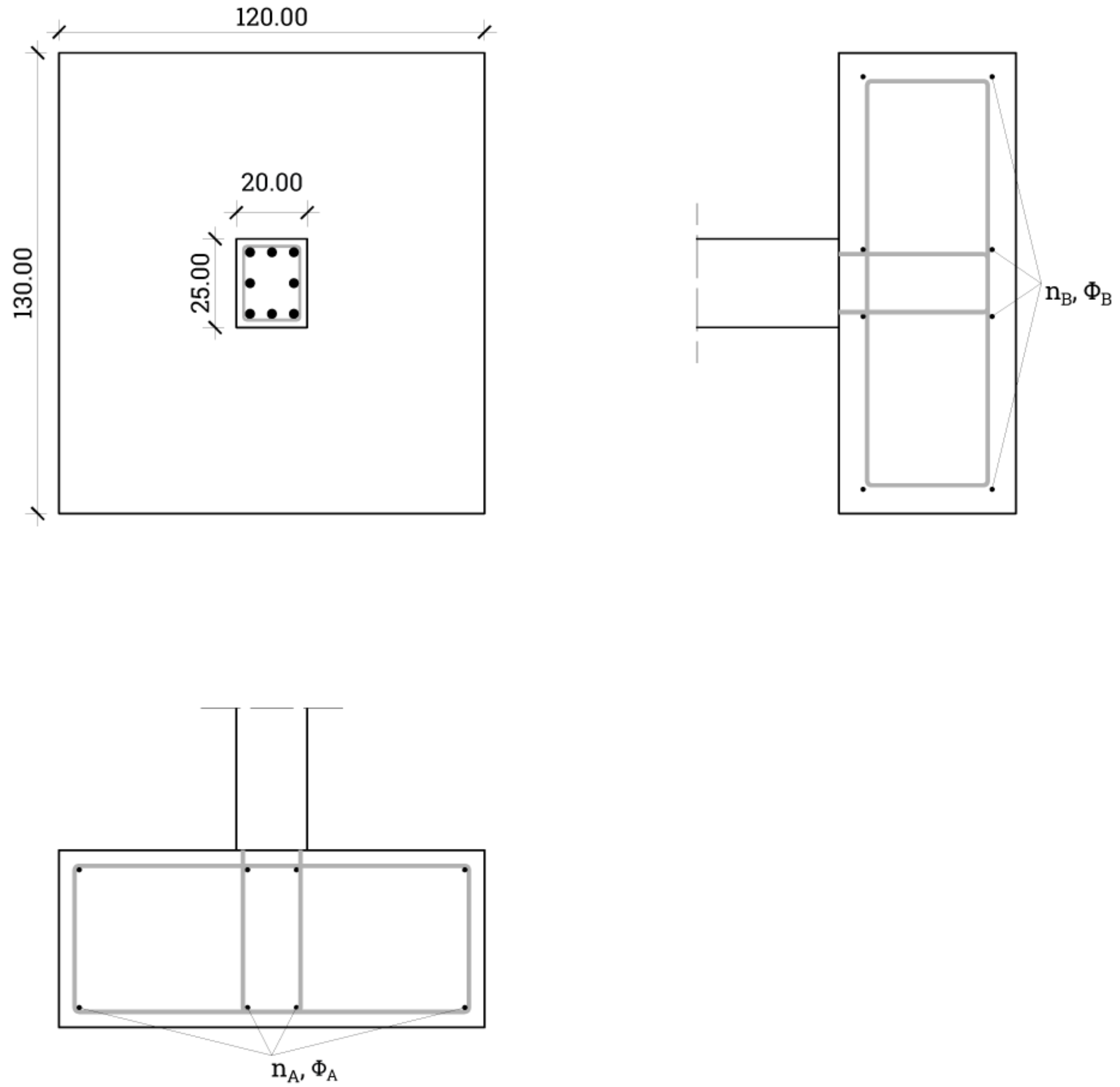




STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P1.5

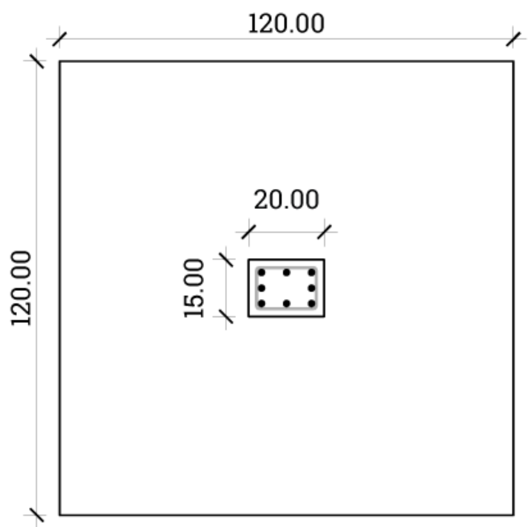
A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1300	500	4	12	4	12

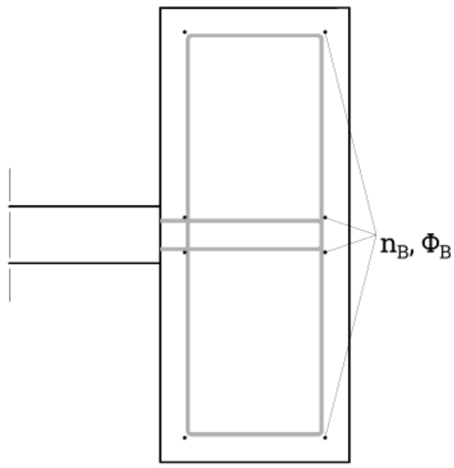


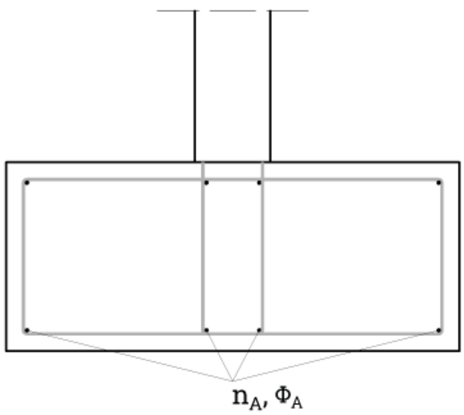
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P1.6

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	10	4	8



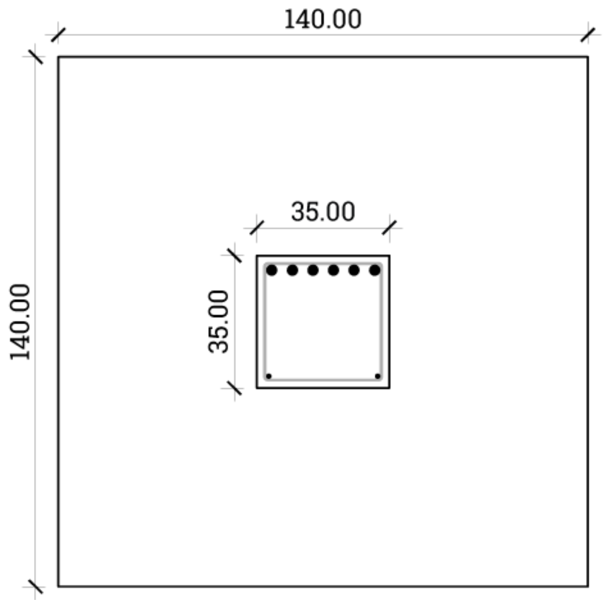


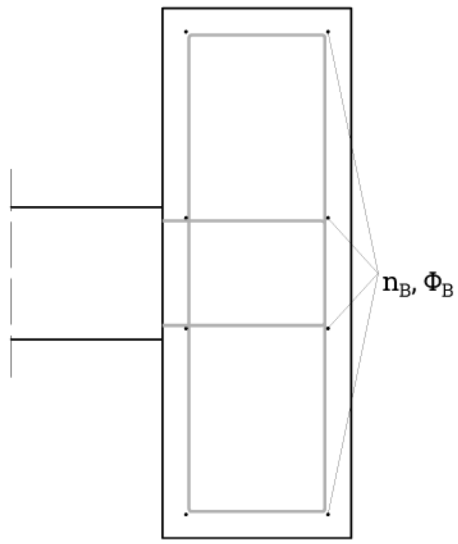


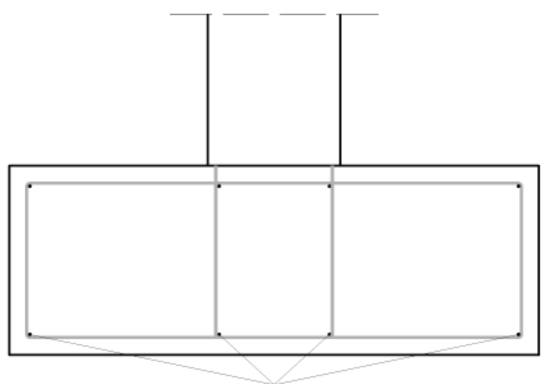
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.1; P2.5

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1400	1400	500	4	8	4	8



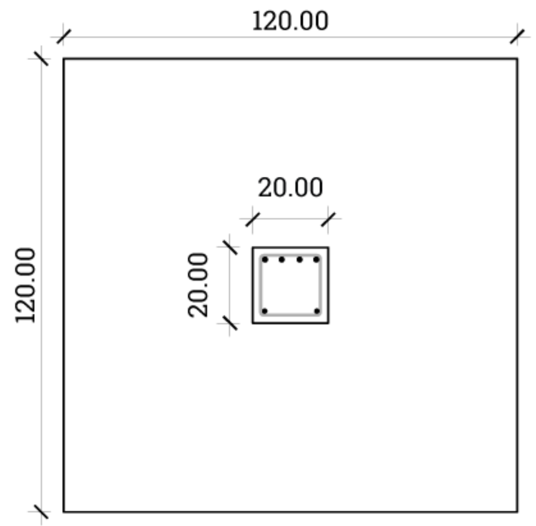


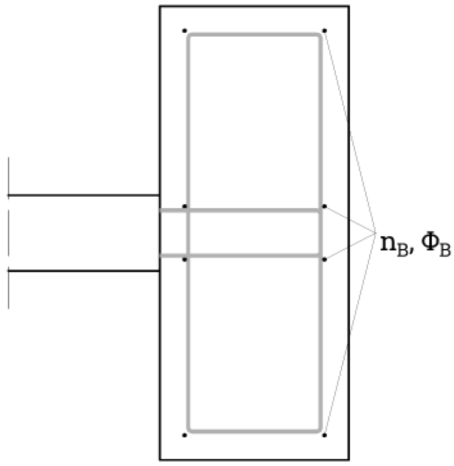


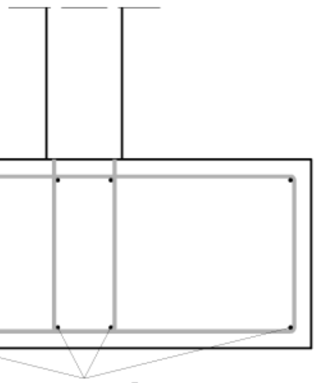
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.2

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	10	4	10



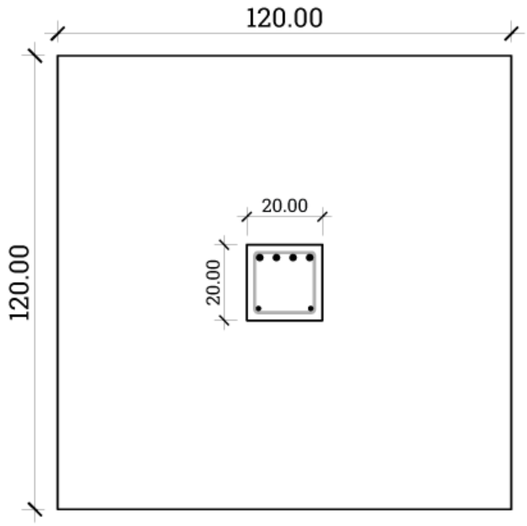


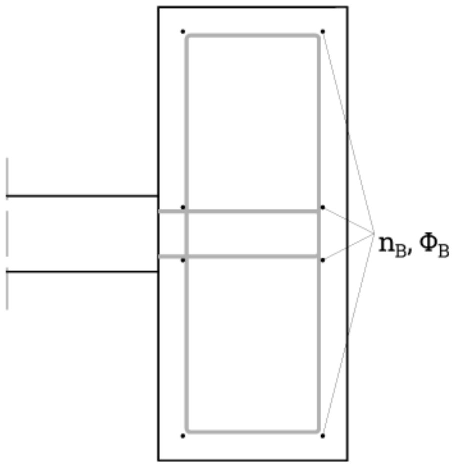


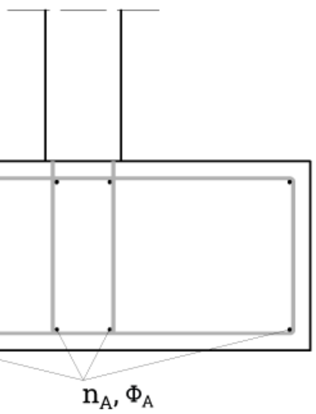
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.3

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1200	1200	500	4	10	4	10



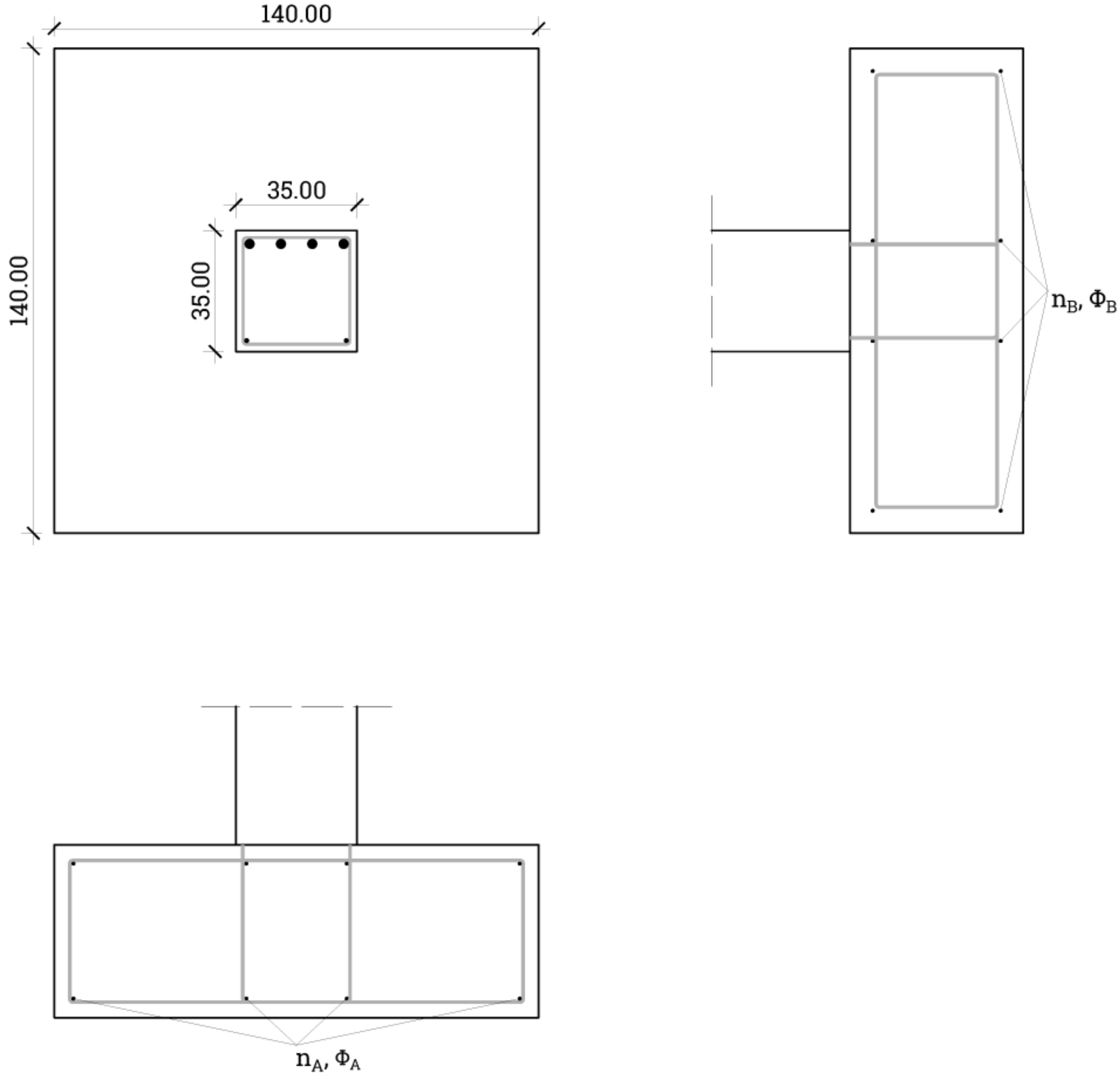




STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.4; P2.8

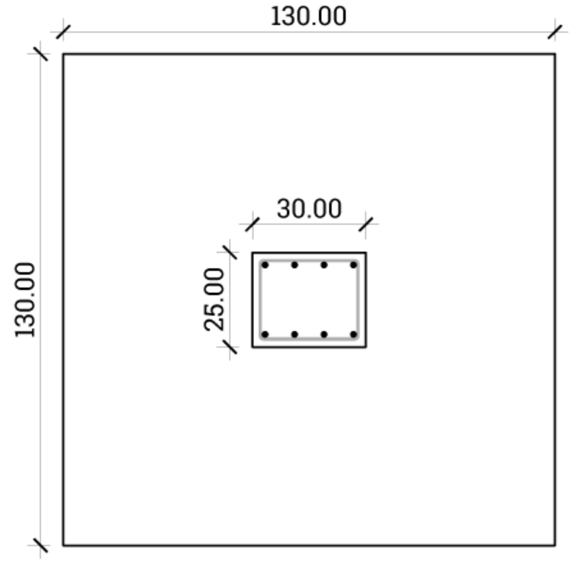
A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1400	1400	500	4	10	4	10

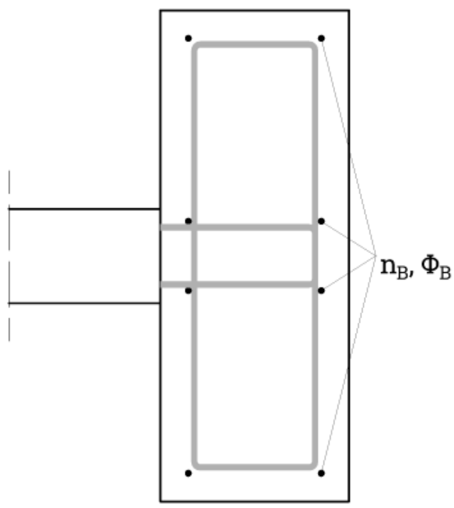


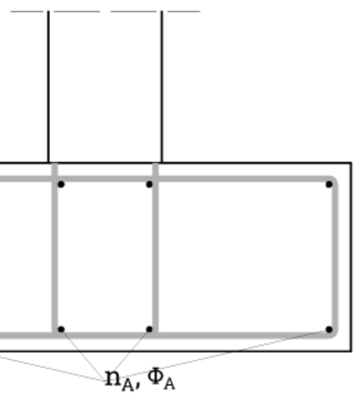
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.6

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1300	500	4	16	4	16



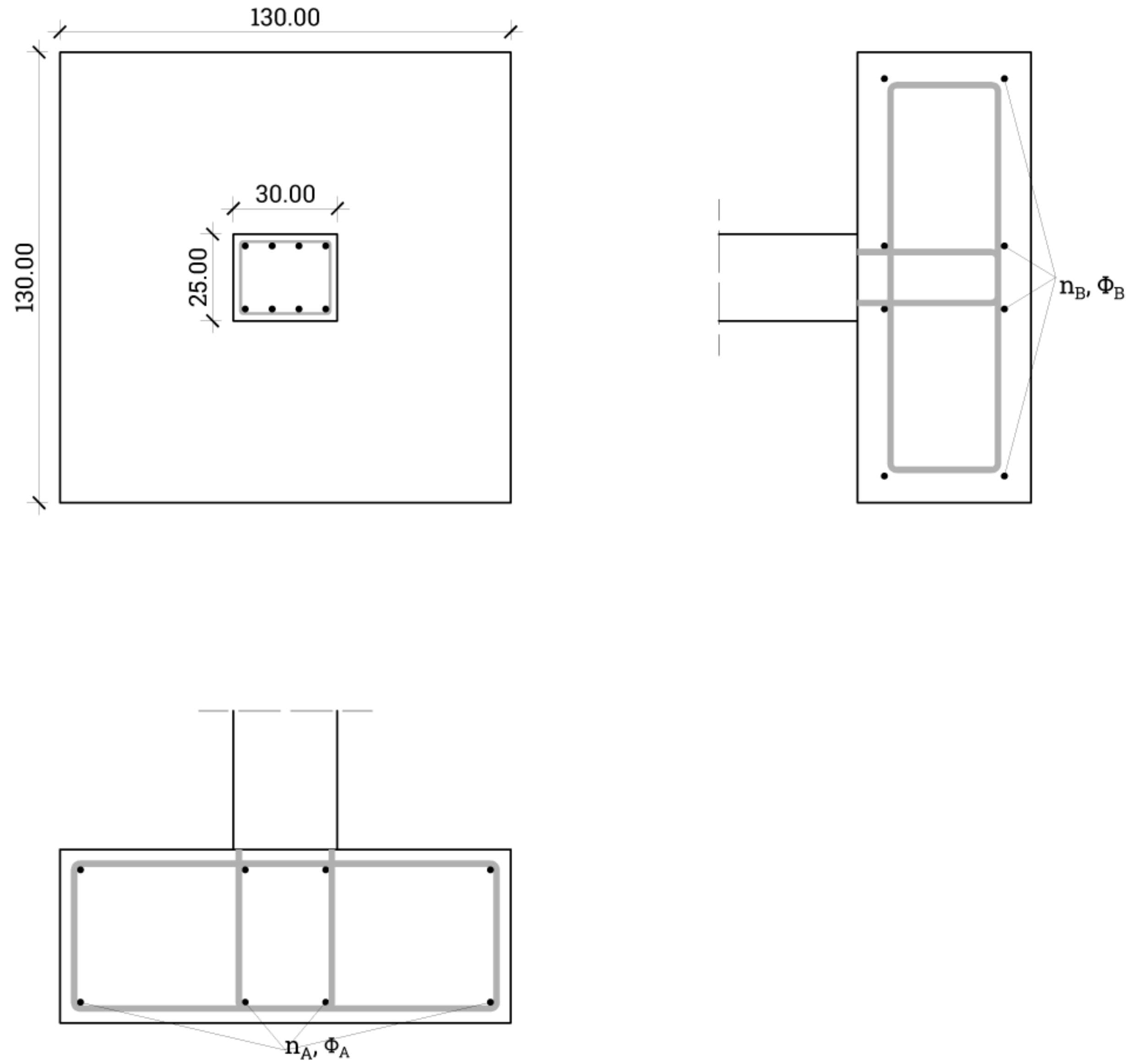




STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P2.7

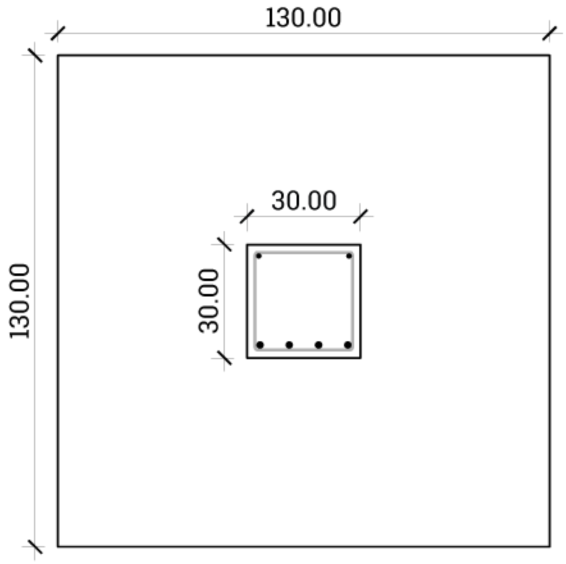
A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1300	500	4	18	4	18

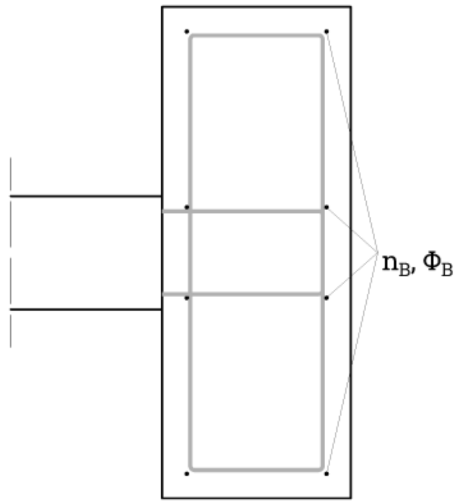


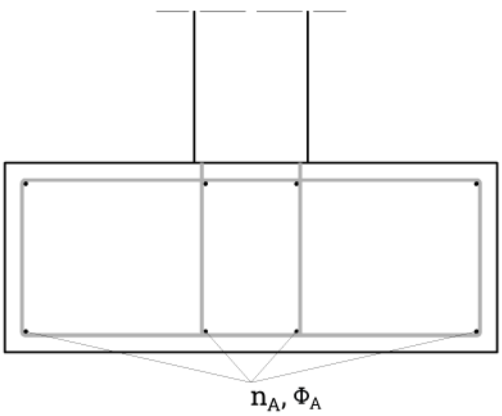
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.1

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1300	500	4	10	4	10



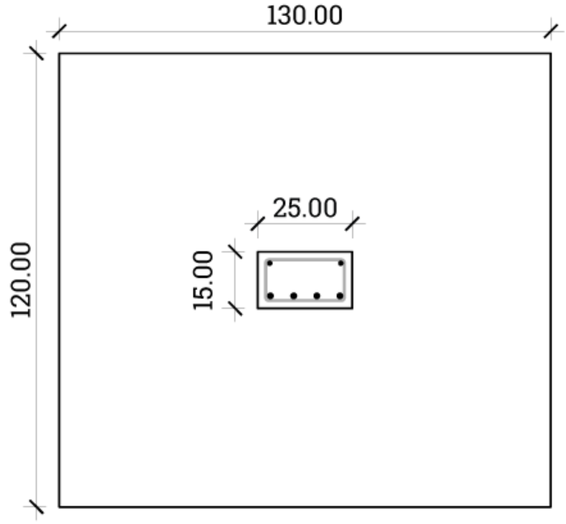


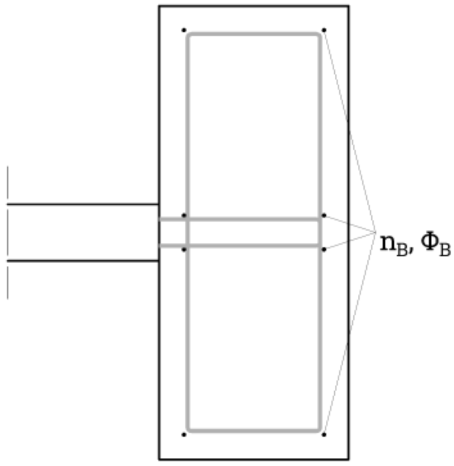


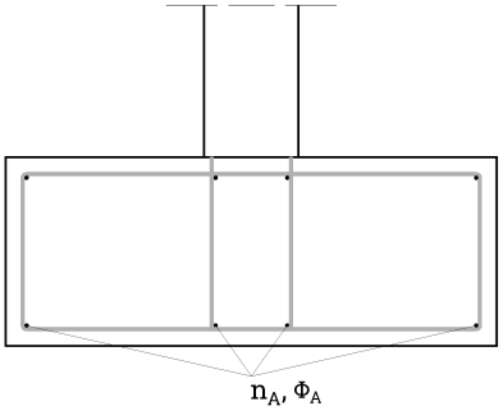
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.2

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1200	500	4	10	4	10



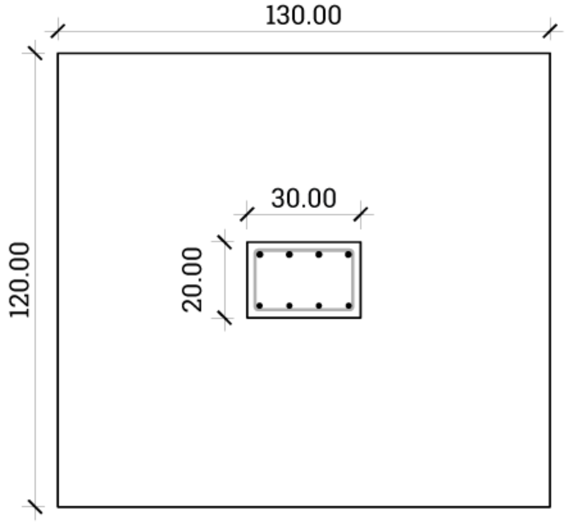


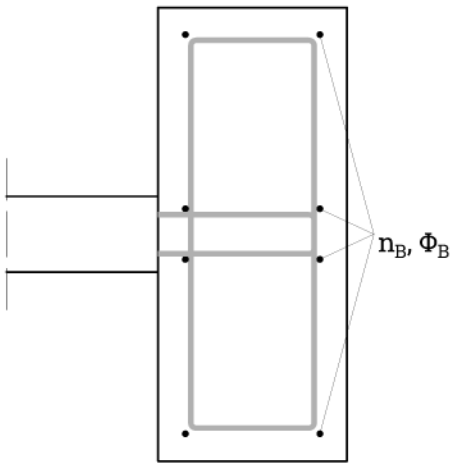


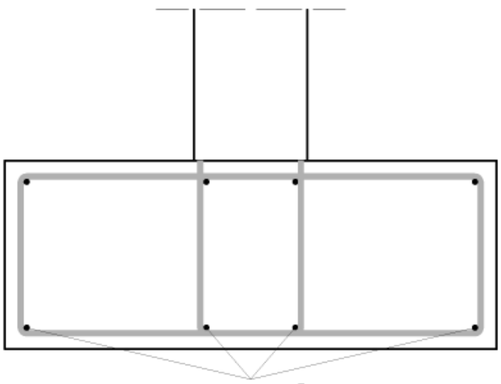
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.3

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1200	500	4	14	4	16



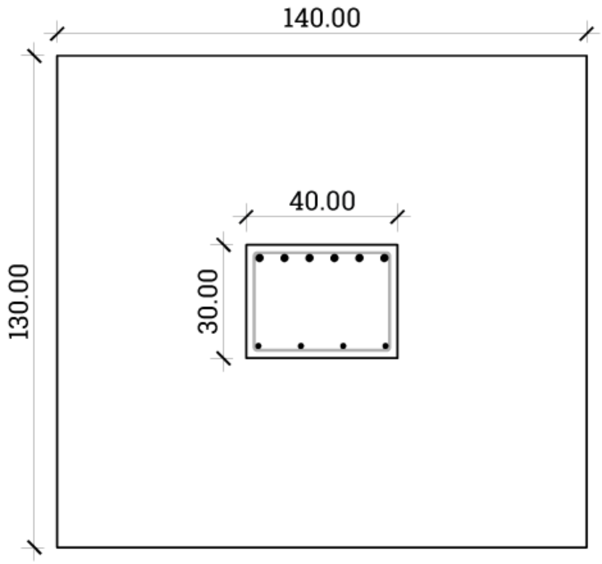


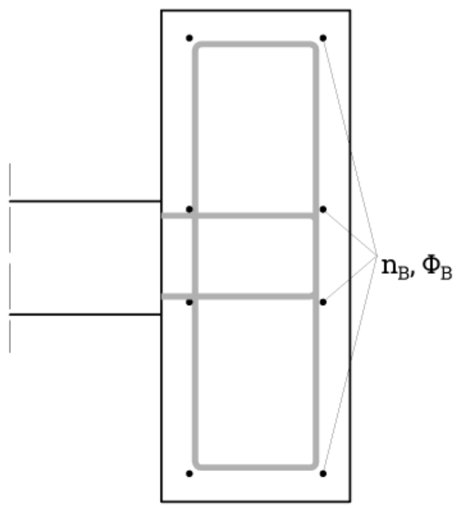


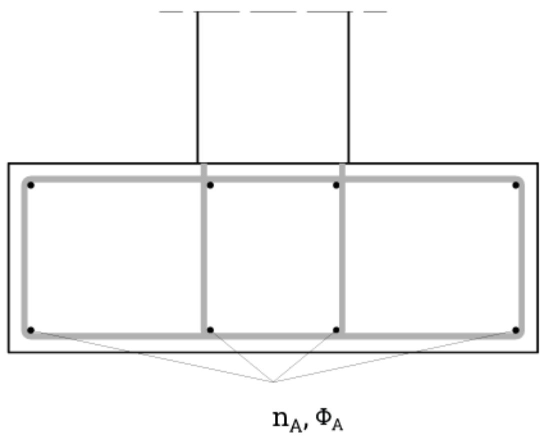
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.4

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1400	1300	500	4	16	4	16



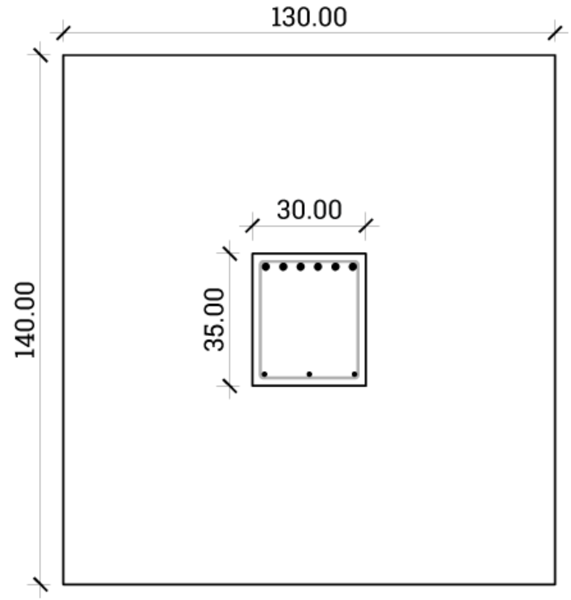


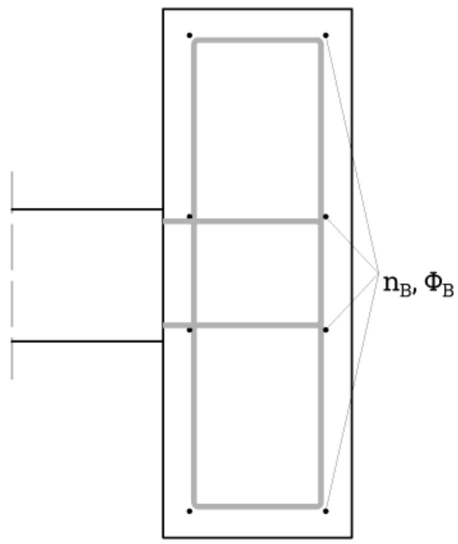


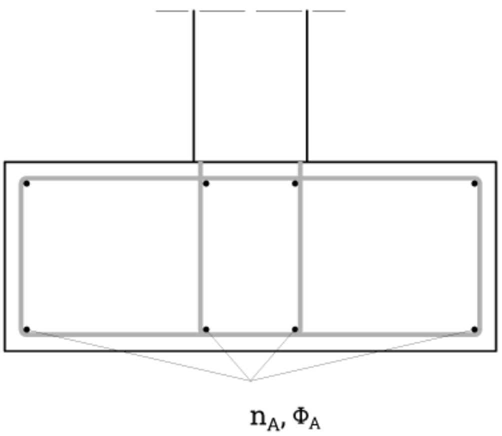
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.5

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1400	500	4	14	4	12



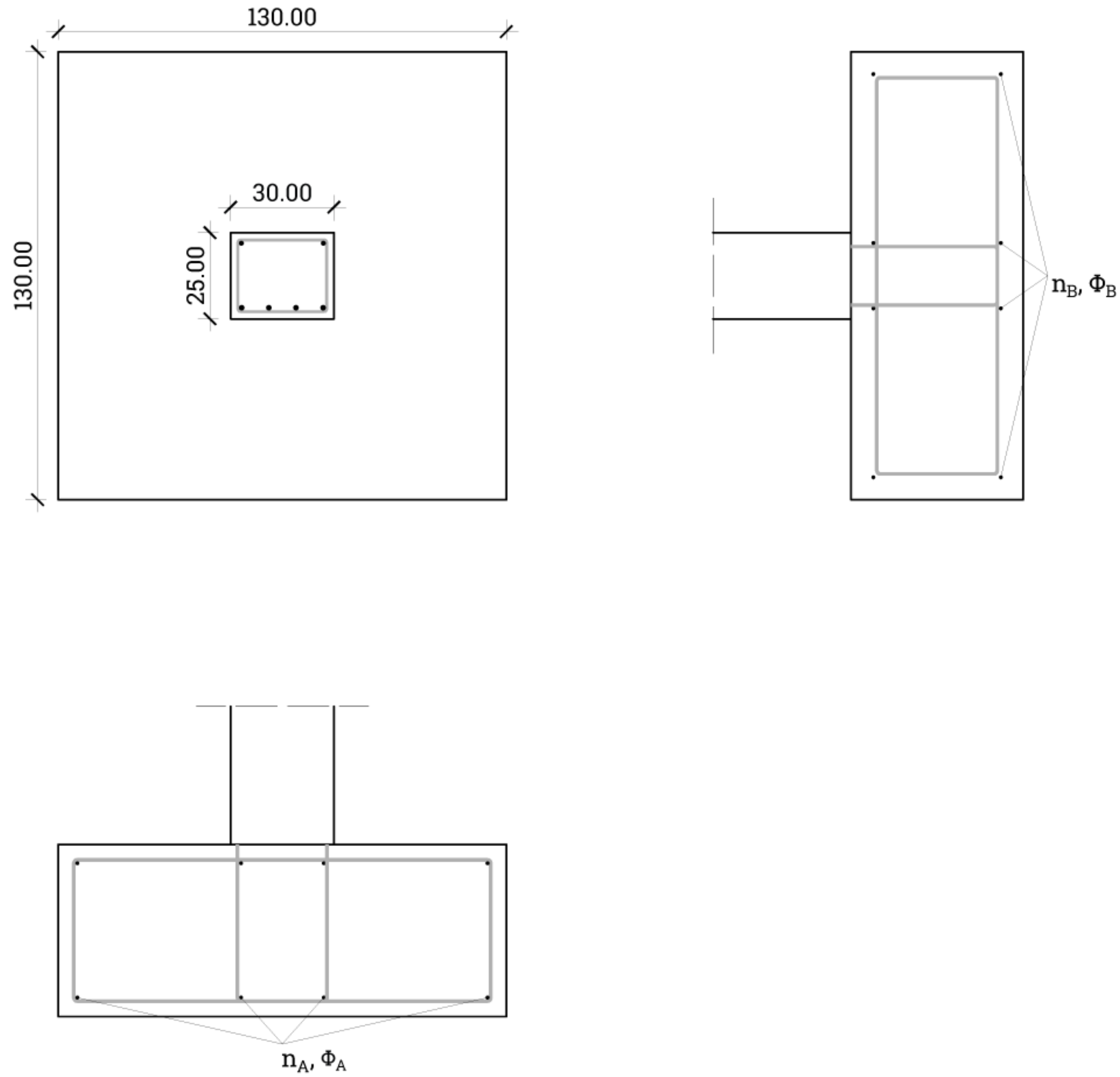




STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.6

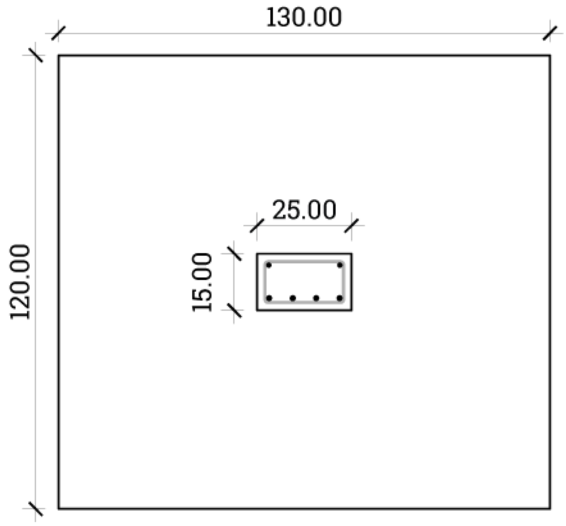
A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1300	500	4	10	4	10

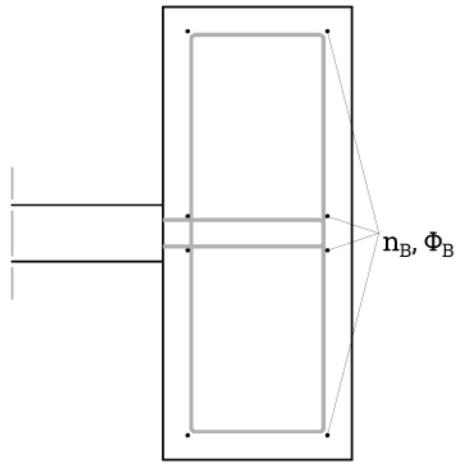


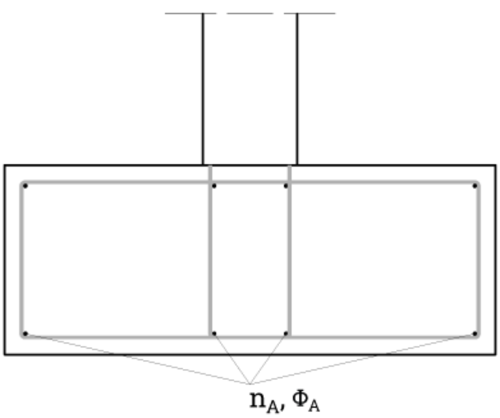
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.7

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1200	500	4	10	4	10





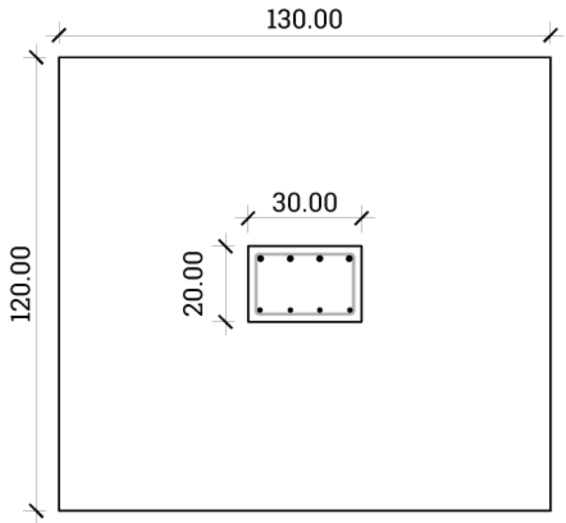


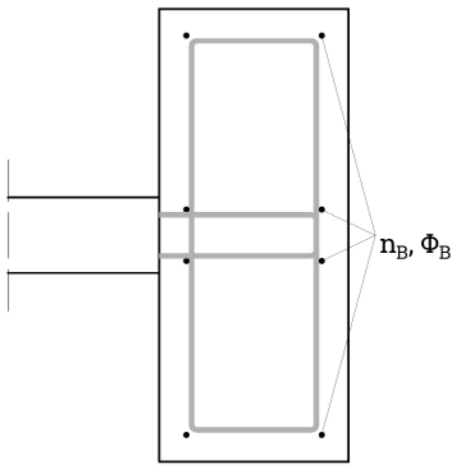
STRUCTURAL SCHEDULE

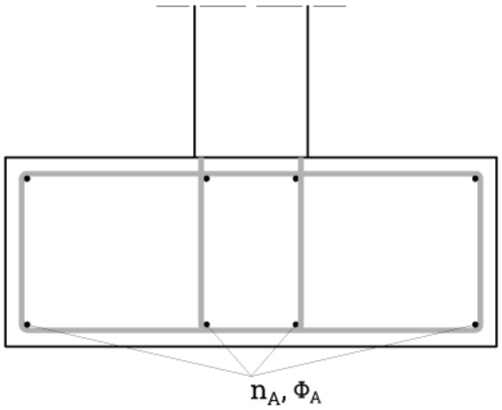
REINFORCED CONCRETE PLINTHS

Plinth:
P3.8

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1300	1200	500	4	14	4	14



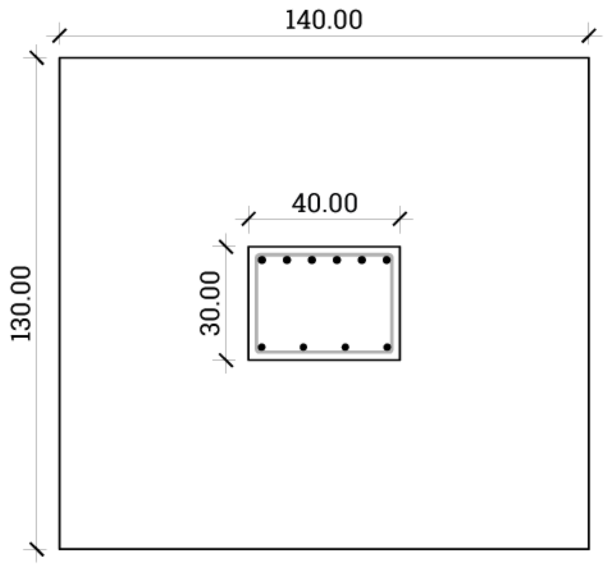


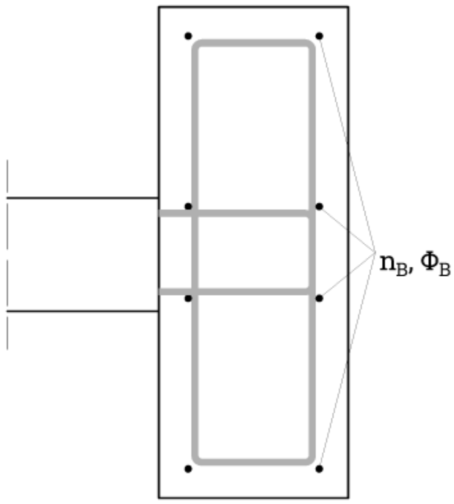


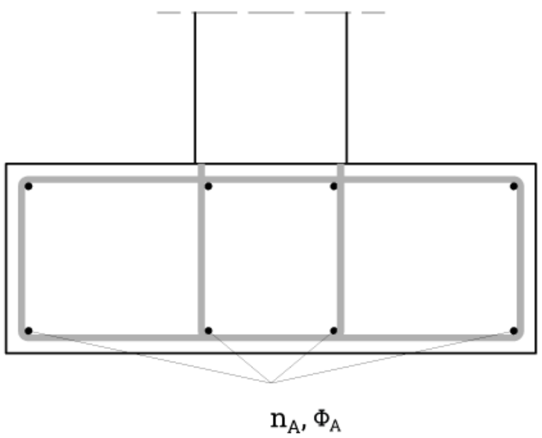
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.9

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1400	1300	500	4	18	4	18



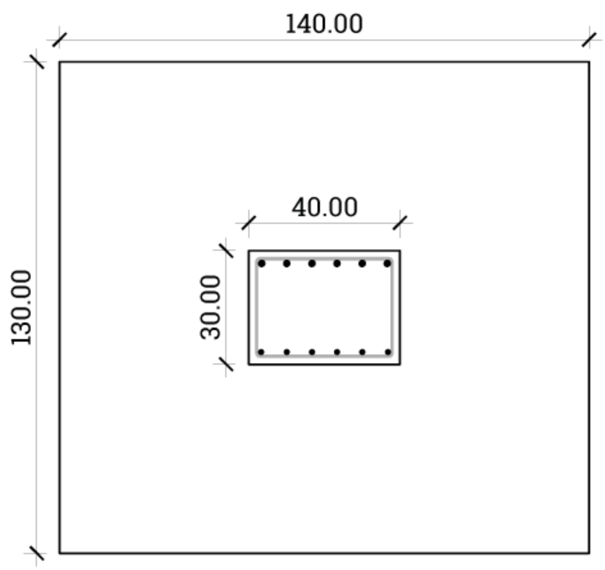


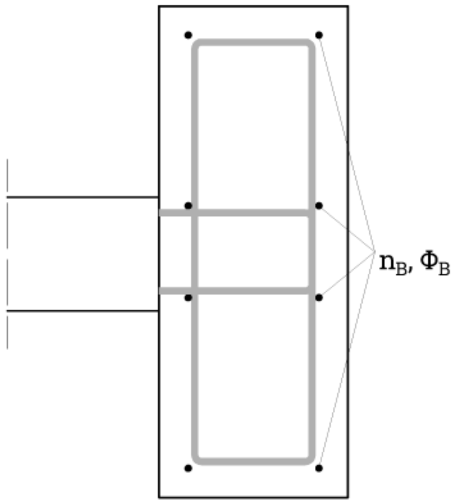


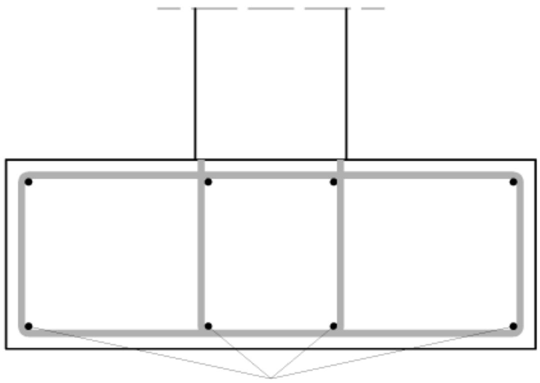
STRUCTURAL SCHEDULE
REINFORCED CONCRETE PLINTHS

Plinth:
P3.10

A [mm]	B [mm]	H [mm]	n_A	ϕ_A	n_B	ϕ_B
1400	1300	500	4	18	4	18







5.3 Materials and technology

5.3.1 Overview

The choice of materials to be employed in this project was heavily influenced by the socio-economical context in which it is meant to be built: Rocinha, and, in general, Brazil. On the one hand, one of the goals of this thesis is to provide sustainable solutions in a very peculiar and informal urban context, on the other, as it has been the case many times in the analyses and solutions of chapters past, said context is the main limiting factor in many of the design choices outlined in the above sections.

Before the survey, the possibility of using non-standard construction materials was contemplated, the most popular solutions being the use of bricks made out of pressed recycled plastic or plastic bottles filled of refuse material, both certainly sustainable technologies used in poorer urban environment where waste disposal is an issue, such as Rocinha. However, as is often the case, this answer, acceptable in theory, fell apart after the survey of the favela, as it didn't take into account the costs associated with recycling plastic into bricks and how normal bricks are both readily available and extremely cheap. In other words, there're no real incentives for the local population (like there could be for other projects proposed in this thesis) to employ the first method, as simply selling recycled plastic and buying bricks would be more convenient than producing them from plastic.

Therefore, the technological design for this project has focused in employing the simplest possible construction methods, to the point where, should the inhabitants of the favela be employed as mostly unskilled labour, they would be able to do it. More realistically, they could alter the internal layout of the apartments or add some modules on the second floor once the building is completed.

As shown in the images below, the walls are made either of concrete or bricks, painted with simple plaster and insulated both acoustically and thermally through readily available materials (Coir and mineral wool) prioritizing cost over performance. It has also been decided that both insulations, especially the thermal layer, would be put on the inside; performance-wise, this is a less than optimal decision, as it makes thermal bridges a certainty, however, not only protection from the cold is almost unnecessary (with 18°C of medium temperature in winter), but it also guarantees a greater protection to the insulation layer, thereby cutting maintenance and replacement costs.

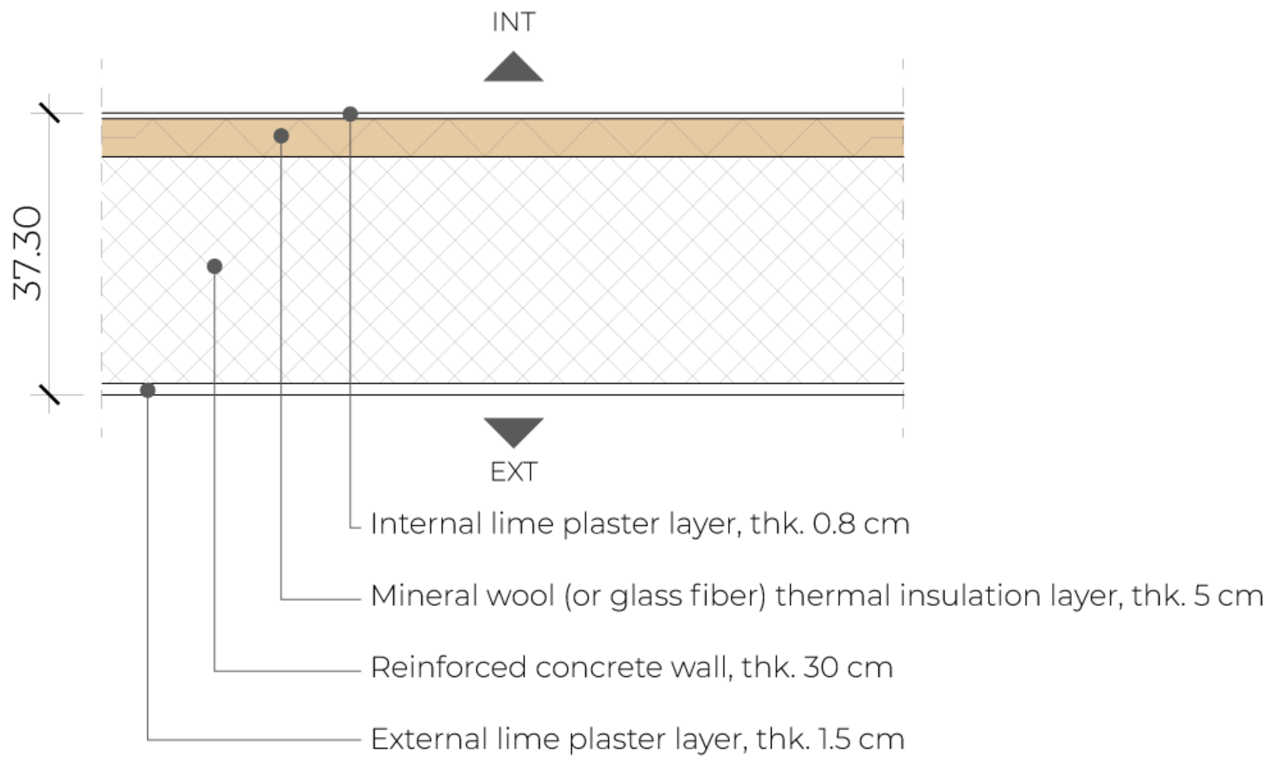
The same can be said of the transparent elements, which are simple aluminium sections for curtain walls and PVC for windows, with little regard to their insulation capabilities. Floors are made of porcelain tiles of various sizes, resistant to impacts, staining and corrosion.

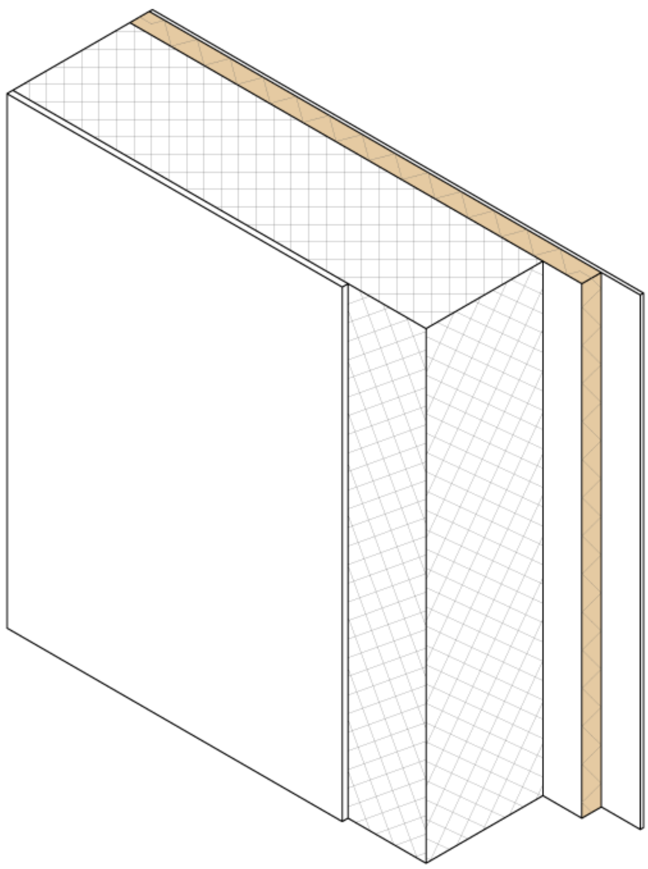
5.3.2 Appendix: technical packages

1. External Wall 01 [EW01].
2. External Wall 02 [EW02].
3. Horizontal Floor 01 [HF01].
4. Horizontal Floor 02A [HF02A].
5. Horizontal Floor 02B [HF02B].
6. Horizontal Floor 02C [HF02C].
7. Horizontal Floor 03 [HF03].
8. Vertical Partition 01 [VP01].
9. Vertical Partition 02 [VP02].

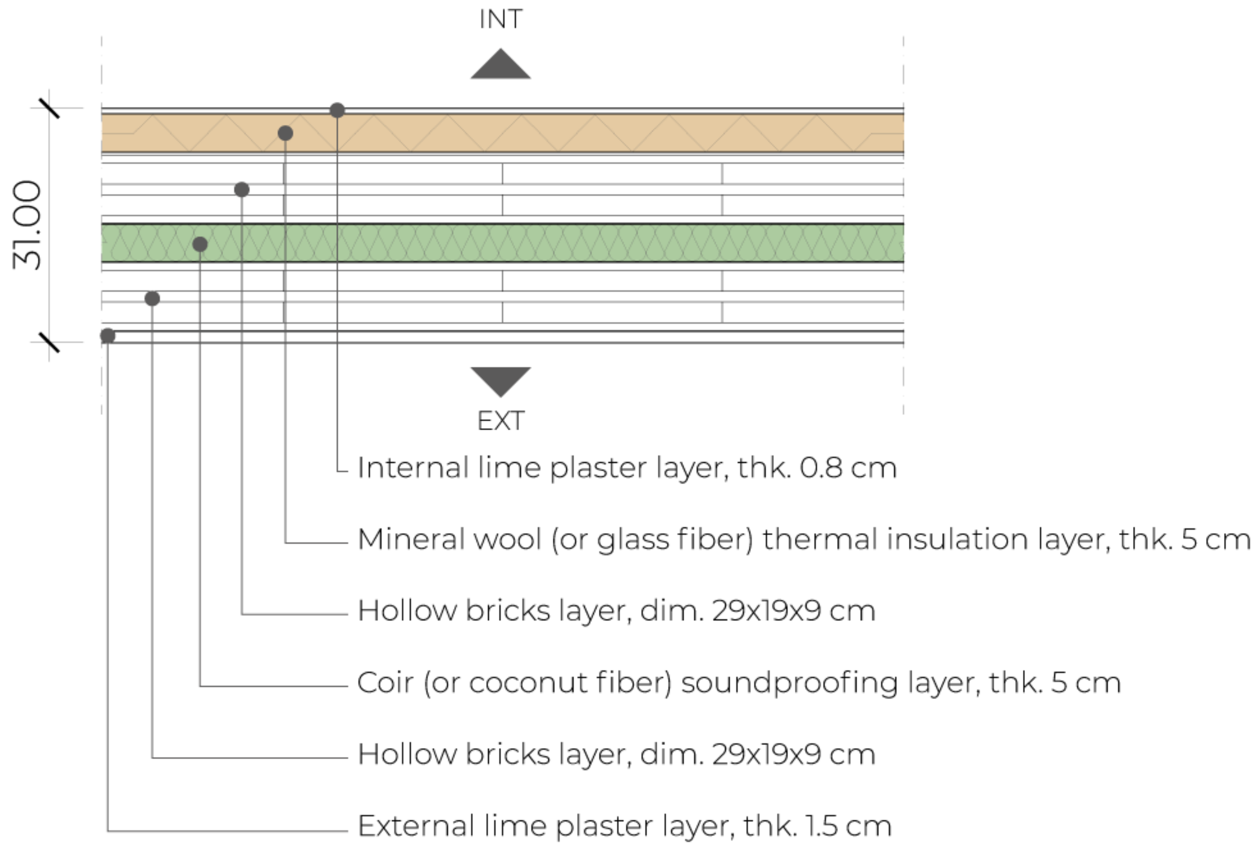
10. Vertical Partition 03 [VP03].
11. Vertical Partition 04 [VP04].
12. Horizontal Partition 01A [HP01A].
13. Horizontal Partition 01B [HP01B].
14. Horizontal Partition 01C [HP01C].
15. Blow-Up 01.
16. Blow-Up 02.

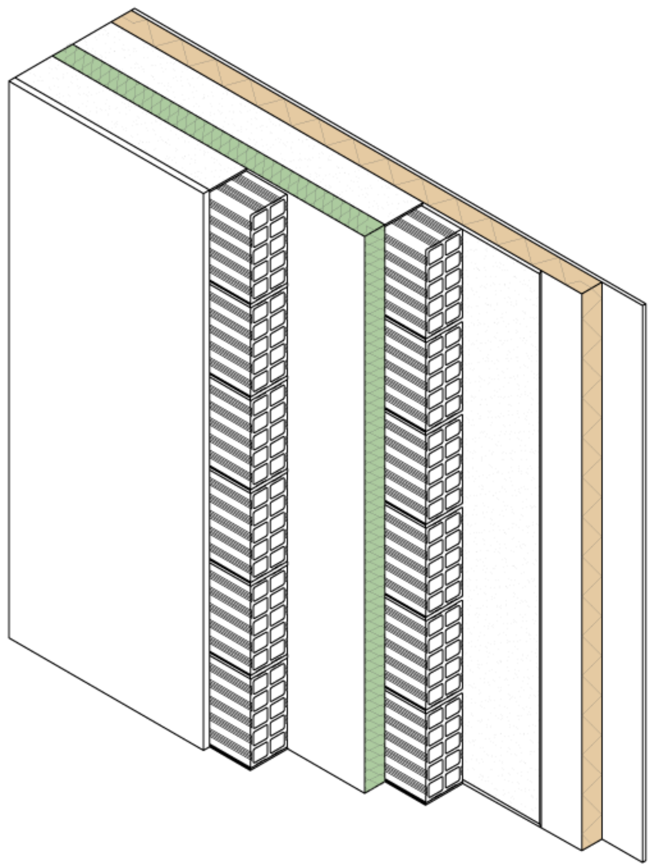
TECHNICAL PACKAGES
EXTERNAL WALL 01, scale 1:10





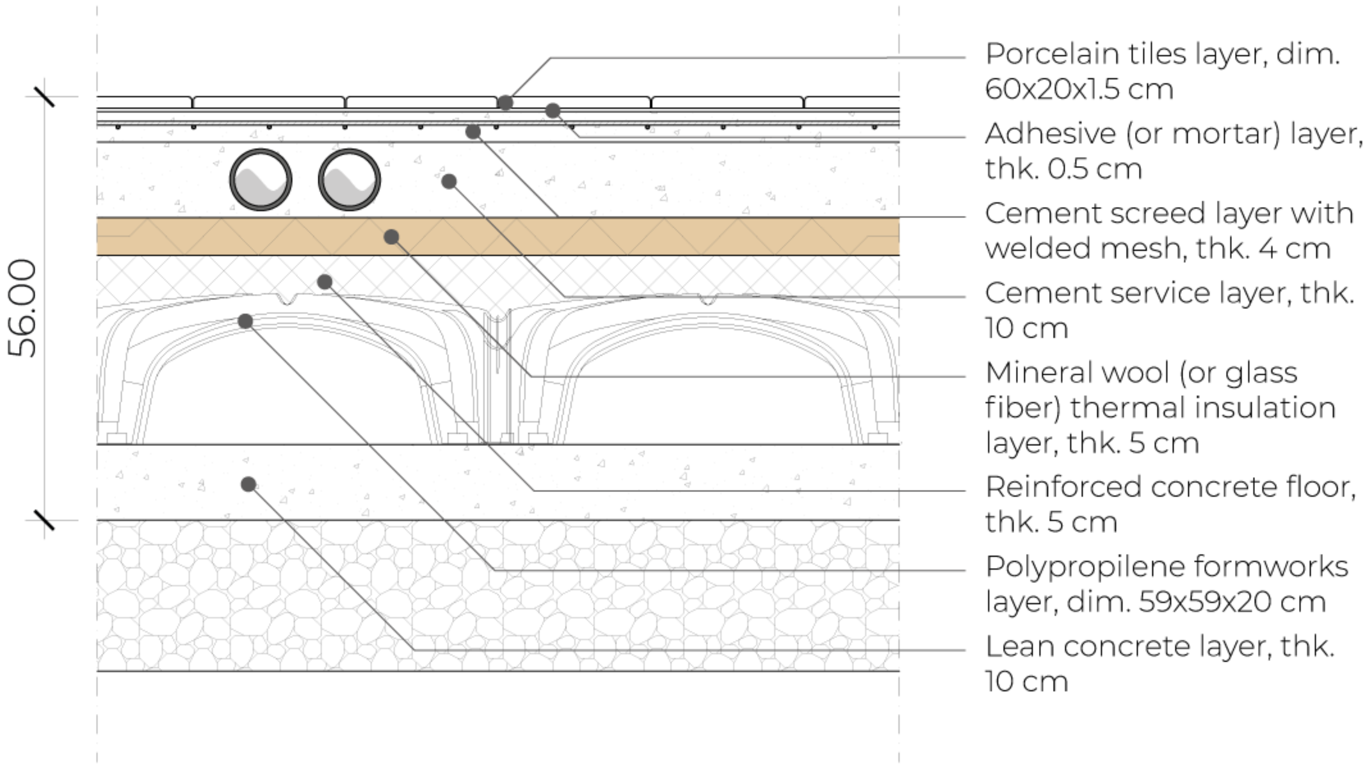
TECHNICAL PACKAGES
EXTERNAL WALL 02, scale 1:10

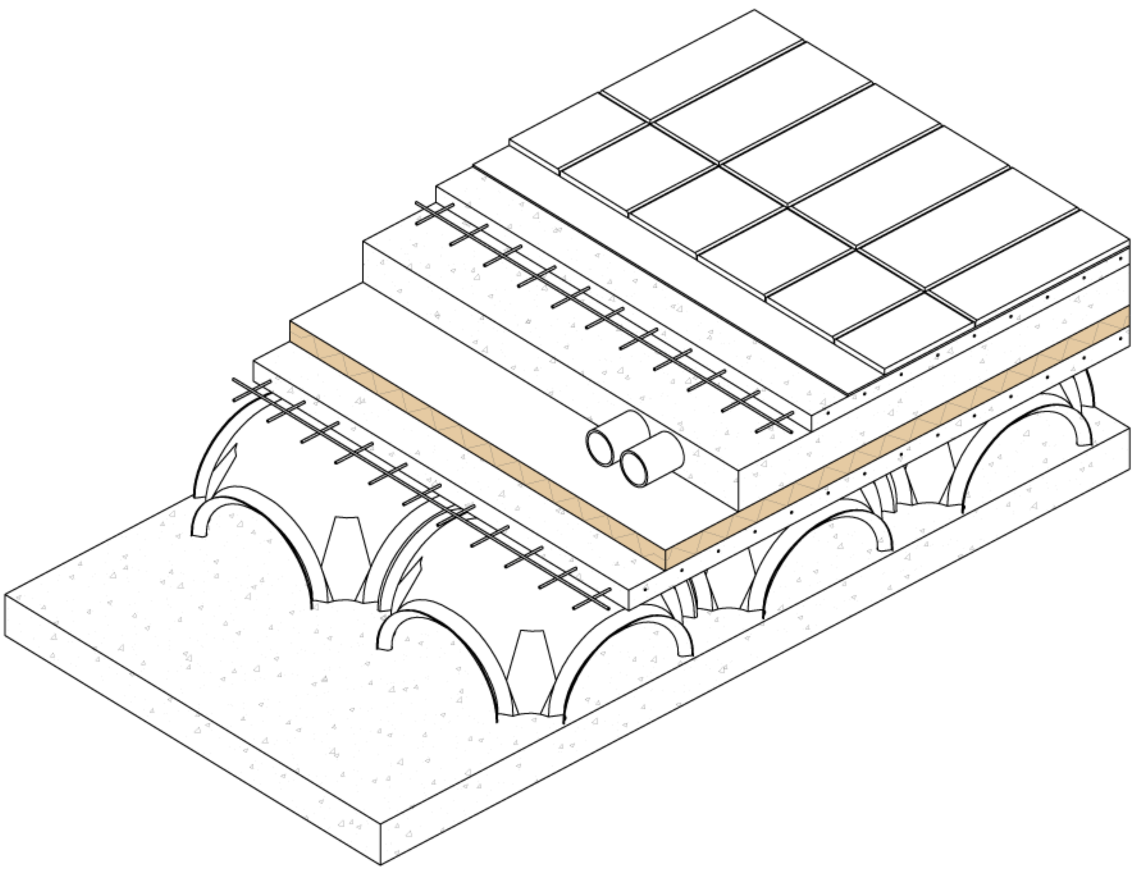




TECHNICAL PACKAGES

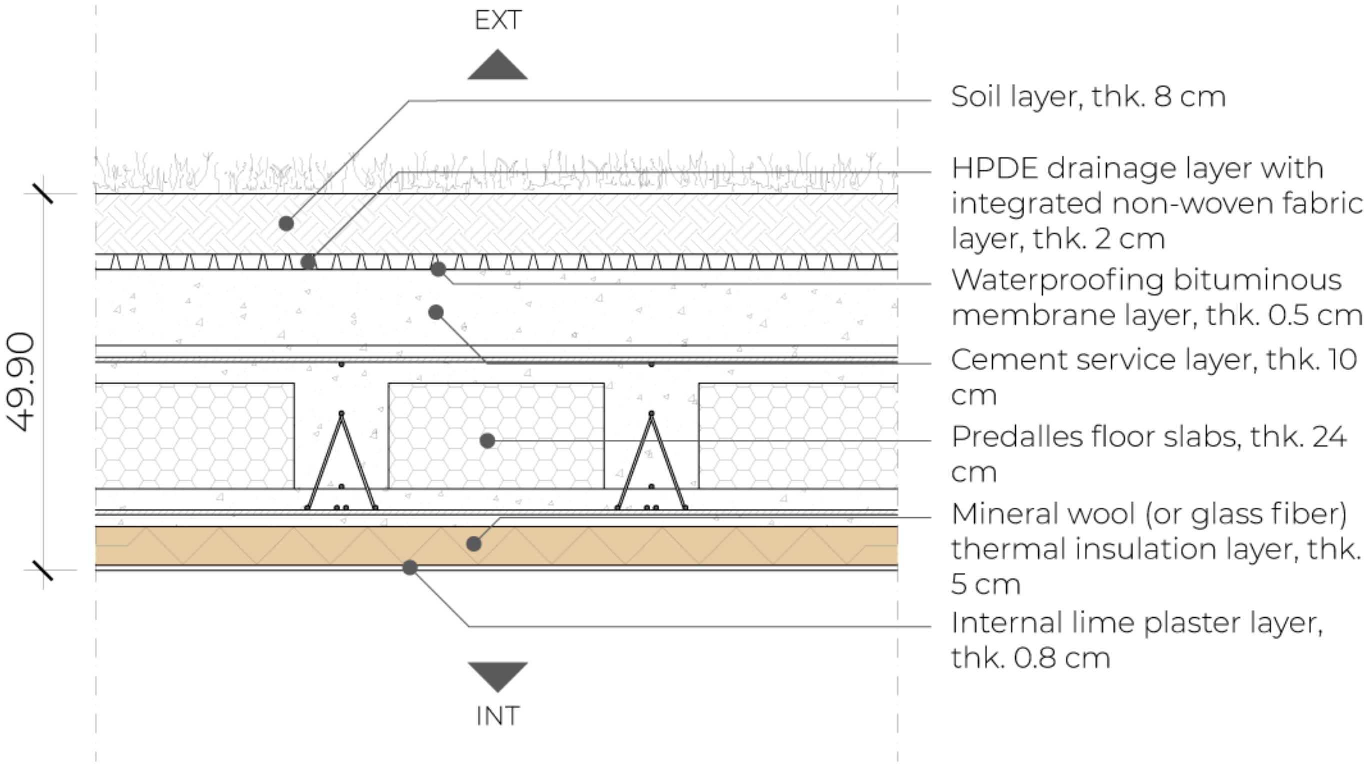
HORIZONTAL FLOOR 01, scale 1:10

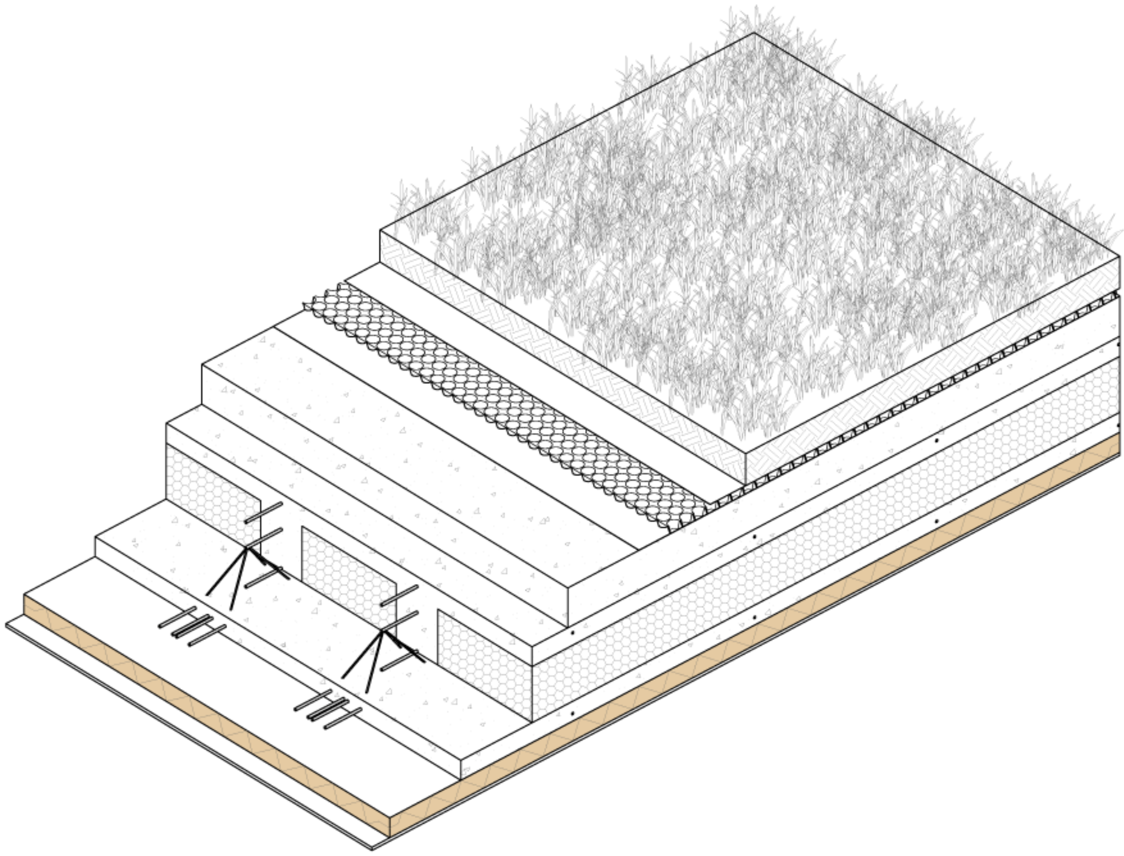




TECHNICAL PACKAGES

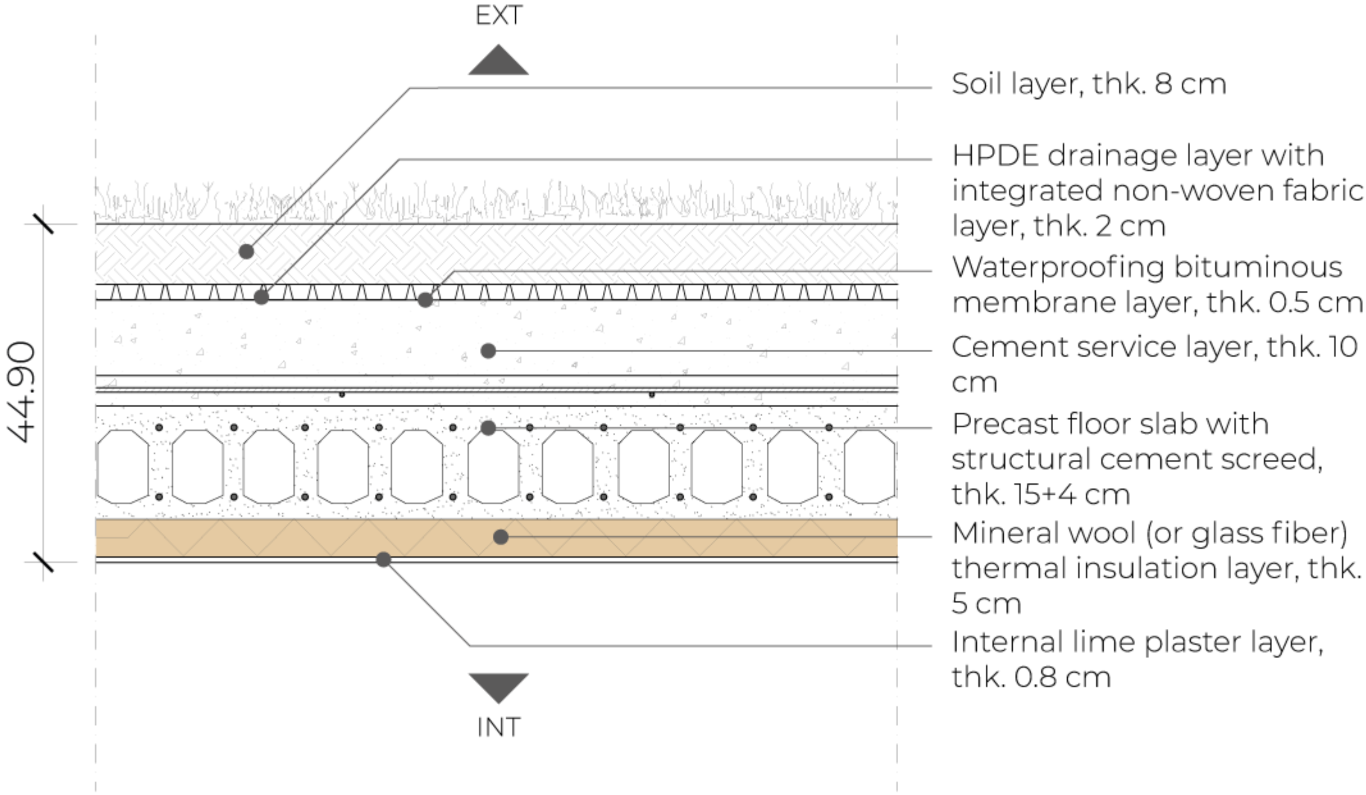
HORIZONTAL FLOOR 02A, scale 1:10

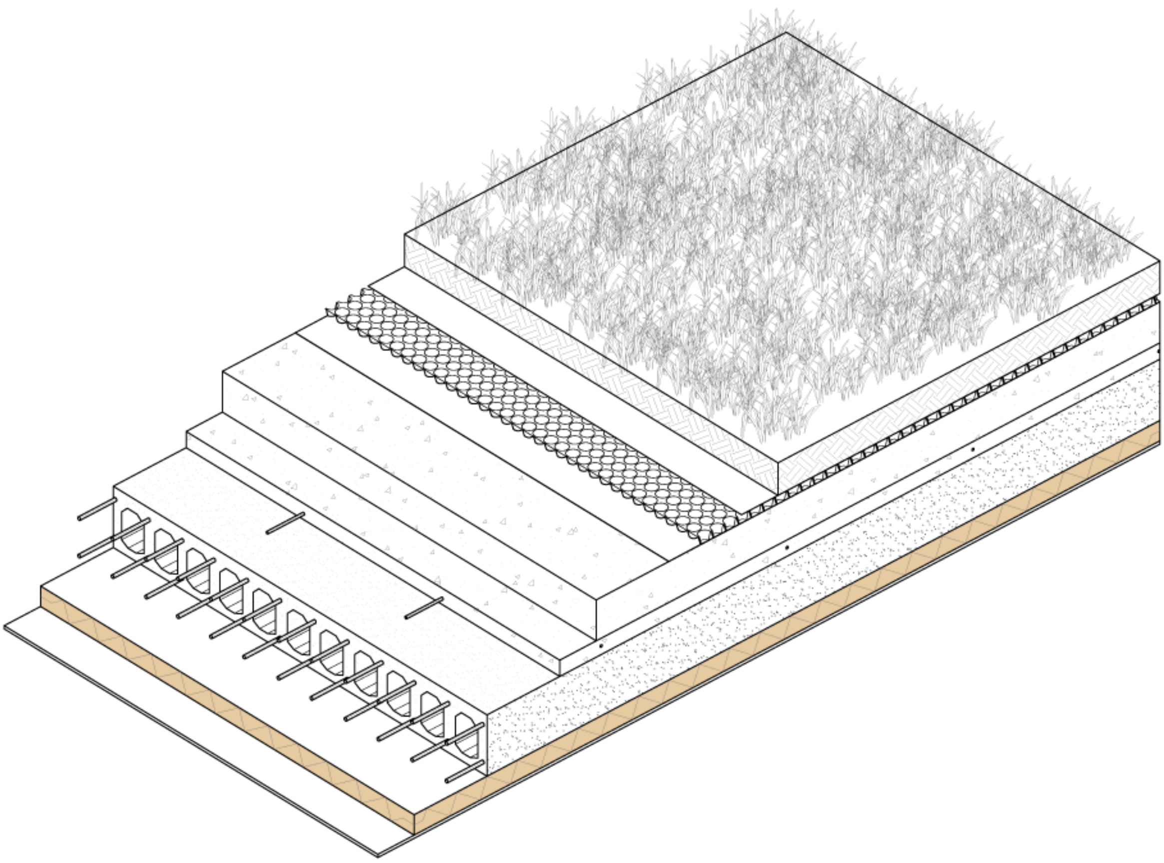




TECHNICAL PACKAGES

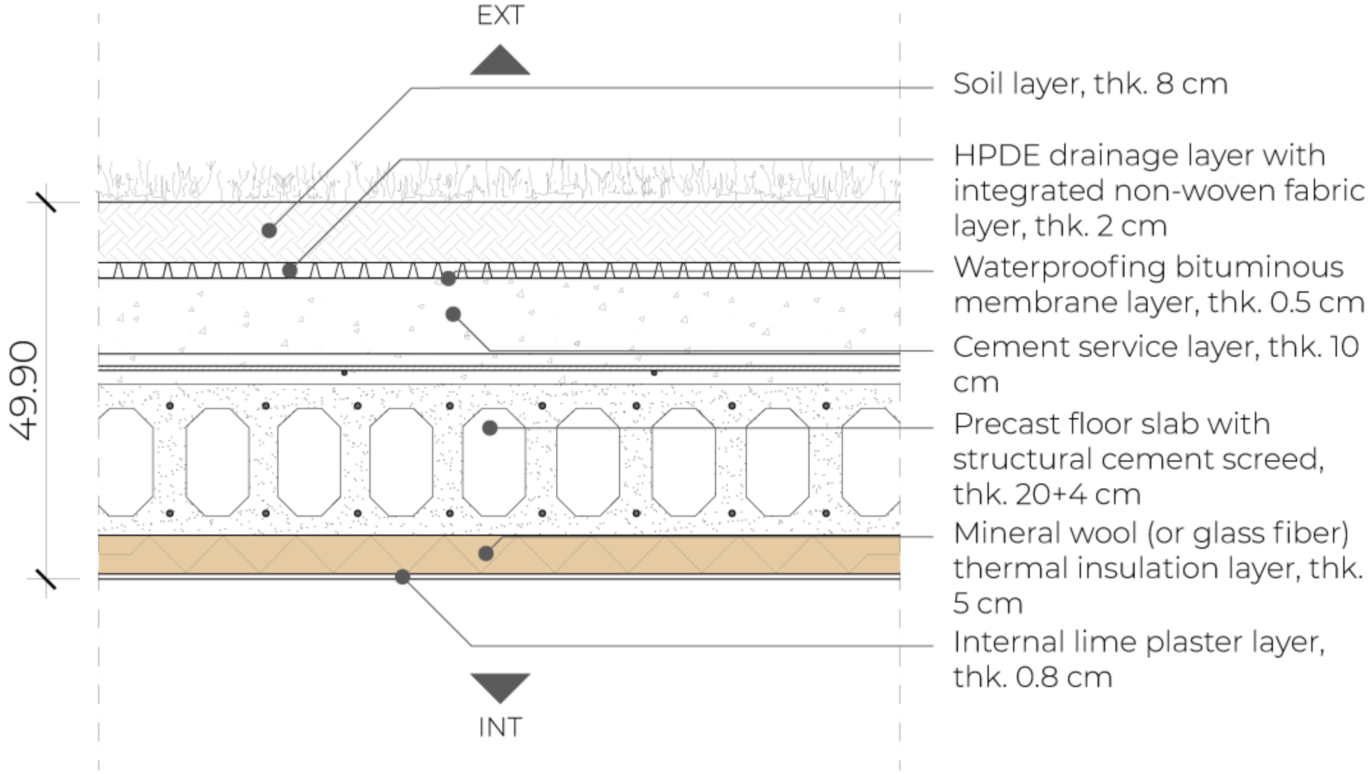
HORIZONTAL FLOOR 02B. scale 1:10

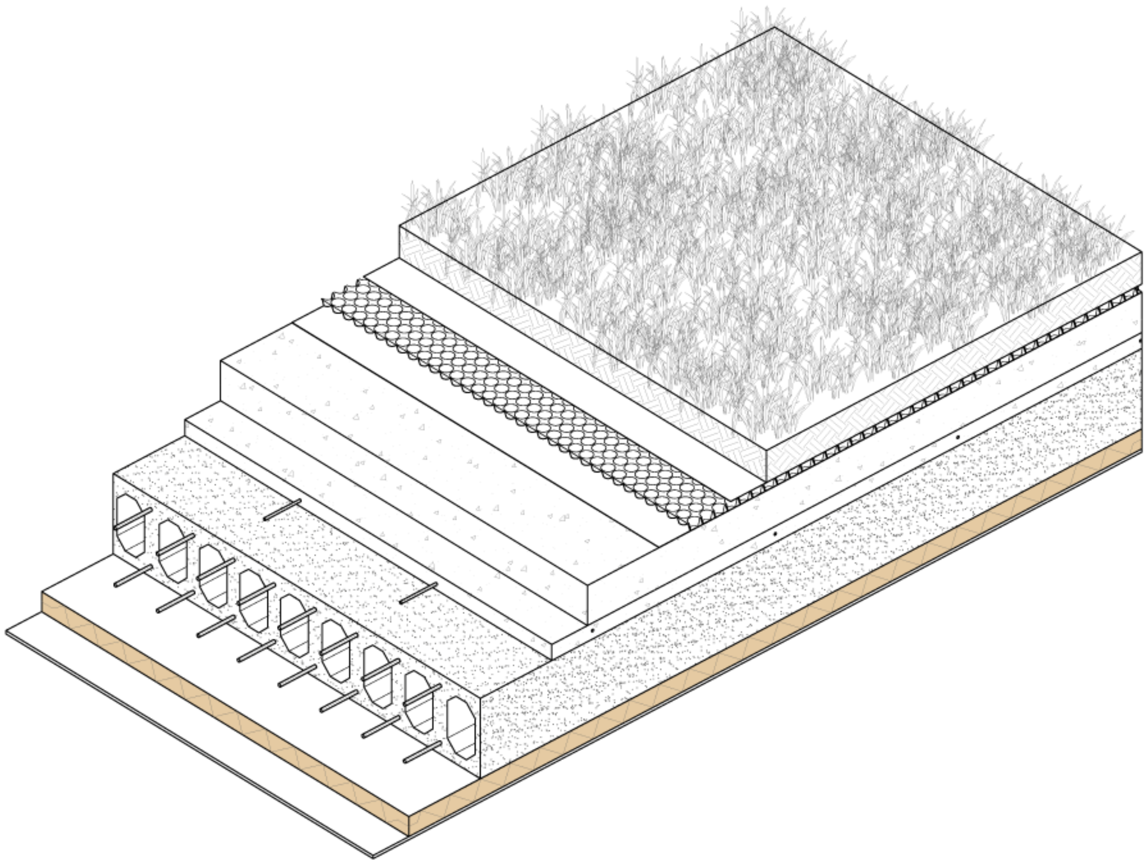




TECHNICAL PACKAGES

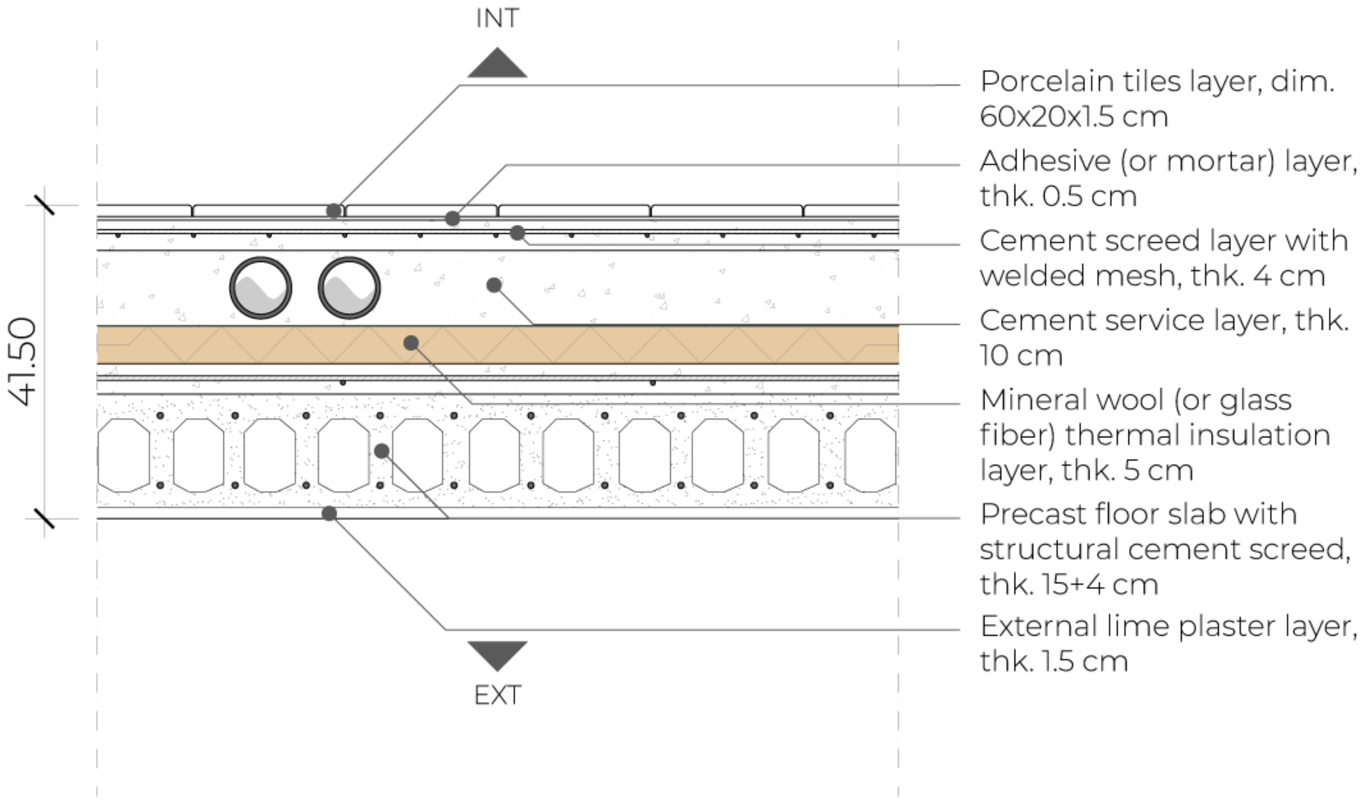
HORIZONTAL FLOOR 02C, scale 1:10

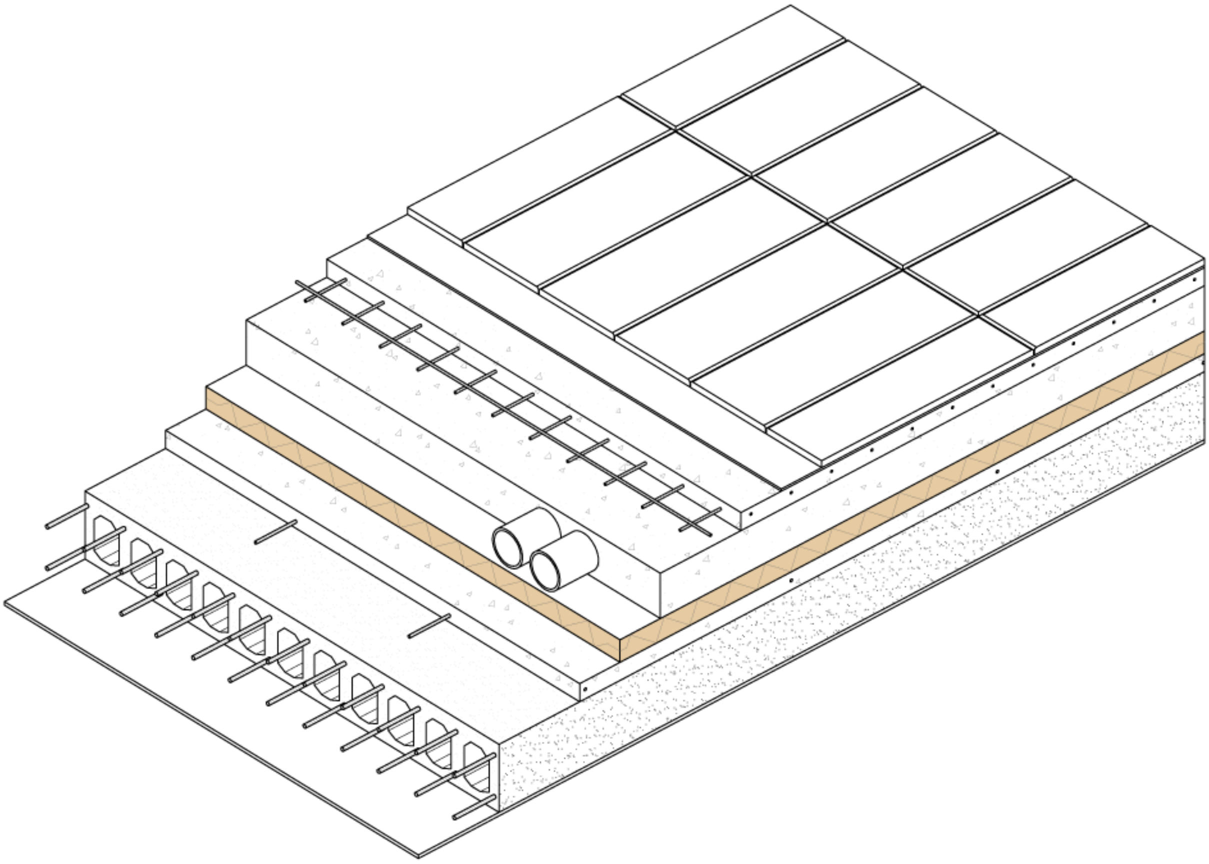




TECHNICAL PACKAGES

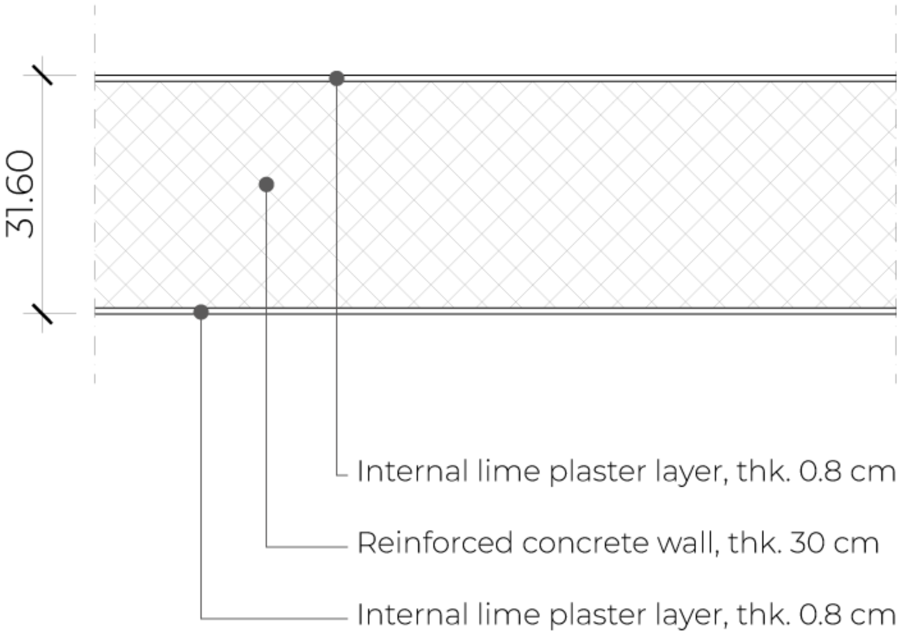
HORIZONTAL FLOOR 03, scale 1:10

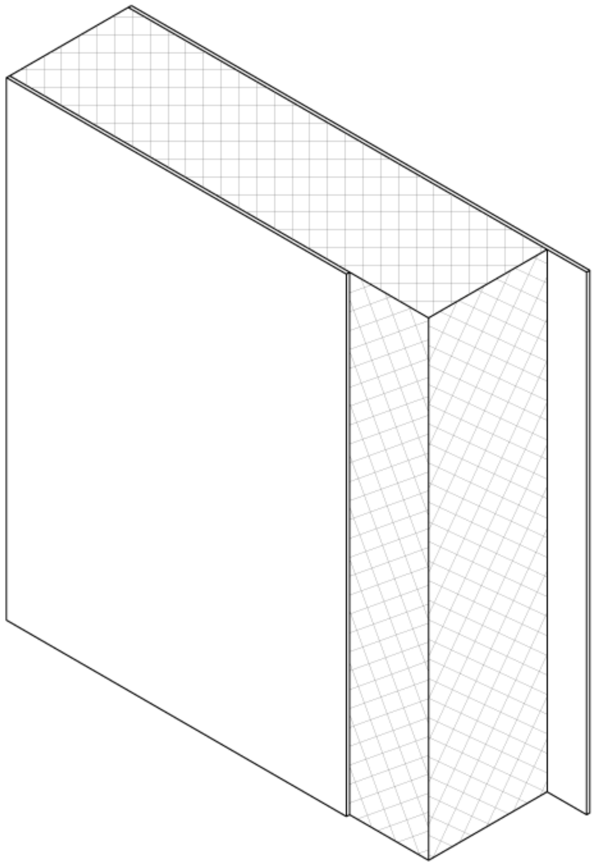




TECHNICAL PACKAGES

VERTICAL PARTITION 01, scale 1:10





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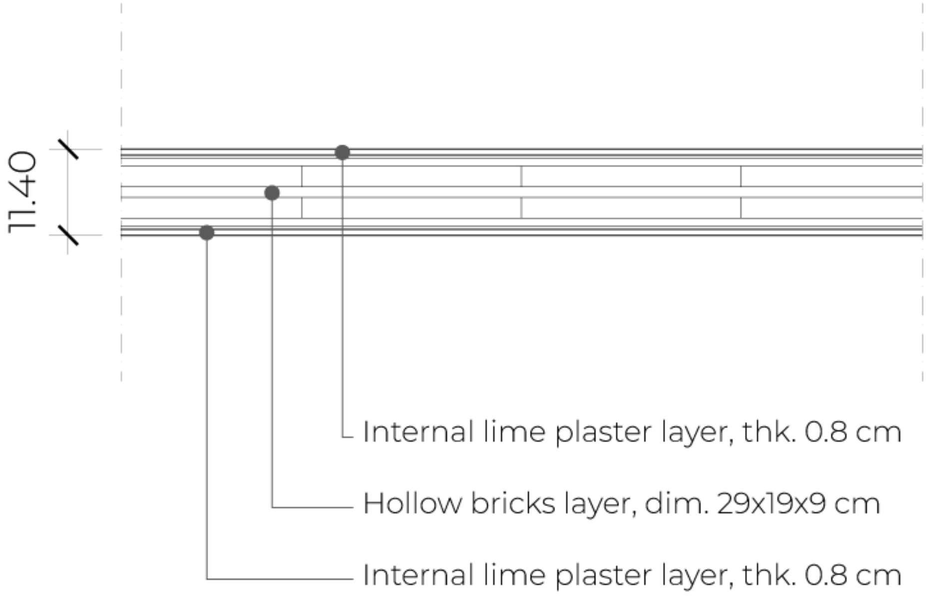

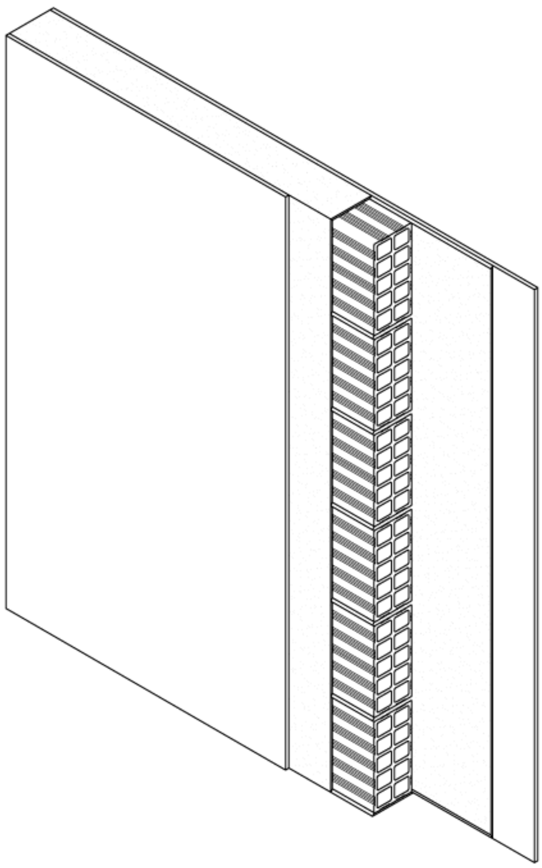

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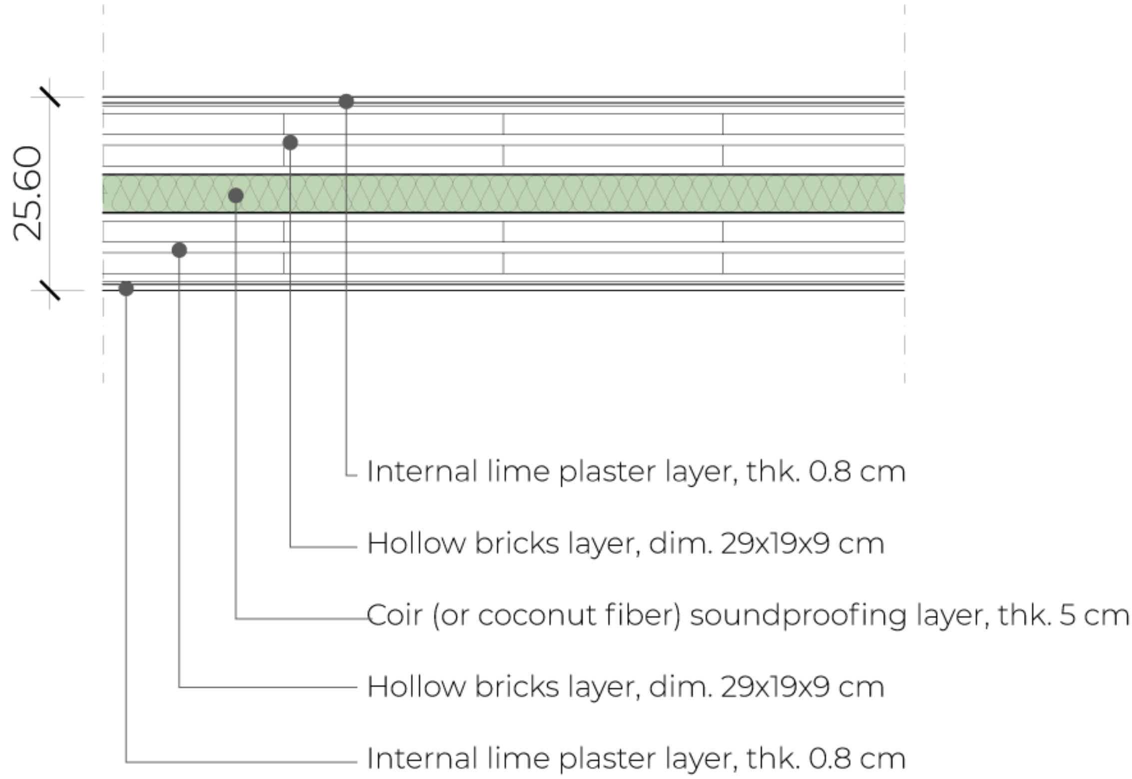

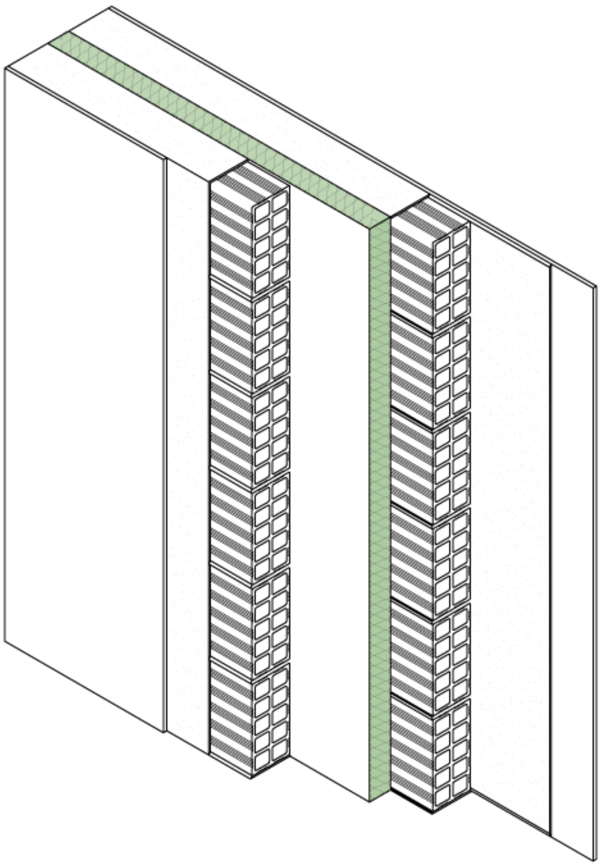

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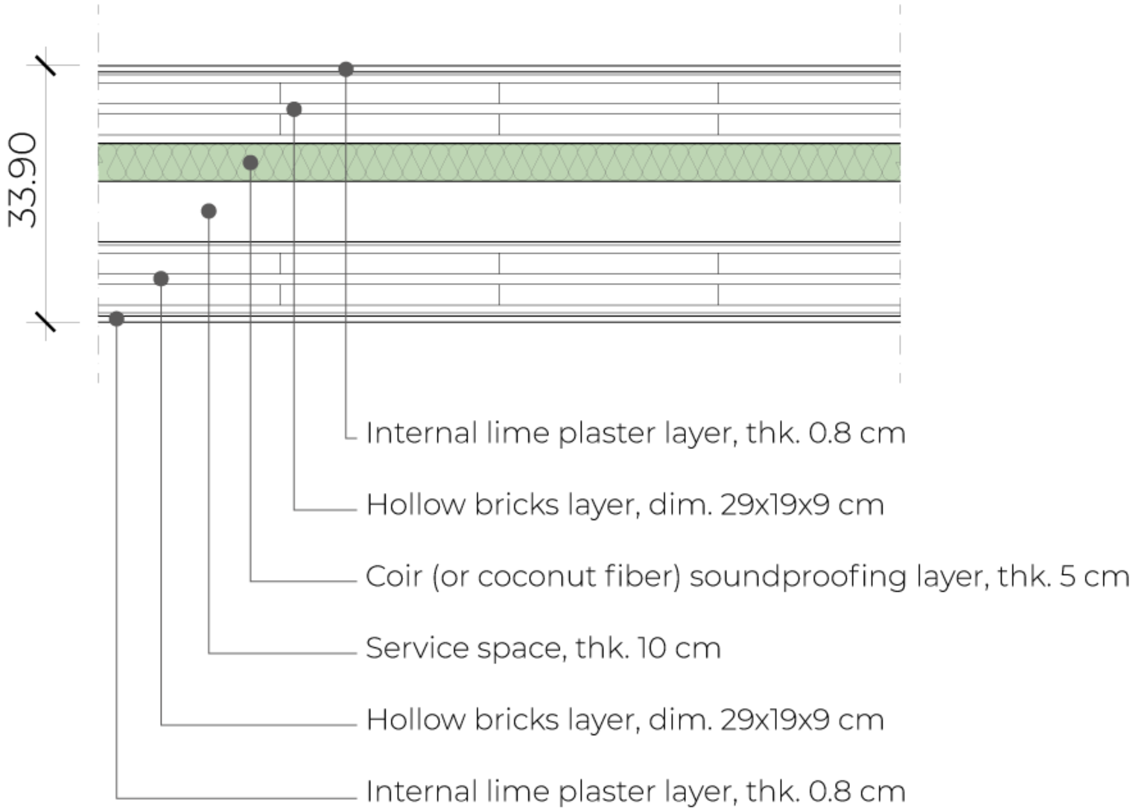

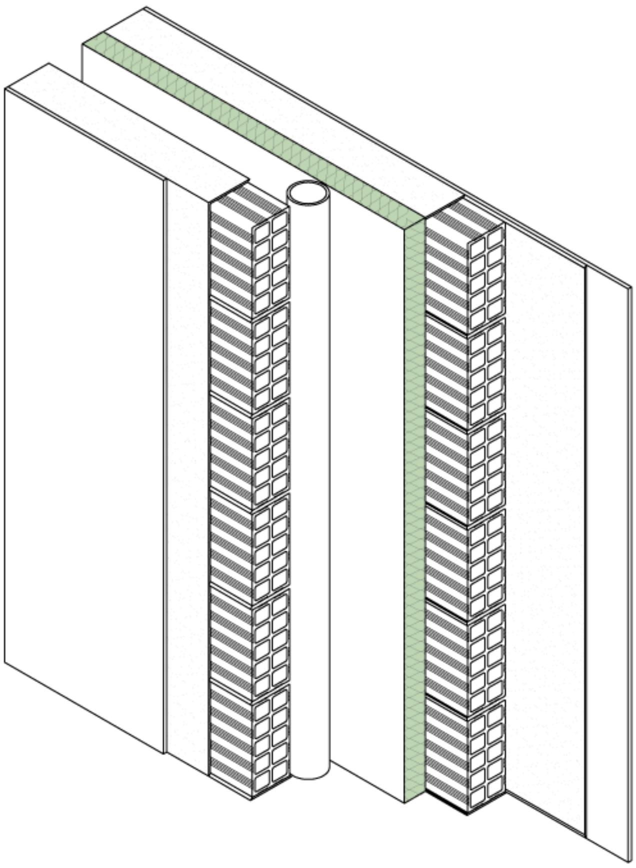

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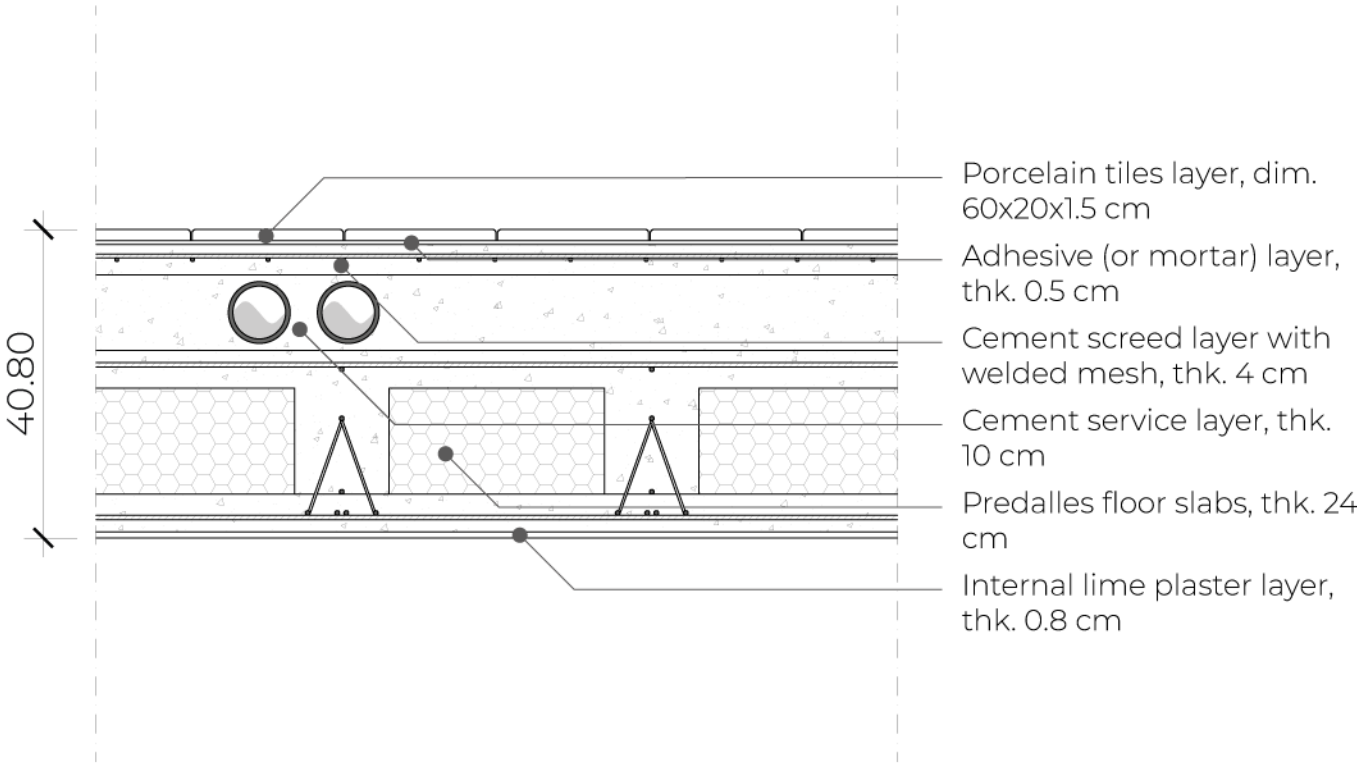

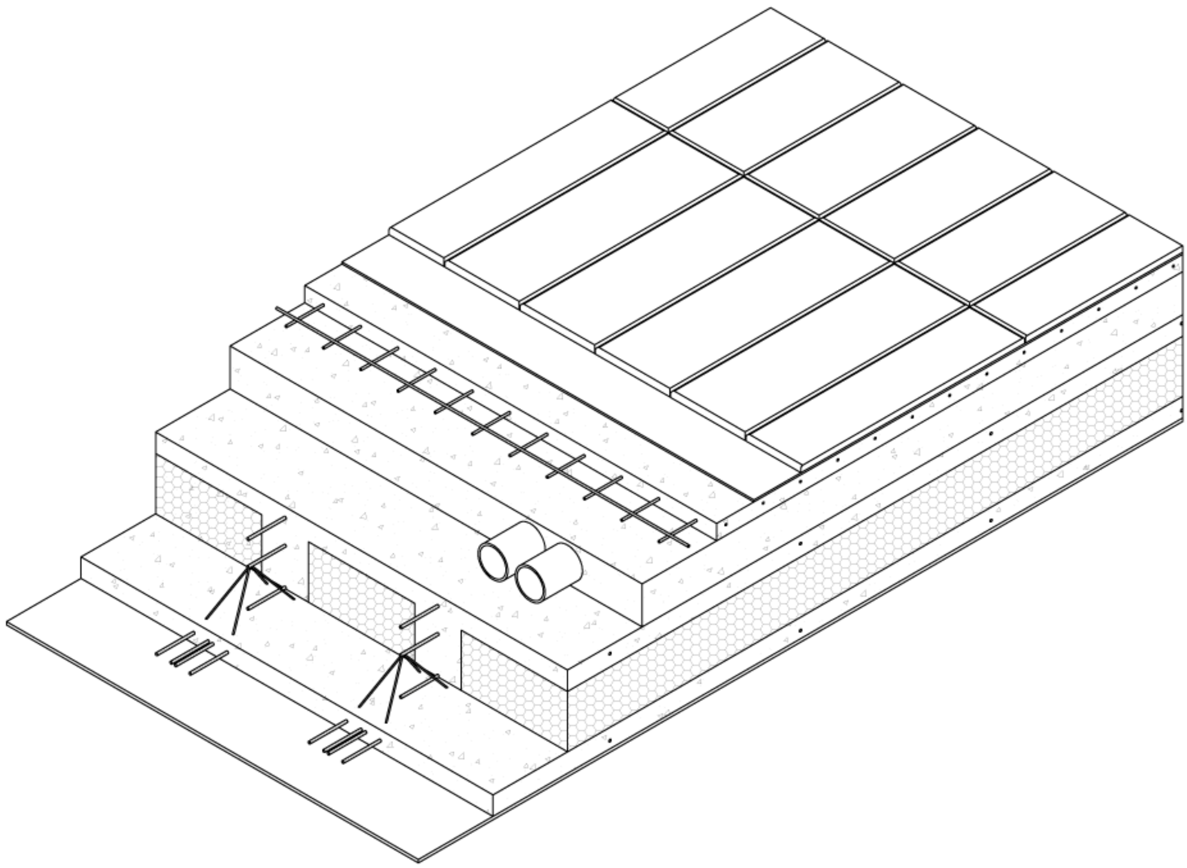

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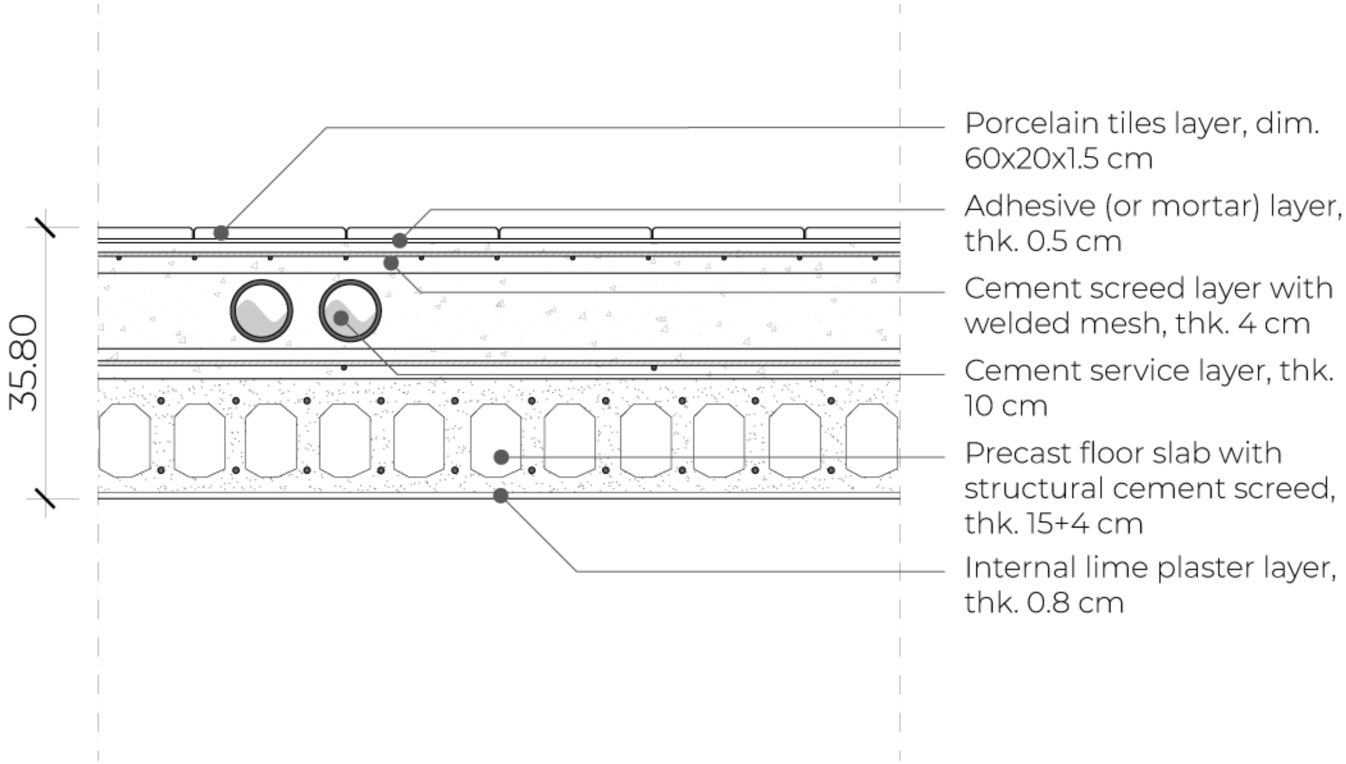

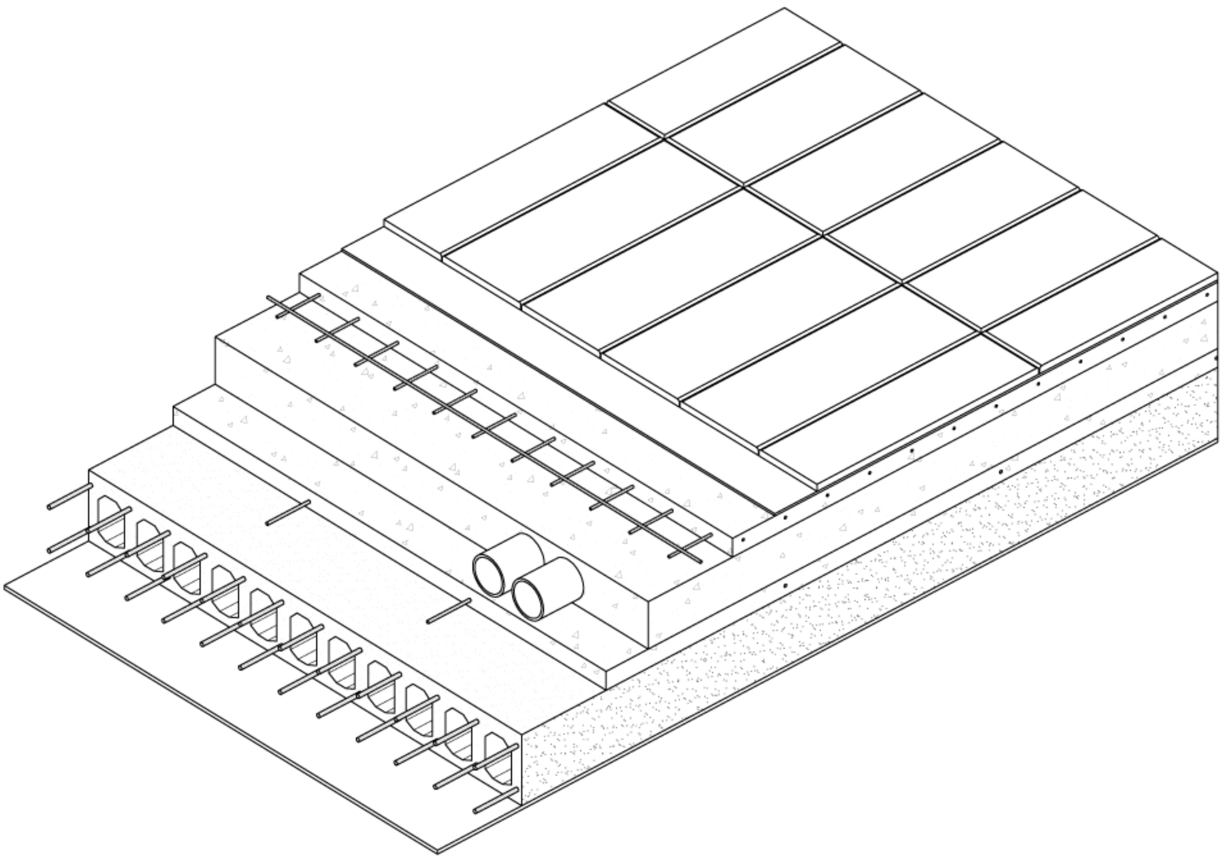

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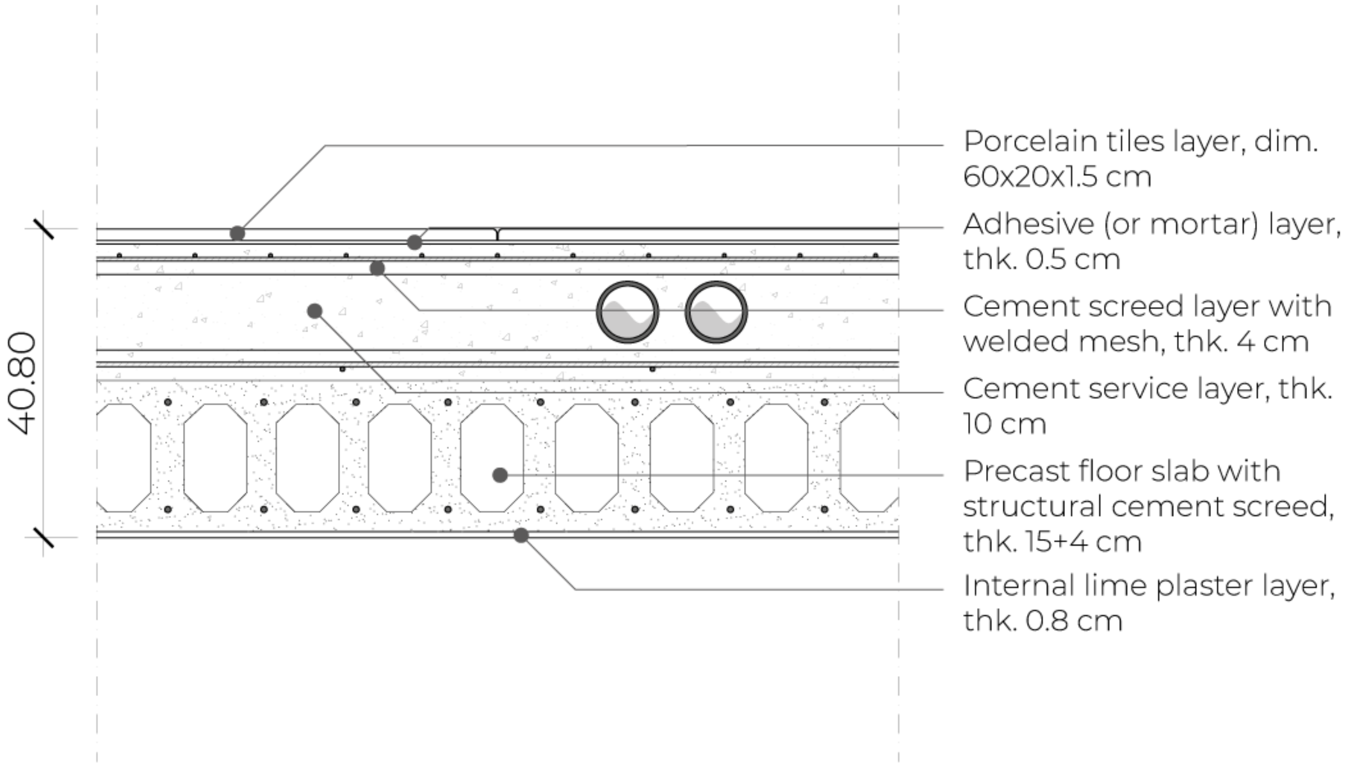

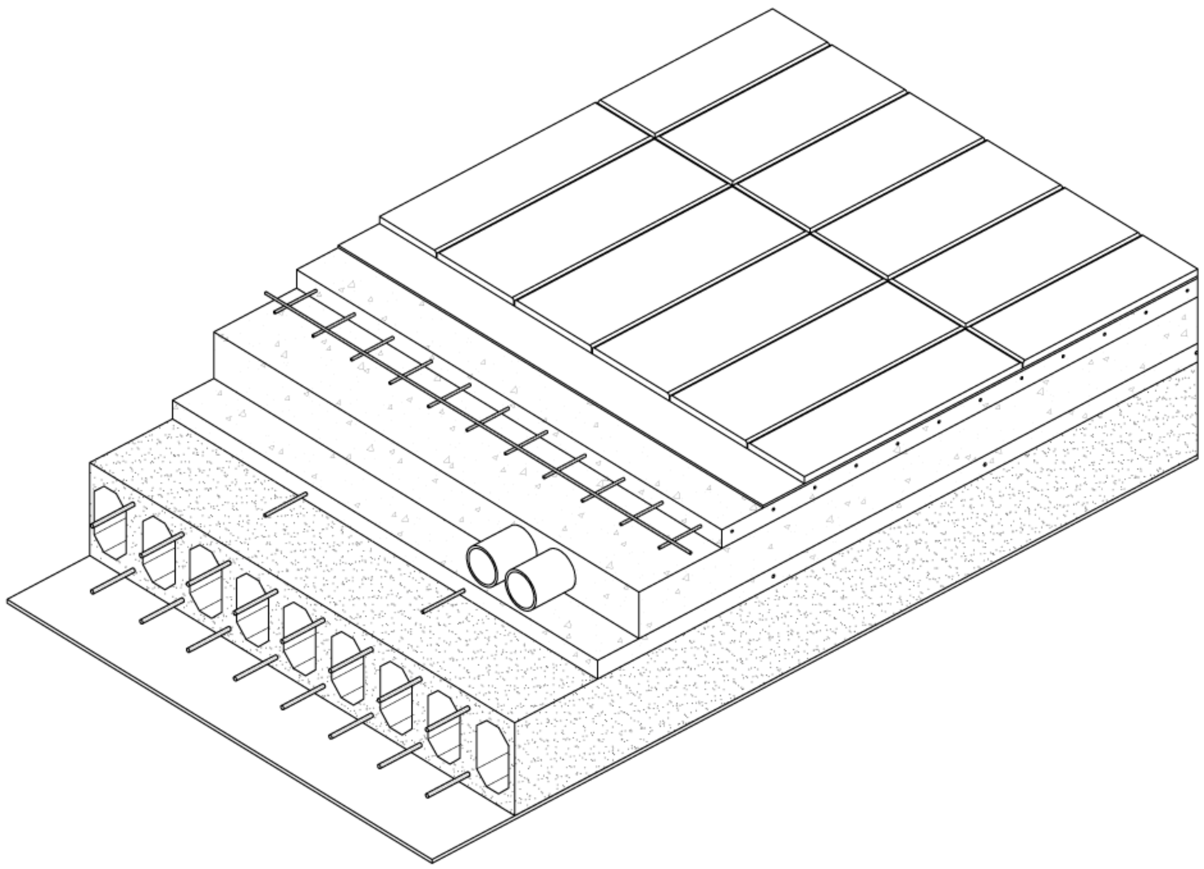

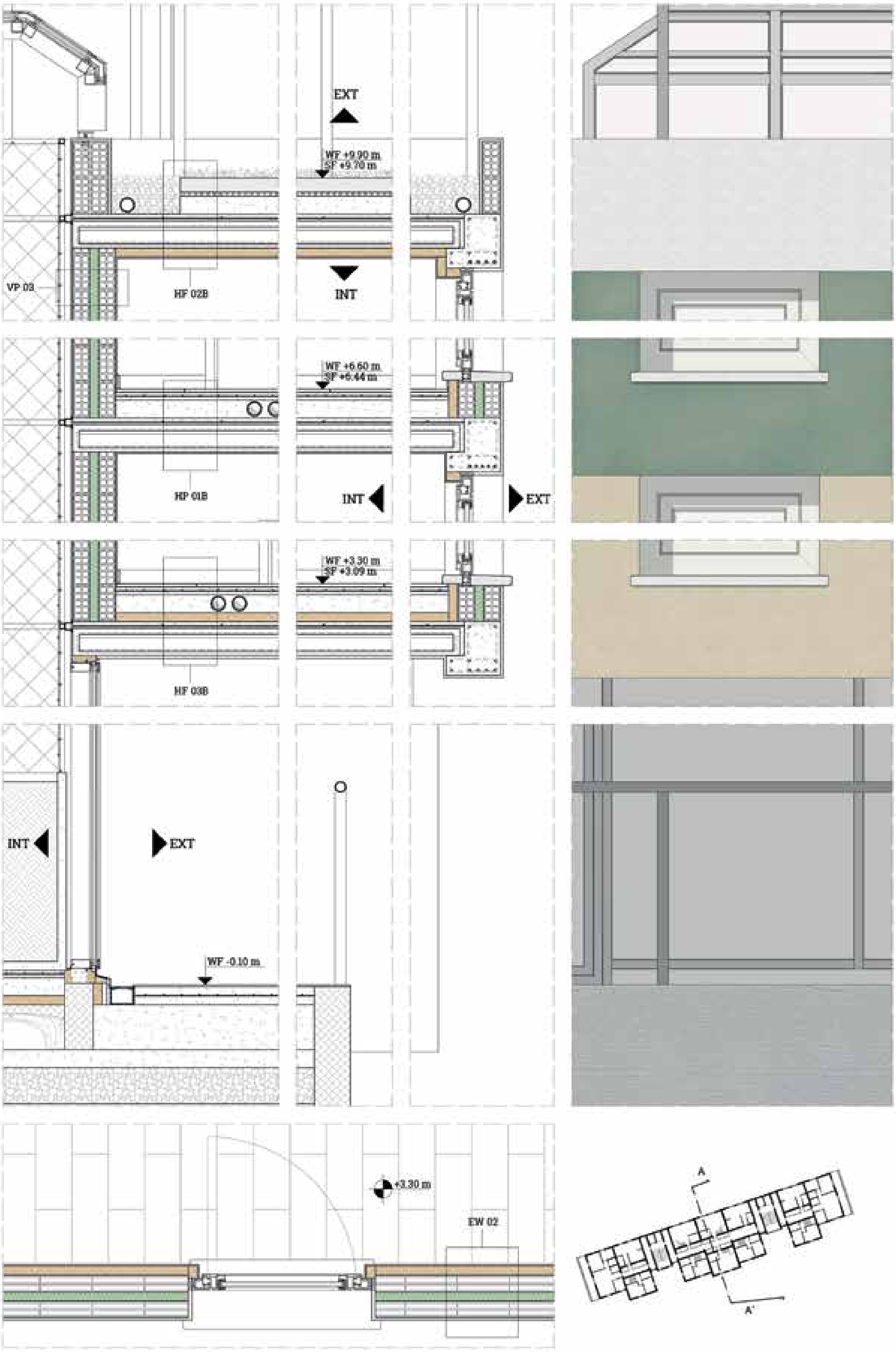
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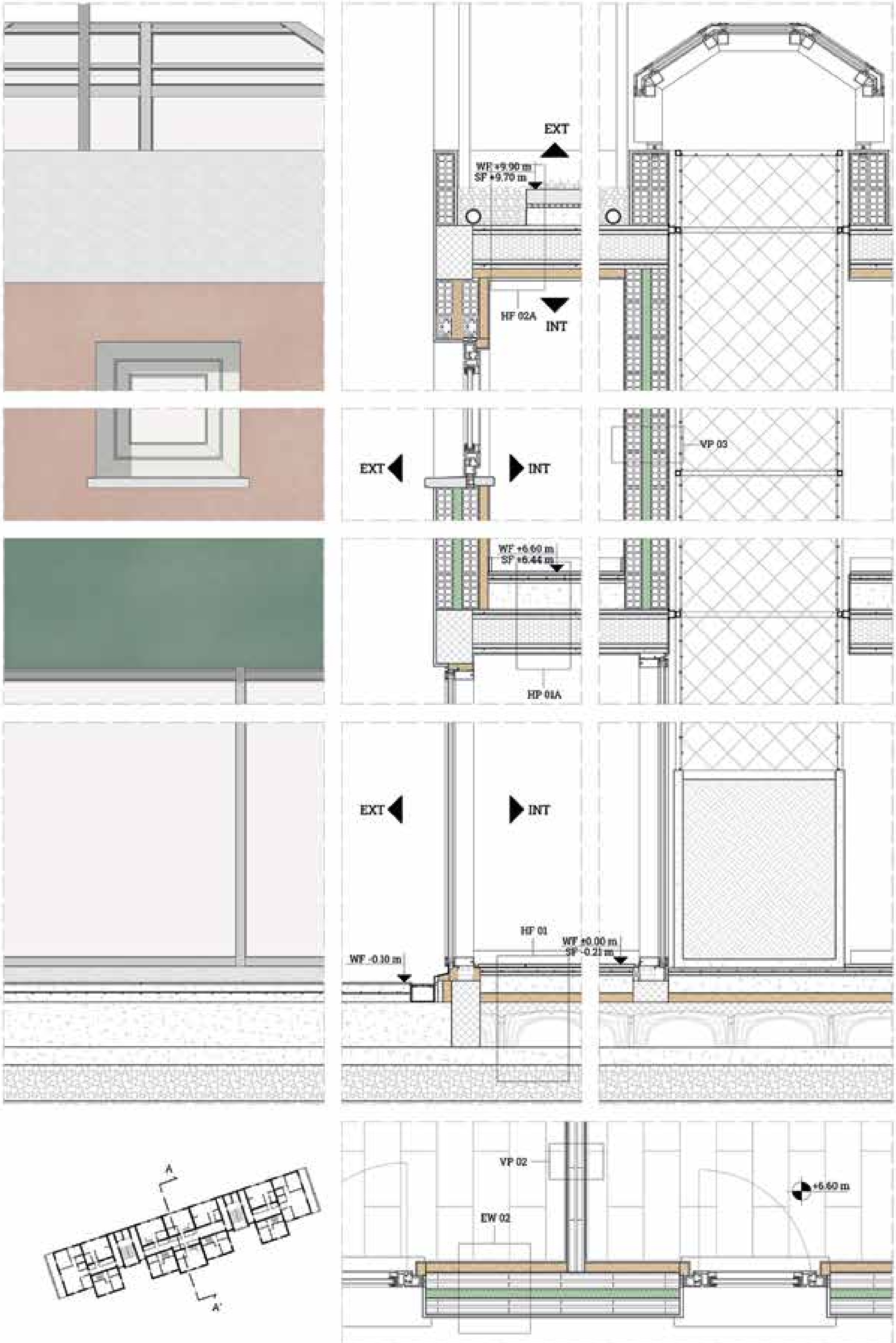
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5.4 Conclusion: project significance and possibilities

The importance of urban intervention and the role of architecture within informal urban environments has risen dramatically over the years, while at the same time there has been a slow, yet steady, shift in the designers approach to the issue, as more and more these contexts are seen less as a problem to be removed, while the understanding of the socio-economical equilibrium these communities have built over the years, often independently from government oversight, has increased and the awareness that many times success or failure of these intervention hinges on the level of acceptance of the inhabitants.

By the same token, however, the designer is very much an active entity in the process, and has to make decisions on issues the population of the favela (or any other informal urban reality) may be blind to, as is the case with many of the projects put forward in this thesis.

In all its aspects, this work has attempted to find a balance between the necessities of sustainable development, something all contemporary urban and architectural project must confront themselves with, and the political, social and economical realities of Rocinha. While this may sound par of course for any urban and architectural intervention, the hope is that reading this thesis sufficiently conveyed the added difficulties to operate in an environment as far removed from the Western world as imaginable, while still being part of a developing country that is, for some of its citizens, practically as advanced as any of its European counterpart.

Even in recent years, perhaps the most popular kind of intervention in informal (or generally poorer) urban districts, is the construction of a single, massive “attraction point” whose wealth of services and functions will, like the gravity well of a star, uplift its neighbourhood. Unfortunately, past applications of this theory have yielded mixed results, many of which can be found in Italy.

Conscious of this facts, and with the added baggage Rocinha brings to the table, this thesis has presented a variety of (relatively) small-scale intervention, that, coming together in a web (or, more formally, a “smart grid”) should prove greater than the sum of its parts and hopefully more resilient than the single attraction point built many times in the past.

Much has been written in previous chapters about the importance of education in this project, as education is the vehicle by which the inhabitants of the favela may exit their certainly functional, but isolated community and take on society at large, as in past their insular nature has been as much of a boon as a, many times, crippling disadvantage (the current political climate notwithstanding).

This thesis, even as part of a larger series of urban interventions, does not attempt to pose as the solution to the many issues plaguing Rocinha; it does, however, present a path towards a progressive betterment of its urban framework, and a bedrock upon which other interventions may be built in the future, using data and facts through the IMM analysis to increase its chances of reaching a positive outcome.

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