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Master Thesis

SUSTAINABILITY IN THE BUILT ENVIRONMENT:

GAMBOA SOCIAL HOUSING

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Abstract

The urbanization, as a global process, already achieved a drastic measure, a variety of issue regarding its environmental impacts came to the spotlight. The space in the world already urbanised had direct in the acceleration on the process of global warming, obvious consequences from the its fast growth and the unbalanced consumption of natural resources necessary for that. Facing the actual environment reality, some questions have major importance. How urban planners, private companies and public authorities can contribute to climate mitigation and and reduction of carbon emission ? Can them deal with the urban vulnerability and focus a new development towards a more resilient urban environment? Can them related the existing urban morphology sustainability in the cities? And how the urbanization process should be further driven facing theses challenges. The relationship between urbanization and environment is evident. Wherefore, the further developments to happen in the cities should implement practical methods in order to guide properly the urban growth linked with sustainable environment . Thus, a major question comes out: how can be performed an urban environment and could be it analyzed, retrofitted and optimized in order to achieve a more sustainable model? A sectorial approach can lead in a negligent result when working in an urban environment, composed by mutual dependencies. However, an integrated approach can lead to better comprehension of its different performances.

IMM®, Integrated Modification Methodology, is a multi-stage, iterative process, applied to urban complex systems, for improving the metabolism of the city as well as its energy performance. The method has been depicted through prior publications by the authors; hence, the current paper solely focuses on one stage of the multi-stage IMM method. Most of the future growth will be insisde the urban space, and it will take place within developing countries and its major cities, where 5% of earth population will live on, and that is the reason why this study wish to present a case study of city of Rio de Janeiro.

In spite of its GDP growth by roughly 50 percent in real terms over the last decade, about 20 per cent of the population in Rio de Janeiro lives in informal settlements known as Favelas. These slum areas have very limited access to urban infrastructure, public services and amenities. Electricity distribution is maybe the only exception, but often informally accessed. As a great number of cities around the world Rio de Janeiro is now experiencing preponderance growth in its margin which has been amplified since 1950´s. Since, just the municipality of Rio de Janeiro has added 3.9 million new residents, while the suburbs and exurbs have the addition of 4.8 million people.

The authors objectives is to analyze how a local design area located in the dense core of a city (Porto Maravilha) can affect affects transformation of the entire CAS (the city of Rio de Janeiro) toward more sustainable development and mitigating marginal growth, social exclusion, low environmental performances, growing pollution and social inclusion.

Keywords: sustainable urbanization, complex adaptive system, integrated modification methodology,, social inclusion.

CHAPTER 1: INTRODUCTION

1. Introduction

The main goal of this study is to demonstrate how the relationship between urban morphology, environmental performances and social inclusion can be used in order to achieve better results during the urbanization process. To achieve such results, these studies used the Integrated Modification Methodology (IMM®) as guidelines for the urban analysis, as well as for all further transformations, the urban itself, but also the architectural and environmental.

The Integrated Modification Methodology (IMM®) is a multi-scale and holistic method, which focuses on transformation of an existing urban system to a better performing one [1]. Considering the city as a Complex Adaptive System (CAS) is the main assumption of the IMM method; accordingly, cities are an arrangement of interconnected heterogeneous elements, and the final result of the whole system is utterly different from every individual constituent's performance [2]. Each CAS is comprised of different elements or smaller CAS's, whilst these elements and sub-systems have competence to learn from prior occurrences and experiences [3]. Assuming the methodology, the study creates adaptation competence of the system. The continuous adaptations occur to foster the system's performance, in a response to new internal and external exposed constraints. CAS is a complex hierarchical configuration of different sub-systems and elements work together as a whole; therefore, the hierarchical nature of CAS requires multi-scale approach if one intends to improve the entire system's performance [4].

Subsequently, when assuming the IMM method, architect should care about every existing part, smaller then the subsystem. Moreover, aiming to transform the bigger scale systems, the methodology point out to work in mid-scales intervention using the local scale systems modification. Using this method, the transformation of the intermediate scale will lead to an entire new arrangement, working as a catalyst element, and provoking a butterfly effect inside the CAS, not matter how big it can eventually be. That is why the selection of the mid-scale is so crucial for the process.

For the presented study, will not go further presenting the IMM methodology itself, instead will be presented the results achieved when application the method to foster urban recovery within an already defined area, in this case, the port central area in the city of Rio de Janeiro, called Porto Maravilha. (Figure 1-1)

Figure 1-1 - Project area in Rio de Janeiro, the Porto Maravilha (source: Google Earth)

1.1. Why Rio de Janeiro and Why the Porto Maravilha Area?

Called “Marvelous City”, or simply Rio, the former Brazil´s and the actual Rio de Janeiro´s State capital, the city of Rio de Janeiro is the second biggest Brazilian city, and also is the third biggest metropolitan area in South America, hosting approximately 12 million people, behind the city of São Paulo and Buenos Aires metropolitan area, respectively [5].

Figure 1-2 - Rio de Janeiro metropolitan area (source: NASA)

Located in the Brazilian southeast region, Rio de Janeiro is the main destination for those who spend vacation within the Brazilian territory as, is one of the major economic, financial, holding the second biggest Brazilian GDP [6] and cultural spots in the country and is worldwide known by its cultural and landscape icons, as the *Pão de Açucar* (Sugarloaf) and Corcovado hills, the *Cristo Redentor* statue, the south coast beaches, Copacabana, Ipanema and Leblon, the Guanabara bay, the bohemian neighborhood Lapa, the Maracanã Stadium, the New´s Year celebration, the *Carnaval*, the *samba* and the *bossa nova*, everything spread out 1 200,278 km² all those factors that gives to the city the standard as Intangible Cultural *Heritage* of *Humanity by the UNESCO, expressed in the site* Rio de Janeiro: “*Carioca Landscapes between the Mountain and the Sea*”.

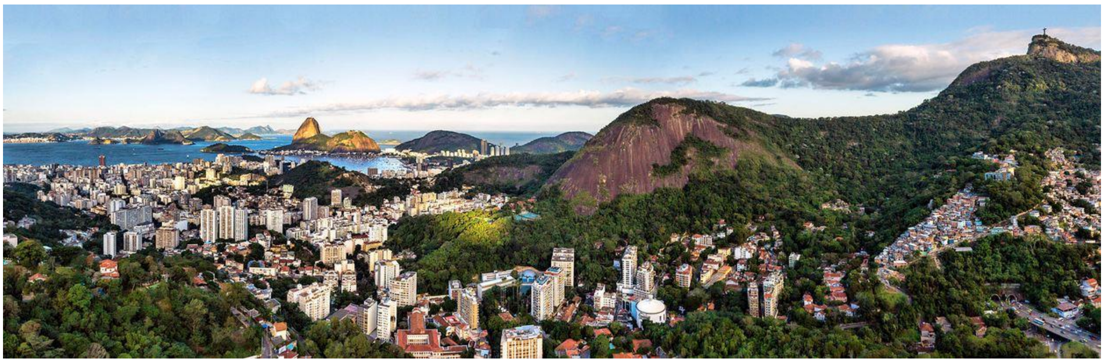


Figure 1-3 - Rio de Janeiro landscape. (source: Chensiyuan)

Rio de Janeiro is also known as being a perfect sample of the country, regarding good and bad aspects. The social and economic gap between some parts in the city provokes serious issues, easily visible when analyzing the HDI city map. When the so called southern Rio is very well develop and present and HDI high as some Nordic countries, as Gavea (0,97) Leblon (0,963) and Ipanema (0,962), others areas present much lower indexes, as Rocinha (0,732) and the Complexo do Alemão (0,711) , according to the municipality. One particularity of the well develop districts and the *favelas* in Rio is that these areas are very close each other, which gives even more evidences about the social and economic unbalanced situation, a strong Brazilian character.

Figure 1-4 - Favela and the urban area relationship (source: Igor Koritowski)

In spite of being one of the biggest city area in the country, around 1,39 million people live in subnormal agglomeration, the so called *favelas*, amount corresponding to nearly 22% of the citizens from Rio de Janeiro (*IBGE 2012*). These occupations take place especially in the hills and are spread out the entire city, due the city´s topography, and lack all type of infrastructure, as water and sewage, light and waste management systems. Alike great number of cities around the world; the city of Rio de Janeiro is, during the last 40 years, facing preponderance marginal growth. Exactly, the municipality of Rio de Janeiro has added 3.9 million residents since then; while the suburbs and exurbs have added 4.8 million *(Cox. W. 2013)*.

All these factors lead to choose the application of the IMM® methodology to the selected area, the Porto Maravilha. As holistic, multi-scale and multi-stage process, the entire methodology is out of the document; instead, the work presented will be focuses on the method application and on its results. In particular highlights the results achieved by the four phases named Investigation/Analysis, Assumption/ Interpretation, Modification/Intervention and, at the end, Transformation/Optimization, or in this case, architectural scale transformation.

The phases are respectively dedicated to investigate the actual morphological configuration and performances of the existing CAS to define a possible way for structurally modifying it, aiming to foster the environmental quality and performance, to then transform it, acting locally according to the defined design principles. It accentuates the role of urban morphology and use of Key Categories (KC) [1] in the IMM process, as well as the role of the transformation Catalysts in this process. In other words, deeply investigating the Porto Maravilha area behavior as intermediate scale and how it affects the entire CAS, now the city of Rio de Janeiro, the study will define a way to, locally acting, create a chain reaction enhancing environmental performance, as well social inclusion and activating the local economy.

During the past decades, even located in a strategic part of the city and have a major historical and cultural value, the Porto Maravilha felt into a huge decay process. The municipality, in partnership with the private initiative, and taking advantages on mega-events to be host by the city – The 2014 Football World Cup Final and the 2016 Summer Olympic Games- planned a major urban intervention in the old industrial Port zone, named now Porto Maravilha, aiming to foster the urban quality, recovering the area from the mentioned decay, at the same time to promoting improvement within the urban mobility and the infra-structure for the neighborhood Saude, Gamboa, Santo Cristo and to the communities of the Morro (hill) Providencia- Livramento and Morro Pinto. Recovering these spaces, intensifying and blending their uses, could create a sustainable urban spaces foster the entire city performance.

This study does not will provide an alternative solution to them plan by the municipality; instead, it will demonstrate an example of good practice confronting the main theme for a sustainable urban development, regarding again, social, economic and environmental issues. By the end, the authors intended to examine how Porto Maravilha and specially the Providencia – Livramento zone, which, is located in the dense core of the area, can affect and mitigate the city's marginal growth as a whole.

CHAPTER 2: URBAN DESIGN

2.1 The Area

Nowadays, the urbanization is dominating the global development process, which has been reaching a dramatic measure and is creating a series of questions that involves sustainability and ecosystems. Moreover, most of future urban growth will occurs in developing counties, which includes Brazil, and will be also relative to megacities, where will live 5% of the world population. By megacity lets understand now that is related to a metropolitan area with more than 10 million habitants, who can be composed by one single city or more, since the area of them converge in one urban fabric, configuration that includes Rio de Janeiro and suburbs, which hold more than 12 million people.

Only the City of Rio de Janeiro has 6.5 millions habitants and is divided, according to its morphology, into six different intermediate zones. We can assume know that the whole city of Rio is our Complex Adaptive System, when analyzed in a metropolitan scale, which is, when used a holistic approach for it.

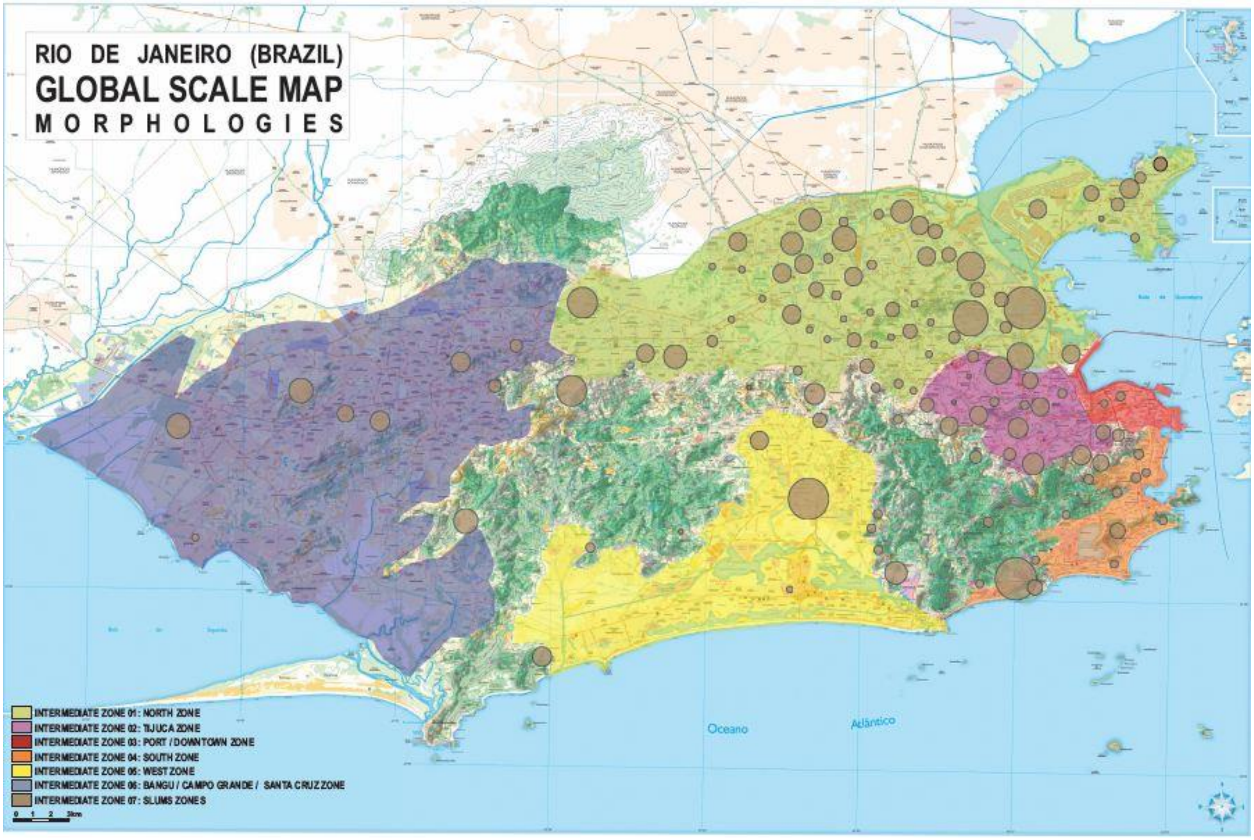


Figure 2-1 - Metropolitan Scale [6]

The zones, separated in color give the picture of the city´s zones division, or the city´s intermediate scales, marked in the green, purple, yellow, orange, pink and red, named as North Zone, West Zone, Barra da Tijuca/Jacarepaguá, South Zone, Tijuca and Downtown/Port Zones, respectively. The areas marked in brown circles are the *favelas*, as mentioned before, spread out the city.

Consequently, new demands may include actions to ensure social inclusion, safety and security, enhancing life quality and sustainability, and a punctual approach could result in neglecting mutual dependencies of these demands. However, an integrated approach can help to sharpen a better comprehension of the different urban assessment as a system and its performances, to further, guide to the application of the new design principle in order to improve the system´s performance.

Within this context, the Porto Maravilha area plays a key role in the system. The port zone is one of the oldest as well the one of the most strategic region of the city, holding much of city's identity and importance. The area which carries the root of Rio's urban development, and is the cause of many economic booms during the city's history, is now facing serious threats of a complete decay.

The port area is located in northeast of Rio de Janeiro and is surrounded by the Guanabara Bay. It is mainly composed by three neighborhoods, which are Santo Cristo, Gamboa, and Saúde. The most important neighbor of the Port area is the Downtown Rio (*Centro*) which is located in its south, and with exception of Santo Cristo that is related to other Rio's important region, the North Zone (*Zona Norte*) through its west and a its south, the only urban connection of the port's neighborhoods is the Centro itself. The area is also connected with the city, morphologically, by the now called "urban plug-in" Maracanã, at the west side and also by the "urban plug-in" Aterro do Flamengo, part of the city that links the port zone with the main touristic spot, the South Zone (*Zona Sul*), where is located Copacabana, Ipanema and Leblon neighborhoods.

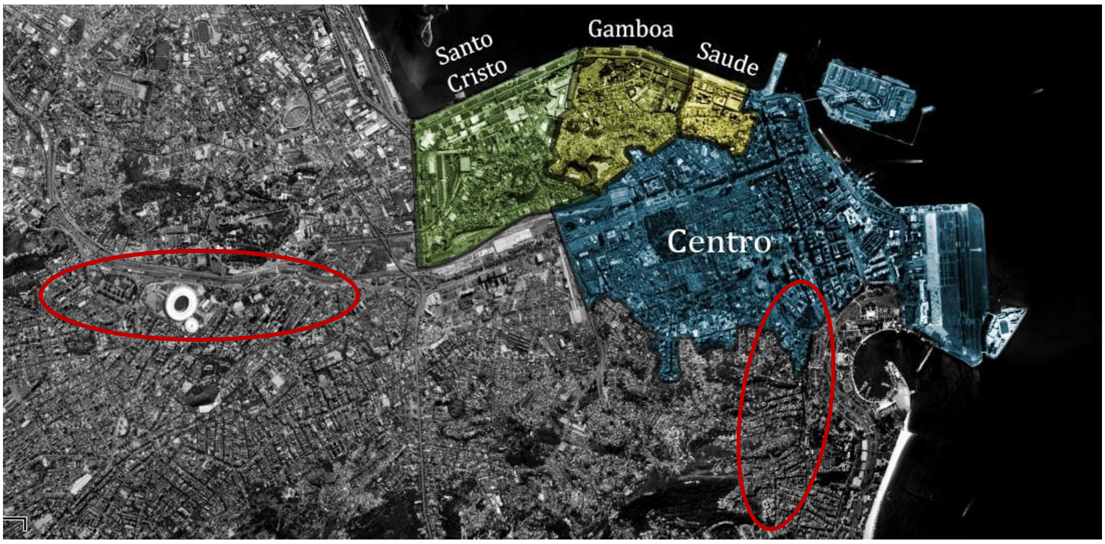


Figure 2-2 - Intermediate scale and its urban plug-ins (source Google Earth/IMM Design Lab)

Currently, an urban operation is ongoing in the area, in line with the project of urban regeneration for port zones worldwide. The operation aims to do a symbolic intervention on the built spaces, in terms of historical, social and cultural aspect, as well aims to renew the real state value of the area, converting the existing urban gaps, as the port´s old storages for example, in a point of attraction. The association of these elements, in association with the incentives proposed by the city´s legislation, creates an auspicious environment for urban changes, where the historical heritage and the renewable interests join forces to promote the development and the integration of the dynamic areas within the city. And, being a waterfront area, the touristic value will definitely be increased.

The proposal made by the city planners, in partnership with the public and private initiatives; aim to explore the eleven homogeneous subzones, enhancing their peculiarities as well developing their potential. These subzones are divided according to their identity, morphology and geography, and are named:

A) Praça Mauá;
B) Morro Conceição;
C) Nova Rua Larga;
D) Senador Pompeu (Zone A and Zone B);
E) Morros Providencia-Livramento;
F) Saude;
G) Gamboa;
H) Santo Cristo;
I) Morro do Pinto;
J) Linha Férrea;
K) Porto Olimpico;

Figure 2-3 - Local scale (source: Porto Maravilha/IMM Design Lab.)

2.2 Subzones Division

A)Subzone Praça Mauá:

The area that is delimited between the Maua Square (Praça Mauá) and the Avenue Barão de Tefé,as well the area compress between the Wharf Zone (Cais do Porto) and the Sacadura Cabral Street. The subsystems main characteristics are the proximity to the wharf, point that arrives touristic cruisers, the strong identity composed by the presence of historic heritage buildings (storages and townhouses), and high density composed by institutional buildings and also strong touristic and entertainment activity.

Figure 2-4 – Subzone Praça Mauá (source Porto Maravilha/ IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
1	Monastery São Bento	Worship Space
2	Museu do Amanhã	Museum
3	Edifício Touring Club	Architectural Heritage
4	Marine District	Architectural Heritage
5	The Week Club	Entertainment
6	Galpão Ação da Cidadania	Cultural
7	MAR – Rio´s Museum of Art	Museum-Cultural
8	Escola do Olhar	Museum-Cultural
9	Imperatriz Wharf	Monument
10	Praça Mauá	Park - Square
11	Valongo Wharf	Historic Heritage
12	Armazéns do Porto	Entertainment
13	Hotel São Bento	Hotel
14	Hotel Barão de Tefé	Hotel
15	Hotel Villa Regia	Hotel
16	Edifício A Noite	Architectural Heritage
17	Barão de Mauá	Monument
18	Marine Transportation Terminal	Transportation

B) Subzone Morro Conceição:

Subzone delimited by the Sacadura Cabral Street, Senador Pompeu Street, Conceição Street, Leandro Martins Street, Acre Street and Liceu Alley. The area is mainly composed by residential houses (townhouses) and historic monuments, with high touristic interest. The hill (*morro*) located at the boundary area of the Maua Square is easy accessible by staircases and sloped streets.

Figure 2-5 - Subzone Morro Conceição (source Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
19	Dockers Square	Park - Square
20	Antigo mictório público	Architectural Heritage
21	Valongo Observatory	Architectural Heritage
22	Cartographic Museum	Museum- Cultural
23	Gamboa Warehouse	Entertainment
24	Morro da Conceição Viewpoint	Viewpoint
25	Pedra do Sal	Historical Heritage
26	Angú do Gomes	Bar - Restaurant
27	Imaculada	Bar - Restaurant
28	Igreja de S. Francisco da Prainha	Worship Space
29	Sá Cabral	Bar - Restaurant
30	Largo São Francisco da Prainha	Park - Square
31	Valongo Suspended Garden	Historical Heritage
32	Conceição Fort	Architectural Heritage
33	Hotel Gallery	Hotel
34	Club Cabaret Kalesa	Entertainment

C) Subzone Nova Rua Larga

Subzone delimited by the Duque de Caxias Palace until the Rio Branco Avenue, and has as axis the Marechal Floriano Avenue, former Rua Larga. It is a consolidated area at the central zone in the city, with presence of high rise institutional buildings and cultural spaces and with streets activities, as a presence of stores, banks, good restaurants, a church and touristic spots, as the Sardinhas Alley.

Figure 2-6 – Subzone Nova Rua Larga (source Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
40	Duque de Caxias Palace	Architectural Heritage
41	Itamaraty Museum	Museum - Cultural
42	Centro Cultural Light	Cultural
43	Colégio Pedro II	Architectural Heritage
44	Banco Central	Architectural Heritage
45	Sardinhas Alley	Bar - Restaurant
46	Navy Library	Architectural Heritage
47	Santa Rita Church	Worship Space
48	Casa Paladino	Bar - Restaurant
49	Pantheón Caxias	Monument
50	Presidente Vargas Subway Station	Transportation
51	Uruguaiana Subway Station	Transportation
52	Málaga	Bar - Restaurant
53	Casarão	Bar - Restaurant
54	Hotel Floriano Peixoto	Hotel
55	IPHAN	Cultural
56	Windsor Guanabara	Hotel
57	Hotel São Francisco	Hotel
58	Hotel Planalto	Hotel

D)Subzone Senador Pompeu (A and B)

Subsystem delimited by the axis and surrounded of Senador Pompeu Street, from the Rail Central Station until the Conceição Street, as zone "A", and is also delimited by the area between the Senador Pompeu Street and the Streets Conceição, Julia Lopes de Almeida,Andradas, Leandro Martins and Camerino at the zone "B". Both areas are composed by high presence of architectural heritage townhouses, although in decay, especially at the zone "A", narrow streets, also in decay, with the majority of its buildings being used as storage or in irregular conditions. Probably the location near the Morro da Providencia-Livramento leads the area to decay.

Figure 2-7 - Subzone Senador Pompeu A and B (source Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
59	Women´s Rights Cultural Space	Cultural
60	Centro Cultural Rodoviários do RJ	Cultural
61	Sentaí	Bar - Restaurant
62	Hotel Amazonas	Hotel
63	Bus Terminal Américo Fontenelle	Transportation

E) Subzone Morro da Providencia - Livramento

It is the region that comprehends the two hills of the Port Zone, delimited by the Livramento and Barão de Gamboa Strees, at the north face, until the America Street and the Rail Central Station at the south face, and also is delimited by the 31 de Março Highway at the west face and the Noemia, Rosa Salão and Camerino Streets at the east face. The subsystem is characterized on being a mainly low incoming residential area, with the majority of the habitants living at the Morro da Providencia-Livramento. The region is in a state of decay, especially at vicinity of America Street. There are also residences in a risk condition, especially those along the edge of the hill. There is also in the area the presence of two of the main government social programs, the UPP Social (police pacification units, common in the Rio´s slums) and the construction program *Morar Carioca*, which aims the urban requalification at the slums as well walkability improvements. At bottom part at the hill there is the presence of the program *Minha Casa Minha Vida*, again a governmental social program, which aims improve or creates opportunity of credit to be use to build new low cost residences. The Morro do Providencia- Livramento is nowadays in a state of aggressive degradations, however is one of the old urban occupations in the city, and has a great historic value.

Figure 2-8 - Subzone Morro Providencia Livramento (source Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
64	Providência Oratory	Worship Space
65	Providência Viewpoint	Viewpoint
66	Costa Barros Staircase	Historic Heritage
67	Hotel Cruzeiro	Hotel

F) Subzone Saúde

Is the subzone delimited by area between Morro da Saúde and Leôncio de Albuquerque Street, as west limit, Barão de Tefé Avenue at east limit, Gamboa Wharf as northern and Livramento Street as southern limit.

The area contains expressive concentration of warehouses and public institutional buildings, as Servidores Hospital, and the Darcy Vargas Foundation. There is also the presence of buildings that composed the National architectural heritage, as the Fluminense Mill Complex, townhouses and houses at the Morro Saúde and the Saúde Church. The church, one of the oldest churches in Rio, restored and currently in use, is one of the area main architectural elements.

Figure 2-9 - Subsystem Saude (source Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
68	Cia de Mystérios e Novidades	Cultural
69	Batalhão da PM	Architectural Heritage
70	Nossa Senhora da Saúde Church	Worship Space
71	Arco e Silo Moinho Fluminense	Architectural Heritage
72	Pretos Novos Cemetery	Historic Heritage
73	Harmonia Square	Park - Square
74	Porto Saúde	Bar – Restaurant
75	AquaRio	Museum
76	Street Mural - theme “indígenas”	Street Art
77	Nilton Bravo´s Street Mural	Street Art
78	Fluminense Mill	Architectural Heritage

G) Subzone Gamboa

Extends from the bottom of Morro da Providência-Livramento to Avenue Rodrigo Alves, between the streets Santo Cristo and Leôncio de Albuquerque.The region of high touristic potential, surrounded by the '*morros*' Saúde, Gamboa and Providência, this area corresponds to where was once before the Gamboa bay, which was embankment to give place to the installations of Porto do Rio. That area is predominated by sites with big dimensions. In the central part we can highlight the Cidade do Samba, with its huge warehouses to make the carnival events. The future installations of Central Bank (in the bottom of Morro da Saúde) and the restoration of the historic railway warehouses (between Vila Olímpica da Gamboa and the Cidade do Samba) will attract even more dynamism to this subzone.

Figure 2-10 - Subzone Gamboa (source: Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
79	José Bonifácio Cultural Center	Cultural
80	Vila Olímpica da Gamboa	Park - Square
81	Raiway Warehouses	Historic Heritage
82	Hospital Nossa Senhora da Saúde	Architectural Heritage
83	Cidade do Samba	Cultural
84	Ingleses Cemetery	Historic Heritage
85	Gamboa Warehouse Marco Nanini	Cultural
86	Nossa Senhora das Graças Chapel	Worship Space

H) Subzone Santo Cristo

It is located between Avenue Rodrigues Alves (from the Bus Station Novo Rio until *Morro* da Gamboa) and the Square Marechal Hermes and Street Santo Cristo (in the south). The area has high accessibility in terms of flow of people, where is located the Bus Station Novo Rio. The center of this area, between the Avenues Prof. Pereira Reias and Cidade Lima, has sport facilities.

Figure 2-11 - Subzone Santo Cristo (source: Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
87	Novo Rio Bus Station	Transportation
88	Santo Cristo Church	Worship Space
89	Spetaculu	Cultural

I) Subzone Morro do Pinto

It is limited by Street Pedro Alves and Highway 31 de Março (West-East), in the Northern side by the Street Santo Cristo and in the Southern side by the bottom of the morro. This area is mainly residential, with houses and low rise buildings, vehicular feasible streets with some urban services. We can highlight the Park Machado de Assis in the top of the 'morro', with viewpoint that gives a broad view for the port area and the cirty center, and the old chocolate factory Bhering, where today is occupied by young artists, ateliers and antiquaries'.

Figure 2-12 – Subzone Morro do Pinto (source: Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
90	Machado de Assis Park	Park - Square
91	Bhering Factory	Architectural Heritage
92	Nossa Senhora de Montserrat Church	Worship Space
93	Machado de Assis Viewpoint	Viewpoint

J) Subzone Linha Férrea

The area extends from Station Estrada de Ferro Central do Brasil to Avenue Francisco Bicalho, in the area between the bottom of the 'morros' of Providência-Livramento and Pinto until the Avenue Presidente Vargas (part of the Ave.) The area is occupied by railway lines of Super via and the subway. The area around the Central is decayed including its urbanization, however provided with important public transportations like trains, subway and bus. There are lots of street vendors spread around all terminals. There is bigger building potential in this core, in the boundary line with Presidente Vargas.

Figure 2-13 - Subzone Linha Ferrea (source: Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
94	Central do Brasil Rail Station	Transportation
95	Bus Station Procópio Ferreira	Transportation
96	Tower – Building of Central do Brasil	Architectural Heritage
97	Subway Station Cidade Nova	Transportation
98	Subway Station Central	Transportation
99	Zumbi dos Palmares	Monument
100	Ancient Gas Factory	Architectural Heritage

K) Subzone Porto Olimpico

It is composed by the Francisco Bicalho avenue axis, bordered on the west by the Street Melo Souza and Gasômetro (included) and bounded on the East by Street Pedro Alves and Bus Station Novo Rio. It extends northwest between the Avenues Rio de Janeiro and Brasil (part of). This area contains large properties (mostly empty sites and warehouses) almost all of them are public properties, situated between the main access roads to city Center, South and North Zones, to suburbs and metropolitan region. The area is object of a national competition and is the area where was given the permission for building the highest buildings, up to 100 meters high. Nowadays the area is under construction.

Figure 2-14 - Subzone Porto Olimpico (source:Porto Maravilha/IMM Design Lab)

POINT	POINT DESCRIPTION	CHARACTER
101	Ancient Carris Station	Architectural Heritage
102	Ancient Leopoldina Station	Architectural Heritage
103	Profeta Gentileza Columns	Street Art
104	Aplause Warehouse	Cultural
105	Porto Olimpico	Architectural Heritage
106	Porto Olimpico	Architectural Heritage
107	Port Corporate	Architectural Heritage

Although each subzone shows lots of singularities, one factor plays the common point, which is its isolation from the city, and also between them, leading every sub-system to work as a detached territory. Due this, the importance of a new urban plan that creates the linkage bonds between the sub-areas and with the entire system, the city and specially its downtown area, the Centro.

The Centro is the historic core of the city, as well as its financial center. There are many urban functions assembled there as tourism activities, the retail and shopping center, and the home of many important companies and businesses. Moreover, many successful public spaces are located there, and the public transportation in Centro is at Rio’s highest level in terms of quality and quantity. It can be assumed as the heart of the city which the main activities are holding there and the functions of other parts of the city are defined with regard to and in compatibility with it. Obviously any new urban project should act with close integration of other parts of the city, and according to IMM this integration is due to happen in a multi-scale manner, approaching on global, Intermediate and local scales.

Locating in a close vicinity to Centro, gives a great chance to the Port area to be modified in a stronger integration with it, and communicate with the whole city through it. As a successful market and retail center the Port area was a well-functioning urban area which played a fundamental role in city's development during the 18th and 19th centuries. It was in recent history that the area has been subjected to a gradual degradation. The decay accelerated by the time and led to waves of abandonment by the people who lived and worked there. Today, despite of its strategic location the Port area is a deserted look district and almost empty from important urban function.

Currently nearly 28.000 people live in the Port area. Through an urban development, the municipality aims to increase this number to 100.000 by 2020. In other words, the area will gain a residential character. Considering this, the decision of the urban functions which will be placed on the future map of the area could be a tool of foreseeing the development. The future residential theme in one hand and the vicinity to the Centro in another hand puts the Port area in a special situation. Functionally, it should support Centro while not repeating it. Therefore in the proposed design services and urban key functions should be assembled in compatibility with Centro which contains the identical activities of Rio. This means that all the concepts in IMM which deal with the types of functions (like *Diversity*) will be defined differently in global scales, as the metropolitan scale for example; intermediate and local scales, and consequently the categories of functions won't necessarily be the same in different scales.

2.3 Considerations and Historical Features

Alike occurs in port areas around the world, such as in New York, Barcelona, Lisbon and Buenos Aires, urban interventions should boost process of real estate speculation within the area which it takes part. At the same time, the local population are often forced to move far away, sometimes due relocations, suffering a process called gentrification. And Porto Maravilha seems to be now under this process

The term Gentrification, widespread by the English sociologist Ruth Glass, is characterized by the forced removal of the low incoming population in central or attractive neighborhoods, due urban interventions, especially those regarding infrastructure and habitation units. Thus, during the process, the area changes not only its urban distribution, but also interrupts the exiting socioeconomic relationships.

It is important to mention the Port of Rio de Janeiro historical value. It was there that the city starts, at the beginning of the XX Century, when slaves brought from Africa were, first received, and then worked receiving and expediting the goods. This age was completely removed when the Princess Isabel from Portugal came to the Portuguese colony Brazil, when the port pass through its first big remodel process.

However was in the decade of 1910 that the port suffer its heaviest intervention, when the port took the place of several small bays situated in the area northern portion (Valongo, Saúde, Gamboa and Praia Formosa bay), starting to work in a centralized manner, controlled by the freshly created *Companhia das Docas* (Dock´s Company)

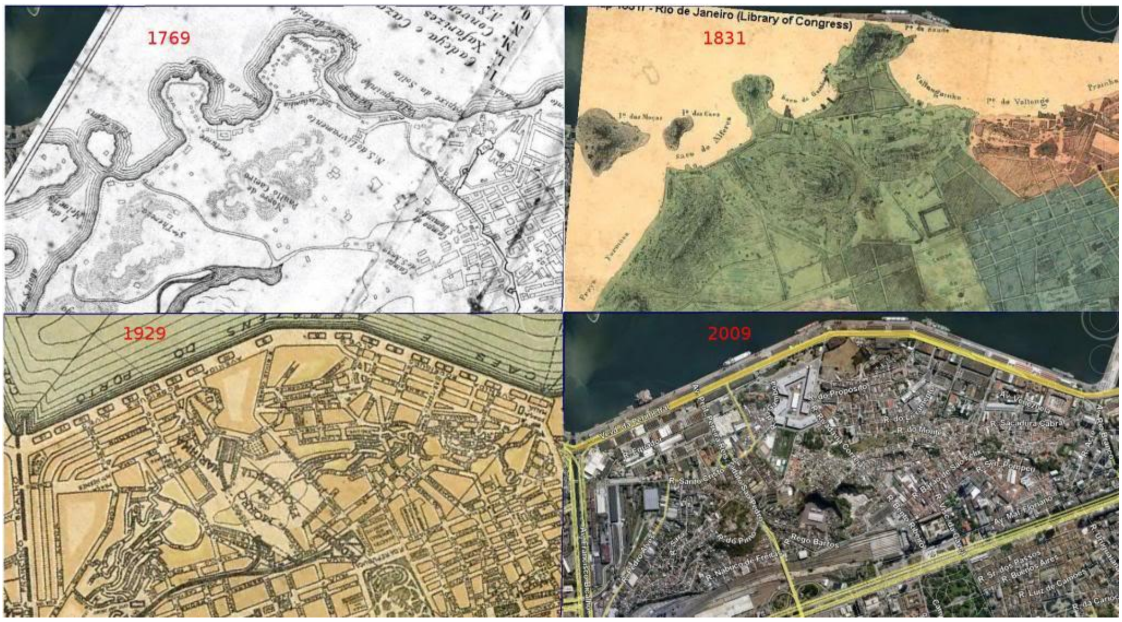


Figure 2-15 - Port urban evolution (source: UFRJ Politecnic Urban Engineering School)

The port area in the city of Rio de Janeiro started to fall in decay by the construction of the Presidente Vargas Avenue and the Highway (*Perimetral*) as well by removing the hydrographic operations to the Itaguai Port, south of Rio de Janeiro.

The modification trapped the port area in an isolated condition, reaching its peak during the decade of 80´s, when gradually decays the warehouses nearby the Rodrigues Alves Avenue, probably due the fact that, in that decade started the use of containers to stores good in ports activities.

Nowadays, in a period of fair economic growth, the municipality starts to look more carefully to the port area. Waterfronts are, as seems worldwide, a great opportunity to host itinerant events, to build urban landscapes aiming to insert a city within the dynamic expected for a global city, and Rio isn´t different. To succeed although, the intervention objectify erase all traces of delay in comparison with modern cities. And the problem lies on this aspect.

Erasing its history in the port zone is erasing the Rio de Janeiro history itself, where the mix between European immigrants, slaves coming from Africa and dealers in general gave the entire social, cultural and economic heritage to the area during the past years.

Talking to the local residents, the common sense is that the Porto Maravilha project is not for them or at least not for their wellness. The biggest concern is in not being included in any decision-making process as well as for not being informed of any ongoing transformation, especially those who take house spaces for implementation of transportation facilities. The locals are frightened by removal, when their community is replaced from the port and central zone to the distant West Zone, far from their jobs, the school of their children as well as far from any public facility.

The project established 4 main areas to be explored as residential uses, but only one with the social interest. The other areas are buildings and houses that should be refurbished, in the area called SAGAS. At the end, the areas nearby the waterfront should be explored as commercial facilities, services, cultural and touristic interests, trough the CEPAC´s, documents emitted by the municipality increasing the buildable area, and what will raise the funds to be invested in the intervention.

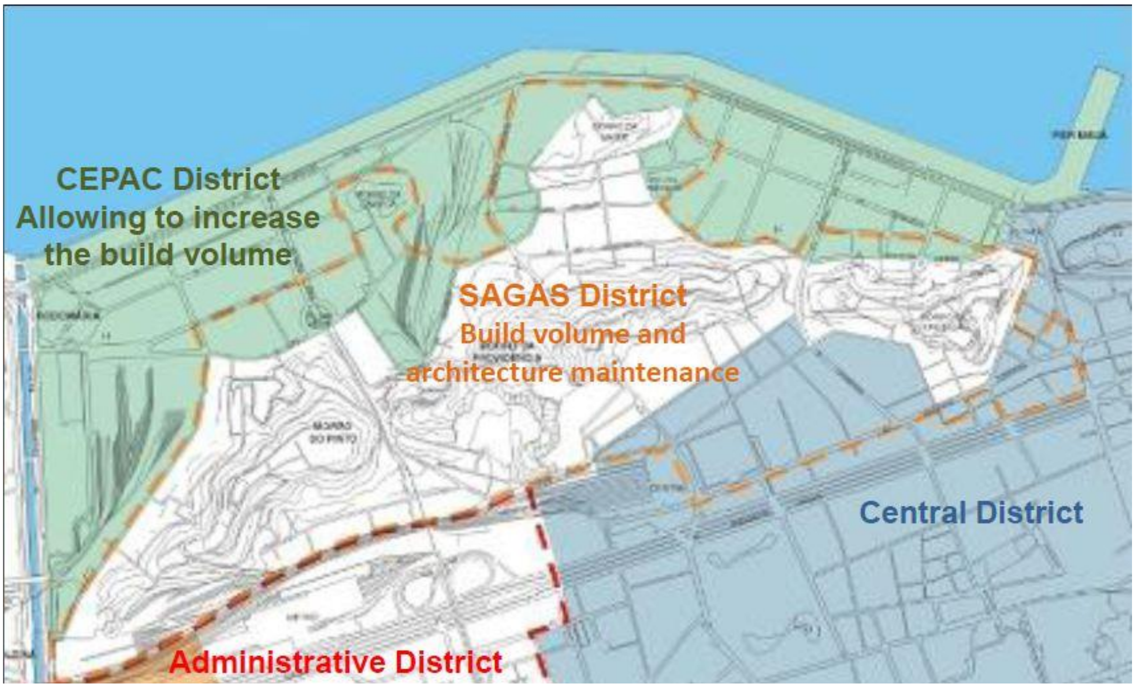


Figure 2-16 - CEPAC distribution (source IMM Design Lab)

Thus, the study case presented establishes 3 mandatory requirements: use all the CEPAC´s potential as a volume require, the ongoing project for the Porto Olimpico and the Santo Cristo neighborhood as central focus for the transformation phase.

2.4. PHASE 01 – Investigation/Analysis

According to the IMM method, city is considered as a Complex Adaptive System CAS, and in order to comprehend its formal complexity, the system should be disassembled into four subsystem generators (the horizontal layers). These layers are namely: Volume, Void, Function, and Transportation [2]

When dismantled the CAS in spitted subsystems turning possible the individual analysis regarding its characteristics, performance, weakness and opportunities.

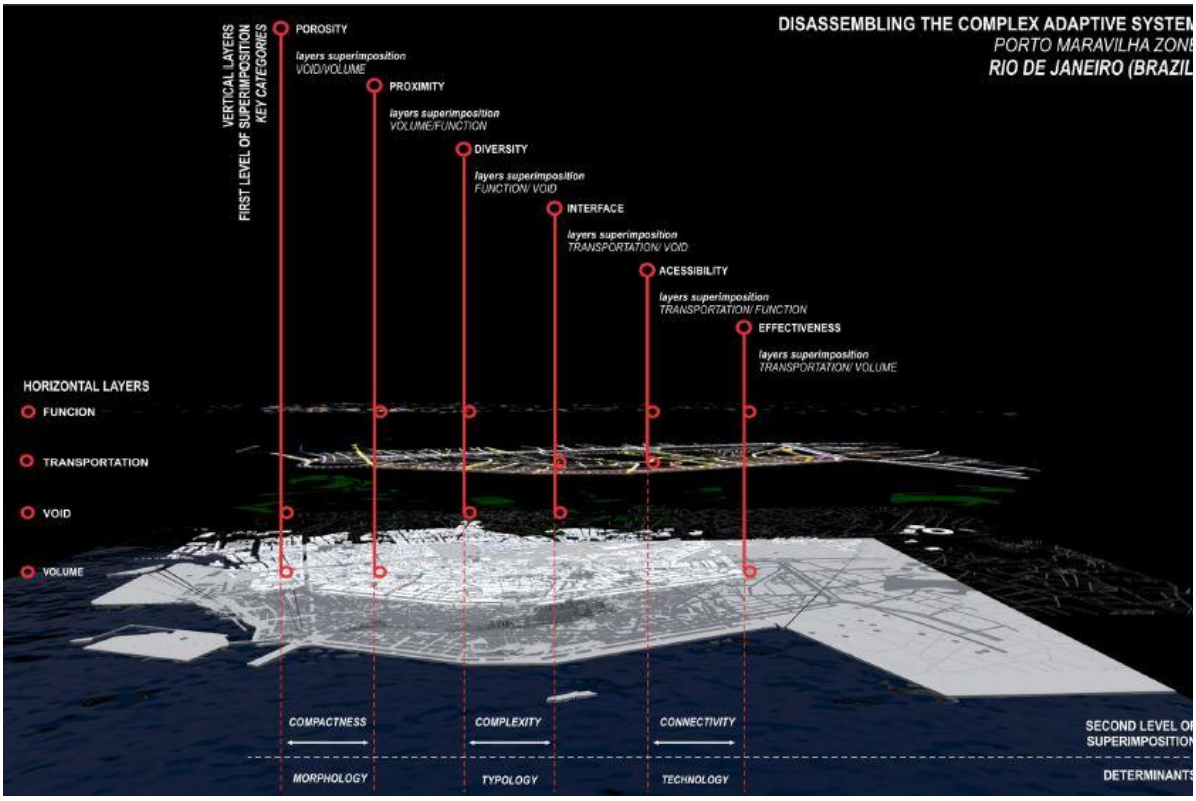


Figure 2-17 - Disassembled Porto Maravilha (source IMM)

2.4.1. Horizontal Investigation

The horizontal investigation is the phase when, once disassembled the Urban System (CAS), is investigated, individually, the built volume (ground used), void (ground not used), transportation network and function nodes within, in the study case, the intermediate scale. During the process, it was analyzed the existing morphology and the actual performance of the CAS. Understanding the characteristic of the related subsystem and it links is crucial for the final project result, once it point out strength, weakness, opportunities and treats related to the area.

A variety of volumes are found in the area, regarding shapes and sizes. The area once occupied by the sea and latter transformed as the Port itself host the larger plots within the intermediate scale, besides the Maracanã Stadium and the Central Station Railway (Estação *Central do Brasil*). The ground use is fulfilling the available surface in 100% at the embankment area and in 70% located at the hills (*UFRJ 2013*).

Figure 2-181 - Horizontal investigation Volume (source IMM Design Lab)

Regarding the voids, the open public spaces area the Aterro do Flamengo Park, at the southeast portion of the intermediate scale, the Praça Mauá near the city center, the Vila Olimpica da Gamboa,at the core of the area, the Quinta da Boa Vista, western portion nearby the Maracanã Stadio and the Campo Santana across the Av. Presidente Vargas in the south portion. The other empty spaces visible in the map are occupied by rails, roads, empty private plots and remains of quarry production sites, nearby the Morro Providencia-Livramento. The voids could be divided according to its covering surface.

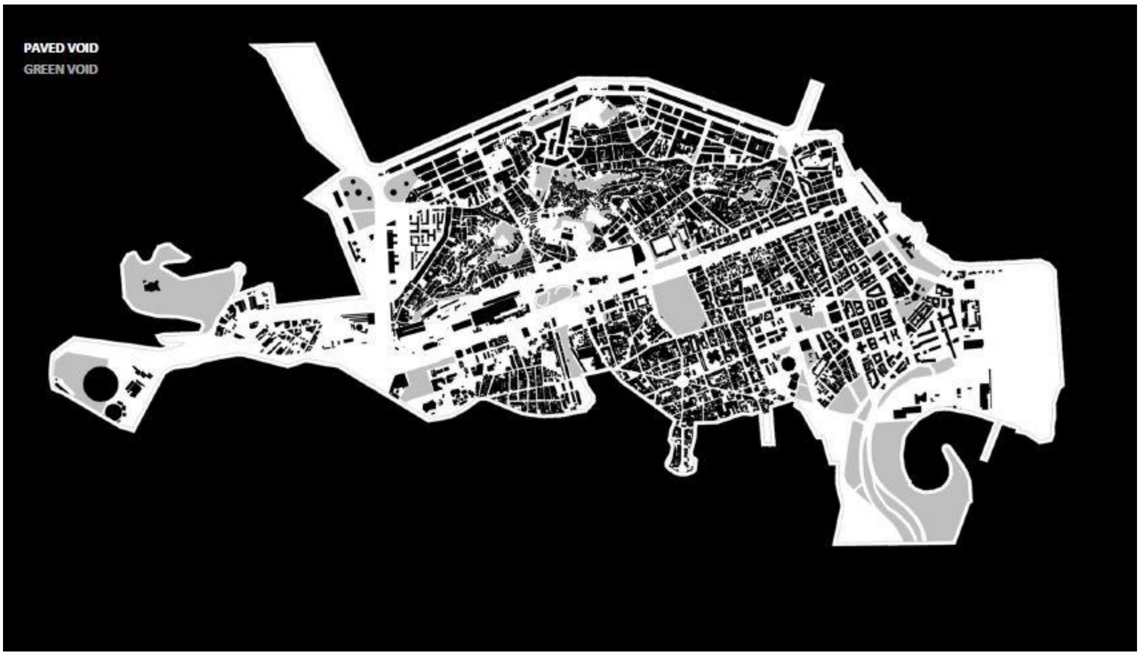


Figure 2-19 - Horizontal investigation Void (source IMM Design Lab)

By transportation network was considered the planned by the Porto Maravilha project, once it is now under construction. Studying its distribution is visible the lack of public transportation in the hills and the focus on the city center and the waterfront.

Figure 2-20 - Horizontal investigation Transportation (source IMM Design Lab)

At the end of the horizontal investigation, the functional analysis presents the uses inside the intermediate scale, with the majority of nodes near the city center and the proximities of the Aterro do Flamengo Park. It is also visible the lacking of functions especially at the waterfront zone and at the areas nearby the hills.

Figure 2-21 - Horizontal investigation Function (source IMM Design Lab)

2.4.2. Vertical Investigation – First Level of Superimposition

The relationship between the subsystems is analyzed by the Vertical Investigation, through the system´s Key Categories (KC). They are the Porosity, Proximity, Diversity, Interface, Accessibility and Effectiveness, giving as outcomes a better understanding of the physical composition, the performance and also allow a numerical evaluation of the CAS, probably the major goal of this phase. The analysis of the KC will turn visible the problem from the morphological perspective.

Thus, the use of the Indicators is effective in order to achieve the numerical value. After the transformation design, the same criteria will be used in the CAS Retrofitting Process. The Indicators are straightly linked to the Design Principle Ordering (DOP), which will be use as guidelines to rearrange the CAS in a boosted way.

The Superimposition of the layers Volume and Void will define the Porosity [1]. A variety of patterns, as mentioned before, are detected in the study are, composing the existing morphology. However, the sizes of the blocks located at the embankment area are bigger than the ones at the older portion, the hills. The existing superblocks are maintained in the Porto Maravilha Project, factor that provokes fewer intersections between the passages ways. Furthermore, the hills follow the topography, composing a spontaneous morphology. And by the end, the denser portion within the area is composed by the Morro Providencia- Livramento, obviously due the fact it is a irregular occupation.

Figure 2-22 - Vertical investigation Porosity (source: IMM Design Lab)

Superimposing the Volume and Function layers will define the Proximity, which means the easiness to reach the urban functions through the gaps between the volumes. The concept indicates the distribution pattern of urban key functions (*Tadi M.Vahabzadeh S. 2013*).

The key functions are mostly located nearby the main avenues at the city center, Presidente Vargas and Rio Branco Avenues, composing a T shaped connection. This factor evidences the streets hierarchical rank and point out the busiest sport, probably the most valuable places in the city center, for real estate reasons. Moreover, hills, being a mainly residential area, do not host any key function.

Figure 2-232 - Vertical investigation Proximity (source IMM Design Lab)

The varieties of functions presented represent the Diversity. The concept come from the superimposition between the Void and Function layers and gives the functional network within the urban area (Tadi M et al. 2013). The analysis made is guide by ranking the urban functions according to their uses, when is strictly related the urban flow, or in other words, by when the function is used. The functions were ranked as Necessary and Regular Activity, schools and activities with high density of jobs opportunities, then Necessary and Occasional Activities, such as banks, post offices, shops, and Optional Activities, mostly related to the leisure and entertainment uses.

The distribution follows the as the proximity terms, with the majority of the necessary activities, regular and occasional located nearby the Rio Branco and the Presidente Vargas, at the city center, but now more visible the appearance of some activities nearby the Central Station, as well the lack of entertainment and leisure activities.

Figure 2-24 - Vertical investigation Diversity (source IMM Design Lab)

The superimposition of the layers Transportation and Void makes the Interface, and its outcome gives the evaluation of the transportation links regarding the easiness of accessing a point from another random point within the network, or simply integration between links which compose the urban network [7]. It is the most relevant key category considering the urban flow and gives the mean depth value for each singular link. Obviously and as mentioned before, the superblocks located at the port area configures a barrier for a good integration, as well the high density and the unorganized urban pattern within the hills. It is important to say that the fact that there is a *favela*, in the area will affect the entire systems, which gives to the area in questions even more importance. It is also important to say that is a very though geography to promote links integrations, due morphological, typological and topographical reasons.

Furthermore, the is visible the gap provoked by the railway lines, the *perimetral* highway, the old quarries productions spaces, as well the fact that there is not any advantage taking from the connections by the urban spaces, once it is mainly surrounded by walls and fences. Thus, the Interface sure configures as one of the most promising key category to enhance the system performance.

Figure 2-25 - Vertical investigation Interface (source IMM Design Lab)

The facility on reaching some urban key function using public transportation is measure by the Accessibility, a superimposition between the Transportation and Function layers [7]. It mostly supported by the technology and infrastructure applied in the public transportation within the analyzed area.

In the intermediate studied scale the level of Accessibility is affected by the distribution of the public transportation nodes, mostly focused at the city center and the proximity of the Aterro do Flamengo Park. The hills as well the waterfront appears lacking Accessibility at all creating specially in the hills case, black holes in the system.

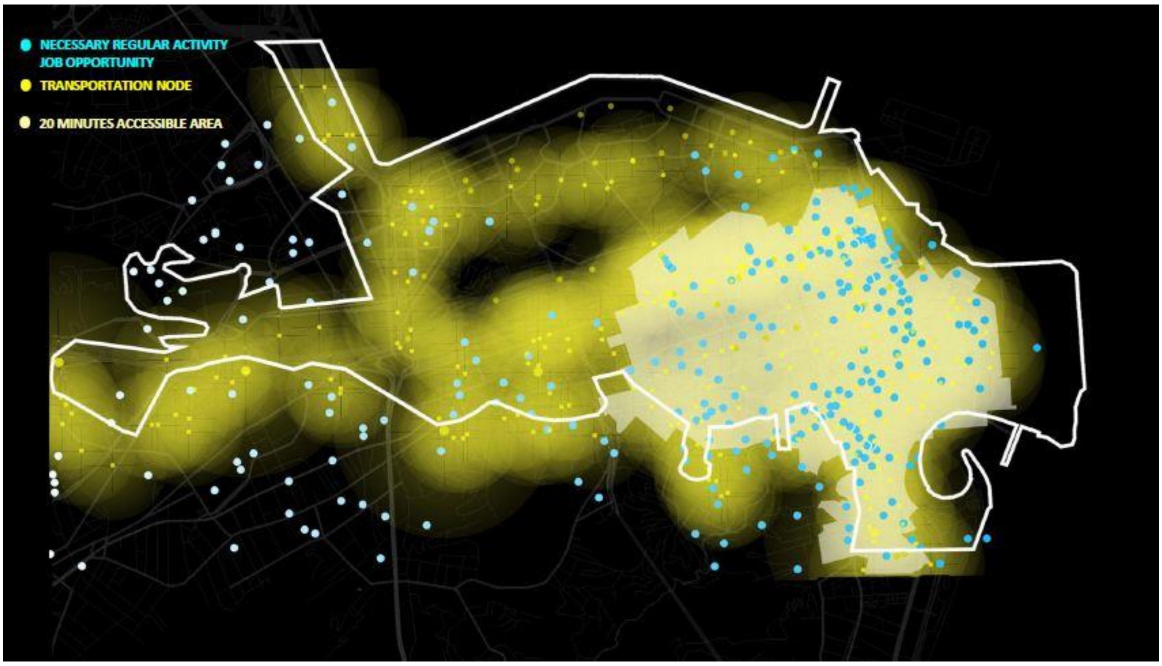


Figure 2-263 - Vertical investigation Accessibility (source IMM Design Lab)

Using the ration between the supply and demand of public transportation, the Effectiveness is the superimposition of the Transportation and Volume layers and gives the reach of the public transportation network, and is the major key for locating dense areas during the design process.

As an example of what happen regarding the Accessibility, the Effectiveness has similar drawbacks, when the city center is provided by the majority of the nodes at the same time as the hills does not.

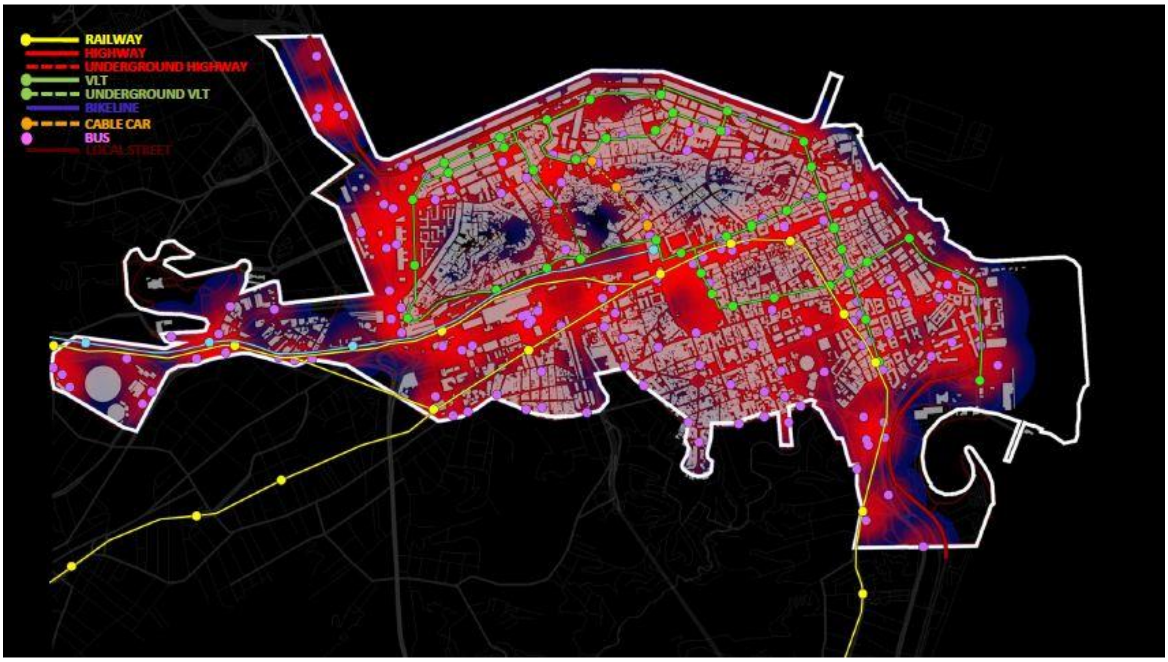


Figure 2-27 - Vertical investigation Effectiveness (source IMM Design Lab)

2.4.3 Porto Maravilha Actual Performance

To evaluate the environmental performance of the studied area using numerical analysis was implemented the analysis of the referring Indicators to, further, lead the new Design Principle Ordering (DOP) to be used as the transformation guideline, and to provide references when comparing the actual and the transformed system performance.

IMM INDICATORS DESCRIPTION - INTERMEDIATE SCALE	INDICATOR	INDICATION	FORMULA	FACTOR
Layer				
Volume	Horizontal	*build area*	Vl=Vbuilt/Area	**1,448**
Voids	Horizontal	*unbuilt area*	Vd=Vopen/Area	**0,644**
Function	Horizontal	*activities in the area*	Fn=Jnumber/Area(HA)	**1,421**
Transportation	Horizontal	*public or private transportation trips*	T=Ntr	**0,935**
Key Category				
Porosity	Vertical	*density*	P = Abuilt Footprint/Area	**0,356**
Proximity	Vertical	*job opportunity within a walkable distance*	$Px=\sum^{n}_{i}nj/N$	**0,100**
Diversity	Vertical	*activities per residences*	$D1=c/c-1\ [1-\sum^{c}_{i=0}(ni/N)]$	**0,027**
Interface	Vertical	*movability into the urban vois*	MD= (∑ d.n)/k-1	**0,599**
Accessibility	Vertical	*feasibility of reaching destination*	Acc= Nj (Ac/At)	
Effectiveness	Vertical	*n° public transportation on total trips*	Ef=Nptr/Ntr	**0,650**

IMM INDICATORS DESCRIPTION - LOCAL SCALE	INDICATOR	INDICATION	FORMULA	FACTOR
Layer				
Volume	Horizontal	*build area*	Vl=Vbuilt/Area	**2,624**
Voids	Horizontal	*unbuilt area*	Vd=Vopen/Area	**0,657**
Function	Horizontal	*activities in the area*	Fn=Jnumber/Area(HA)	**0,603**
Transportation	Horizontal	*public or private transportation trips*	T=Ntr	**0,935**
Key Category				
Porosity	Vertical	*density*	P = Abuilt Footprint/Area	**0,343**
Proximity	Vertical	*job opportunity within a walkable distance*	$Px=\sum^{n}_{i}nj/N$	**0,100**
Diversity	Vertical	*activities per residences*	$D1=c/c-1\ [1-\sum^{c}_{i=0}(ni/N)]$	**0,027**
Interface	Vertical	*movability into the urban vois*	MD= (∑ d.n)/k-1	**0,577**
Accessibility	Vertical	*feasibility of reaching destination*	Acc= Nj (Ac/At)	
Effectiveness	Vertical	*n° public transportation on total trips*	Ef=Nptr/Ntr	**0,650**

Table 2-1 - CAS Actual Performance (source IMM Design Lab)

2.5 PHASE 02 – Assumption/Interpretation

Choosing the Catalyst Element and the D.O.P. Ordering

The Assumption/Interpretation phase previews the Transformation Phase and link it with the Investigation. It´s mostly dedicated to create the hypothesis that will work as a guideline to improve the CAS actual performance. The goal is to detect the strength and weakness points, as wall manners to treat the opportunities and threat presented in the studied area, and by detecting the catalyst element to be change in order to such achievement.

The catalyst is chosen associating the Key Categories with the Indicators, and uses a layer to start the chain reaction within the system. In this study case, the Investigation gives evidences to the points not developing its full capacity, and the opportunities detected were those related to the Void layer, which strictly affect the Porosity and Interface.

The key feature in the Porto Maravilha area is to use the Void changing its actual role, which is just a corridor to reach the Downtown for those who came from the suburbs, from the north. Changing this feature the horizontal catalyst will react with the system, at the same time that one of the vertical layer as a catalyst. The catalyst choice also drives the new Design Principle Ordering (D.O.P.), which is now defined according to the following order:

1- Create connected open spaces and protect the urban biodiversity;
2- Foster mixed used spaces;
3- Promote walkability;
4- Promote cycling and reinforce the public transportation;
5- Foster local energy production, using the building as a component;
6- Change from multimodality to intermodality concept;
7- Promote ground use balance;
8- Prevent the negative impact of waste;
9- Implement water management;
10- Convert the city to a food producer;

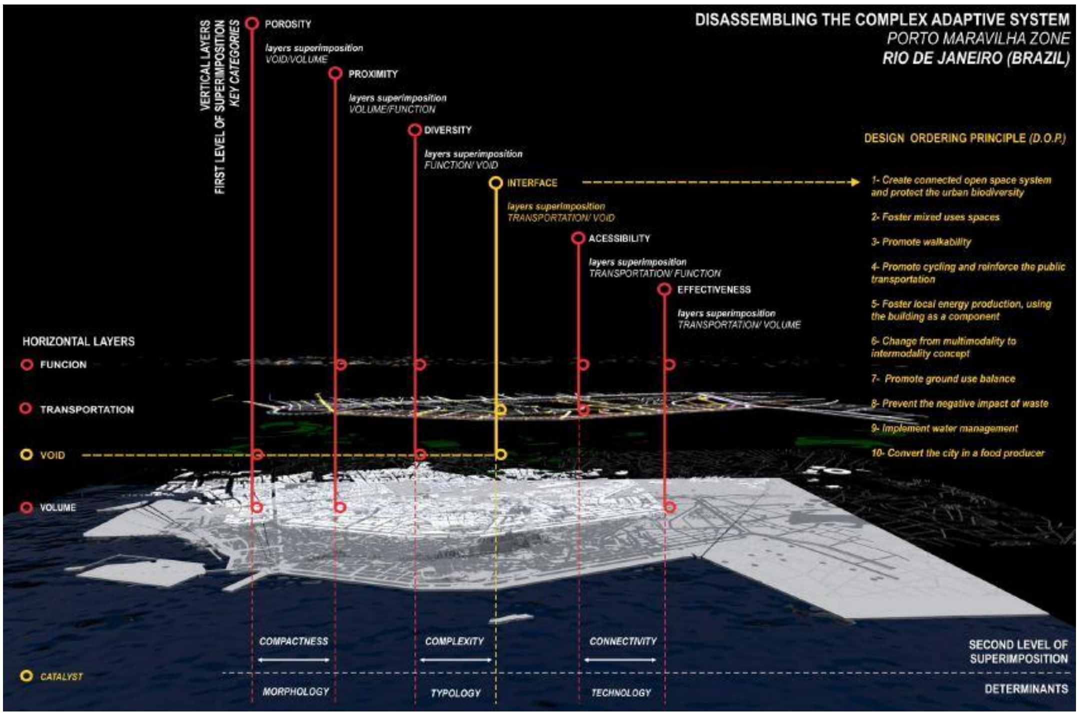


Figure 2-284 - The Catalyst choice and the D.O.P. (source IMM Design Lab)

Furthermore, the investigation point out that the Porto Maravilha is isolated from the rest of the city, due the surrounded highways and the presence of the railway line. This transportation lines are now blocking the access from those who want to reach the waterfront, provoking its decay. If those urban empty spaces are now creating the weakness aspects, they represent as the opportunity to guide the local transformation, initiating the aimed chain reaction. When giving a use for such spaces, a green system could be connected, reaching the global scale.

2.6. PHASE 03 – Modification/Intervention

The starting concept is first, convert those empty spaces to green ones, and then, connect new urban green spots to those spread out the city, passing through the Porto Maravilha, and using the two urban plug-in in order to link the area with the Parque Nacional da Tijuca, the biggest urban park in the world, create a green cycle, promoting the biodiversity into the urban tissue.

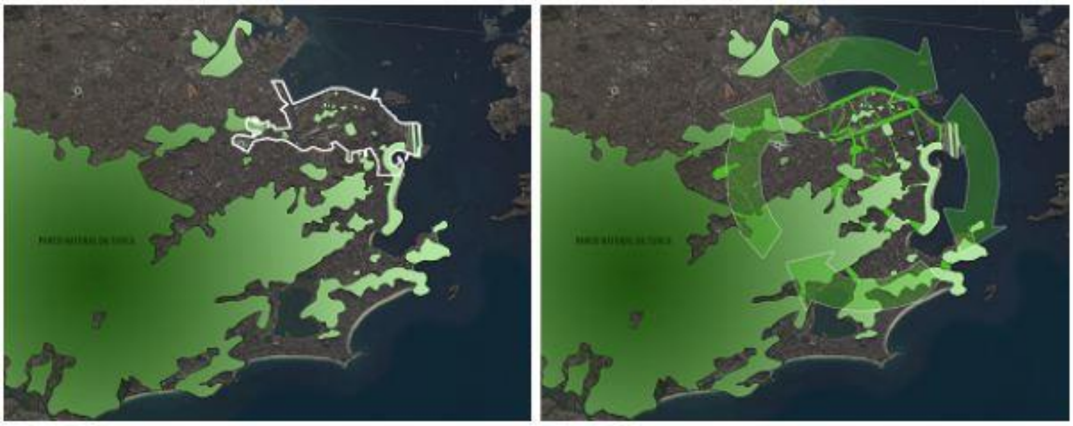


Figure 2-29 - The Green Cycle (source IMM Design Lab)

The Investigation also point out the location of the potential urban empty spaces at the area, and how they can be explored integrated to the Interface. The recovery of those spaces will not only improve the Interface itself, but also will work together with the Diversity enhancing the Complexity and the Compactness of the entire intermediate scale.

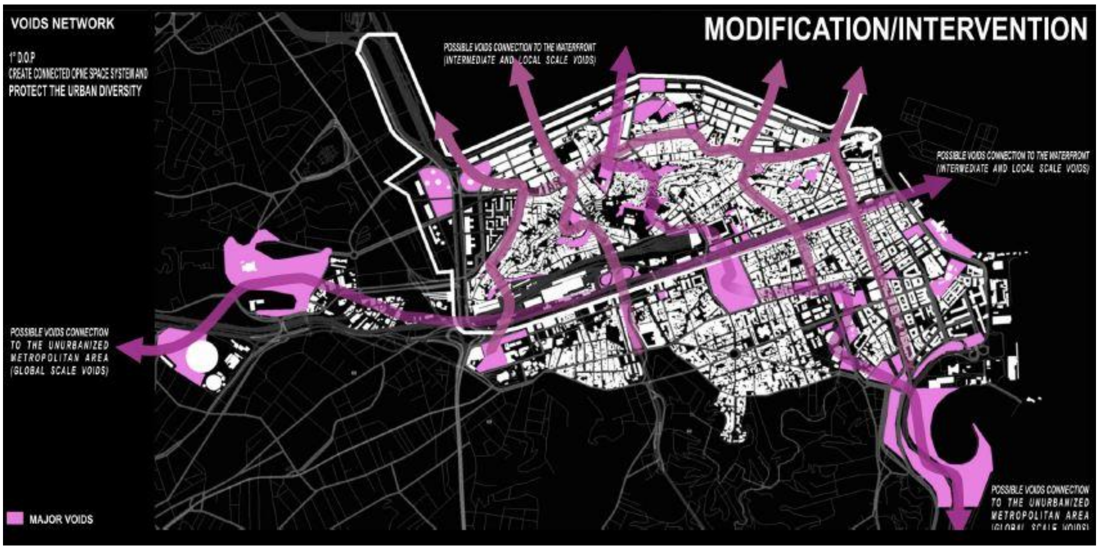


Figure 2-30 - Voids Modification (source IMM Design Lab)

Morphologically investigating the urban tissue is possible also to explore the weak point in term of Interface, which is the superblocks at the port area, near the waterfront, enhancing it when broke the blocks, and well the connection on the Interface does not exist, increasing the number of links, connecting the Porto Maravilha to the urban fabric, specially the city center.

Obviously, by morphological and topographical characteristic already mentioned presented at the hills (Morro Conceição, Morro Providencia-Livramento and Morro do Pinto) and its surrounding, as well the waterfront line cannot be changed, but could receive different treatment as pavement and street signs, for example, in order to achieve better mobility within these areas.

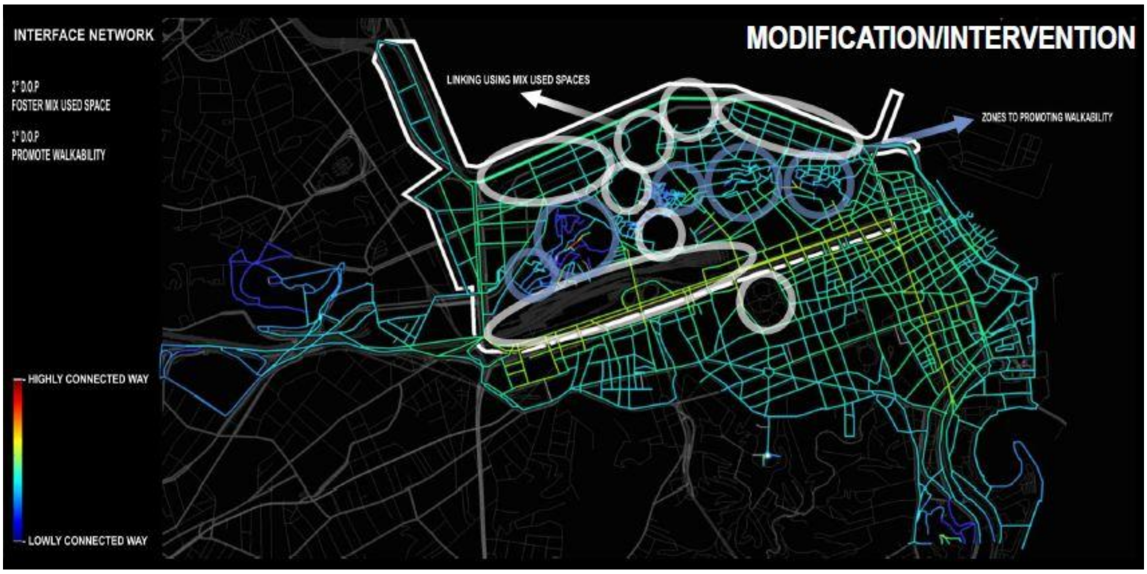


Figure 2-31 - Interface Modification (source IMM Design Lab)

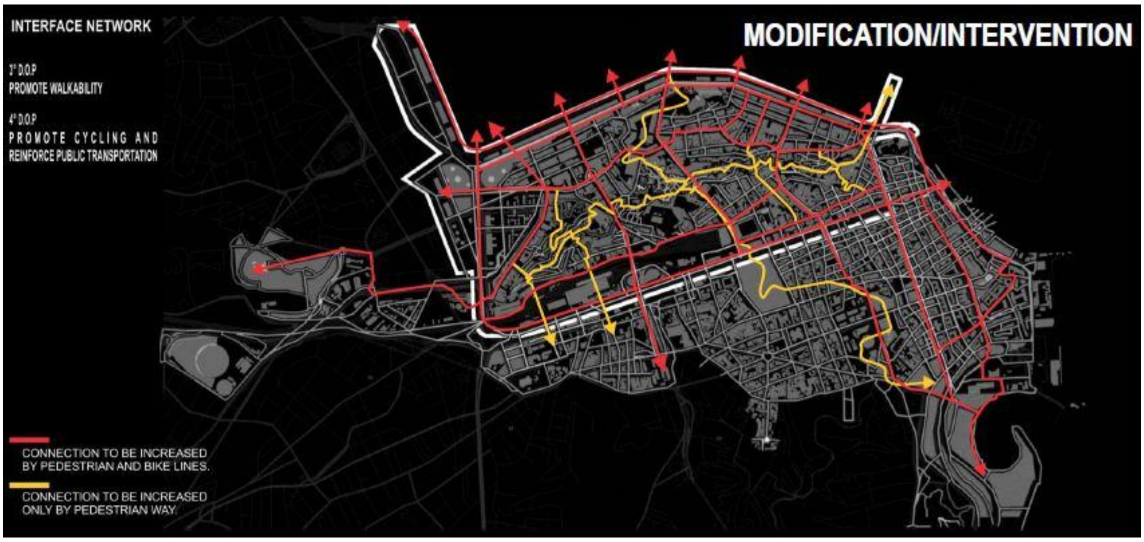


Figure 2-325 - Interface Modification (source IMM Design Lab)

The results point out that the areas which need more transformation are the ones which correspond to the hill regarding the movability, accessibility and function; and the waterfront regarding functions and Diversity. Consequently, as the modification is in the Void and the Interface, the other three horizontal layers (Volume, Transportation and Function) will work as Reactants as well the other five vertical (Porosity, Proximity, Diversity, Accessibility and Effectiveness). The modification of the Voids aims to create a new green network integrated to the horizontal layers network, creating a new morphology. Furthermore, increasing the number of links, will be increased also the integration within the area as well the connection with the area and the global scale, as simultaneously will be enhanced the Accessibility and the Effectiveness and then, the Diversity will be boosted by the integration with the Transportation and the Function layers improved.

2.7. PHASE 04 – Transformation/Optimization

Voids and Interface Transformation

The transformation phase start recognizing the actual morphology and separating the streets grid.

Figure 2-33 - The Actual CAS Intermediate Scale (source IMM Design Lab)

After the separation, the further actions are within the Void layer. First, the location at the intermediate scale of every promising open space, to then give then a rank according to them actual conditions (as paved spaces, green spaces and spaces to be recovered).

After the recognition of these spaces, the transformation moves towards the treatment pf all the spaces as green nodes. Major importance is converting the waterfront to a linear park, coming from the Praça Maua and taking advantages of the courtyard at the Cidade do Samba and also the spaces around the Vila Olimpica da Gamboa. It is important to mention that opening of the biggest green space within the area, the Campo Santana, will enhance the Interface.

Figure 2-34 - The Void Detection (source IMM Design Lab)

Figure 2-35 - Ranking the Voids Potentials (source IMM Design Lab)

Figure 2-36 - Transforming the all the Voids in Green Spaces (source IMM Design Lab)

Once transformed as green spots, the aiming is now connecting them by using two orthogonal and car free axes. One comes behind the warehouses, using the space before occupied by the *Perimetral* Highway as a green boulevard and connects the Porto Maravilha area to the city center ending at the Praça do Mercado Municipal, where there is the Ferry/Boat Station. The second is connected perpendicularly to the first one passing between the Morro do Pinto and the Morro Providencia Livramento, also working as green linear connector.

The two main axes will be supported by three adjacent links, converting the already established connections to green fingers, allowing the urban biodiversity to infiltrates into the Porto Maravilha.

Figure 2-37 - Creating the Orthogonal Green Boulevards (source IMM Design Lab)

Figure 2-38 -Converting the Green Existing Connection into Green Fingers (source IMM Design Lab)

The further steps are related to the transformation of the Interface, and are strictly related to the morphology and the existing topography.

The major transformation is the breaking of the superblocks that now gives to the port zone blocks with the same dimension as the rest of the city as Ipanema, Copacabana and the city center (*centro*). This transformation will drastically improve the Interface. From the new links, as well the existing ones will receive trees planting, moderating the heat island effect, increasing the shade spaces and reducing the air pollution.

Figure 2-39 - Breaking the Superblocks: Creating exploring the existing links as Green Sidewalks (source IMM Design Lab)

Figure 2-406 - Breaking the Superblocks: Adapting the area to the Rio´s morphology (source IMM Design Lab)

At the end, linking strategic points at the hills and through the railway lines will increase the Interface where it has its lower values, enhancing the entire CAS and connection the *favelas* to the urban equipments.

After transforming the Interface the Porto Maravilha is not anymore a detached part within the Rio de Janeiro´s urban tissue.

Figure 2-41 - Adapting the walkability to the Morphology/Topography (source IMM Design Lab)

Figure 2-42 - CAS Transformed (source IMM Design Lab)

2.8. PHASE 05. Retrofitting and Optimization

According to the ongoing plan, the volume built will be crucial for the intervention success. The plan made by the municipality is based on the partnership between public and private companies. The city do not have the capital to invest in the recovery construction, thus the CEPAC (*Certificado de Potencial Adicional de Construção*, or Certificate for Construction Additional Potential, in free translation) was created. Simplifying, the system works as a trade between municipality and private initiatives. Changing the construction laws within the area, the city of Rio de Janeiro will provide certificates giving the so called "right for building", allowing companies to build more surface than the actual city plan. For such benefit, the companies should buy the certificates, giving to capital necessary to the city for recovering the area, in term of infrastructure and maintenance. Therefore, the study will adapt the volume planned by the municipality into the new blocks broken by the Interface transformation.

The optimization takes as first action calculating the same volume planned entire monolith, spreading it uniformly. This will give the same volume as the planned, hypothetically using all the area allowed by the CEPAC´s.

The method use was multiplying the surface area by the average buildable index (maximum buildable area allowed) than dividing it by 80% as allowable foot print. Considering the fact that now the occupation allowed in a single plot is 100% as foot print the index by each zone was balanced.

In this way is achieved as common heights 7 floors within the entire CEPAC area. The graph below shows the blocks division, according to the interface previously analyzed and the total volume.

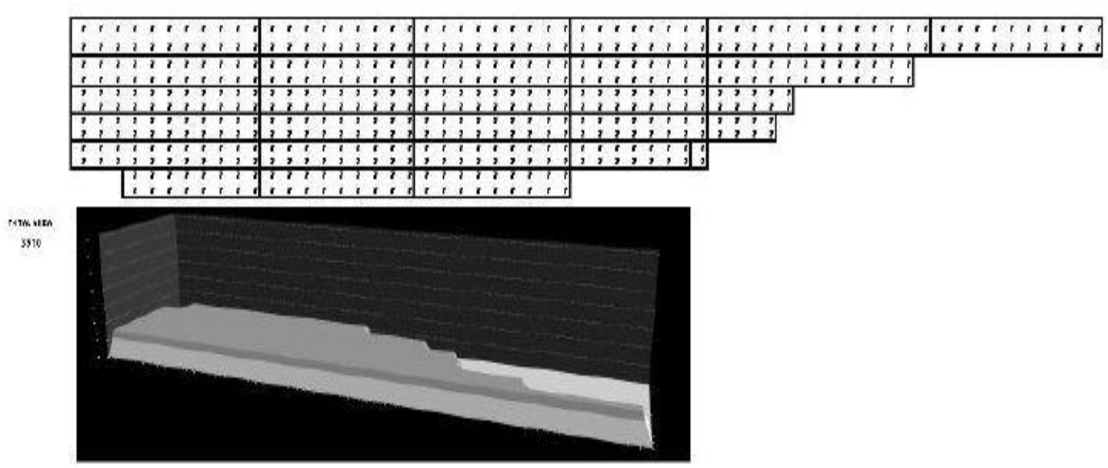


Figure 2-43 - Volume Optimization (source IMM Design Lab)

Working with total (aimed) Volume, the optimization excavates the streets cavities necessary for the new Interface, regarding the links perpendicular to the coast line, dividing the blocks and giving the streets hierarchy division. Completing, the action taken is to open the street cavities regarding the inner area connections, in parallel with the cost line.

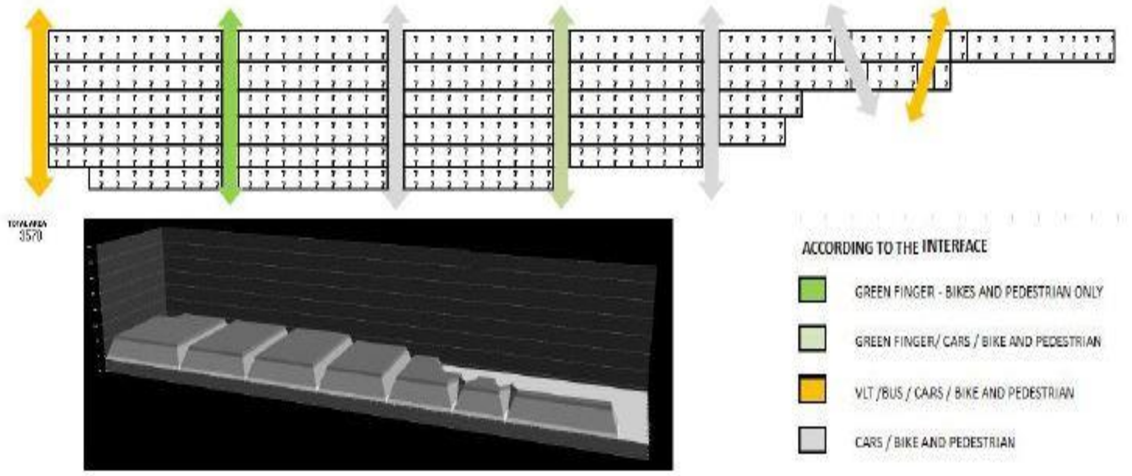


Figure 2-44 - Volume Optimization (source IMM Design Lab)

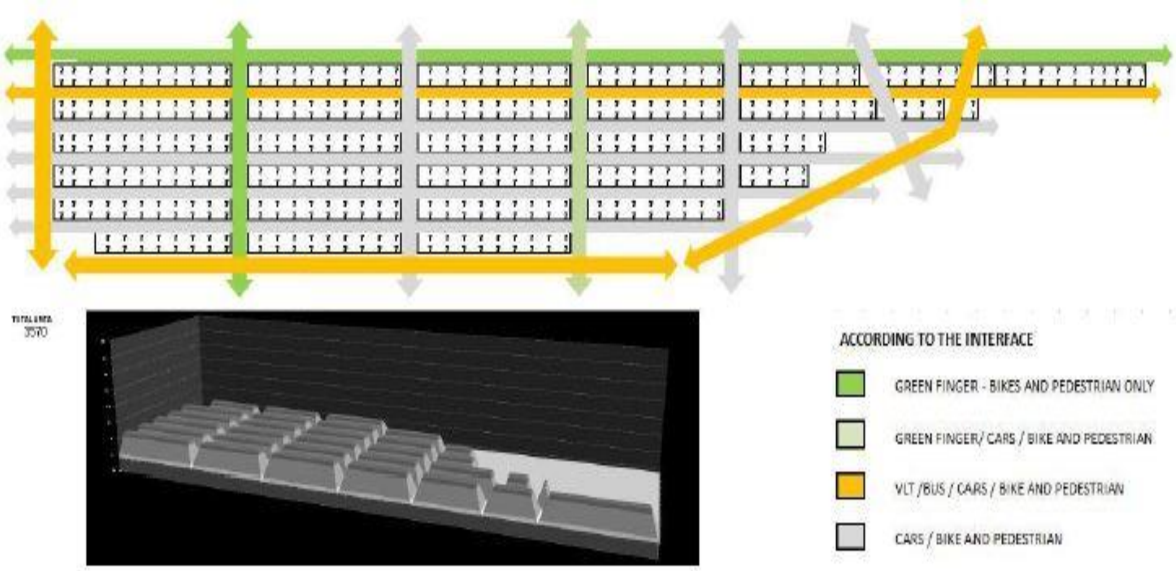


Figure 2-45 - Volume Optimization (source IMM Design Lab)

Furthermore, the optimization is driven no more dividing the volume equally. Instead, the blocks were broken in smaller portions, the plots, creating the opportunities for enhance the Diversity and balancing the ground use. For each plot was given hierarchy value, as consequence of its position in relation with the Transportation layer, as well the local typology and topography, which in the case will be the surrounded neighborhood or the area SAGAS, and the waterfront line . The plots closer (walking distance) to the bigger multimodal hubs will host more volume, as well the plots located in the study area boundaries will host less volume.

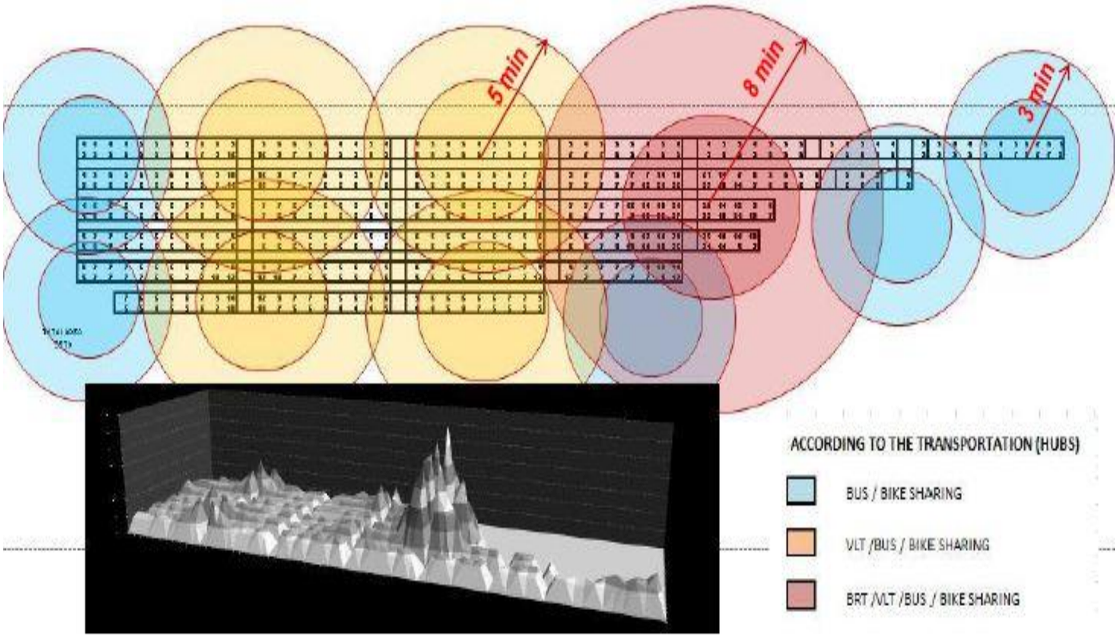


Figure 2-46 -Volume Optimization (source IMM Design Lab)

Afterwards, the same Volume, as well all the opportunities for the CEPAC´s implementation, is adapted to the modified Interface, to the Transportation, to the local typology and topography.

Figure 2-47 - Volume Optimized (source IMM Design Lab)

2.9. The New CAS Performance

Figure 2-487 - New CAS Volume (source IMM Design Lab)

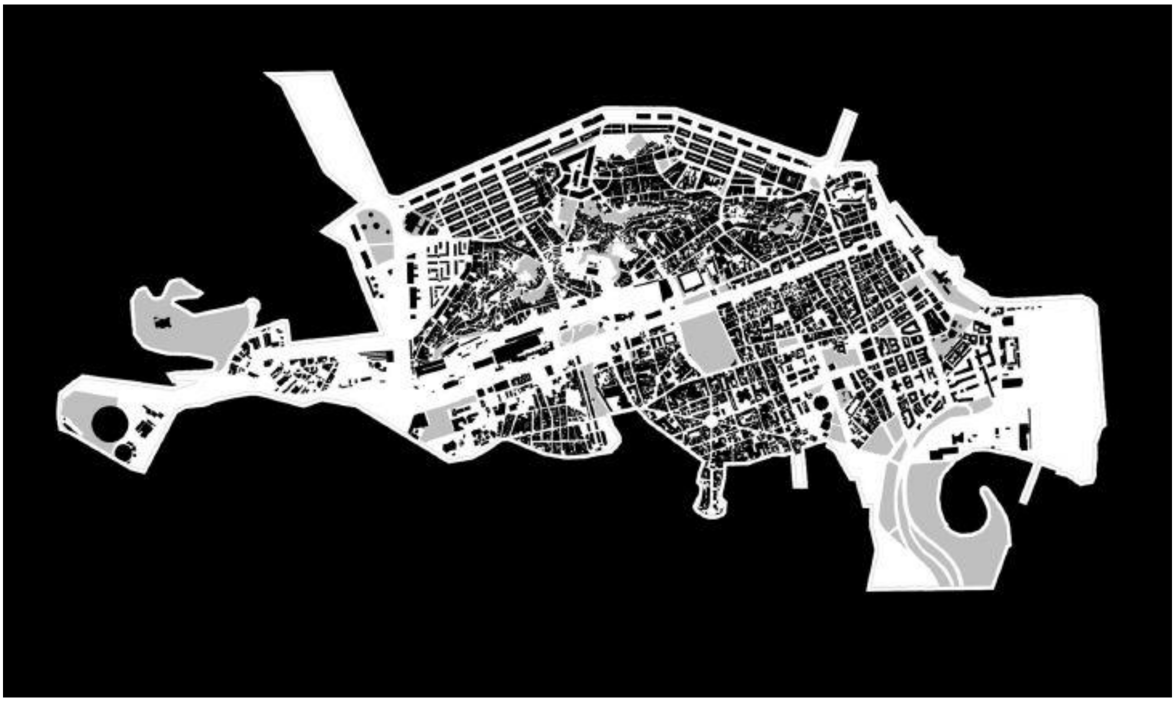


Figure 2-49 - New CAS Void (source IMM Design Lab)

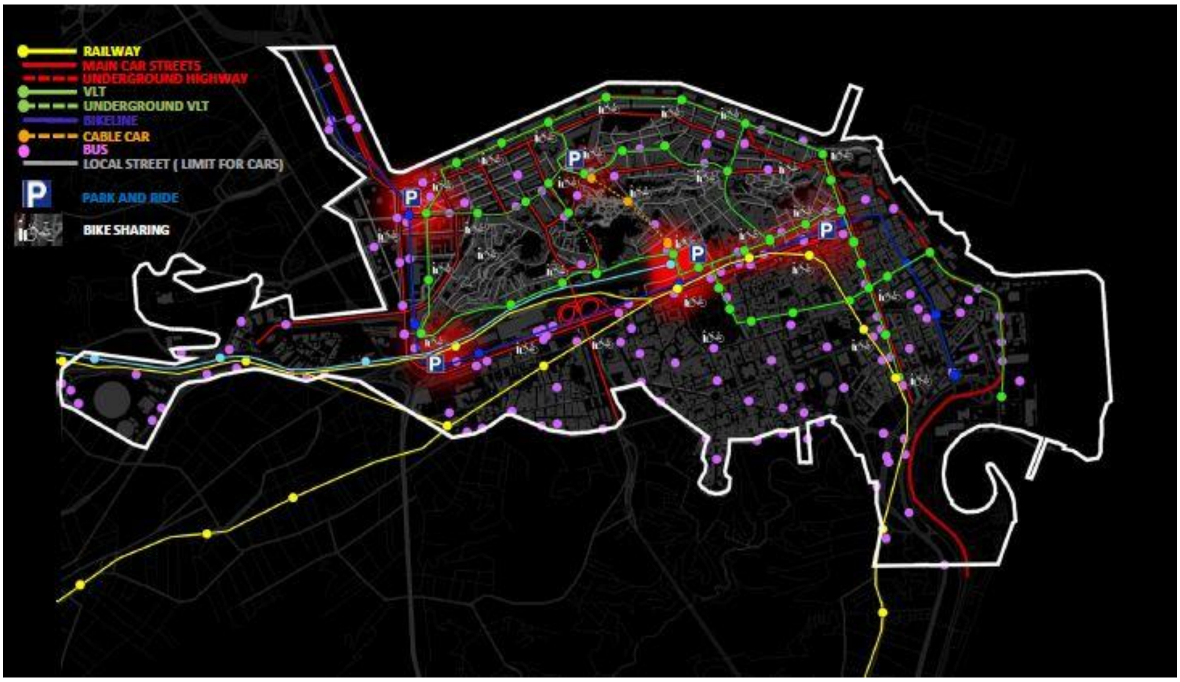


Figure 2-50 - New CAS Transportatio (source IMM Design Lab)

Figure 2-51 - New CAS Function (source IMM Design Lab)

Vertical Investigation - First Level of Superimposition

Figure 2-52 - New CAS Porosity (source IMM Design Lab)

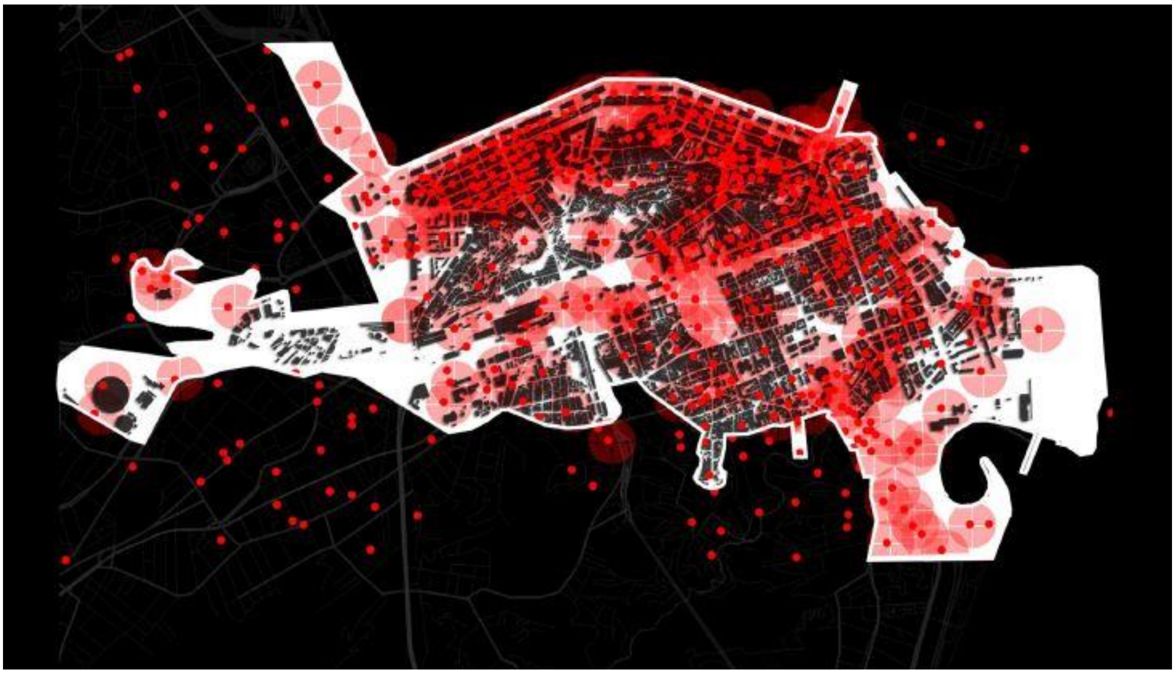


Figure 2-53 - New CAS Proximity (source IMM Design Lab)

Figure 2-54 – New CAS Diversity (source: IMM Design Lab)

Figure 2-55 - New CAS Interface (source IMM Design Lab)

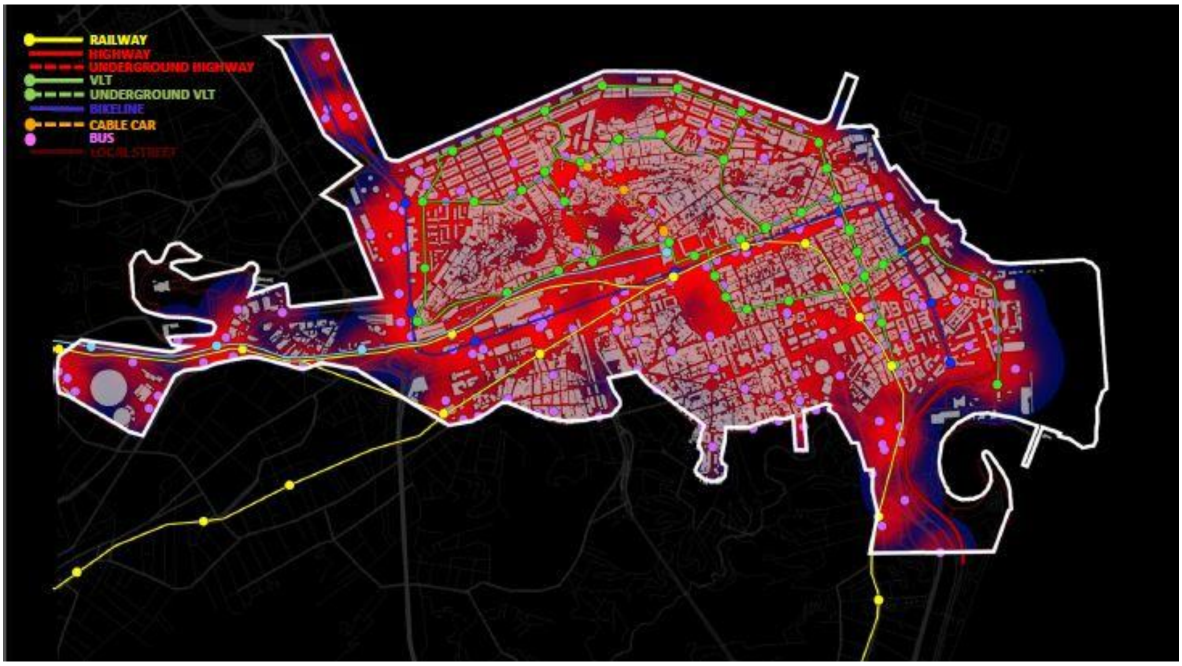


Figure 2-568 - New CAS Accessibility (source IMM Design Lab)

2.10. Porto Maravilha New Performance

Evaluating the environmental performance of the new CAS, is used the same numerical analysis implemented at the analysis done before, the referring Indicators to compare the actual and the transformed system performance.

IMM INDICATORS DESCRIPTION - INTERMEDIATE SCALE BOOSTED	INDICATOR	INDICATION	FORMULA	FACTOR
Layer				
Volume	Horizontal	*build area*	Vl=Vbuilt/Area	**1,889**
Voids	Horizontal	*unbuilt area*	Vd=Vopen/Area	**0,673**
Function	Horizontal	*activities in the area*	Fn=Jnumber/Area(HA)	
Transportation	Horizontal	*public or private transportation trips*	T=N_{tr}	**0,935**
Key Category				
Porosity	Vertical	*density*	P = Abuilt Footprint/Area	**0,327**
Proximity	Vertical	*job opportunity within a walkable distance*	Px=$\sum^{n}_{i}$nj/N	**0,274**
Diversity	Vertical	*activities per residences*	D1=c/c-1 [1-$\sum^{c}_{i}$=0 (n_i/N)	**0,041**
Interface	Vertical	*movability into the urban vois*	MD= $(\sum d.n)/k-1$	**0,712**
Accessibility	Vertical	*feasibility of reaching destination*	Acc= $N_j (A_c/A_t)$	
Effectiveness	Vertical	*n° public transportation on total trips*	Ef=N_{ptr}/N_{tr}	**0,650**

IMM INDICATORS DESCRIPTION - LOCAL SCALE BOOSTED	INDICATOR	INDICATION	FORMULA	FACTOR
Layer				
Volume	Horizontal	*build area*	Vl=Vbuilt/Area	**4,301**
Voids	Horizontal	*unbuilt area*	Vd=Vopen/Area	**0,660**
Function	Horizontal	*activities in the area*	Fn=Jnumber/Area(HA)	
Transportation	Horizontal	*public or private transportation trips*	T=N_{tr}	**0,935**
Key Category				
Porosity	Vertical	*density*	P = Abuilt Footprint/Area	**0,340**
Proximity	Vertical	*job opportunity within a walkable distance*	Px=$\sum^{n}_{i}$nj/N	**0,274**
Diversity	Vertical	*activities per residences*	D1=c/c-1 [1-$\sum^{c}_{i}$=0 (n_i/N)	**0,041**
Interface	Vertical	*movability into the urban vois*	MD= $(\sum d.n)/k-1$	**0,698**
Accessibility	Vertical	*feasibility of reaching destination*	Acc= $N_j (A_c/A_t)$	
Effectiveness	Vertical	*n° public transportation on total trips*	Ef=N_{ptr}/N_{tr}	**0,650**

Table 2-2 - New CAS Performance

2.11. CAS´s Comparison

As was maintained the same planned by the Porto Maravilha project, the Volume was increase in 65% as the actual situation only for the port area, increasing 30% if considered the area of the intermediate scale. The increasing of area is justified by the goals of the project, which are increasing the population and activities in the port, increasing its Function and Diversity.

Figure 2-57 - Volumes Before and After Transformation (source IMM Design Lab)

At the same time, the empty surface also increase 4,4%, due the fact that the plot footprint decrease from 100% to average 80%, giving to the ground a different balance then was before. Also contributes for the voids increasing the new urban cavities made for the new Interface.

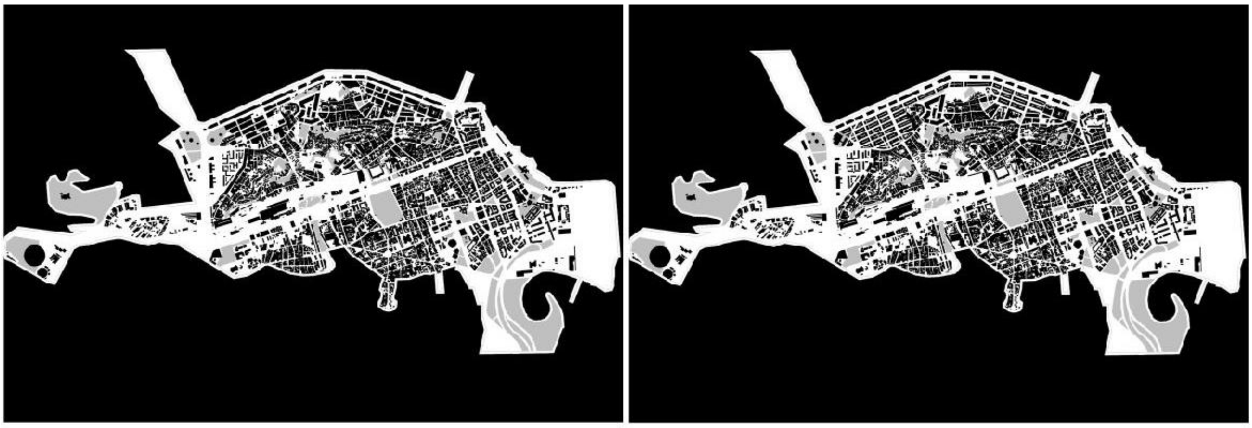


Figure 2-589 – Voids Before and After Transformation (source IMM Design Lab)

Regarding the transformation on the Transportation the biggest change happen in the VLT lines, at the Port area, especially regarding the Santo Cristo neighborhood. At that point the transformation changed the VLT returning line (towards the city center) from the water from, or from the Via Binario do Porto, to locate now to base of the Morro do Pinto, in the Santo Cristo street. This change will provide better access to the VLT lines by those who live in the Morro do Pinto and the Morro Providencia-Livramento as well.

The main car traffic now is restricted to the streets Cordeiro da Graça, Santo Cristo and the Street to be created by the extension of the Vidal de Negreiros street, at the Port are located in the Santo Cristo portion, and by the streets União, Livramento, Sacadura Cabral, Venezuela, Barão de Tefé and Silvino Montenegro, at the port area located at the Saúde neighborhood. Expect by these streets, the traffic should have speed and access controlled.

After, once defined the public transportation system, bike sharing and park-and-ride spots were spread out within the port zone, integrated the public transportation nodes.

At the end, the underground tunnel already planned by substitute the *perimetral* highway was extended in 350 m, achieving the surface level at the Cordeiro da Graça street corner.

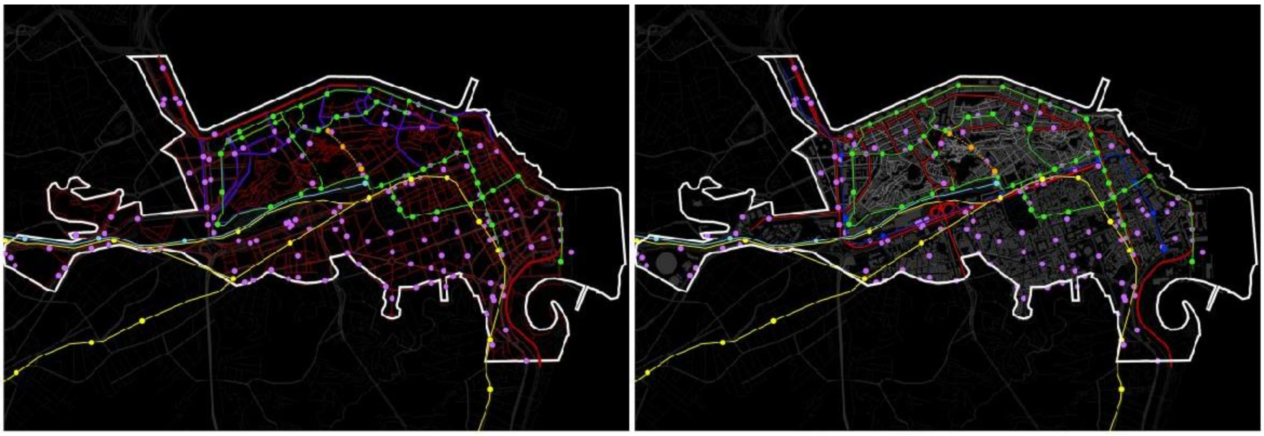


Figure 2-59 - Transformations Before and After Transformation (source IMM Design Lab)

As consequence from the volume increasing at the port area, specially the area at the Santo Cristo neighborhood, and the zone definition itself, the number of functions will be enhanced.

Figure 2-60 - Functions Before and After Transformation (source IMM Design Lab)

As a superimposition between Void and Volume, the new Porosity will also be enhancing as a consequence from the amount of voids increase, once the volume exceed is stored at the upper floors. By the same terms, the Proximity will be boosted, as well the diversity.

Figure 2-61 - Porosity Before and After Transformation (source IMM Design Lab)

Figure 2-62 - Proximity Before and After Transformation (source IMM Design Lab)

Figure 2-63 - Diversity Before and After Transformation (source IMM Design Lab)

The interface dramatically increase, as a consequence of the creation of new urban links at the Morro Providencia-Livramento, Morro do Pinto and Morro Conceição. Strategic spots play the role of catalyst element within the Interface network, as well the urban cavities created by the breaking of the superblocks at the port area.

Contribute to the enhancement also the advantages taken from the Cidade do Samba courtyard and the open spaces at the Vila Olimpica da Gamboa.

After the transformation, the Interface at the intermediate scale is boosted in 21%.

Figure 2-64 - Interface Before and After Transformation (source IMM Design Lab)

The Accessibility, as a response strictly related to the technologies applied to the public transportation system will not be presented at the study case, due the fact it cannot be accurately measured.

At the, the Effectiveness, as the superimposition from the Volume and Transportation layer, will be directly response to the volume footprint and the transportation network adaption. The latter, supported by the VLT adaption at the botton of the hills (Providencia-Livramento, Pinto and Conceição), will now be covered by the public transportation system in its majority territory.

Figure 2-65 10 - Effectiveness Before and After Transformation (source IMM Design Lab)

IMM INDICATORS DESCRIPTION - INTERMEDIATE SCALE	FORMULA	FACTOR	IMM INDICATORS DESCRIPTION - INTERMEDIATE SCALE BOOSTED	FORMULA	FACTOR	IMPROVING
Layer			**Layer**			
Volume	Vl=Vbuilt/Area	1,448	Volume	Vl=Vbuilt/Area	1,889	31%
Voids	Vd=Vopen/Area	0,644	Voids	Vd=Vopen/Area	0,673	4,4%
Function	Fn=Jnumber/Area(HA)	1,421	Function	Fn=Jnumber/Area(HA)		
Transportation	T=Ntr	0,935	Transportation	T=Ntr	0,935	
Key Category			**Key Category**			
Porosity	P = Abuilt Footprint/Area	0,356	Porosity	P = Abuilt Footprint/Area	0,327	
Proximity	$Px=\sum^{n}_{i} nj/N$	0,100	Proximity	$Px=\sum^{n}_{i} nj/N$	0,274	
Diversity	$D1=c/c-1\ [1-\sum^{c}_{i=0} (ni/N)]$	0,027	Diversity	$D1=c/c-1\ [1-\sum^{c}_{i=0} (ni/N)]$	0,041	
Interface	$MD= (\sum d.n)/k-1$	0,599	Interface	$MD= (\sum d.n)/k-1$	0,712	21%
Accessibility	Acc= Nj (Ac/At)		Accessibility	Acc= Nj (Ac/At)		
Effectiveness	Ef=Nptr/Ntr	0,650	Effectiveness	Ef=Nptr/Ntr	0,650	

IMM INDICATORS DESCRIPTION - LOCAL SCALE	FORMULA	FACTOR	IMM INDICATORS DESCRIPTION - LOCAL SCALE BOOSTED	FORMULA	FACTOR	IMPROVING
Layer			**Layer**			
Volume	Vl=Vbuilt/Area	2,624	Volume	Vl=Vbuilt/Area	4,301	65%
Voids	Vd=Vopen/Area	0,657	Voids	Vd=Vopen/Area	0,660	4,4%
Function	Fn=Jnumber/Area(HA)	0,603	Function	Fn=Jnumber/Area(HA)		
Transportation	T=Ntr	0,935	Transportation	T=Ntr	0,935	
Key Category			**Key Category**			
Porosity	P = Abuilt Footprint/Area	0,343	Porosity	P = Abuilt Footprint/Area	0,340	
Proximity	$Px=\sum^{n}_{i} nj/N$	0,100	Proximity	$Px=\sum^{n}_{i} nj/N$	0,274	
Diversity	$D1=c/c-1\ [1-\sum^{c}_{i=0} (ni/N)]$	0,027	Diversity	$D1=c/c-1\ [1-\sum^{c}_{i=0} (ni/N)]$	0,041	
Interface	$MD= (\sum d.n)/k-1$	0,577	Interface	$MD= (\sum d.n)/k-1$	0,698	21%
Accessibility	Acc= Nj (Ac/At)		Accessibility	Acc= Nj (Ac/At)		
Effectiveness	Ef=Nptr/Ntr	0,650	Effectiveness	Ef=Nptr/Ntr	0,650	

Table 2-3 – CAS´s Comparison Table (source IMM Design Lab)

2.12. The Masterplan

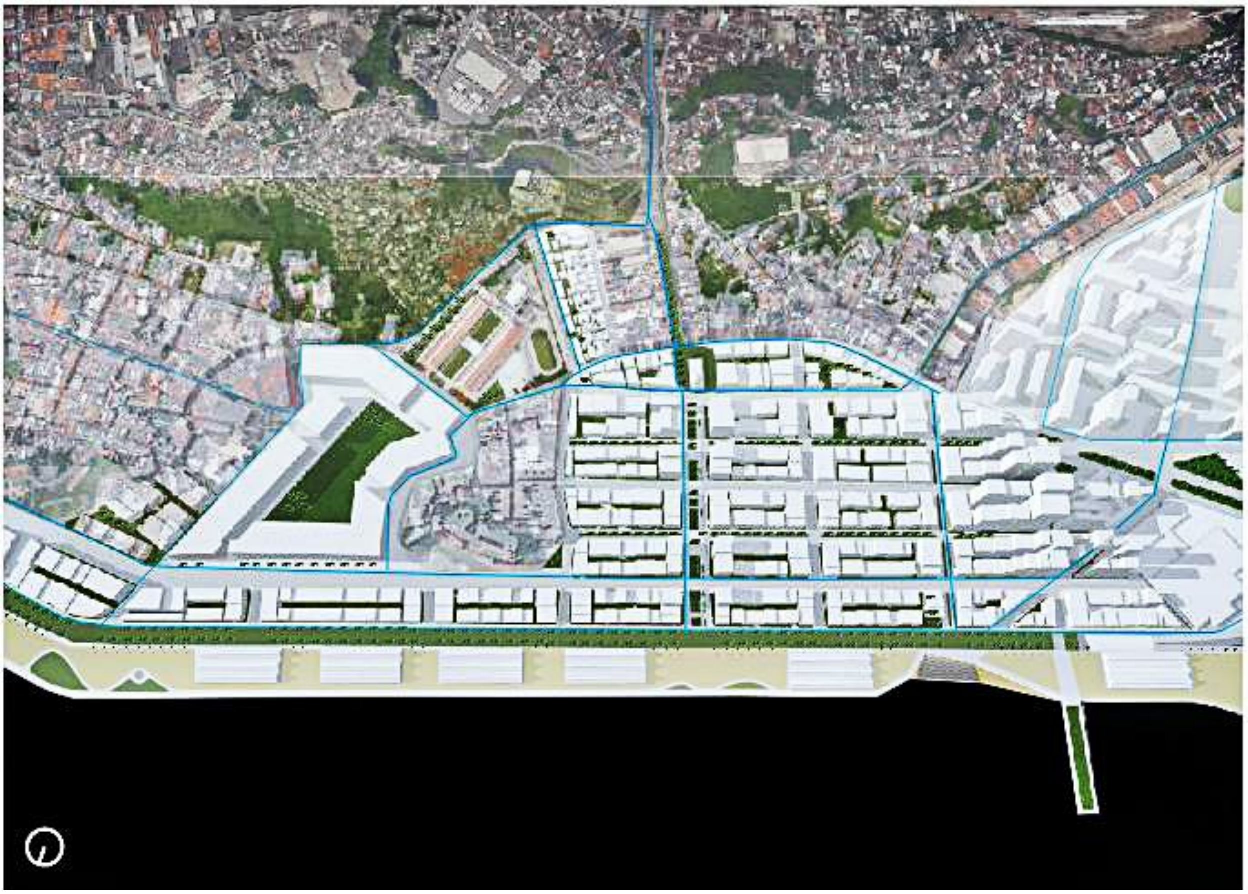


Figure 2-6611 – Final Masterplan of Porto Maravilha (source IMM Design Lab)

The local Area

Taking in consideration that the biggest issue faced by the actual Porto Maravilha project is the resistance by the local population to the proposal, especially those regarding the popular participation and the fact that, according to the local actors, the project does not aim the mixture between social classes within the area, the study will develop further a particular point on these terms which is the social housing.

The local population claims against the fact that the project has not their involvement and does not brig any enhancement for the life of those who live there. They claim also the fact that the Porto Maravilha does not have as guideline the social integration considering the existing ones. As well, the complains are related to the fact that lacks initiatives in terms of protection to the local memory, heritage, and history, arguing to the point the the Porto Maravilha is driven to an sterile conditions, with no memory and with no integration to the city of Rio de Janeiro and its rich history.

Standing against the intervention, social movement is already established in the region. And if they may differ on their specific requirements, the all have a common point and their claims: they fight for the right to live there. Moreover, is important to mention the fact that housing deficit is one main issue in the city of Rio de Janeiro, reaching nearly 290.000 units, almost 7% of the total residences in 2012 (*IBGE/PNDA IBGE/PNAD*), leading the people from the Porto Maravilha area to, during the last 10 years, deal with the problem by themselves, getting organized groups and occupying public abandoned buildings, some in a squatter model, highlighting four of them: Chiquinha Gonzaga, Zumbi dos Palmares, Flor do Asfalto and Quilombo das Guerreiras.

The study understand that linking the communities, especially the most populate on, located at the Morro Providencia-Livramento, is the only way to proportionate resilience to the Porto Maravilha, not only to integrate the community to the new recovery urban area, but also to explore their potential, social and economic. Therefore, for the architectural scale, the site choosen was the block destinated by the original plan as for social housing interests at the base of the Morro Providencia-Livramento.

Figure 2-6712 - Architectural Scale and the Urban Links

During the architectural chapter, the study aims to show a good practice when working with such topic, with resilience and sustainability as major goals, developing an affordable, flexible and urban integrated social housing.

CHAPTER 3: ARCHITECTURAL DESIGN

3.1 Objectives, Issues and Considerations.

The human rights are the definition of basic standards inherent to the dignity of a person. The right referring to the habitation field does not mention only the right to have a shelter, but involves a much more broad meaning. The right is extended to all, and as consequence, all the society and all of their individuals should have access to a home supported by the basic infrastructure.

The right to have a house is also part of the economic and social rights. These rights are characterized by demanding to the government an action on their implementation. However, the reality presents a difficult situation when clamming from its effectiveness, the economic and social rights should not have left for a second plan.

While the duty to respect, basically involves a series of limits on the actions by the governments, the obligation in promoting it requires recognition of various dimensions of right to housing and takes steps to ensure that will not have any action taken in order to reduce or restrict it. The promotion also requires states to give sufficient emphasis to the full realization of the right to house, through a series of active measures, including the recognition of this right in the various laws, the incorporation of the right to housing in construction policies, aiming their full enjoyment by all sectors of society.

It is the government tasks to avoid the violation of the right to housing and to protect the people from abuses provoked from those who look for restrict or limit it. Measures to protect people from removals, racial discrimination, and all types of restrictions to have and maintaine a house have to be established, and is the government obligation to fulfill its demands aiming to ensure that every citizen will have opportunity to have a house to live.

The second conference of the United Nations in Istanbul for the Human Settlements, in 1996, debate around the housing topic and the condition for it worldwide. The commitment to accept in a progressive way the right to housing was signed also by the brazilian government. Special programs, aiming to analyze the solutions available to enhance the live quality within the urban centers, using as criteria the efficiency in recovering degraded areas, the use of sustainable technologies and innovation is selected. During the conference was also established that the concept for a proper house will be more than just a shelter. It should means that the unit will provide privacy, proper space, accessibility, safety, structural stability and durability, proper lighting, heating and ventilation, basic infrastructure, environmental quality, good locations and should be affordable. This concept could be adapted from a country to another, depending on cultural, social, economic and environmental aspects.

Although it is obvious the importance in respecting the right to housing, it is visible that there is a sort of indifference regarding the question. According to the United Nations estimates more the one billion people are living in impropriated houses and more than one hundred million does not have even a house around the world. Thus, is easy to guess the countries where the society is unbalance host the bigger amount of those people, and Brazil is one of them

The problem is boosted by the territorial disorganization. In the big cities, the housing expansion did not follow its demand, consequently forming the suburbs and the *favelas*, where lacks of proper infrastructure for living or connecting to the city. Especially in the brazilian case, the housing crisis and the lack of social housing are consequences due the low salaries, unemployment and massive informal sub-employment creating just in the city of Rio de Janeiro a housing deficit around 290 thousand units.

In the Porto Maravilha area, probably the major concern by the population it the removals that the project implementation will demand. According to the first survey, made by the municipal program *Morar Carioca* [16], around 1000 units should be removed only from the *favela* located at the Morro Providencia-Livramento just for the hill re-urbanization or for being in risk areas, fact that was proven to be wrong for the independent survey made by the local population helped by a group of engineers, and had it accomplishment block by the national public ministry. However, since the beginning of the interventions, more than 200 families were removed from the Morro Providencia-Livramento, and most of them were relocated far from their neighborhood, from their schools and their jobs.

The fact that the social housing is being forgotten by the project Porto Maravilha highlights the importance in analyzing it further. By these terms, the choice for developing the area left by the use was the study case choice as local optimization. Thereby, the study case aims to show a good practice when working within a delicate territory as well showing good alternatives when the removals are necessary in order to achieve the right to housing requirements.

3.2. The Urban Block

The area chosen is the block compressed by the streets Barão da Gamboa, Cardoso Marinho, Santo Cristo and the street are to be created by the new plan, linking the Largo José Francisco Fraga to the other side of the hill, at the street Rêgo Barros, through a tunnel.

Actually the area host a *favela,* composed by 32 units, the remains of the São Pedro Church, architectural heritage, 75 established construction between mid-class housing and portuguese colonial style townhouses and lacks of green space, which evidences the dense occupation. There is also the provisory presence of a concrete factory, which supports the Porto Maravilha urban intervention.

Figure 3-1 - Site Surrounding and the remains of the São Pedro Church (source Google)

The spatial structure is defined by the surrounded streets, as well by narrow pass ways that divides the block in 8 smaller portions. Seven of them are occupied in a fairly organized way, leaving the eighth portion to be shared by the *favela,* a worship space belonging to the universal church, the ruins of the São Pedro Church (architectural heritage) and the provisory factory installations.

,

Figure 3-2 - Morphology Division (source Google Earth)

Figure 13-3 - Morphology Division (source Google Earth)

The entire block share the mix use concept, hosting small business, services and residential spaces, occurrence very typical in *favelas* or mid-classes areas in Brazil, what configures in a fairly balance environment.

The space lacks of any kind of urban equipment or open spaces, even having the Villa Olimpica da Gamboa across the street, due the fact that the sportive complex is close to the community, trapping its potential. Whence, for the proposal success is crucial a good integration between spaces.

Figure 3-4 - Vila Olimpica and the Site actual relationship (source Google Earth)

Figure 3-5 - Relationship Opportunity (source Google Earth)

Nowadays the area counts with electrical network, lighting, sewage and potable water supply system, as well is included within the municipal waste management program.

3.3. The Concept

The starting point for the design process is driven by the tree major principles: resilience, flexibility and sustainability. By terms of resilience and flexibility the concept is guide by the criteria already adopted by the *favelas*, but now in a planned way. The *favelas* occupations least for years in Brazil, and they are mostly metamorphic. As the availability of a free plot in the urban tissue is very rare, the houses in the *favelas* always change during the years, of due the increasing of number of members in the family, or by economic matters, as to host a small business spaces at the ground floor and live in the upper, for an example. The house, but the same fact, which is lack of free land, always grows to the vertical direction. Thus, planning the typology changes when working with social houses has the major importance. Designing flexible houses will give to the unit resilience and will allow the families to live longer in comfort. The second guideline is the sustainability. Given the fact that in Brazil, the biggest domestic energy consumption is due the use of the cooling system (*EPE Brazil*) the thermal insulation and the ventilation plays a key.

Furthermore, the design goal is to study and present flexible, sustainable and affordable solutions for a standard brazilian townhouse, and its possible variations. The proposal consists in 43 units composed by the variation of the standard one, in an example of arrangement for the *favela* located in the block and as an alternative for the removal issue at the same time composing in integration with the neighborhood typologies and the Vila Olimpica da Gamboa.

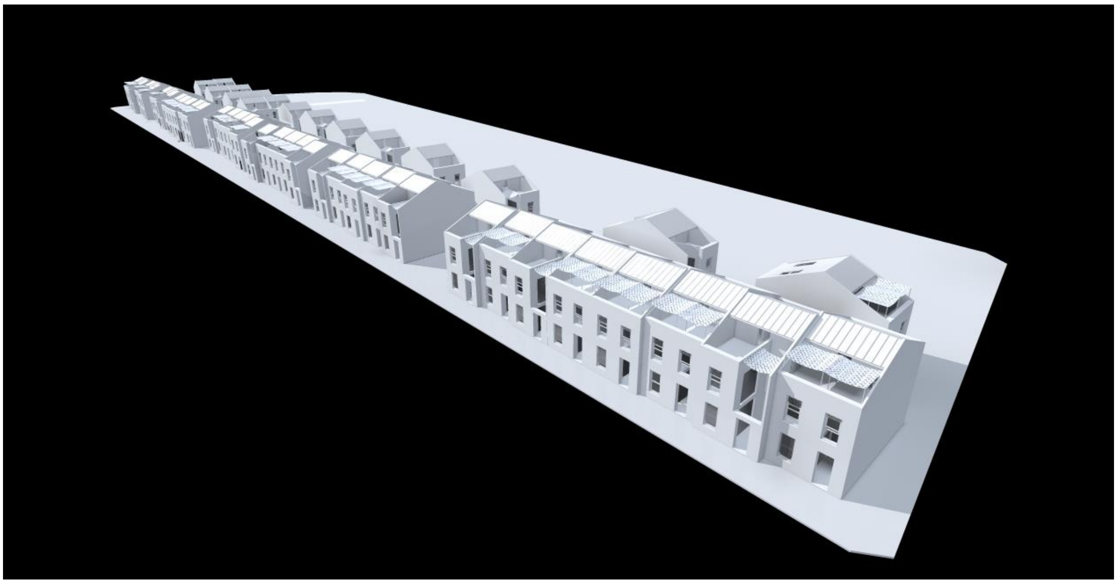


Figure 3-6 - Houses Arrangement 3D View

Figure 3-7 - Houses Arrangement 3D View

3.4. The Design

The option for the house typology, the brazilian townhouse (*sobrado*) is chosen in line with the intentions to do modify as less as possible the life style of those families. The townhouse is also characteristic typology in such areas.

The central idea is to ensure for those families the maintenance of the social relationship and the community atmosphere, already established. Thus, the proposal consist in propitiate a flexible and resilient house. The program planned is dividing the house in social and intimate areas always, or by locating the areas in different levels or at the same level but in different portions within the space.

By rooms location, area where were located the space supported by hydraulic system (laundry, bathrooms kitchen and the water reservoir) and the changeable areas. The idea centralizes the pumping system, enabling its installation at the same time that creates different possibilities for the adjacent spaces. The bathrooms, also located at the ground level, can be easily adapted for people with special needs.

Moreover, the same principle of centrality was adopted to locate the vertical and horizontal circulations on plan, giving more spaces for the rooms, which can be used also to enhance the sack effect and take of the house eventual overheated air. By the end, the plan with the elongated shape and the opening located at the extremities guarantee the cross ventilation at the ground floor.

Further, the bedrooms for the standard house will be located in the second floor, as well the terrace will play the role of roofing the unit.

The proposed townhouse typology allows addition in two directions, vertical and horizontal, as well variation within the plan. The suggestion is to delivery to the dwellers the house as the standard model, and the variations could be executed during the time. This will give the conjunct its own identity, and in the future will enable a mixture of colors and materials eventually, connecting even more the complex to the urban landscape.

Starting from the minimum plot (around 90,00m² average), the units can present a variety of open spaces between each other, public and private, enabling privacy, ventilation and circulation within., however every unit can have its own access, as it was before.

Thus, the program consists in a standard single family house, with 71,60 m², according to the ABNT and the Rio de Janeiro´s Building Code, compose by:

- Living room
- Kitchen
- Laundry
- Bathroom
- Storage

- Main Bedroom
- Second Bedroom
- Private Courtyard
- Terrance

The description corresponds to the standard house for a single family, or the typology 01. Further, the unit can be, when adding slabs and walls, remodeled in other 08 different arrangements. The single family standard unit, hosting a couple and two children, can be increased according to the future needs, adding a private courtyard working as a closed *patio*, as well adding one or two more rooms, increasing its capacity from 04 to 08 people (typologies 02, 03 and 04 respectively).

Moreover, by using half of the terrace area as a ceiling room, the same standard home can be transformed in a 3 floors multifamily housing (typology 05), a hostel for 12 guests, in a double floor apartment with a small business space on the ground and in two more single house with a store on the ground floor, hosting 04 and 08 people, respectively (and also respectively typologies 06, 07, 08 and 09). After all the additions the house will reach 105,25 m².

To achieve such flexible plans, the decision was leaving strategic gaps between the houses, in order to create a hierarchy with the spaces, defined in outside, inside and in between. The strategy will give more privacy to the inner spaces, one the plot is very tide and close to the street line. The gap, or in between will also work promoting shadows to those spaces, will allow more surface for placing the openings, enhancing the natural ventilation and will help to maintain the temperature inside the spaces comfortable. By the end, the space so called in between will play the key role when necessary the constructions off the mentioned expansions.

The diagram below explains in the first line the foot print occupation. Usually, the houses in the neighborhood are locate as a perfect square or rectangle, depending on the site, with the intentions to divide the public and the private open spaces, or as the diagram named, in and out. The solution adopt was dividing the space in two portions, then sliding then towards the plot front and back limits, to after correct the geometry according to the sun analysis and the internal circulation. The sliding movement will create the gap without increasing the area, although increasing significantly the façade surface. As opposing the methods used in cold weather country, in this case the intention is increasing the shape factor to increase the opportunity to place openings, and consequently, increasing the opportunity for natural ventilation.

The second diagram shows the possibilities for the ground use, and the variations enable regarding public, demi-public (spaces such as courtyard, *patios*, balconies, etc...) and private spaces.

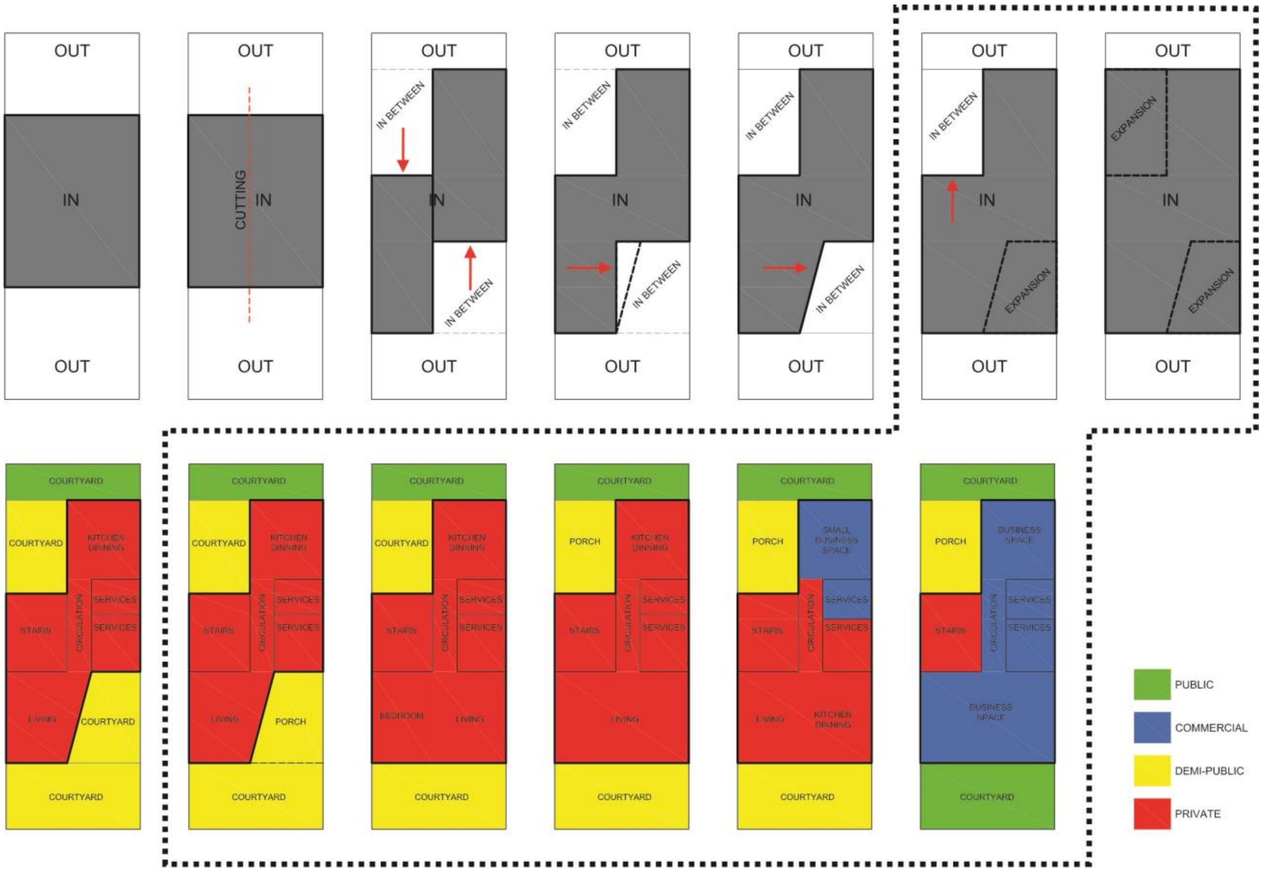


Figure 3-8 - Foot Prints and Ground Uses Evolution and Variations

By sakes of the study case, the proposal to be presented will show a possible future configuration, point out how the transformation could enable to the urban block ground use balance and diversity

3.5. Material Selection

The design aims to enhance the use of the most common technology applied in the brazilian constructions for two basic reasons: to activate the local economy, by employment of the people from the community on the construction site, as well to use only local products, decreasing the necessity of long transportation.

3.5.1. Ceramics - Structural Bricks, Tiles and Roof Tiles.

The option for choosing the ceramic brick is due the several aspects. The major one is the fact that is the most common wall enclosure used in Brazil, has low cost, is very easy to find and with a huge range of supplier options. The structural one took in consideration the possible savings when not using the wood as concrete molds, enabling to build the structure just using cement and reinforcing steel inside the bricks as advantages from the hollow inner spaces. The same characteristic contributes to pass the pipes through it when necessary, avoiding bricks breaking an unnecessary waste during the construction.

This technology is well known for any brazilian working, allowing to contract local workers, possible for the Porto Maravilha area. The brick has a flat and smooth surface. It will decrease the difficulty during the finishing phase and also saving the material used for levering the walls, decreasing the plaster thickness.

The brick has also bigger durability than the other common material used as enclosure, and better resistance against impact and fire, two usual problems when building within such area, as well present lower thermal transmittance.

The same advantages is also applied to the tiles used for flooring and roofing, with the additions related to the maintenance (easiness in cleaning and substituting pieces when necessary), and in the case of the roof tiles, compose properly the aimed integration within the existing landscape.

Even with the recent declines, Brazil is a major player in the world of ceramic market. The country ranked second in world production with 713.4 million square meters in 2008, second only to China with 3.3 billion square meters. Italy ranks third with 527 million square meters, and Spain comes in fourth with 494.7 million square meters. [17]

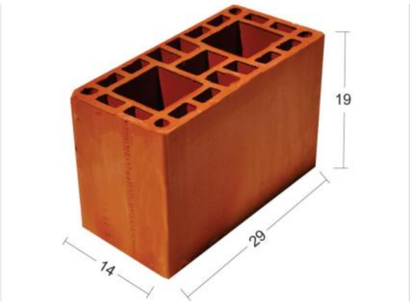


Figure 3-9 - 14cm Structural Brick [8]

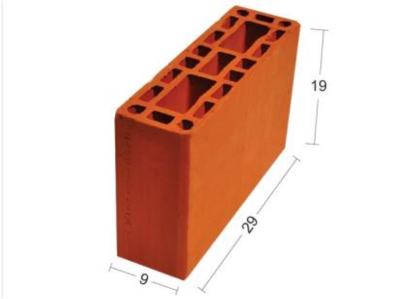


Figure 3-10 - 9cm Structural Brick [8]

<u>Advantages of the ceramic blocks:</u>

1. The high insulating properties.
2. The strength and durability. Compressive strength is competitive with the solid brick.
3. High-speed of construction: 1 m3 can be erected in about 1 hour.
4. High vapour resistance and excellent sound insulation.
5. Environmentally friendly.
    - Exploration and production of bricks requires a minimum of energy and practically does not harm the environment. The modern concept of factories allows producing ceramic blocks with almost no harmful emissions, using clean primary energy sources;
    - Doesn't require transportation which significantly reduces the carbon dioxide contribution in the atmosphere;
    - The material provides a comfortable natural microclimate in the house.
6. Perfect dimensional accuracy to facilitate brickwork and subsequent finishing.
7. Low weight of the wall, and hence reduced cost of the foundation
8. Low cost of the construction:
    - Low cost of material compare to solid bricks, concrete, metal;
    - The material is produced locally: no transportation expenses;
    - Minimum of technological operations during the construction: availability of cheap low-qualified local labor.

Figure 3-11 - Ceramic Flooring [9]

Figure 3-12 - Ceramic Roofing [10]

3.5.2. Pre-fabricated Ceramic Grinder Inter-Joists Slab

As flooring structural material, the choice for the pre-fabricated ceramic grinder inter joists slab follows the same principle as for the other ceramic elements. The absence of molds, easiness for finishing, leveling, the decreasing of waste, as the fact that is very common, easy to find the material, to transport as well the low complexity to work with, allowing the local workers to take part on it were some of the points analyzes.

There are several types of pre-fabricated ceramic slabs, the most used are: with lattice beams and the beams with reinforced concrete.

Figure 3-13 – Prefabricated slab with prestressed beams

Figure 3-14 – Prefabricated slab with concrete joists

Figure 3-15 – Prefabricated slab with lattice beams

<u>Advantages of the pre-manufactured ceramic slabs:</u>

1. High bearing capacity with a lot reduced weight (when compared to reinforced concrete slabs).
2. Being assembled from small blocks, they allow to avoid high expenses of using heavy lifting and transportation machinery (crane, etc.).
3. Installation of the slabs doesn't require the formwork which can highly accelerate the construction.
4. Installation of the slab is possible even with the presence of the roof - this is very useful for reconstruction works.
5. Ceramic floors have high sound absorption and thermal resistance, additional soundproofing and insulation are not required.

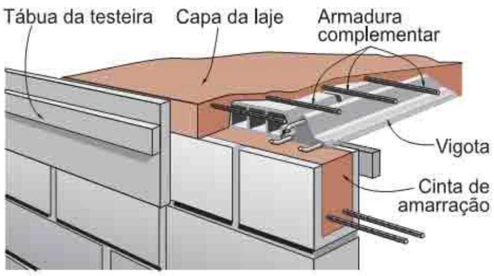


Figure 3-16 - Slab Detail [12]

Figure 3-17 – Installation of prefabricated slab system [18]

3.5.3. Double Hung PVC Guillotine Windows

By the windows the option was for the guillotine model. The choice is also related to the aesthetics, once the majority of the houses in the surrounded area, by being built according to the portuguese colonial style, but not only for that. The type of window provides good ventilation, flexible ways for opening, enabling to open the top and the bottom at the same time, and the possibility to easily follow future remodeling. The PVC is also widespread in the brazilian constructions, is a common material, provides good thermal insulation when using the extruded frames, has good durability and maintenance, easy to lock and install.

Figure 3-18 - Double Hung PVC Guillotine Window [13]

Figure 3-19 - Double Hung PVC Guillotine Window Detail [13]

3.5.4. Floating Wooden Deck

The choice in using wood as finishing material at the terraces is due the solar exposition of these areas. The wood has good thermal insulation, has low cost in Brazil, is reciclable good workability and is also a common and local material. The use of a green roof was discussed, but its high cost and complexity to execution turn it unfeasible. The wood was also used in flooring the open areas in the ground floors, such as the porches, dispensing for instance the use of slabs in those areas.

Figure 3-20 - Wooden Deck [14]

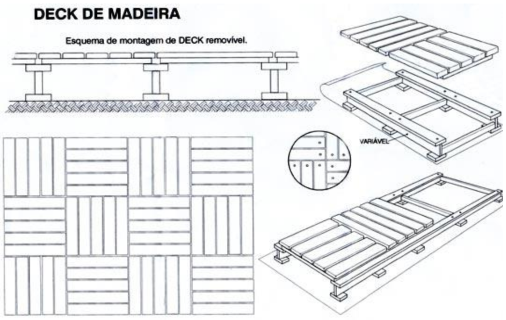


Figure 3-21 - Deck Assembly [14]

3.5.5. Cellulose Batt Panel Insulation

Brazil does not have history in applying insulation materials to the constructions. The use is not common within the country, probably as a consequence from the mostly warm weather. However the cellulose batt panel seems a good solution for insulating a building in Brazil. As the weather is warm, the overheating is the biggest issue. Even Brazil being a country with big longitudinal dimensions, most part of the territory is between the parallel 20´ south and the Equator line, the roof is the most susceptive part of the build to get overheated. The cellulose production has increased during the past 3 years, and the material rice within the brazilian marked have decrease.

The choice for the material passed also through its characteristics as its thermal performance, sound insulation, fire resistance, and mold and algae control. By the end, the batt panel technology was chosen to increase its workability, being easier to install than the dense pack installation.

Figure 3-22 - Cellulose Batt Panel [15]

Figure 3-23 - Cellulose Batt Panel [15]

3.5.6. Wooden roof

Advantages of the wooden roof:

1. The most important and very significant advantage – light weight of the construction. Having sufficient strength, the wooden system is much lighter than metal and, moreover, reinforced concrete, thus it's avoiding the construction of thick load-bearing walls that can withstand the enormous weight of such structures.

2. Cost. The wood is a lot cheaper than metal and concrete, its use for construction of roof systems allows to obtain substantial savings in building materials for the construction of walls.

3. Durability - modern means of treating wood to protect it from pests and rot, as well as methods of mechanical protection of wooden structures from moisture can achieve reliable operation of the terms that are comparable with a lifetime of roof systems made of other materials.

4. Ease of installation - for construction of roof systems made of wood there is no need of special lifting equipment. Installation of roof system can be made by a team of 2-4 people. In contrast to metal and concrete roof systems, roof elements of wood can be fit easily on site. In addition there is no need to drill holes, hammer anchors, make welding work – the time spent for installation is a lot less than the one for metal and concrete.

5. Environmentally friendly – the installation of the roof system doesn't require chemical processes. Wood is environmentally friendly and harmless to health material. Under the wooden roof there is neither electromagnetic interference, nor static electricity, as in houses with metal roofs.

6. Availability of modern fasteners - a large selection of modern means by which the hoisting system makes installation of the wood even more convenient and fast.

3.6. Construction Phases

The possibility to be removed from their homes is by far the scariest aspect of the urban interventions by those who live in the area. Usually the local community, when removals are necessary, is relocated to part far from the city, without infrastructure, transportation and services.

Inspired on the problem faced by the community every time that a urban intervention takes part in Rio de Janeiro, the study case aim to present an alternative solution for when removals are necessary in other to guarantee the standards required by the human rights for the right to housing.

For the studied urban block was planned the intervention divided in 3 phases, always relocating the families removed to the same urban block, maintaining the central idea in protecting community social relationships.

The constructions phases are describe in the image below.

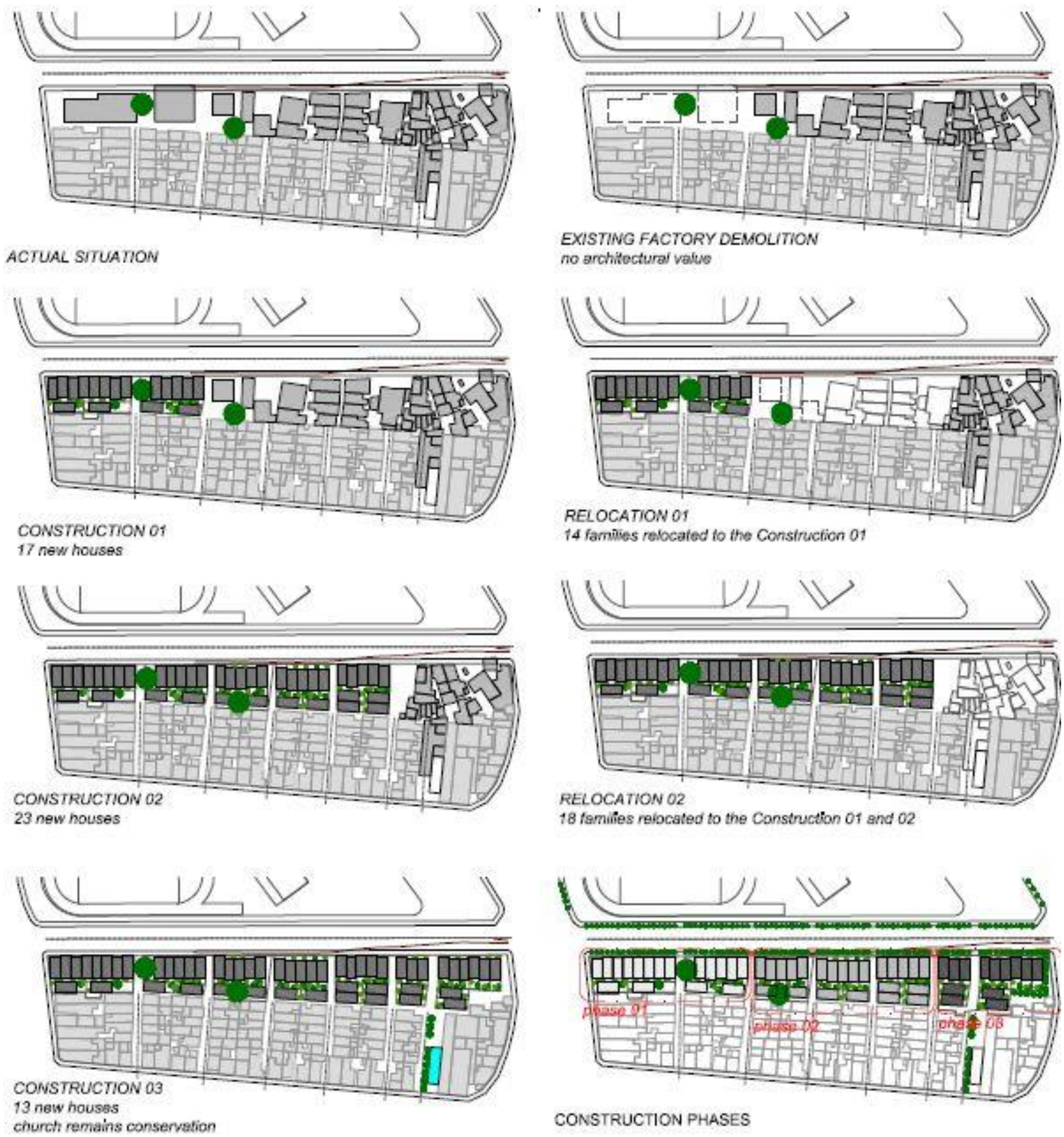


Figure 3-2414 - Construction Phases

3.7. Architectural Drawings

3.7.1. General plans

Figure 3-2515 – General Plans. Ground Floor

Figure 3-2616 – General Plans. First Floor Level

Figure 3-2717 – General Plans. Terraces Level

3.7.2. General facades

Figure 3-2818 – General Facades

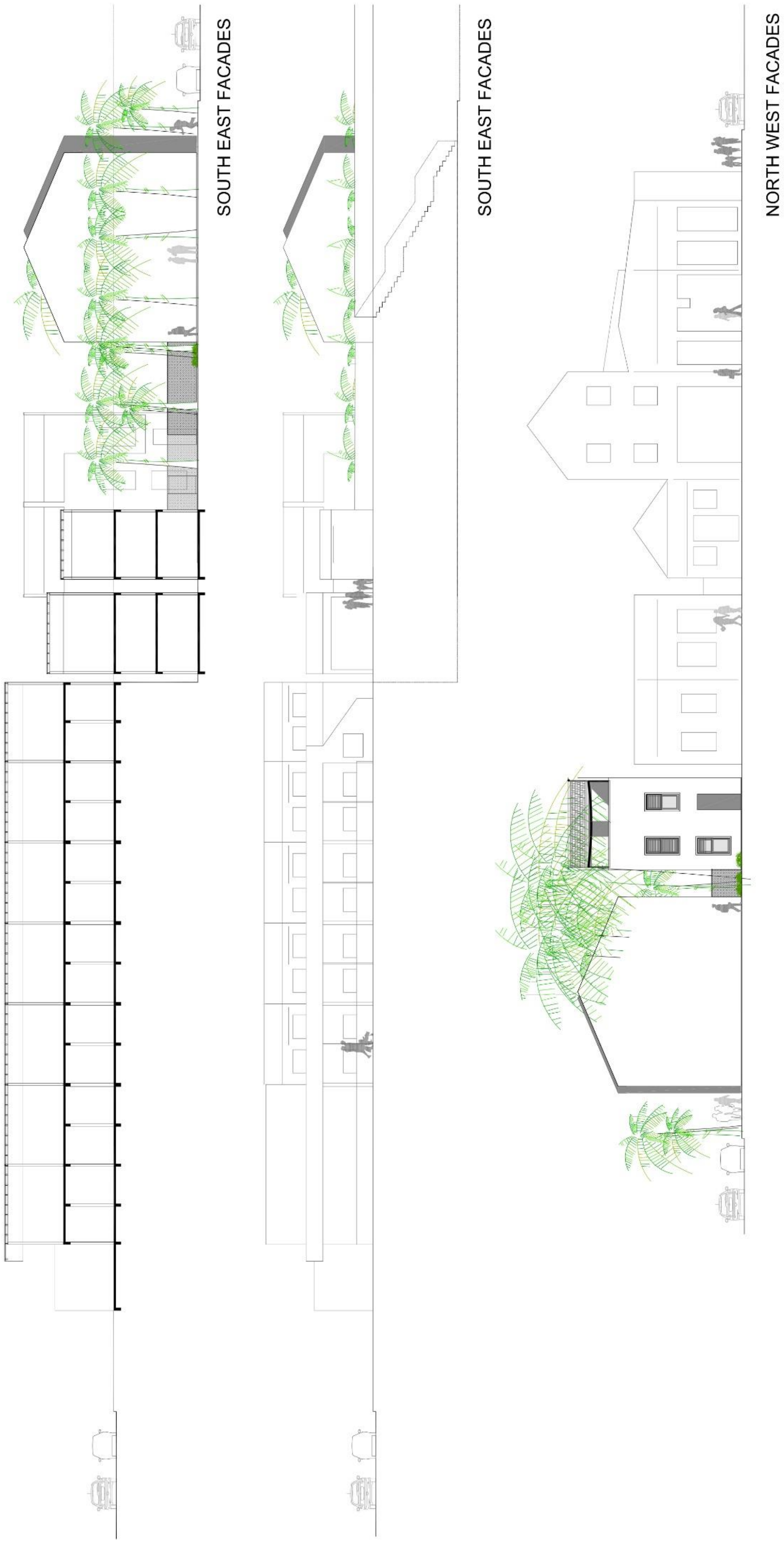


Figure 3-2919 – General Facades

3.7.3. Typology plans

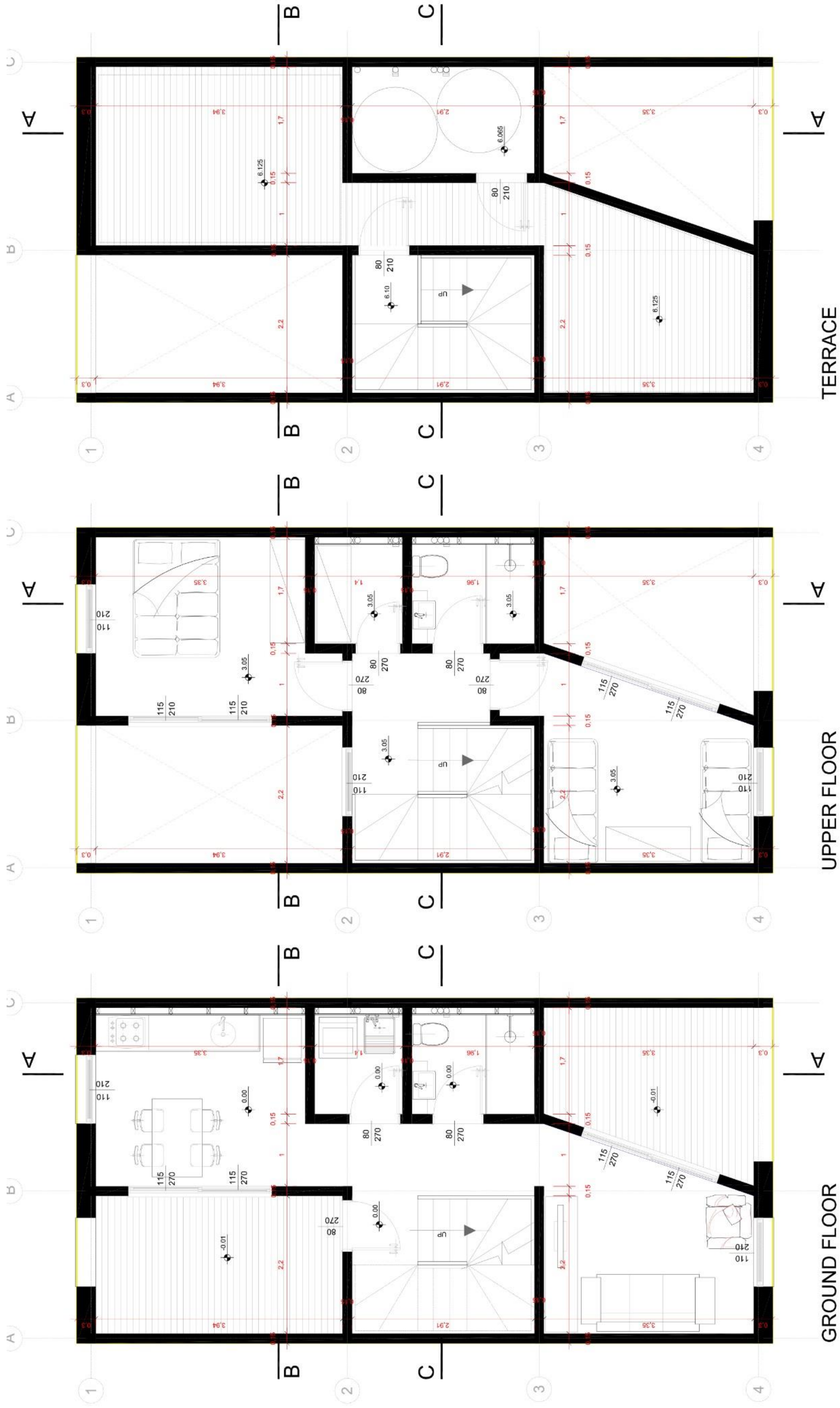


Figure 3-3020 – Plan. Typology 1.

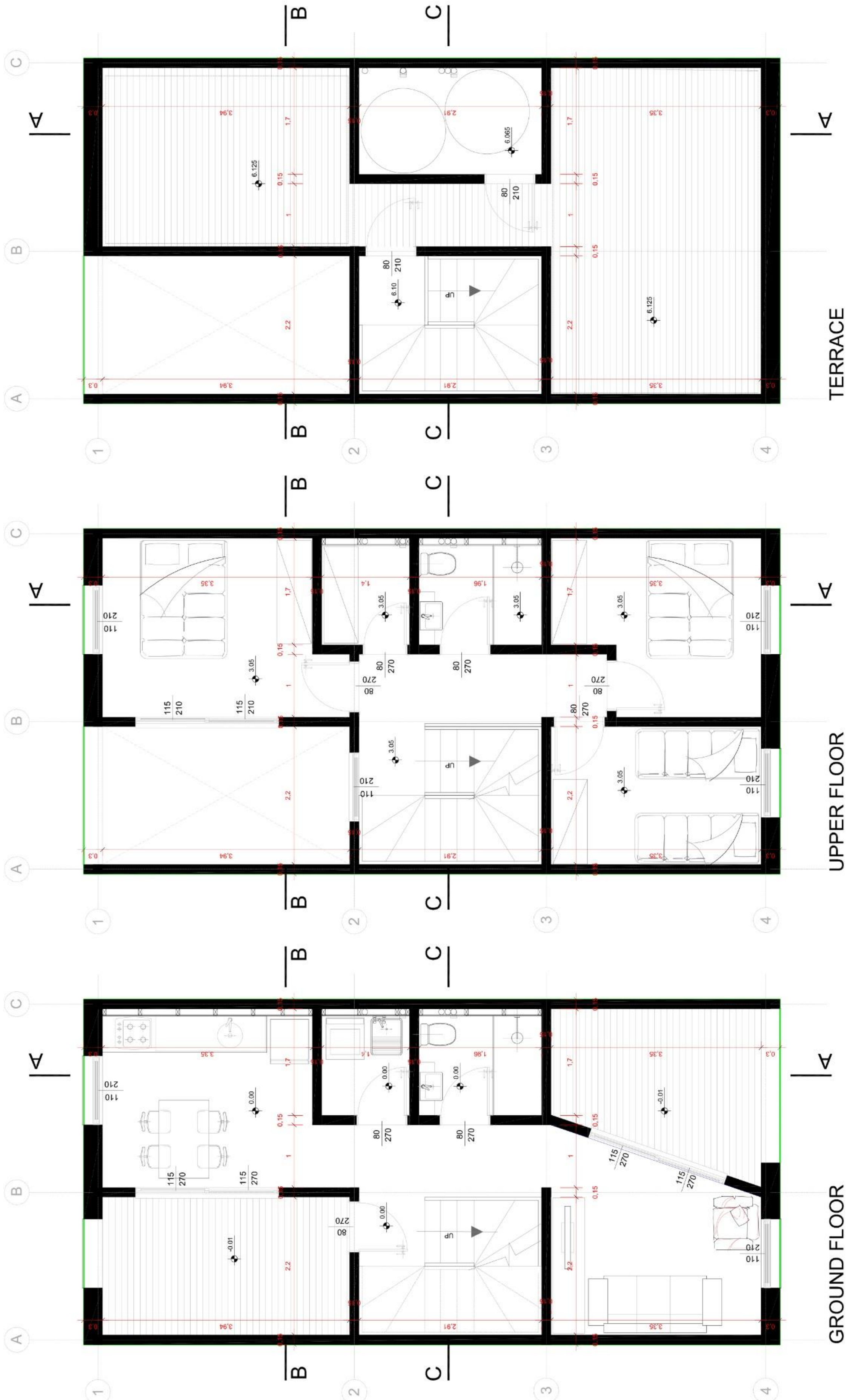


Figure 3-3121 – Plan. Typology 3

Figure 3-3222 – Plan. Typology 5

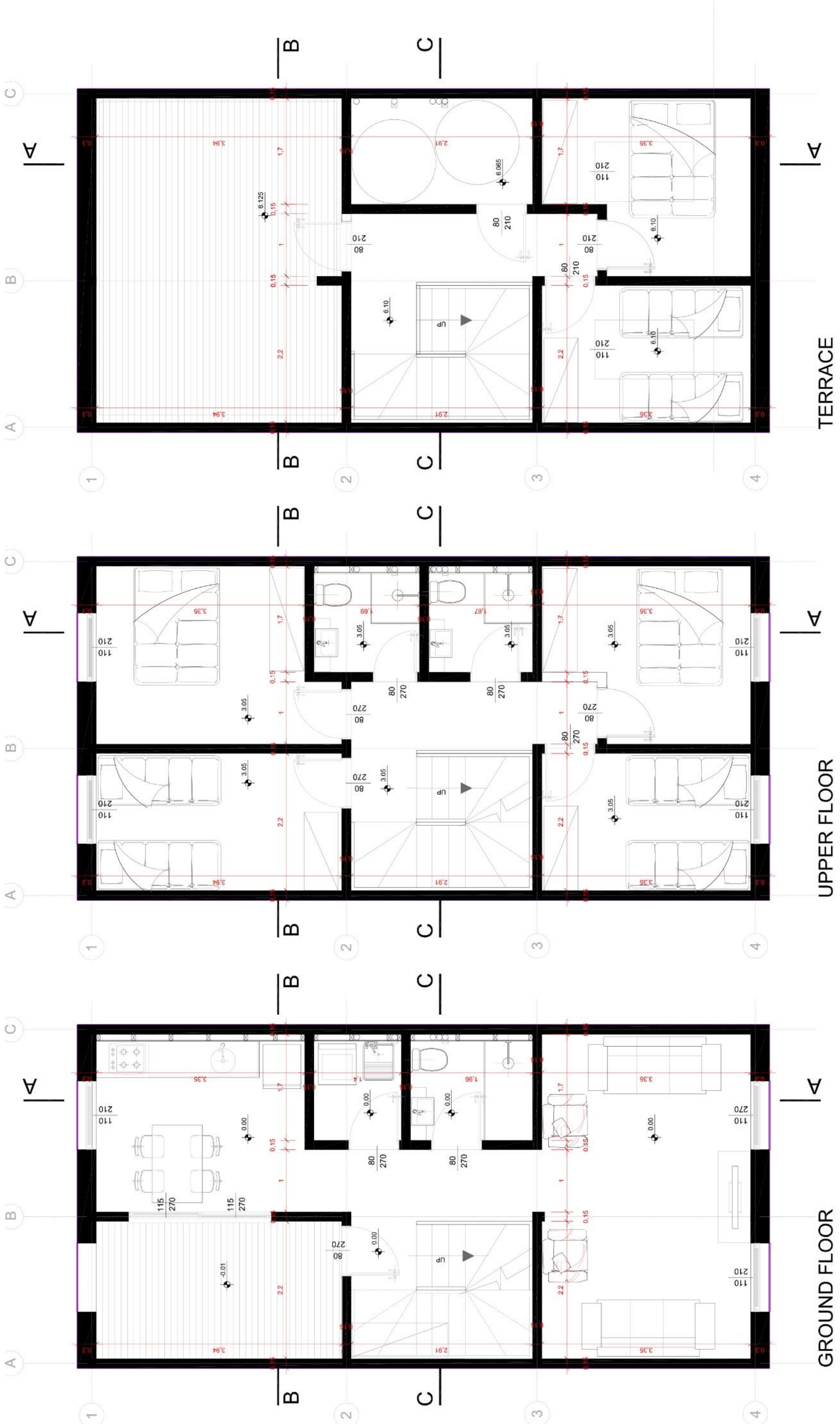


Figure 3-3323 – Plan. Typology 6

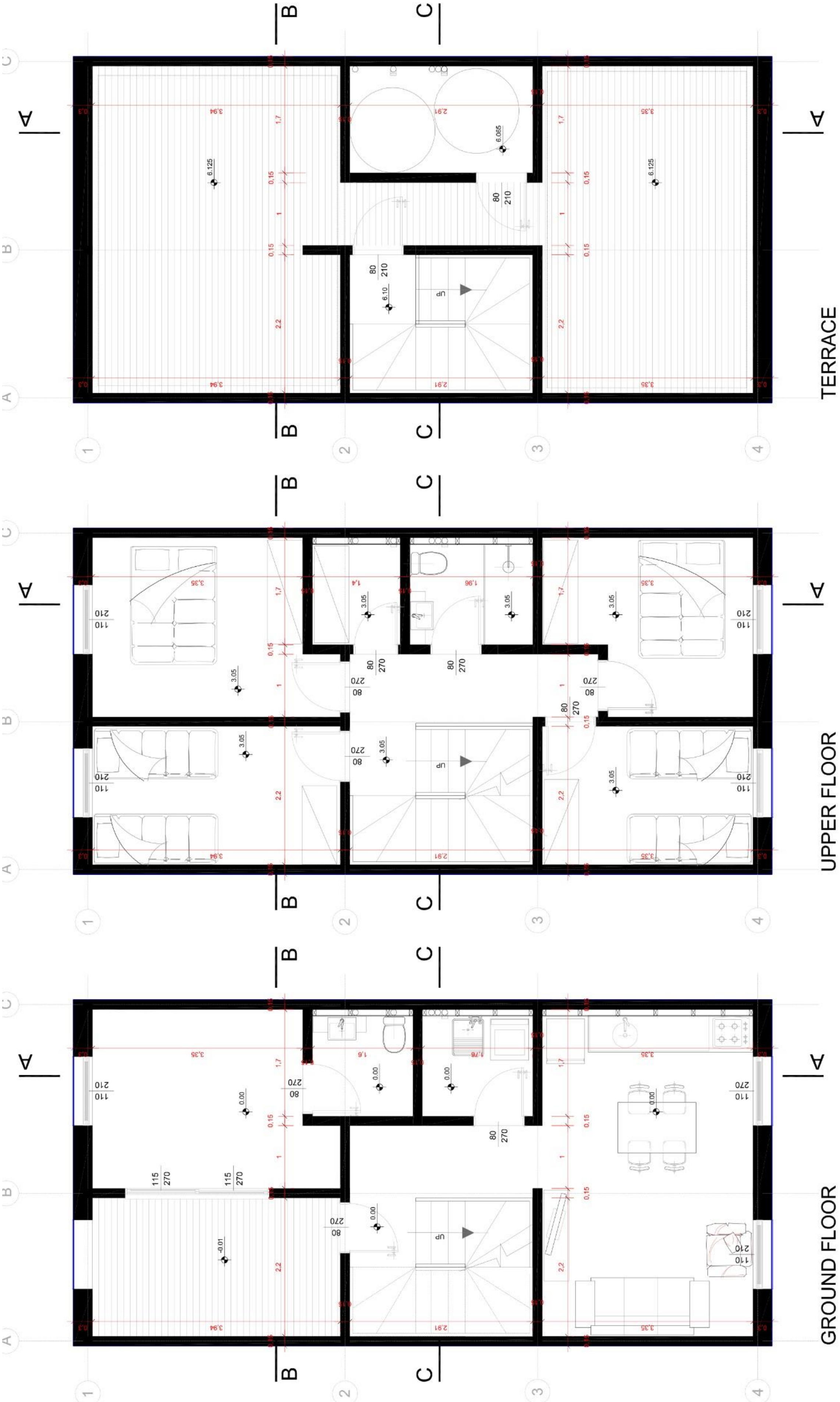


Figure 3-3424 – Plan. Typology 7

Figure 3-3525 – Plan. Typology 9

3.7.4. Typology sections

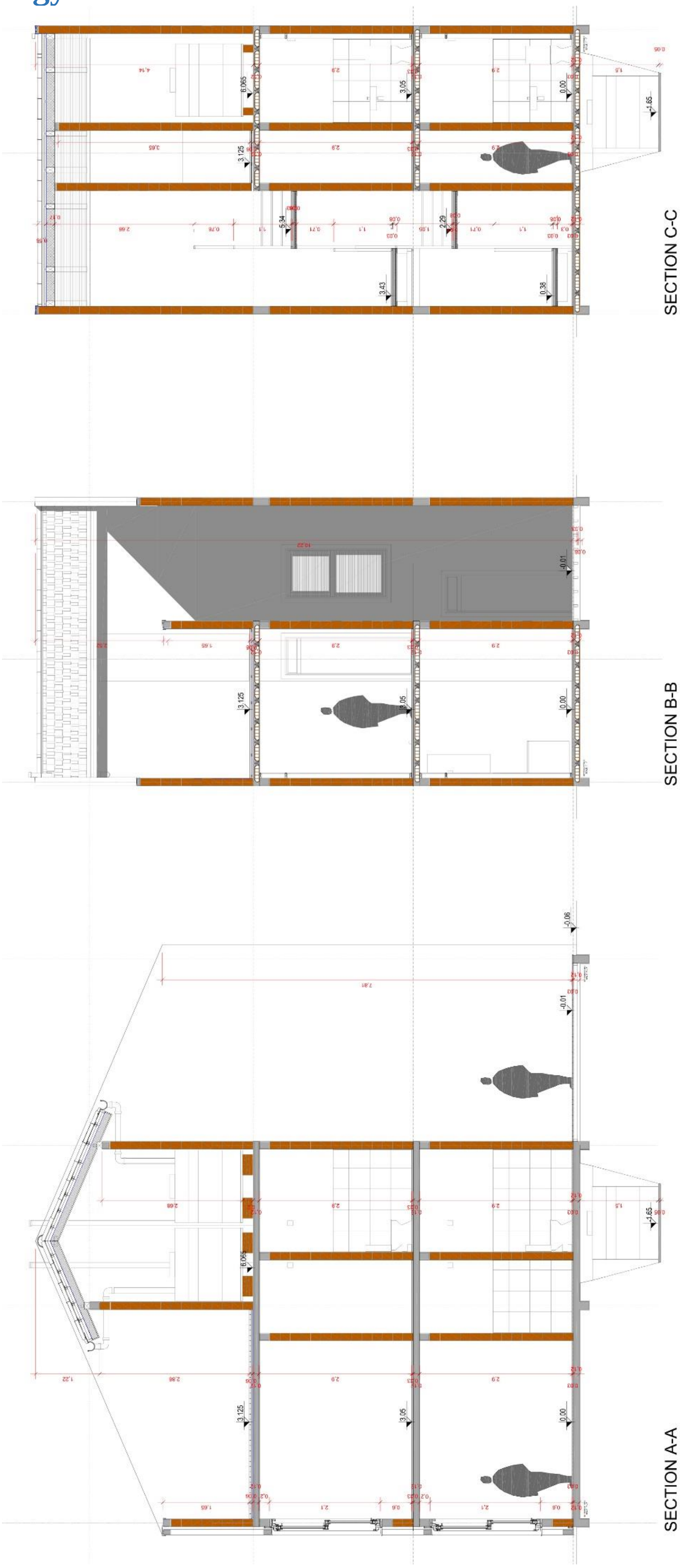


Figure 3-3626 – Section. Typology 1

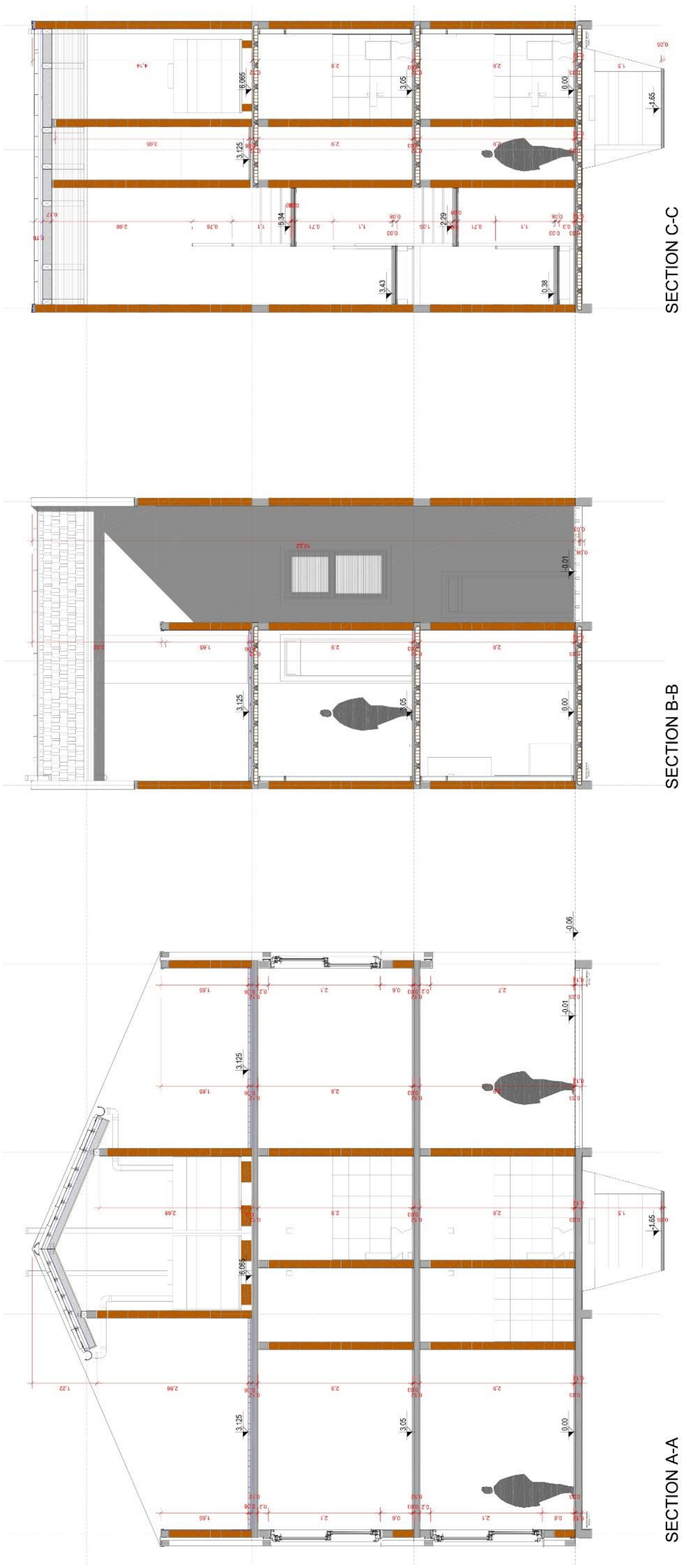


Figure 3-3727 – Section. Typology 3

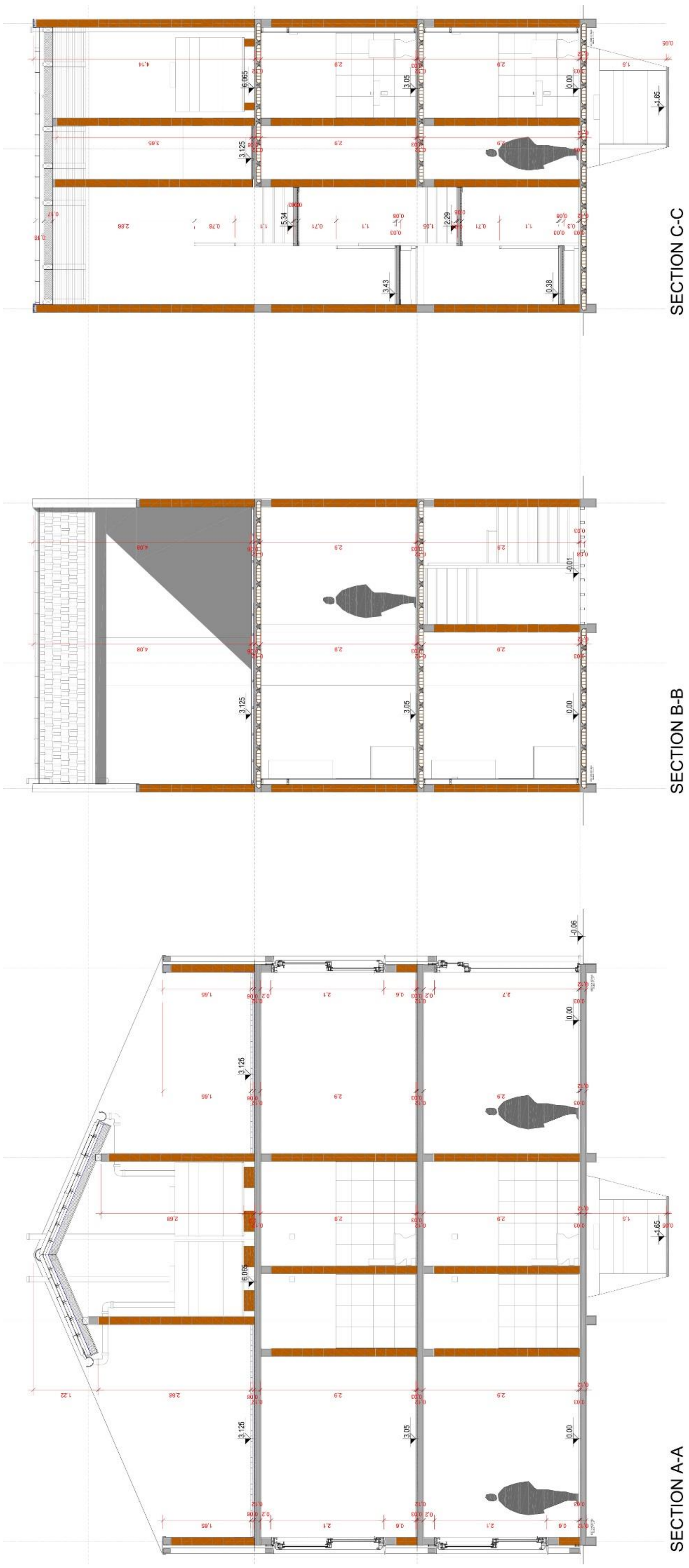


Figure 3-3828 – Section. Typology 5

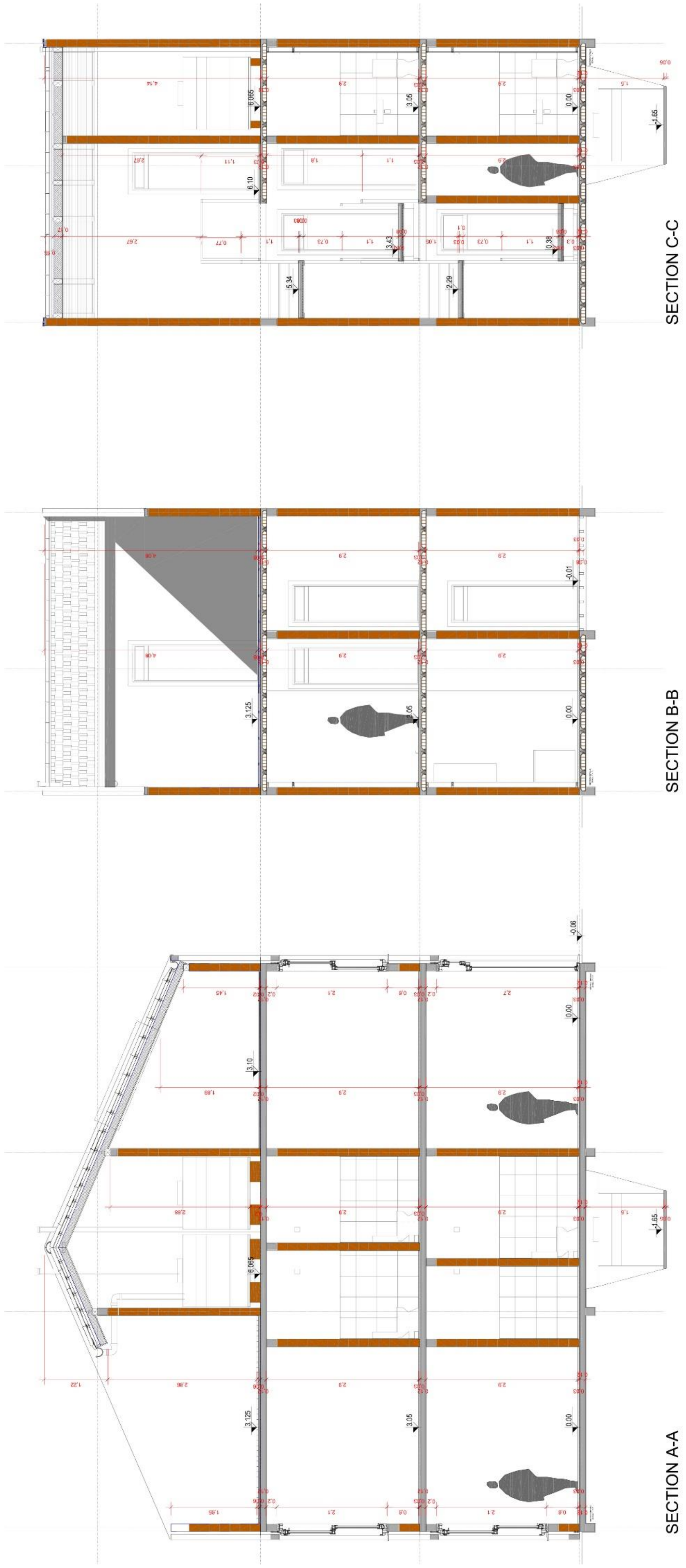


Figure 3-3929 – Section. Typology 6

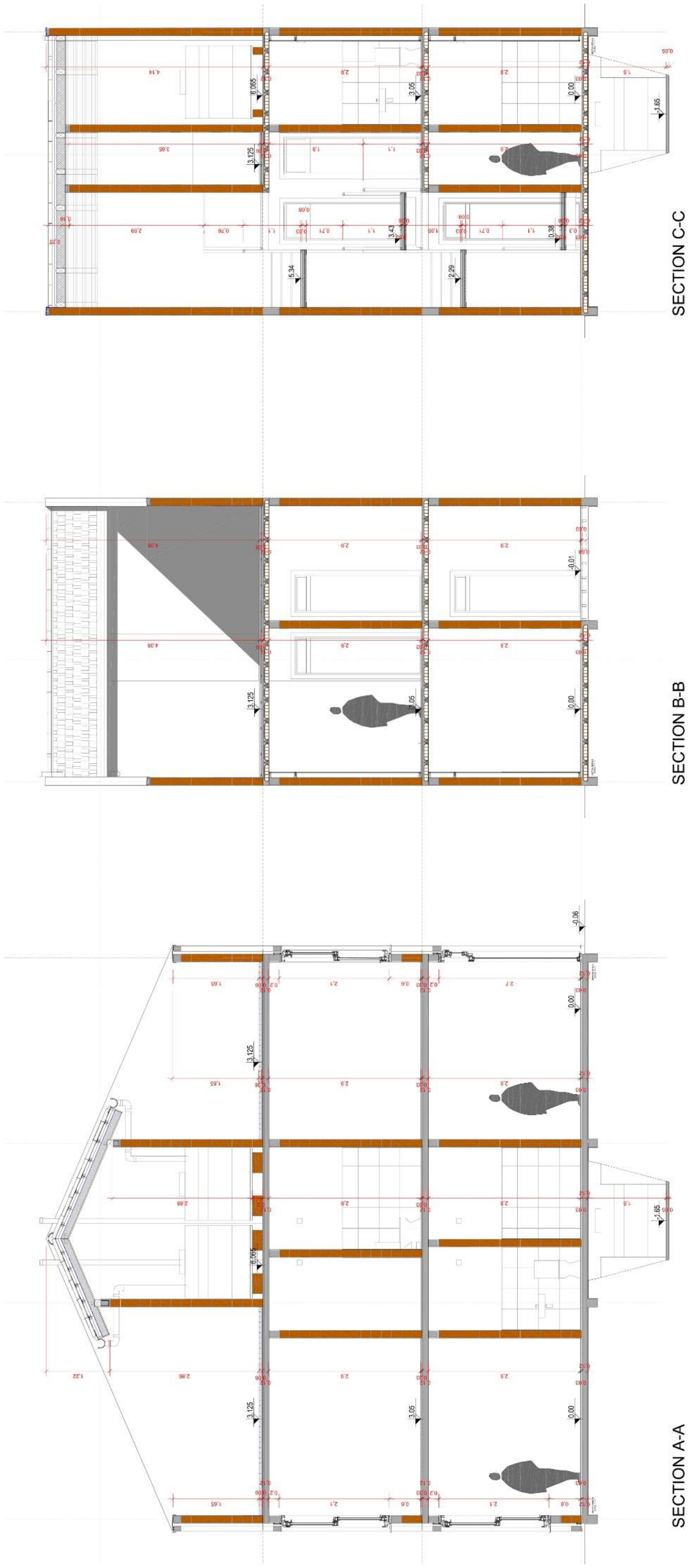


Figure 3-4030 – Section. Typology 7

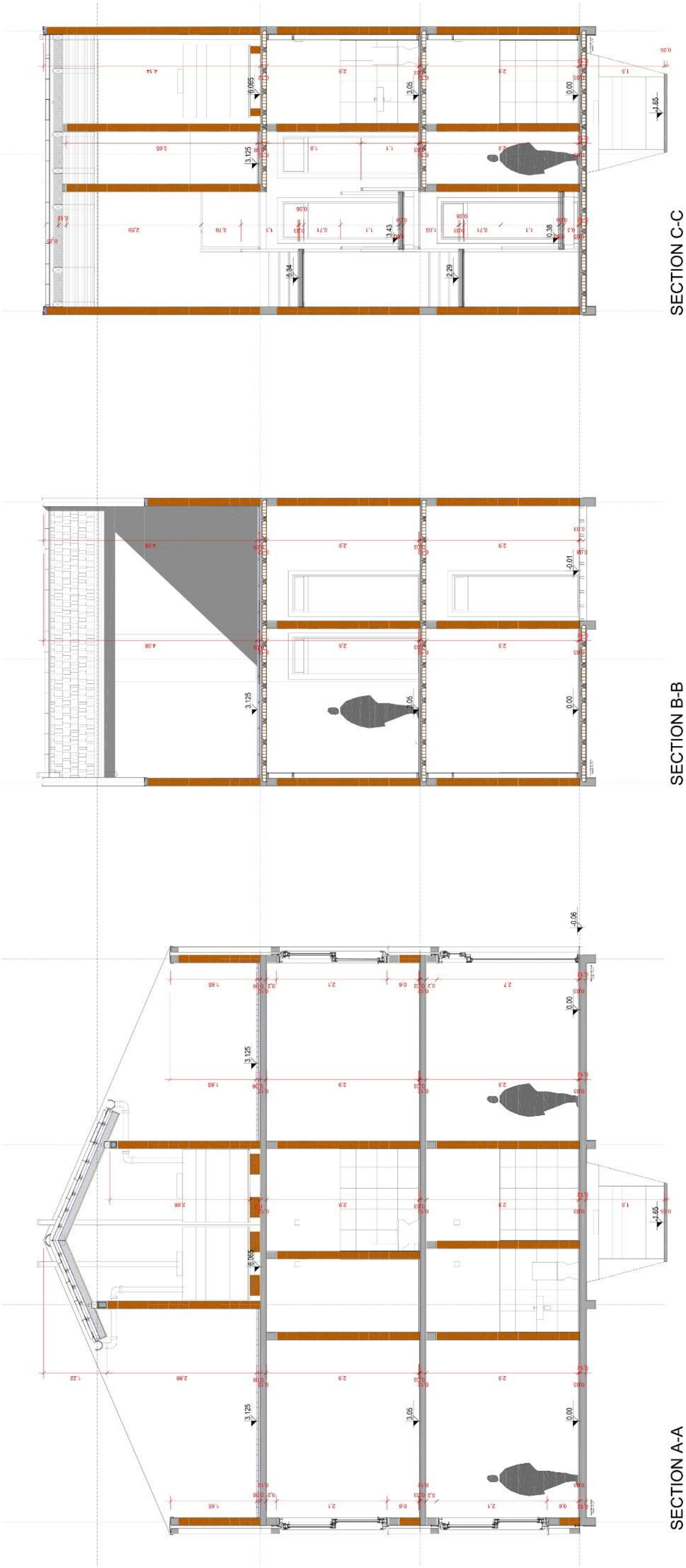


Figure 3-4131 – Section. Typology 9

3.7.5. Renders

Figure 3-4232 – 3D View

Figure 3-4333 – 3D View

Figure 3-4434 – 3D View

Figure 3-4535 – 3D View

Figure 3-4536 – 3D View

Figure 3-4637 – 3D View

CHAPTER 4:

TECHNOLOGICAL DESIGN

4. Introduction

Rio de Janeiro's built environment is undergoing large scale redevelopment and improvement, stimulated by the hosting of the 2016 Olympic Games.

Energy efficient buildings and the appropriate use of renewable energy technology will help to ensure that Rio develops sustainably and that the 2016 Olympic Games leave a positive legacy for the city. Incorporating these principles into building projects will help to mitigate against the effects of climate change and will provide a range of environmental, social and economic benefits. Our aim is to help planners and developers address sustainable energy issues in new developments and major refurbishments.

4.1. Contribute to the Rio Low Carbon City Development Program

The Rio Low Carbon City Development Program was jointly developed by the City Government of Rio de Janeiro and the World Bank. Launched in June 2012, the program aims to reduce the City's carbon emissions by 2.3 million metric tons by 2020. This reduction is equivalent to 20% of the city's 2005 emissions. The program will include:

- An urban reforestation and maintenance programme
- Bus rapid transit systems
- An integrated solid waste management system
- Recycling policies
- Improved energy efficiency in buildings
- "Bike Rio" – a bicycle rental project and bicycle pathway expansion scheme

Some of these are already underway, such as doubling the city's network of bike paths, the opening of the first of four exclusive Bus Rapid Transit (BRT) lanes, and the universalization of basic sanitation in Zona Oeste, the city's most populous area. The program is certified to ISO standards and will monitor and account for climate change mitigation actions across the city, using the greenhouse gas (GHG) inventory, a measurement of the city's total GHG emissions.

By law, the GHG Inventory will be updated every four years (beginning 2012), using the GHG protocol tool. This will enable the city to better understand, quantify and manage GHG emissions.

4.2. Project location

Pic.1

Figure 4-1. The city Rio de Janeiro is located at: 22° 54′ 30″ S, 43° 10′ 40″ W
Latitude: -22.9083 | Longitude: -43.197077

Pic.2

Figure 4-2. The site for development is located at: 22° 54′ 02″ S, 43° 11′ 59″ W
Latitude : -22.900057 | Longitude : -43.199932

Figure 4-3. Proposed location of the buildings

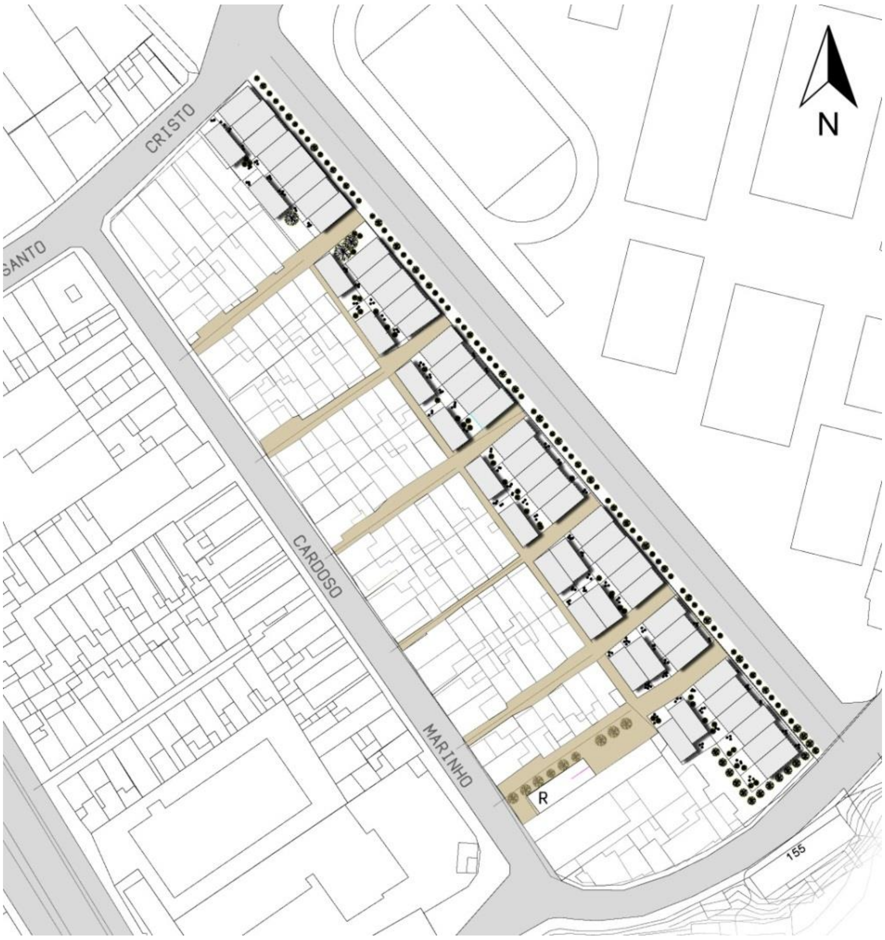


Figure 4-4. Proposed location of the buildings

- New buildings of the expansion were classified in nine different typologies according to their use and orientation.
- In order to simplify the calculations and modifications in the Autodesk Ecotect Analysis, we changed the North direction (counterclockwise - 49.934637 degrees).

4.3. Environmental conditions

This report describes the typical weather at the Rio de Janeiro-Galeão International Airport (Rio de Janeiro, Brazil) weather station over the course of an average year. It is based on the historical records from 1961 to 1990. Earlier records are either unavailable or unreliable.

Rio de Janeiro has a tropical savanna climate with dry winters. The area within 40 km of this station is covered by croplands (33%), oceans and seas (27%), built-up areas (23%), forests (11%), and grasslands (7%).

Climate data for Rio de Janeiro (1961–1990)[nota 1] [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	38.1 (100.6)	37.7 (99.9)	37.4 (99.3)	37.1 (98.8)	36.3 (97.3)	32.5 (90.5)	33.3 (91.9)	35.9 (96.6)	37.2 (99)	36.8 (98.2)	38.2 (100.8)	39 (102)	39 (102)
Average high °C (°F)	30.2 (86.4)	30.2 (86.4)	29.4 (84.9)	27.8 (82)	26.4 (79.5)	25.2 (77.4)	25 (77)	25.5 (77.9)	25.4 (77.7)	26 (79)	27.4 (81.3)	28.6 (83.5)	27.3 (81.1)
Daily mean °C (°F)	26.3 (79.3)	26.6 (79.9)	26 (79)	24.4 (75.9)	22.8 (73)	21.8 (71.2)	21.3 (70.3)	21.8 (71.2)	22.2 (72)	22.9 (73.2)	24 (75)	25.3 (77.5)	23.8 (74.8)
Average low °C (°F)	23.3 (73.9)	23.5 (74.3)	23.3 (73.9)	21.9 (71.4)	20.4 (68.7)	18.7 (65.7)	18.4 (65.1)	18.9 (66)	19.2 (66.6)	20.2 (68.4)	21.4 (70.5)	22.4 (72.3)	21 (70)
Record low °C (°F)	17.7 (63.9)	18.9 (66)	18.6 (65.5)	16.2 (61.2)	11.1 (52)	11.6 (52.9)	12.2 (54)	10.6 (51.1)	10.2 (50.4)	10.1 (50.2)	16.5 (61.7)	17.1 (62.8)	10.1 (50.2)
Rainfall mm (inches)	137.1 (5.398)	130.4 (5.134)	135.8 (5.346)	94.9 (3.736)	69.8 (2.748)	42.7 (1.681)	41.9 (1.65)	44.5 (1.752)	53.6 (2.11)	86.5 (3.406)	97.8 (3.85)	134.2 (5.283)	1,069.4 (42.102)
Avg. rainy days (≥ 1 mm)	11	7	8	9	6	6	4	5	7	9	10	11	93
% humidity	79	79	80	80	80	79	77	77	79	80	79	80	79.1
Mean monthly sunshine hours	211.9	201.3	206.4	181	186.3	175.1	188.6	184.8	146.2	152.1	168.5	179.6	2,181.8

Source: Brazilian National Institute of Meteorology (INMET).[36][35][34][37][47][48][49][43][42]

Table 4-1. Average environmental conditions per seasonal year.

The lowest temperature ever recorded was 10.1 °C (50.2 °F) on October 1977, and the highest temperature reached 39 °C (102.2 °F) on December 1963. The highest accumulated rainfall in 24 hours was 167.4 mm (6.6 in) in January 1962.

4.3.1. Temperature and climate

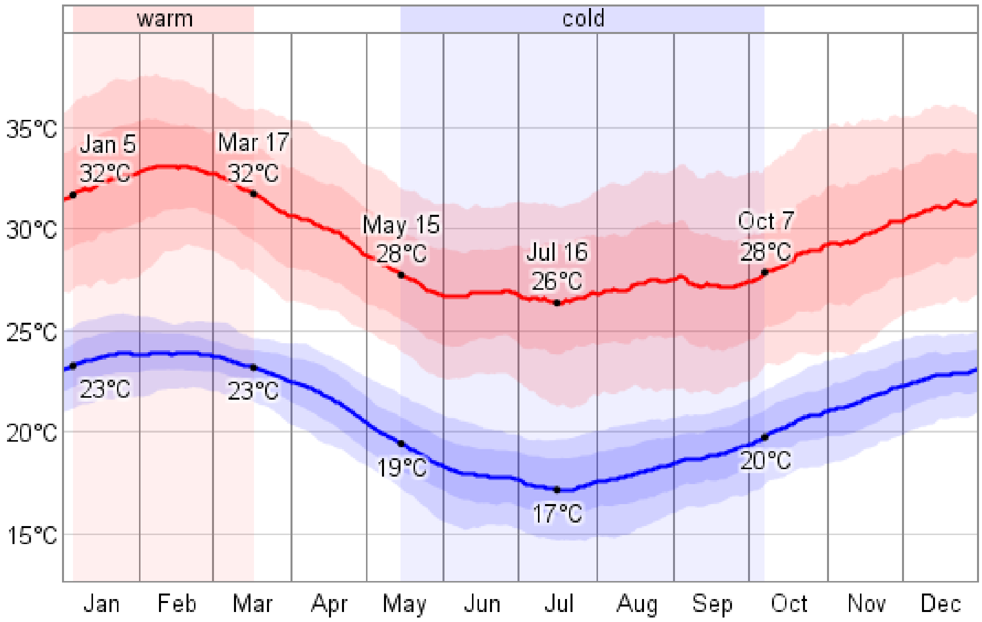


Figure 4-5. The daily average low (blue) and high (red) temperature with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

Rio has a tropical wet and dry or savanna type that closely borders a tropical monsoon climate according to the Köppen climate classification, and is often characterized by long periods of heavy rain from December to March. In inland areas of the city, temperatures above 40 °C (104 °F) are common during the summer, though rarely for long periods, while maximum temperatures above 27 °C (81 °F) can occur on a monthly basis.

Over the course of a year, the temperature typically varies from 17°C to 33°C and is rarely below 15°C or above 38°C.
The warm season lasts from January 5 to March 17 with an average daily high temperature above 32°C. The hottest day of the year is February 19, with an average high of 33°C and low of 24°C.

The cold season lasts from May 15 to October 7 with an average daily high temperature below 28°C. The coldest day of the year is July 16, with an average low of 17°C and high of 26°C.

4.3.2. Precipitation

The probability that precipitation will be observed at this location varies throughout the year. Precipitation is most likely around January 1, occurring in 57% of days. Precipitation is least likely around July 10, occurring in 25% of days.

Probability of precipitation at some point in the day

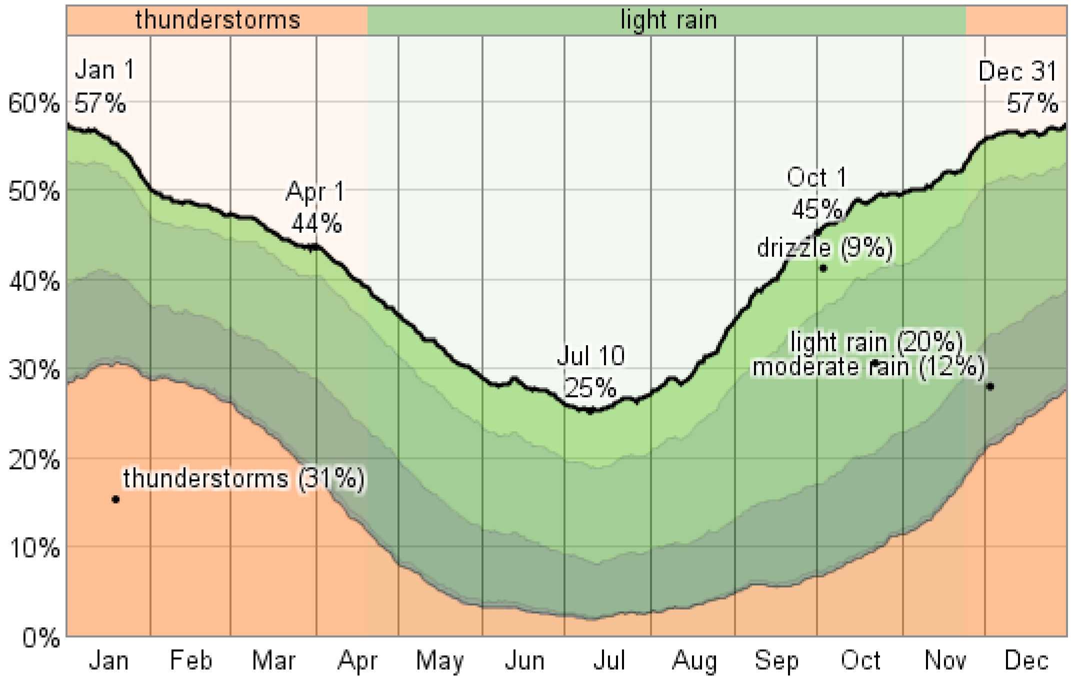


Figure 4-6. The fraction of days in which various types of precipitation are observed. If more than one type of precipitation is reported in a given day, the more severe precipitation is counted. For example, if light rain is observed in the same day as a thunderstorm, that day counts towards the thunderstorm totals. The order of severity is from the top down in this graph, with the most severe at the bottom.

Over the entire year, the most common forms of precipitation are light rain, thunderstorms, moderate rain, and drizzle.

Light rain is the most severe precipitation observed during 32% of those days with precipitation. It is most likely around October 22, when it is observed during 20% of all days.

Thunderstorms are the most severe precipitation observed during 32% of those days with precipitation. They are most likely around January 19, when it is observed during 31% of all days.

Moderate rain is the most severe precipitation observed during 22% of those days with precipitation. It is most likely around December 3, when it is observed during 12% of all days.

Drizzle is the most severe precipitation observed during 13% of those days with precipitation. It is most likely around October 3, when it is observed during 9% of all days.

Types of precipitation throughout the year

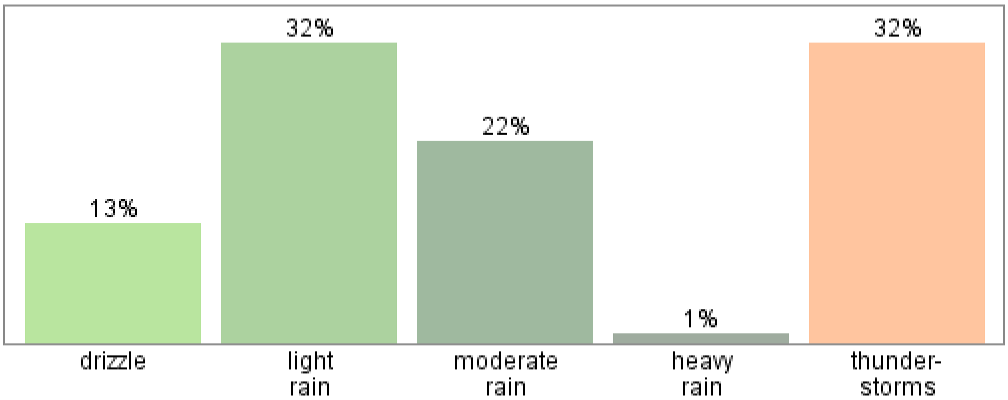


Figure 4-7. Relative frequency of various types of precipitation over the course of a typical year.

During the warm season, which lasts from January 5 to March 17, there is a 50% average chance that precipitation will be observed at some point during a given day. When precipitation does occur it is most often in the form of thunderstorms (55% of days with precipitation have at worst thunderstorms), light rain (21%), moderate rain (17%), and drizzle (6%).

During the cold season, which lasts from May 15 to October 7, there is a 32% average chance that precipitation will be observed at some point during a given day. When precipitation does occur it is most often in the form of light rain (41% of days with precipitation have at worst light rain), moderate rain (25%), drizzle (21%), and thunderstorms (12%).

Warm Season Precipitation **Cold Season**

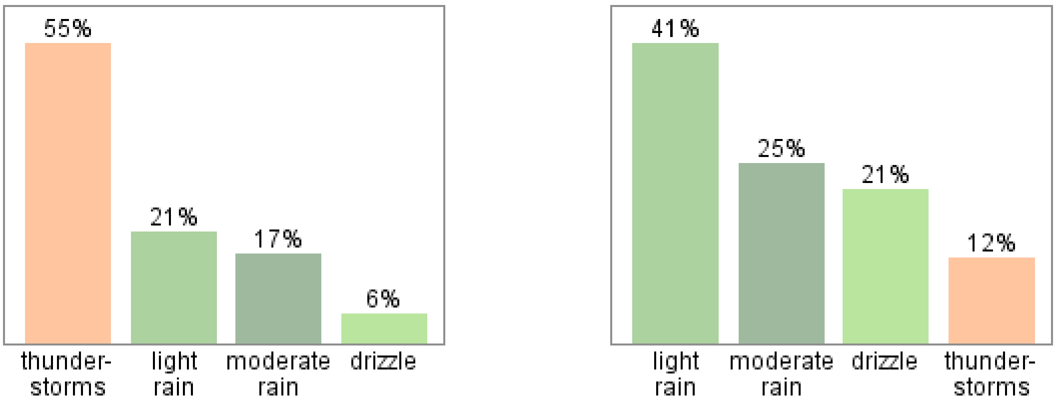


Figure 4-8. Relative frequency of various types of precipitation during the warm and cold seasons respectively.

4.3.3. Snow

Either snow is exceptionally unlikely to fall at any time during the year at this location or this station does not reliably report precipitation types.

4.3.4. Humidity

The relative humidity typically ranges from 53% (mildly humid) to 98% (very humid) over the course of the year, rarely dropping below 32% (comfortable) and reaching as high as 100% (very humid).

The air is driest around August 17, at which time the relative humidity drops below 63% (mildly humid) three days out of four; it is most humid around May 2, exceeding 95% (very humid) three days out of four.

Relative Humidity

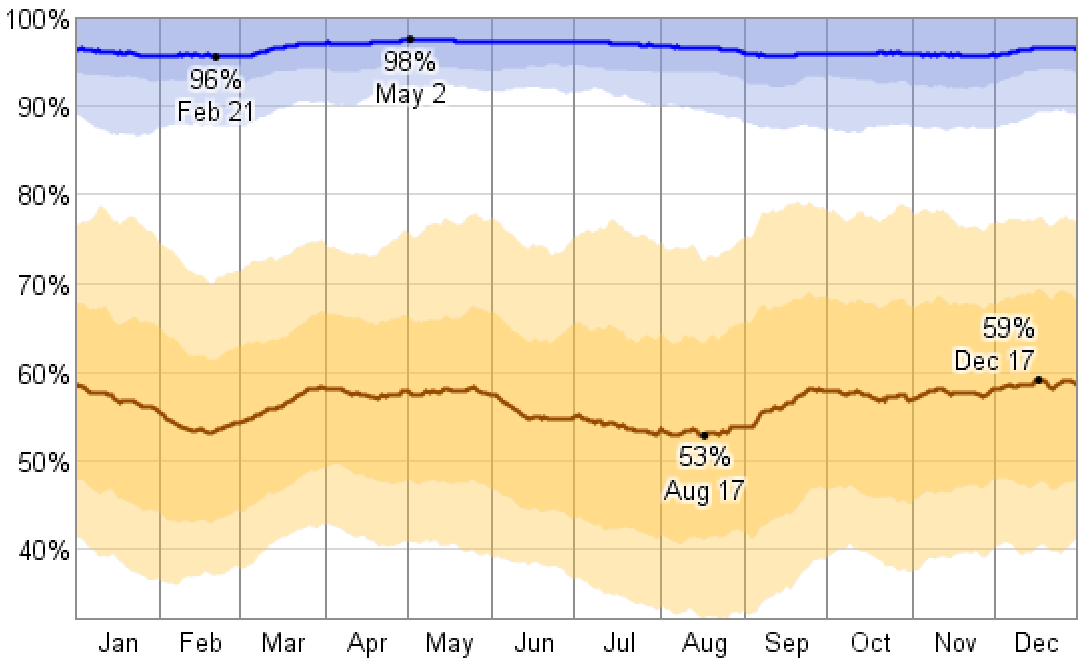


Figure 4-9. The average daily high (blue) and low (brown) relative humidity with percentile bands (inner bands from 25th to 75th percentile, outer bands from 10th to 90th percentile).

4.3.5. Wind

Over the course of the year typical wind speeds vary from 0 m/s to 7 m/s (calm to moderate breeze), rarely exceeding 9 m/s (fresh breeze).

The highest average wind speed of 15 m/s (high wind) occurs around October 29, at which time the average daily maximum wind speed is 7 m/s (moderate breeze).

The lowest average wind speed of 2 m/s (light breeze) occurs around June 22, at which time the average daily maximum wind speed is 4 m/s (gentle breeze).

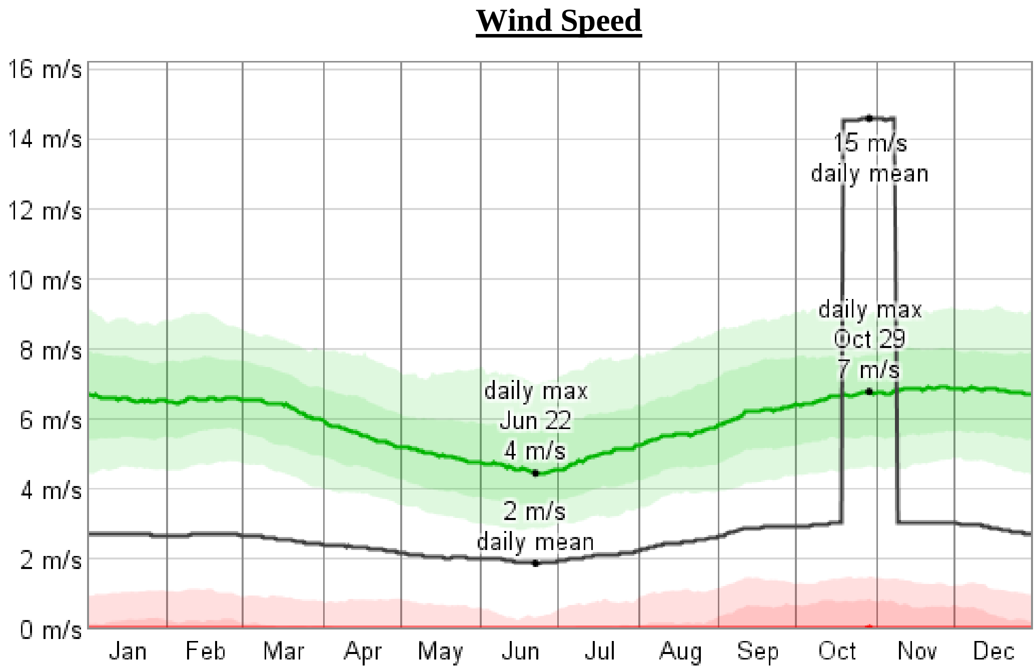


Figure 4-10. The average daily minimum (red), maximum (green), and average (black) wind speed with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

The wind is most often out of the *south east* (19% of the time) and *east* (14% of the time).

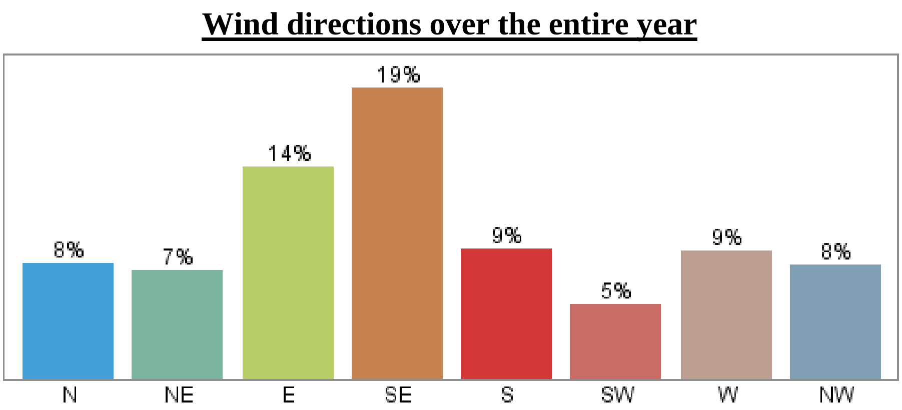


Figure 4-11. The fraction of time spent with the wind blowing from the various directions over the entire year. Values do not sum to 100% because the wind direction is undefined when the wind speed is zero.

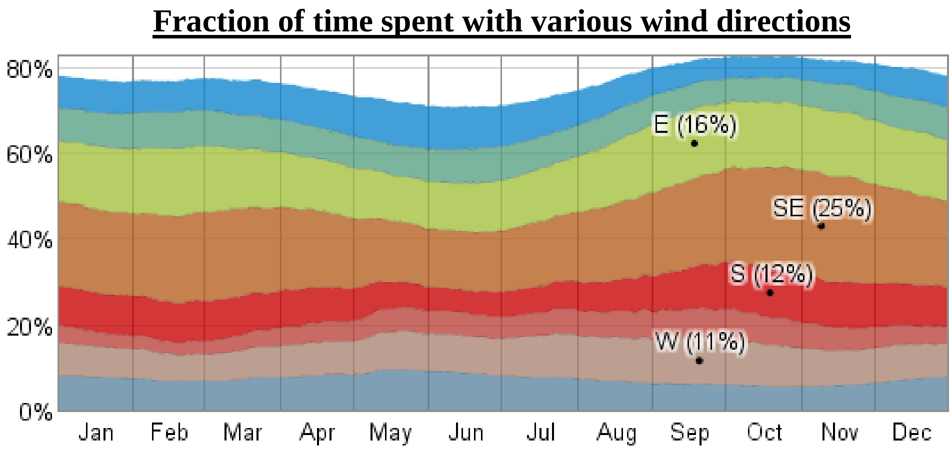


Figure 4-12. The fraction of time spent with the wind blowing from the various directions on a daily basis. Stacked values do not always sum to 100% because the wind direction is undefined when the wind speed is zero.

Wind Roses

Wind roses are information packed plot providing frequencies of wind direction and wind speed. A wind rose can quickly indicate the dominant wind directions and the direction of strongest wind speeds.

18 – 24 mph - Fresh breeze Moderate sized branches move (small trees sway).

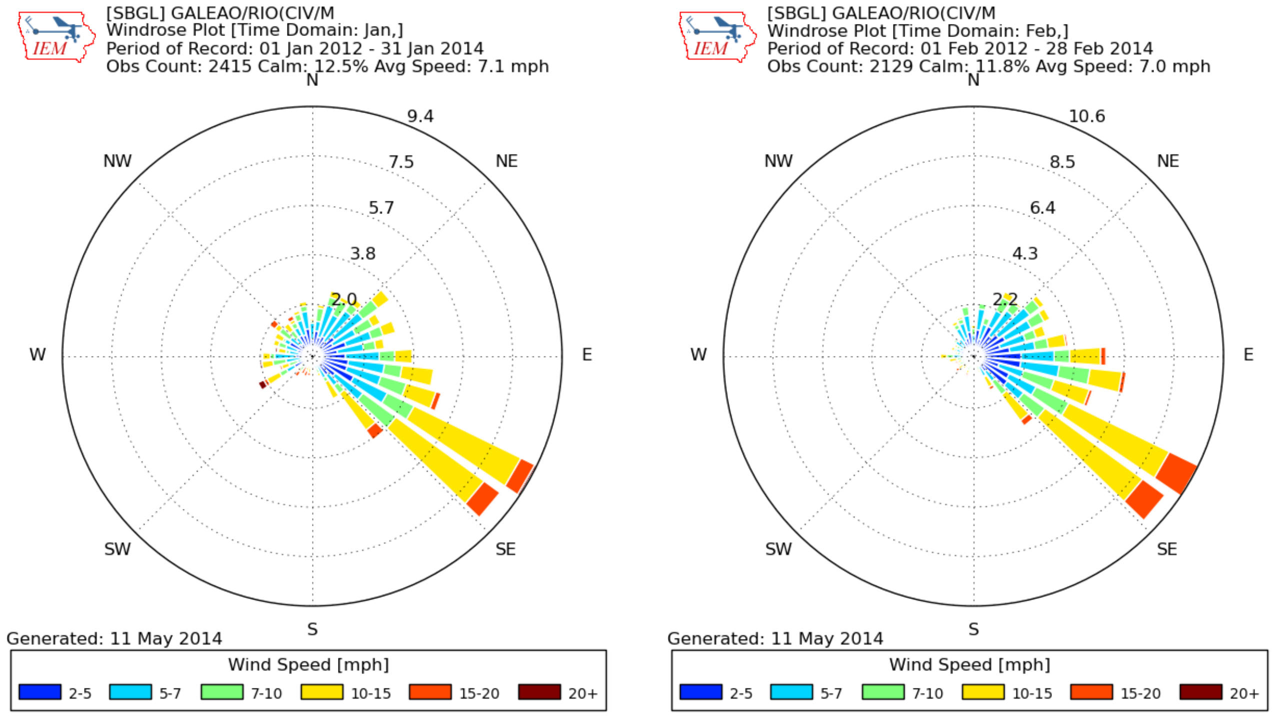


Figure 4-13. Windrose plot during January (left) and February (right)

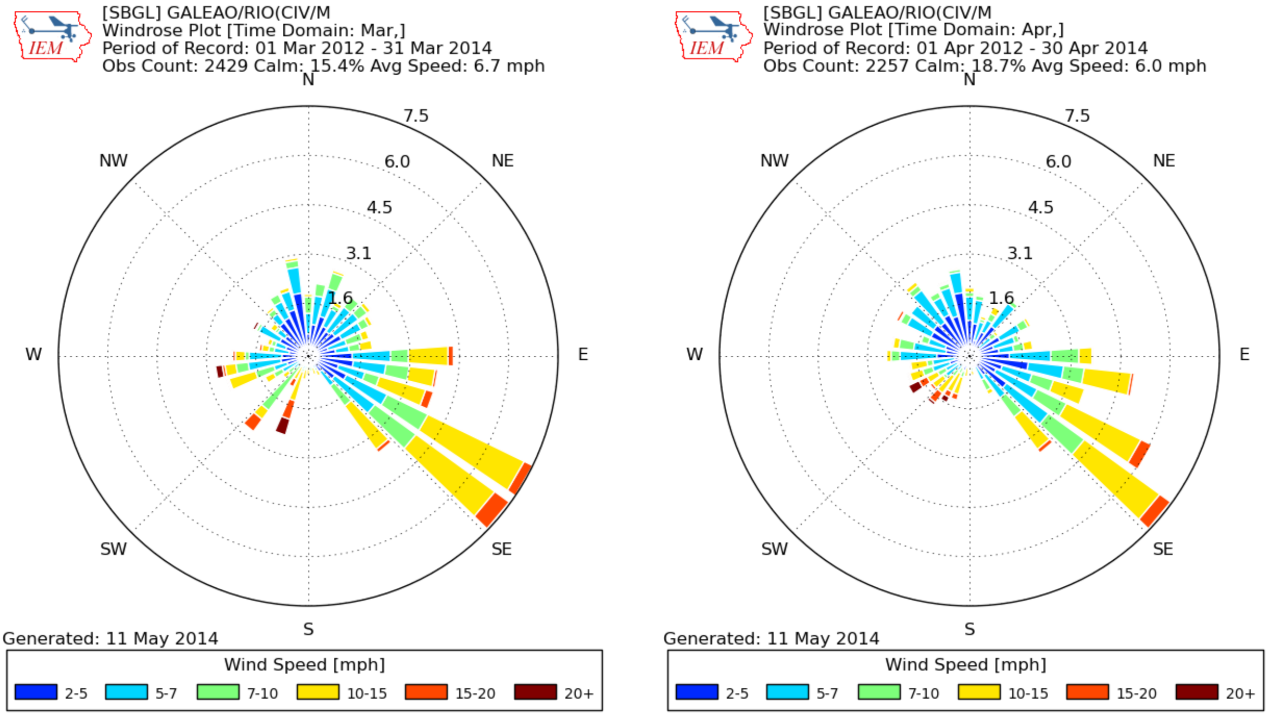


Figure 4-14. Windrose plot during March (left) and April (right)

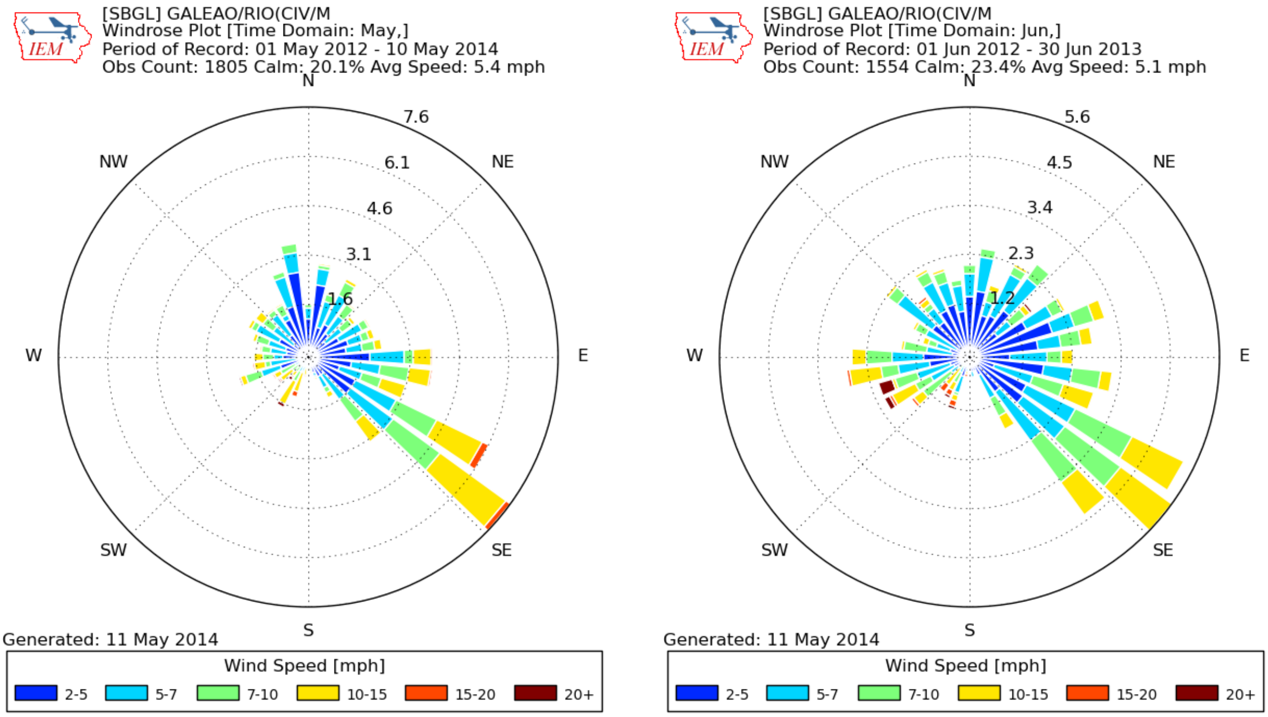


Figure 4-15. Windrose plot during May (left) and June (right)

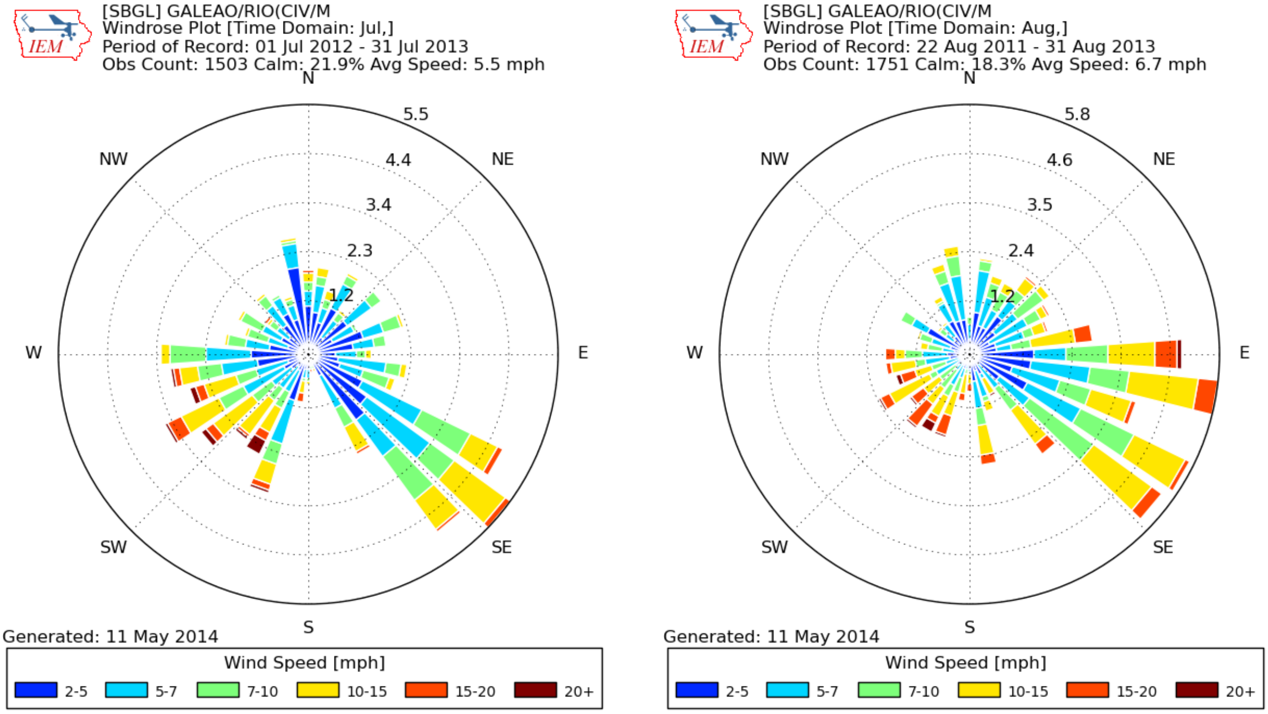


Figure 4-16. Windrose plot during July (left) and August (right)

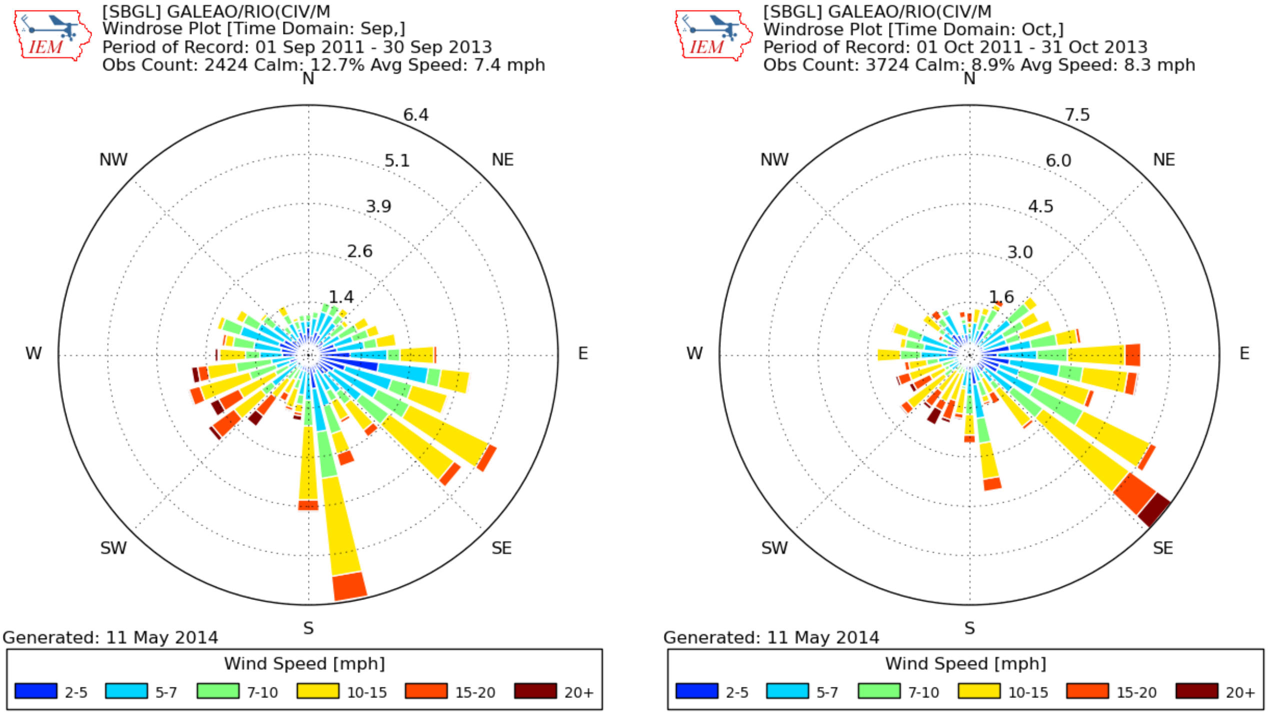
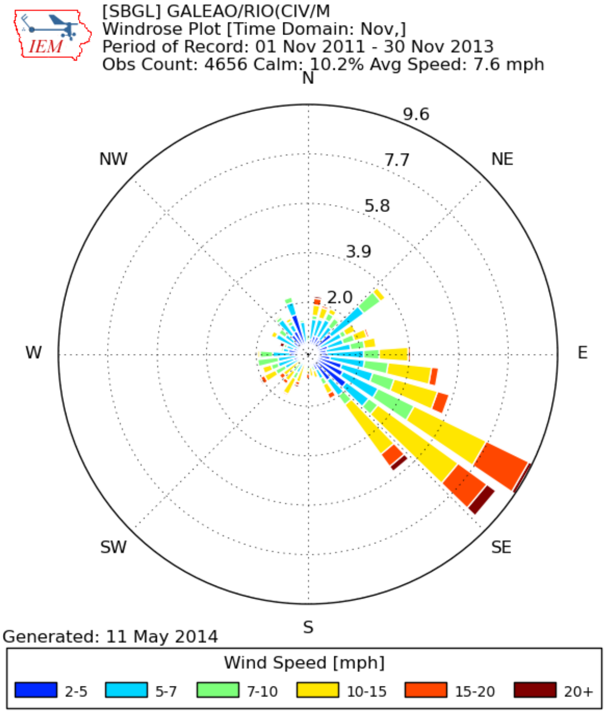


Figure 4-17. Windrose plot during September (left) and October (right)



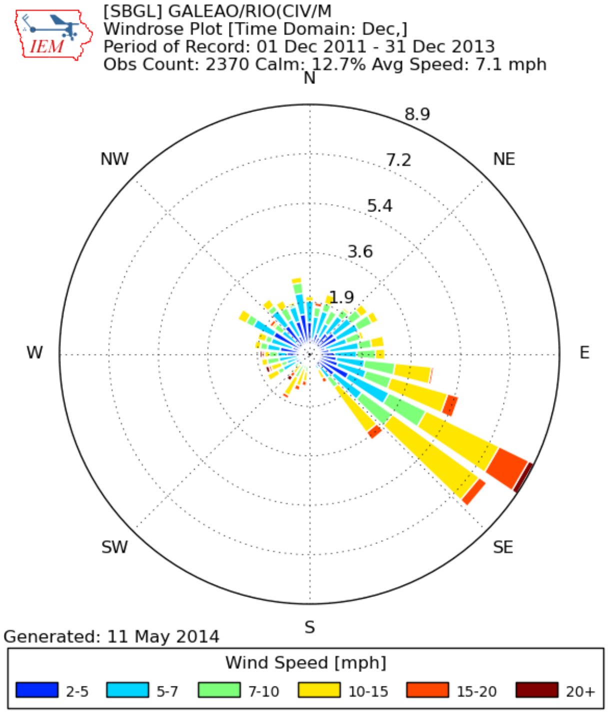


Figure 4-18. Windrose plot during November (left) and December (right)

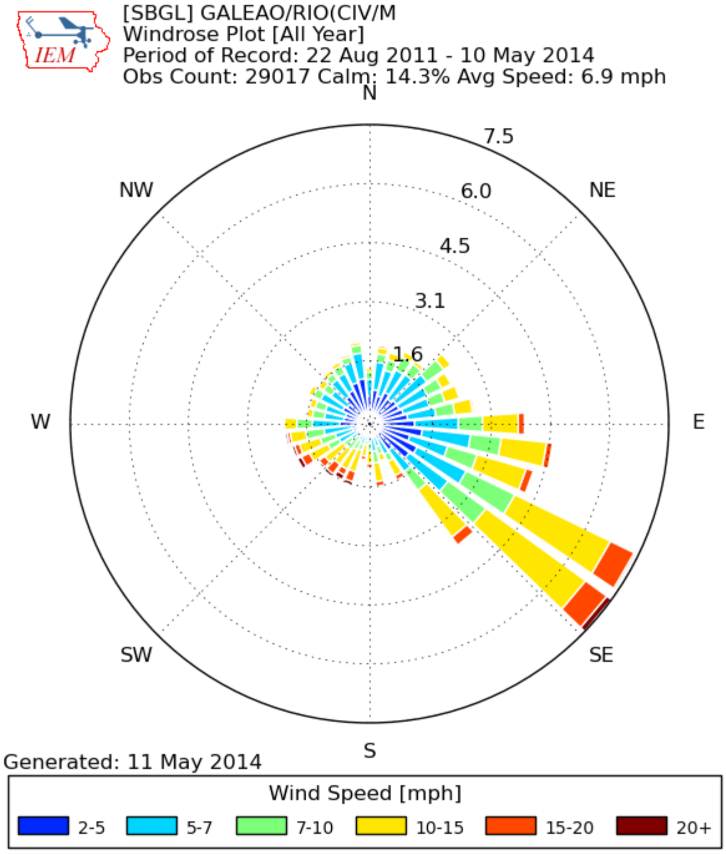


Figure 4-19. Windrose plot during All Year

4.3.6. Solar radiation

The length of the day varies significantly over the course of the year.

The shortest day is June 20 with 10:44 hours of daylight; the longest day is December 21 with 13:33 hours of daylight.

In the picture below we represent the chart with the number of hours during which the Sun is visible (black line), with various degrees of daylight, twilight, and night, indicated by the color bands. From bottom (most yellow) to top (most gray): full daylight, solar twilight (Sun is visible but less than 6° from the horizon), civil twilight (Sun is not visible but is less than 6° below the horizon), nautical twilight (Sun is between 6° and 12° below the horizon), astronomical twilight (Sun is between 12° and 18° below the horizon), and full night.

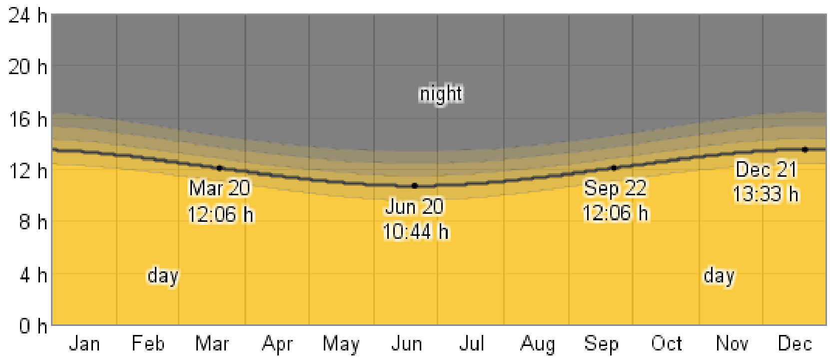


Figure 4-20. Daily Hours of Daylight and Twilight

The earliest sunrise is at 5:16am on October 20 and the latest sunset is at 7:44pm on January 15. The latest sunrise is at 6:47am on February 24 and the earliest sunset is at 5:15pm on June 4.

Daylight savings time (DST) is observed in this location during 2012, starting in the spring on October 21 and ending in the fall on February 25.

The next chart represents the solar day over the course of the year 2012. From bottom to top, the black lines are the previous solar midnight, sunrise, solar noon, sunset, and the next solar midnight. The day, twilights (solar, civil, nautical, and astronomical), and night are indicated by the color bands from yellow to gray. The transitions to and from daylight savings time are indicated by the "DST" labels.

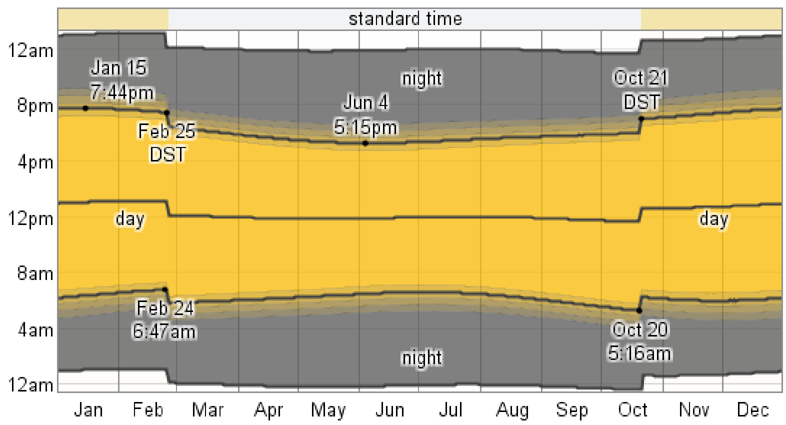


Figure 4-21. Daily Sunrise & Sunset with Twilight and Daylight Saving Time

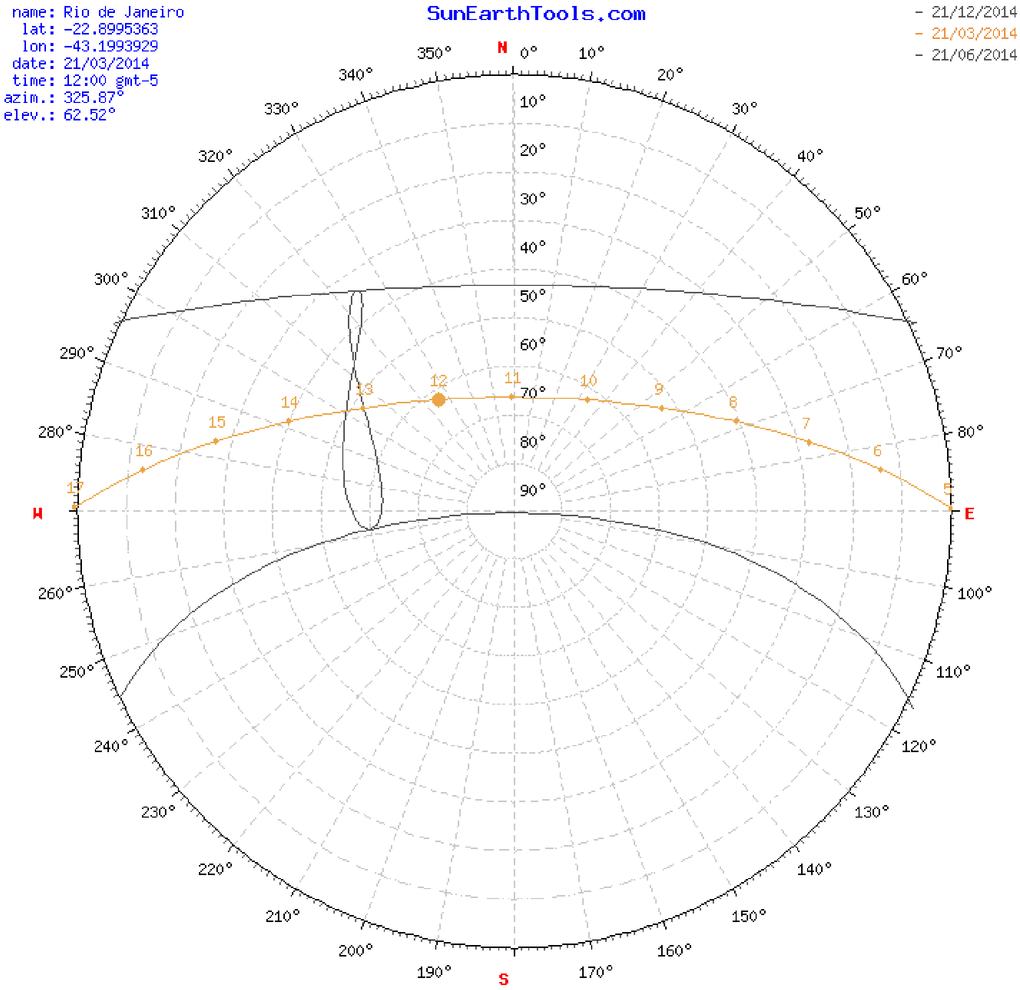


Figure 4-22. Sun path diagram for Rio de Janeiro on March 21th, solar representation

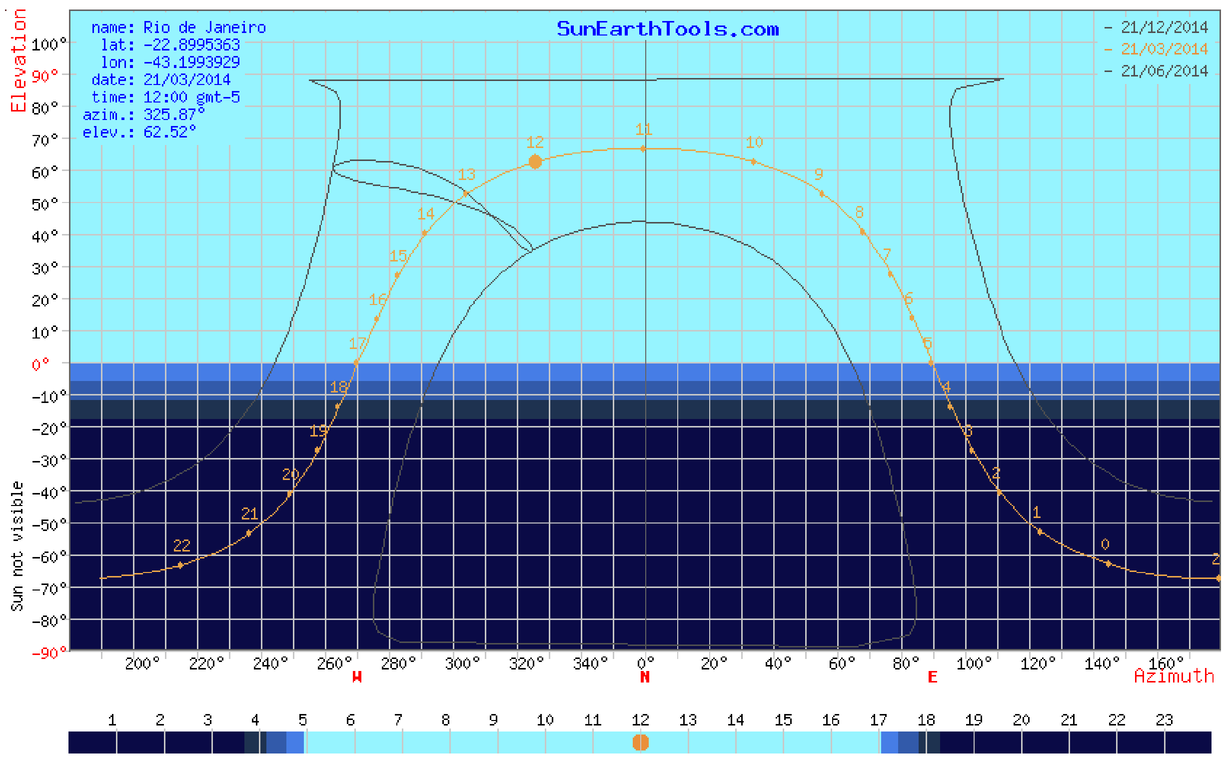


Figure 4-23. Sun path diagram for Rio de Janeiro on March 21th, Cartesian representation

4.4. Predesign Environmental Concept

The preliminary climatic diagnosis highlighted the importance of shading and light colors as well as the possibility of natural ventilation as the main passive strategies to reduce heat gains in buildings and improve thermal comfort both indoors and outdoors.

4.4.1. Orientation & Zoning

It should be noted that site-specific considerations need to be taken into account when deciding on building orientation. In some cases, shade from existing buildings, landscape and geographic features can contribute to passive design measures.

The studies below from Ecotect show that elongating the building in the East-West direction can help optimize both passive cooling (prevailing summer winds strike perpendicular, controlling summer sun) and passive heating (harnessing winter sun).

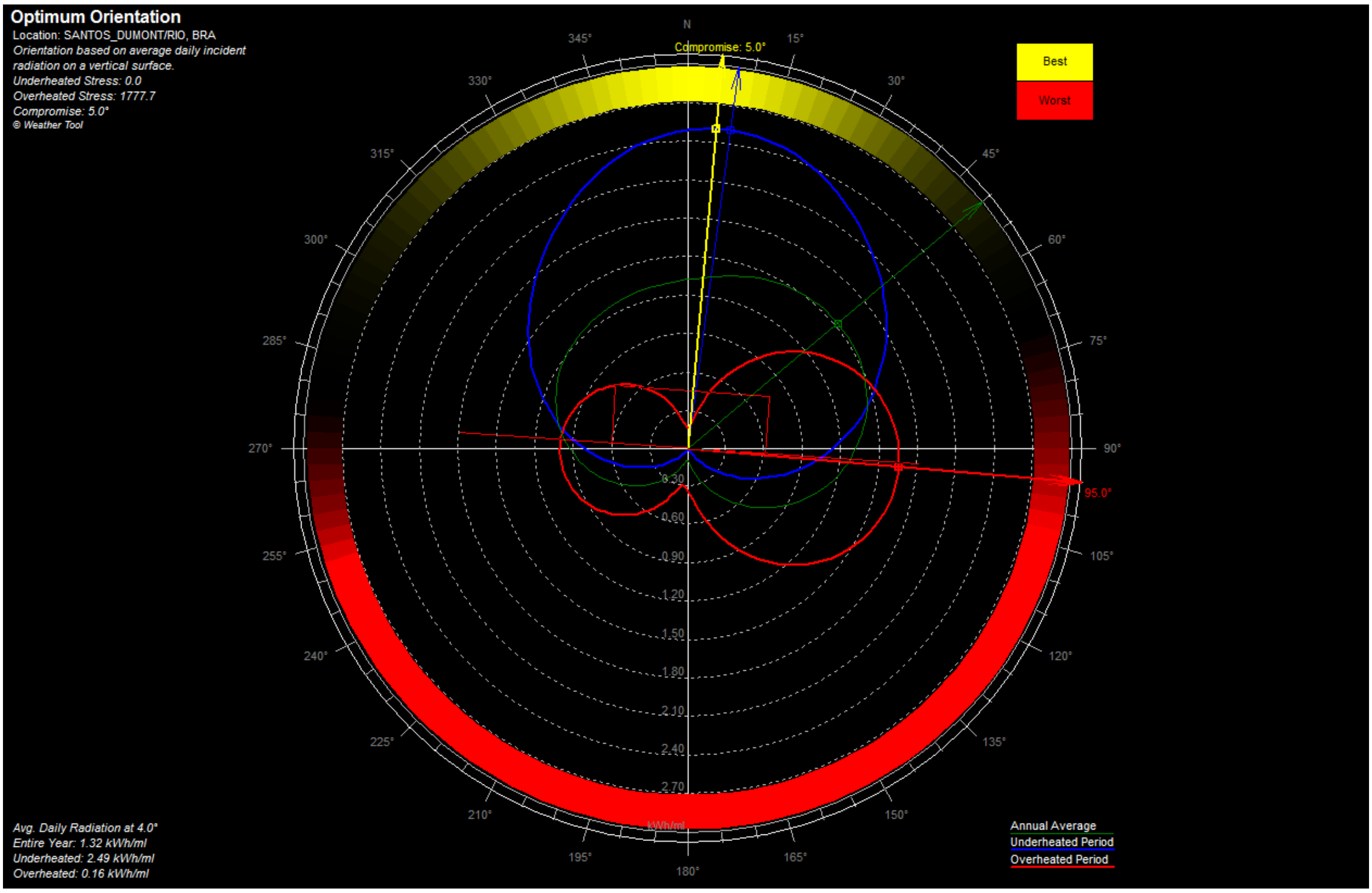


Figure 4-24. Best orientation diagram from Autodesk Ecotect

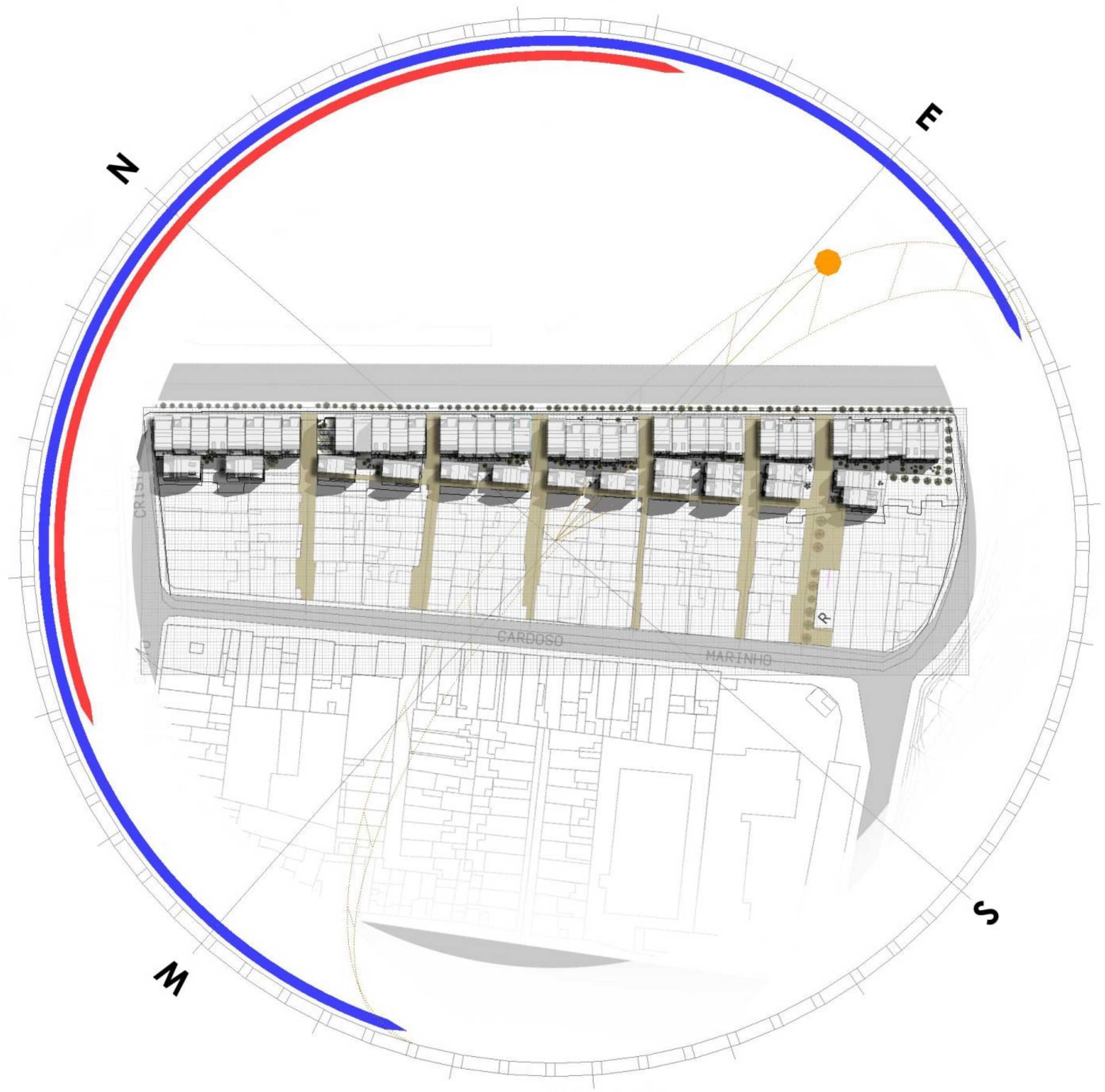


Figure 4-25. Our proposed buildings orientation

Reducing Solar Gain

Reducing solar gain on buildings in Rio de Janeiro should be a major design objective – serving to lighten the cooling load and improve energy efficiency.

In terms of building orientation, preventing solar gain is probably more important than the facilitation of natural ventilation and buildings should be designed with this in mind.

4.4.2. Vertical Surfaces & Solar Gain

The horizontal surfaces of buildings receive the most intense solar radiation due to the high sun angle in Rio de Janeiro. Solar heat gain on these surfaces can be reduced by the use of light colored paints and green roofs. Roof ponds and other evaporative cooling measures may also help reduce solar gain on horizontal surfaces.

During winter, the next highest intensity is received by north facing walls. In summer, when cooling loads are most significant, east and west façades receive the most solar radiation and are hence most likely to contribute to solar gain.

The following table shows incident solar radiation on vertical surfaces in Rio de Janeiro:

Season	Winter kWh/m^2	Summer kWh/m^2
North	340	180
East/West	220	305
South	95	220

*Table 4-2. Data related to kWh per square meter measured over the three months of summer and winter periods of the year [**Ошибка! Источник ссылки не найден.**].*

West facing surfaces pose a particular problem in Rio de Janeiro, since the maximum intensity of solar radiation received by west walls coincides with the hottest part of the day [**Ошибка! Источник ссылки не найден.**].

Where possible, buildings in Rio de Janeiro should be oriented so that east and west exposure to the sun is minimized. Only minor openings of unimportant rooms should be sited on the east and west sides of buildings, and windows on these façades should be limited. Vertical service cores should be sited on east and west sides to provide buffer zones to insulate internal spaces and shading to occupied areas [**Ошибка! Источник ссылки не найден.**].

Transitional zones should be sited on the north side of buildings. This zone receives less solar radiation during the summer months. Total climatic control in these spaces can likely be avoided, once natural ventilation has been maximized [**Ошибка! Источник ссылки не найден.**]

Large windows protected by horizontal shading on the north side of buildings in Rio de Janeiro would admit light whilst avoiding direct solar radiation.

South facing windows would admit diffuse light for most of the year – though may require shading from the rising and setting sun during summer. These measures would minimize solar gain while maintaining good levels of natural light.

Such windows would also maximize the potential for natural ventilation, since they would take advantage of the prevailing breeze in Rio de Janeiro.

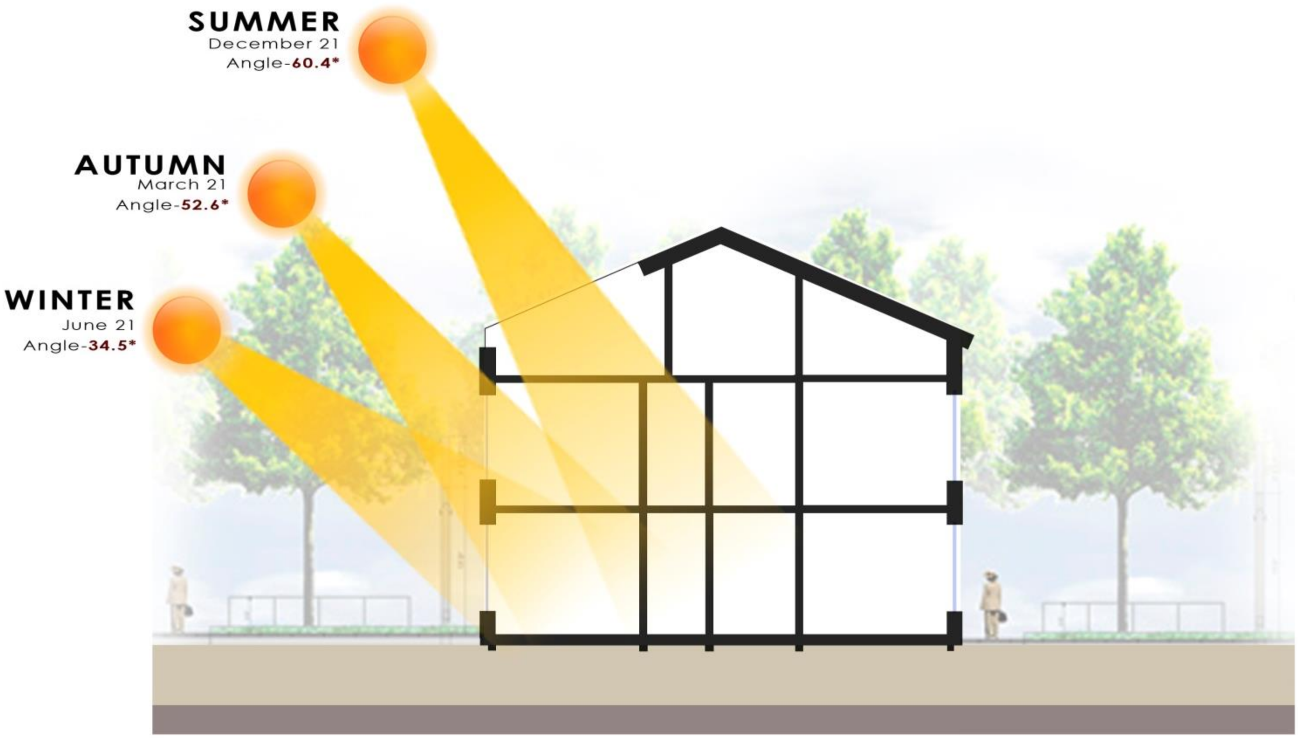


Figure 4-26. Sun positions in different time of the year.

4.4.3. Natural Ventilation

In terms of building orientation, natural ventilation can be maximized by exposing windows and openings to prevailing breezes. Prevailing winds in Rio tend to be southerly, with occasional northerly winds. Buildings oriented on an east-west long axis could be expected to have the lowest possible solar gain whilst providing good opportunities for cross-ventilation.

In Rio, ambient temperatures are usually below 35 deg. C. Even in the hottest months (January & February) daytime relative humidity is frequently below 80%. Under these conditions, natural ventilation can help people tolerate high temperature and humidity without discomfort. As such, incorporating natural ventilation into buildings in Rio is likely to improve energy efficiency by reducing the need for air-conditioning.

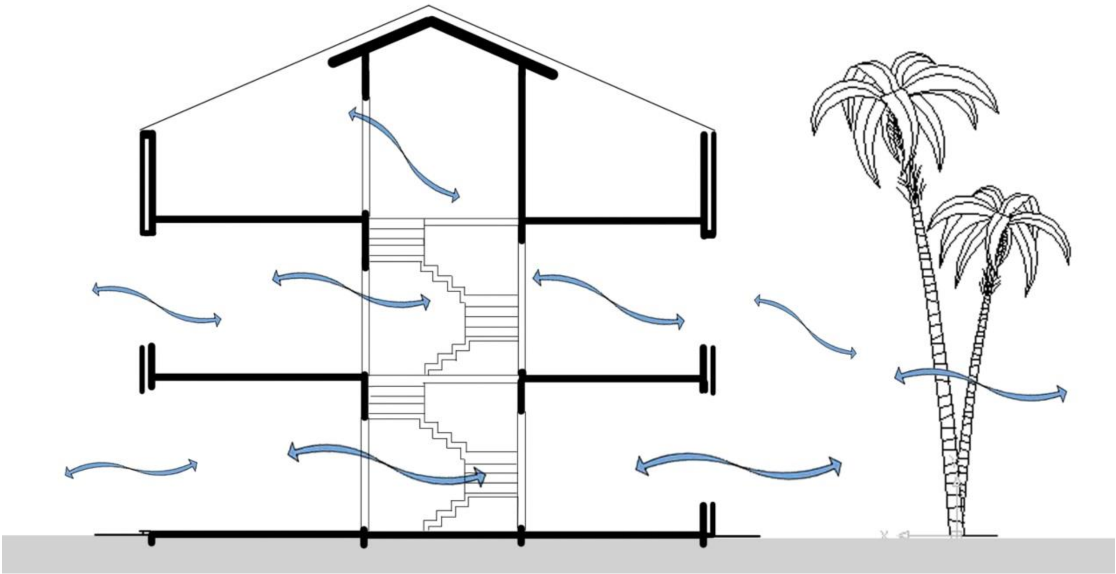


Figure 4-27. Wind motion on Vertical section

Stack ventilation, or convective air movement, relies on the increased buoyancy of warm air which rises to escape the building through high level outlets, drawing in lower level cool night air or cooler daytime air from shaded external areas (south) or evaporative cooling ponds and fountains. Cool breezes work best in narrow or open plan layouts.

Studies suggest that in hot humid environments (such as that found in Rio) effective ventilation is best achieved by large operable windows on either side of a building, with one of them facing the prevailing wind. If necessary, prevailing winds can be “funnelled” into the building by proper positioning of trees, shrubs and hard-landscape elements. Appropriately placed internal partitions can also help channel air through the occupied zone of a building [**Ошибка! Источник ссылки не найден.**].

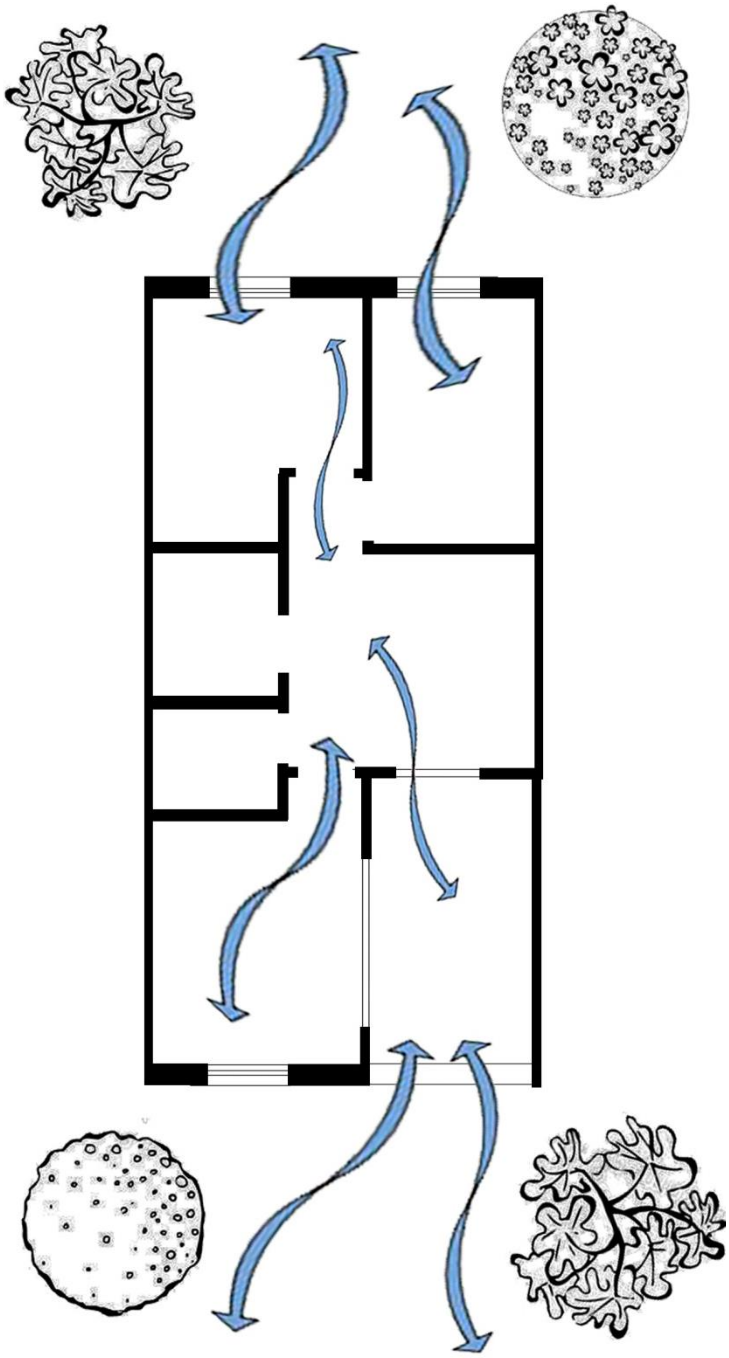


Figure 4-28. Wind motion on horizontal section

Natural Ventilation: Summary

Natural ventilation should be considered for buildings in Rio de Janeiro. Properly designed and implemented natural ventilation has the potential to significantly reduce energy consumption, running costs and greenhouse gas emissions whilst maintaining thermal comfort. It should be noted that natural ventilation systems can be rendered ineffective by moving equipment around the building or by users who do not understand how the system works. These limitations should be considered at the design stage.

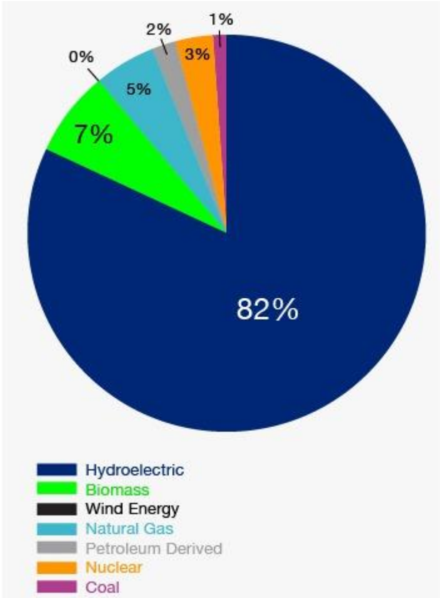
4.5. STRATEGIES

4.5.1 Renewable energy technologies and energy efficiency measures

After we analyzed the site placement and weather information, we developed the summer and winter strategies to be implemented in our design.

Our goal was to improve energy efficiency and reduce annual operating costs to building owner through advanced technology and a variety of sustainable design practices. Environmental development design best practices and goals are achieved through attention to proper siting, building form, glass properties and location, materials selection, heating, cooling, ventilation, day-lighting, and increasingly, water conservation.

4.5.2 Why Renewables?



In 2011, almost 90% of Brazilian electricity was generated from renewable sources [**Ошибка! Источник ссылки не найден.**]. Brazil is a leading nation in terms of centralized generation of electrical power by means of renewable energy sources, and has a clear national strategy that involves increasing renewable energy capacity [**Ошибка! Источник ссылки не найден.**].

Brazil has one of the largest river systems in the world, and the vast majority of electric power in the country is produced from hydroelectric power stations. In addition, large scale wind, solar and biomass projects are being rapidly developed. Development of this additional renewable power will give more diversity to Brazil's energy matrix and help secure Brazil's energy supply. In this context, simply plugging in and using electricity from the grid would appear to be an environmentally-friendly approach.

Most of the electricity in Brazil is generated by large hydroelectric power plants. Although hydroelectricity is an extremely efficient way of generating energy, delivering this energy to Rio de Janeiro involves transmission lines that are hundreds of kilometers in length [**Ошибка! Источник ссылки не найден.**]. Transmission of electricity is an inherently inefficient process and grid losses in Brazil amount to 17% [**Ошибка! Источник ссылки не найден.**].

Micro-generation of renewable electrical energy at the building-scale (by means of solar PV or biomass/biofuel powered CCHP) can help to even out peak demand, thereby reducing reliance on central electricity generation. In addition, renewable technologies such as solar-thermal systems serve to reduce the demand for electricity, which helps reduce reliance on a single energy source.

Local micro-generation of electricity can help to increase the security of supply by reducing reliance on long transmission lines.

4.5.3 Summer

As mentioned above, only minor openings should be sited on the east and west sides of buildings, and windows on these façades should be limited, in our case we orient our buildings 40 degrees from east-west direction. So big opening are oriented to north-east and south-west. During summer, these surfaces are protected by shading system and in the days with very high sun big trees located in front of the buildings protect from straight solar rays. There are also horizontal shaders on the windows which are oriented to north-west. Additional shade in the north-west oriented building is created by the very close located old buildings. Also the buildings have a light colored paint roofs, which reduce the amount of solar heat transmitted to the building, helping to keep the building cool. And we install the fabric canopies on the horizontal parts of roof.

There is a feature for energy production implemented in the building. Photovoltaic systems are used at the roof of the building. These panels are facing north-east and the roof slope is optimized to receive maximum solar energy. Beside production of energy, energy saving is considered. For this purpose, the building uses energy efficient artificial lighting.

Ventilation system in summer operates under natural upwards displacement strategy. This strategy does not require wind to drive the flow, so ventilation is provided throughout the summer, even on still days.

Finally, there is a rainwater harvesting tank beneath the building which reduces demand on the municipal water supply. Rainwater from the roof is lead through shaft inside the building and to the tank. People may use it for watering flowers.

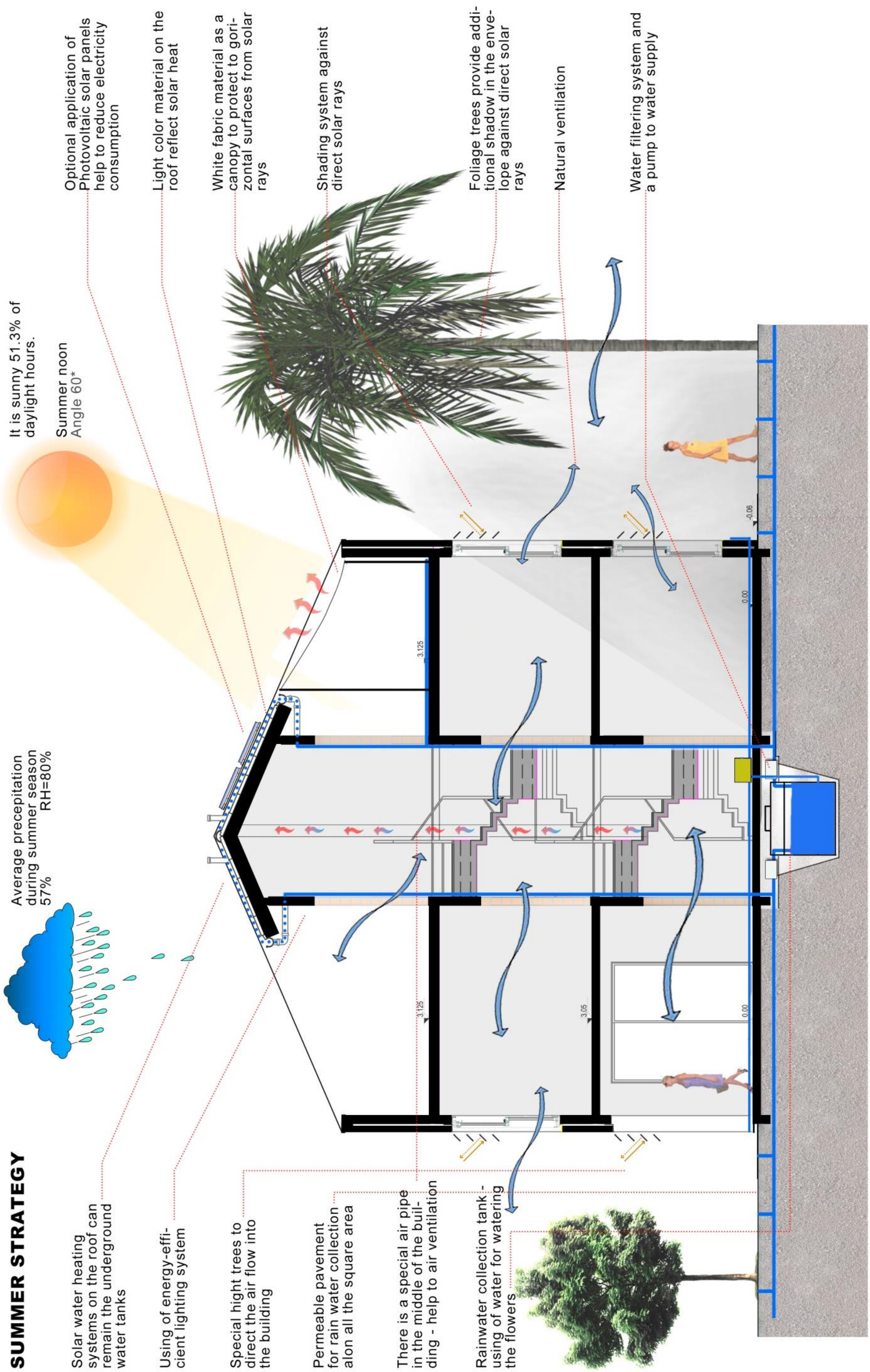


Figure 4-29. Summer strategy diagram.

4.5.4 Winter

In overall the strategies are not different from each other. The biggest differences are: sun inclination and amount of precipitation. One of the first sustainable strategies that were considered is orientation of the building. Building is opening to the South-West and closing to the East and West. Bedrooms are located in the south-west and south-east parts and we create kind of small and blocked from the sun courtyards which protect big openings on the east and west parts. As we said before, snow is not possible in this area. During winter, the next highest intensity is received by north facing walls.

The sun angle is about 34 degree. Trees still protect the buildings from the direct solar rays. There are also horizontal shaders on the windows which are oriented to north-west and north-east sides. Solar thermal water heating uses energy from the sun to heat water, which can be used for washing and domestic purposes. Also energy efficient lightings are used to reduce energy consumption.

Rainwater harvesting tank beneath the building which reduces demand on the municipal water supply. Rainwater from the roof is lead through shaft inside the building and to the tank.

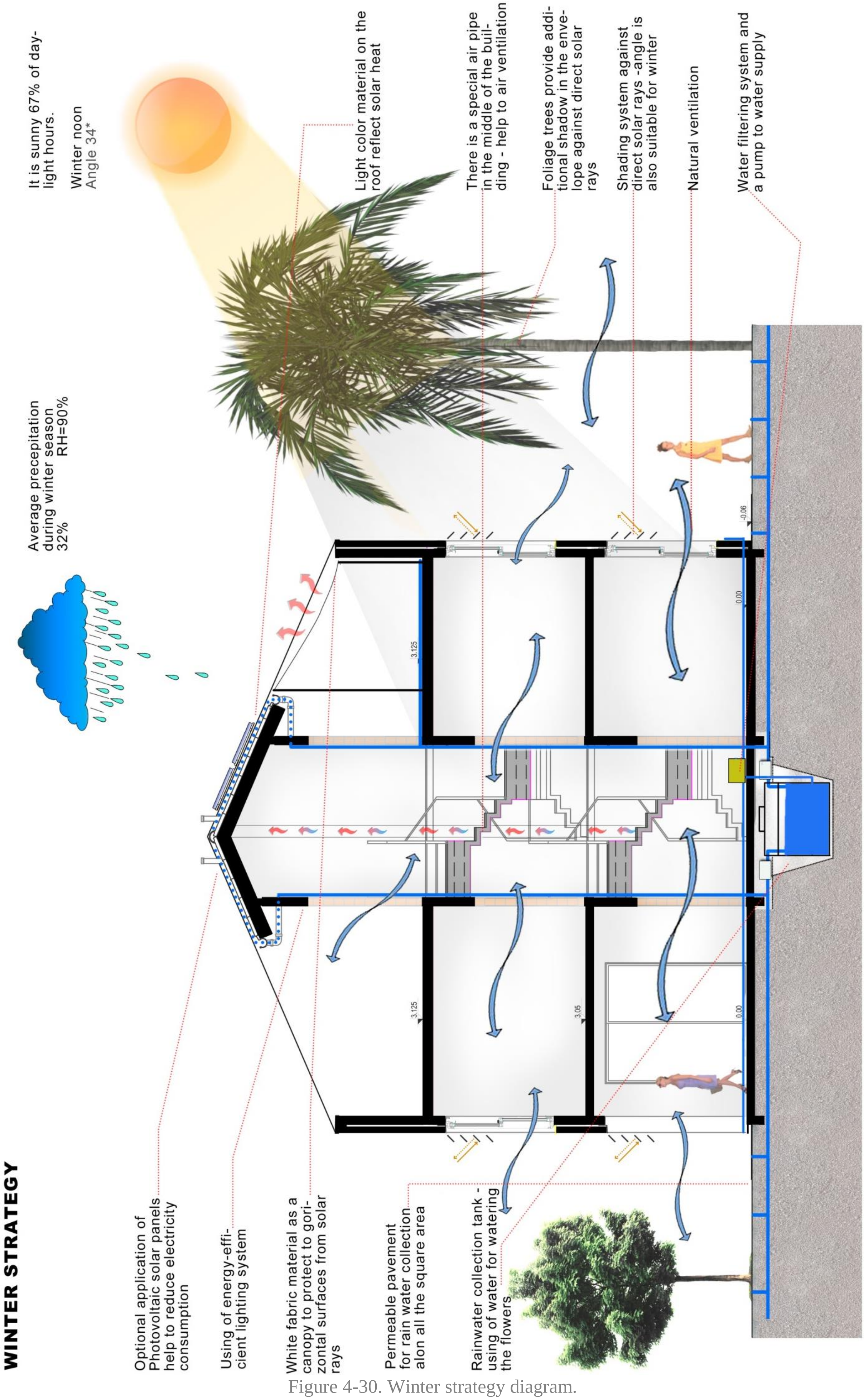


Figure 4-30. Winter strategy diagram.

4.5.5 Cool Roofs: A Cheap Way to Improve Energy Efficiency

Cool roofs reflect solar heat and emit absorbed radiation. In this way, they reduce the amount of solar heat transmitted to the building, helping to keep the building cool.

Cool roofs are relatively cheap to install and can significantly reduce the cooling load for areas beneath the roof. The cooling energy savings associated with cool roofs are in the order of 20%.

Cool roofs can also prolong the life of roofing materials and help to reduce urban heat island effects.

Cool roofs need not be white – there are many cool-color pigments that reflect energy in the near infra-red range of the solar spectrum.

In general, in areas where winter heating is not required, cool roofs provide cost savings. As such, they should be strongly considered for buildings in Rio de Janeiro.

4.5.6 Solar Photovoltaics

Brazil has extremely favorable conditions for the production of energy through photovoltaic systems. Particularly in the Northeast and Midwest of the country, where we can observe a large and constant incidence of solar radiation throughout the year. Brazil, however, occupies only the 10th place in the ranking of countries that most use solar energy (behind China, Israel, Austria, India, Turkey, Germany, United States and Australia).

Solar energy is growing in popularity amongst Brazilian consumers – partly due to a government program called PROESCO. The program aims to provide financial support for end-users and electricity supply companies wishing to install solar energy systems.

Producing power from rooftop solar panels in Brazil costs less than electricity sold by 10 of the country's 63 power distributors, according to the national energy agency Empresa de Pesquisa Energetica. Electricity from a typical 5 kilowatt system costs about 602 reais ($299) per megawatt-hour. Distributors charge between 240 and 709 reais for residential power. Power from rooftop solar systems is increasingly competitive as compared with electricity from utility companies (including Ampla Energia e Servicos SA and Cia. Energetica de Minas Gerais) [**Ошибка! Источник ссылки не найден.**]. When end-users fund solar PV projects using PROESCO, the cost for solar PV generation falls to 586 reais per MWh.

The competitiveness of distributed solar photovoltaic generation has been analyzed by Empresa de Pesquisa Energética, the State energy research company [**Ошибка! Источник ссылки не найден.**]. The analysis compared the estimated cost of generation with the rate paid by the consumer to the utility company. The analysis followed EPIA methodology to determine the cost level, and made the following assumptions:

- A discount rate of 6% per year (actual rate, ie, discounting inflation, for an annual inflation of 4.5%, for example, the nominal discount rate would be 10.8% per year)
- Life cycle of plant: 20 years (except inverters: 10 years)
- Annual cost of operation and maintenance: 1% of the investment cost
- Maturation period of investment (construction): 3 months
- Loss of efficiency of panels: 0.65% per year, with a corresponding decrease of the energy produced
- Efficiency factor: 15.1%

4.5.7 Solar Thermal Water Heating

Solar thermal water heating uses energy from the sun to heat water, which can be used for washing and domestic purposes. The energy in sunlight is captured by collectors, usually placed on roofs. Liquid is circulated in the collector, is warmed by the sun and transfers heat to water in a thermal reservoir.

In this way, water is progressively heated when the sun shines and stored in an insulated tank for convenient use.

Solar thermal water heating is a much more efficient process than generating electricity by means of solar photovoltaic technology – converting a high proportion of the incident energy to usable heat. Furthermore, solar thermal heating of domestic water is effective even when sunlight is diffuse.

Solar thermal systems are a clean and renewable way of decentralizing energy production. Such systems can deliver significant savings of electrical energy even when water is only partially heated by the solar-thermal system.

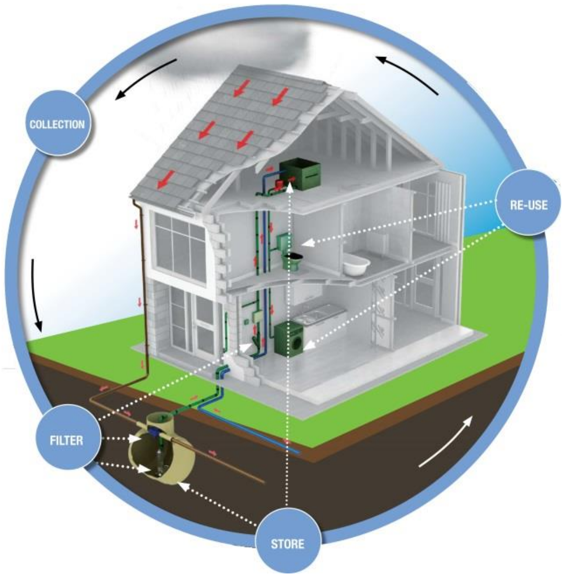
In the context of Rio de Janeiro, solar thermal water-heating is extremely significant. A large percentage of Brazilians use electrically heated showers on a daily basis – usually after work, during the peak hours between 18:00 and 21:00. These showers have a typical power consumption of up to 5,400 Watts.

This energy usage is extremely significant – it has been estimated that electric shower usage accounts for 22.6% of the electric energy consumption of the Brazilian residential sector – about 6% of the total national electric energy consumption [**Ошибка! Источник ссылки не найден.**]. Using solar energy to heat water for showers reduces demand on the electrical system and frees up more energy during peak hours. According to GIZ, solar thermal systems in Brazil may reduce energy consumption for heating water by up to 35%.

In January 2008, the state government of Rio de Janeiro approved a law that makes the installation of solar water heating systems mandatory for public buildings. Under state law Lei N° 5184 (in effect from January 2008), solar thermal systems are mandatory for new and refurbished public buildings in Rio de Janeiro. Solar energy must cover 40% of the annual hot water demand. Exemption is made for public buildings in which it is technically impossible to install a solar thermal system. The materials and equipment used in implementing the system have to comply to the Brazilian norm NBR, and the Brazilian Technical Standards Association (Portuguese: ABNT) [**Ошибка! Источник ссылки не найден.**].

Solar heating has grown rapidly in Brazil, with an area of over 5 million square meters of solar collectors installed in recent years [**Ошибка! Источник ссылки не найден.**]. Indeed, more than 1 million square metres of solar collectors were set up in 2011 [**Ошибка! Источник ссылки не найден.**].

4.5.8 Rain water harvesting



Harvesting the natural rainwater is one of the oldest and most elemental ways in which we can live sustainably with nature. Only now is the value of water being recognized as it becomes an increasingly precious resource. In our buildings we collect rainwater for domestic use such as laundry and flushing the toilet. Also for irrigation of surrounding private area.

Integrated Rainwater Harvesting Systems

The rainwater that falls onto a building's roof is channeled through standard guttering and pipework. Rather than going into the drain, the water passes through a mesh filter (to remove leaves or debris) before entering a storage tank.

When needed, this water is then automatically pumped back into the building and, (after further filtration), is put to use in non-potable applications, such as toilet flushing, laundry or commercial wash-down areas.

Float level switches within the tank alert an electronic control device to divert to mains supply should the storage tank run empty. The system will always draw on harvested water first.

System variations include the use of a header tank and booster sets, but in essence any integrated rainwater harvesting system follows the same process in its operation [**Ошибка! Источник ссылки не найден.**].

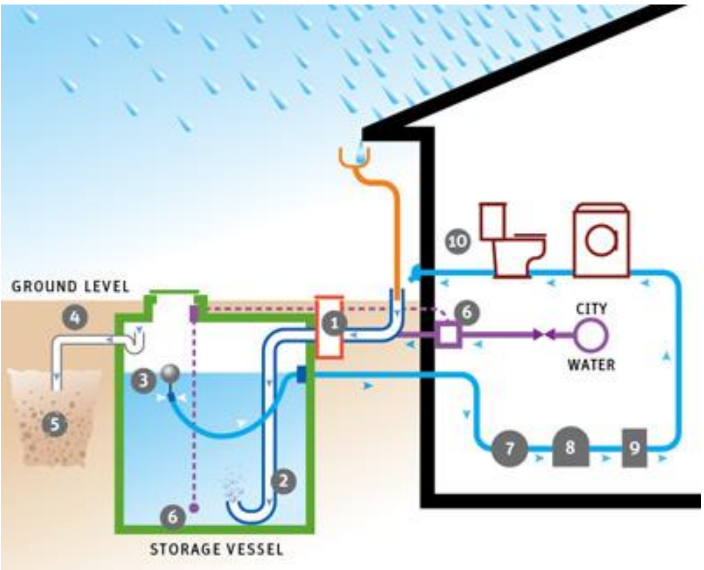


Figure 4-31. Rainwater Harvesting System

4.5.9 Summing it up

The environmental studies of the expansion of social housing area in Núcleo Gamboa district in Rio de Janeiro had four main objectives: assess the thermal comfort in the open spaces created by the horizontal disposition of buildings on site; maximize the benefits of daylight, assess the thermal performance of free running buildings where natural ventilation was required as a function the program; and finally assess the performance of architectural solutions for air-conditioned buildings, where active cooling was a design premise.

4.6. Calculation of U-value for opaque and transparent components.

A U value is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an ‘overall heat transfer co-efficient’ and measures how well parts of a building transfer heat. This means that the higher the U value the worse the thermal performance of the building envelope. A low U value usually indicates high levels of insulation. They are useful as it is a way of predicting the composite behavior of an entire building element rather than relying on the properties of individual materials.

We have 9 different types of buildings. For the simplification of calculations we are presenting the data of one building (Typology №04) which is located in the middle of the social housing area and can give us the average results which can be suitable also for other typologies.

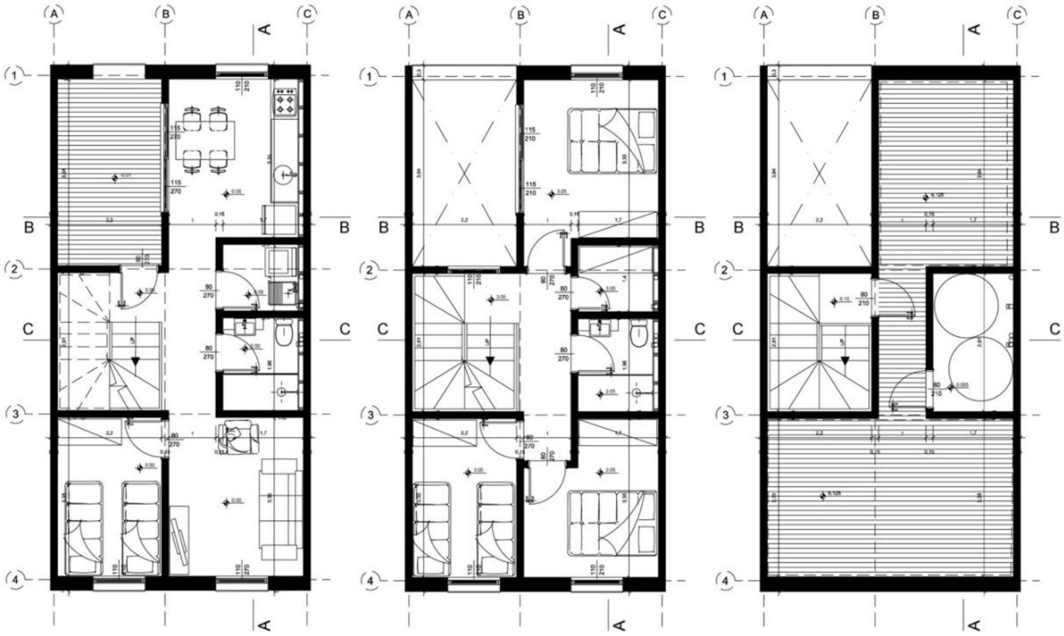


Figure 4-32. Plans of the selected building (Typology 04)

The structure is composed of three stories of 51.1 m2, and each floor is 2.9 m high. The building is characterized by big amount of windows, as shown in picture above. This has an important impact on the building's energy demand, because of the climatic conditions of Rio de Janeiro in terms of solar radiation. The roof is pitched.


Figure 4-33. Top view of selected building (Typology 04)

4.6.1 Used parameters for dispersant surfaces

Let's see in particular how these technological elements are composed in the specific:

Wall: **U-Value = 0.9 W/m²K**

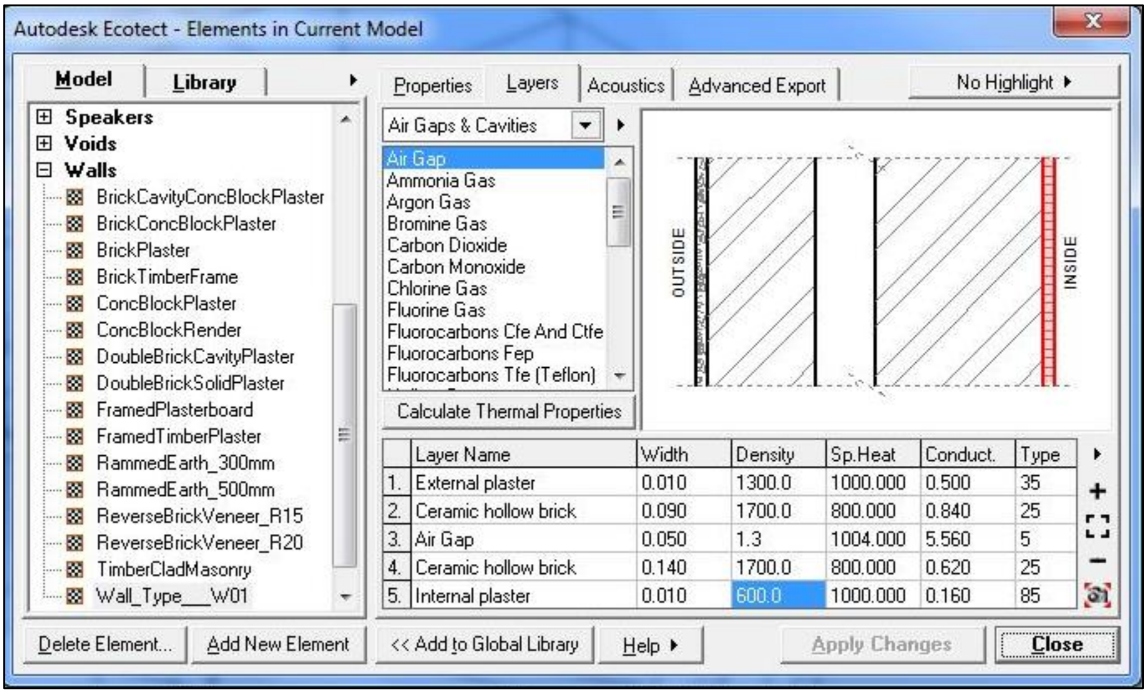


Figure 4-34. Table with the wall material properties

Roof: **U-Value = 0.25 W/m²K**

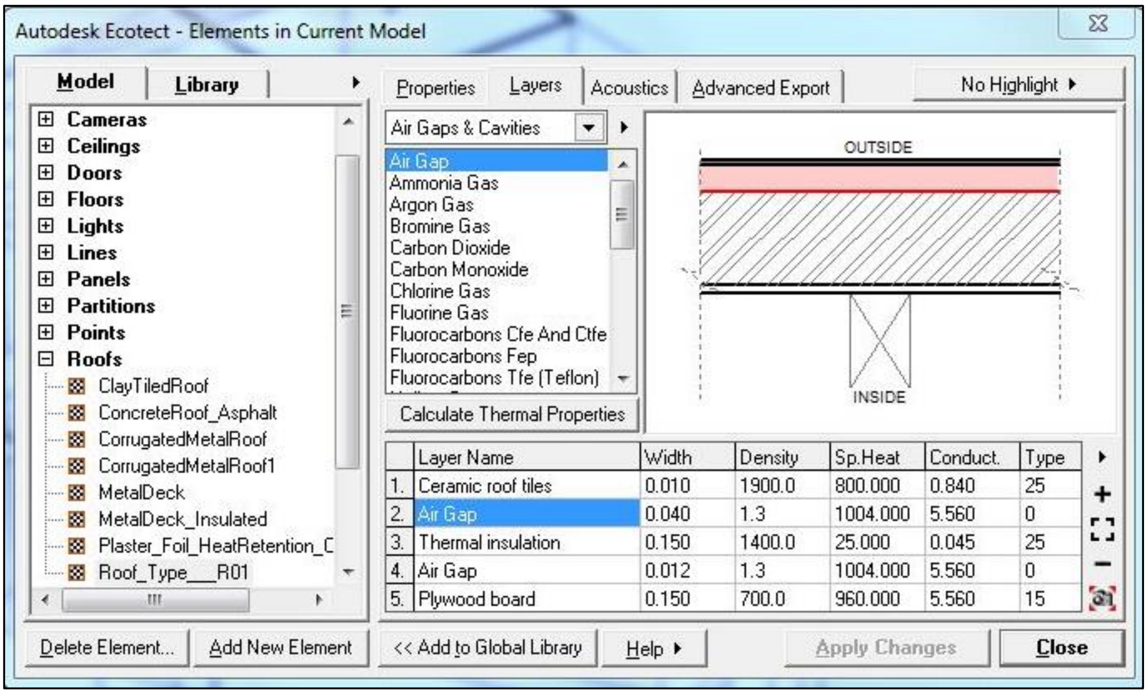


Figure 4-35. Table with the roof material properties

Floor: **U-Value = 1.4 W/m²K**

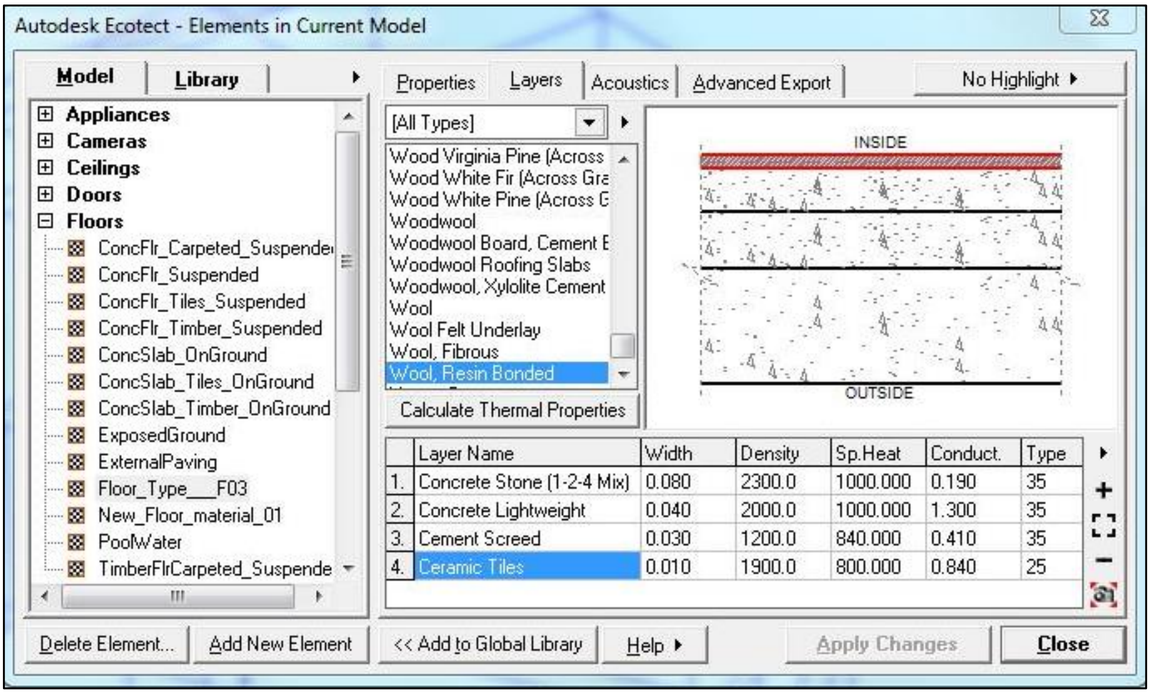


Figure 4-36. Table with the floor material properties

Windows: **U-Value = 2.26 W/m²K**

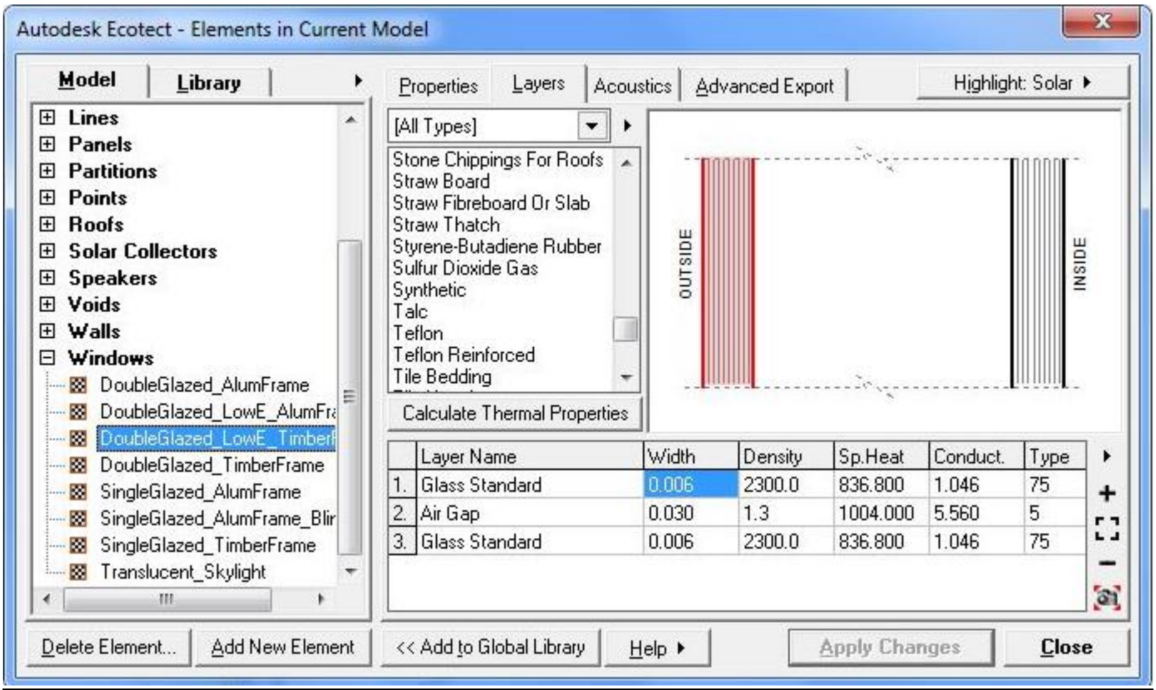


Figure 4-37. Table with the window material properties

The U value of this element is not very good (numbers are high). But the envelope of the building is made not from many layers and there is almost no thermal insulation. The reason of this solution is to save money on the construction and to use green strategies to avoid possible discomforts.

4.7. Lighting analysis

4.7.1 Introduction

In order to have an idea about the amount of the solar radiation loads on our site, according with the presence of the surroundings building, we made a shadow analysis in 3 significant days in the year:

- 21^{st} of March (Equinox of Spring)
- 21^{st} of June (Equinox of Winter)
- 21^{st} of December (Equinox of Summer)

We didn’t take into account the 21^{st} of March (Equinox of Spring) because the situation is equal to the 21^{st} of September one.
Thanks to this study we can approach in a more rational and effective way designing elements of control of the solar radiation, like sunscreens and other elements of shading, in order to be able to control excessive thermal load due to sun irradiance during the summer and to keep free thermal gain during the winter.

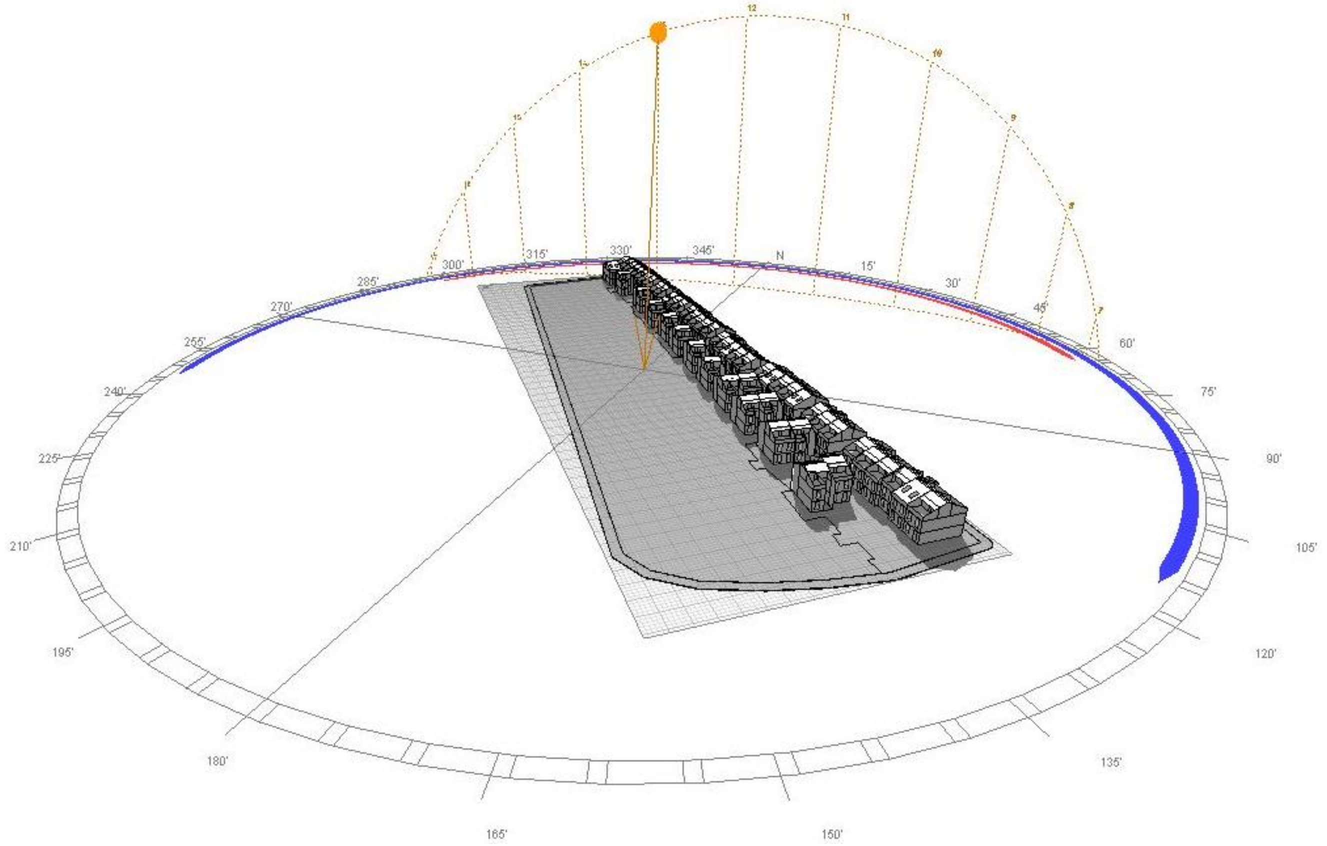
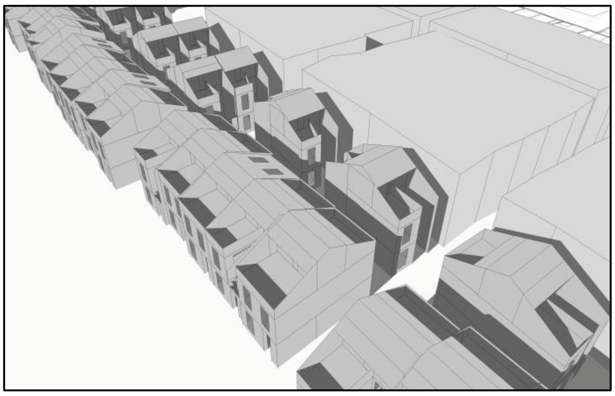
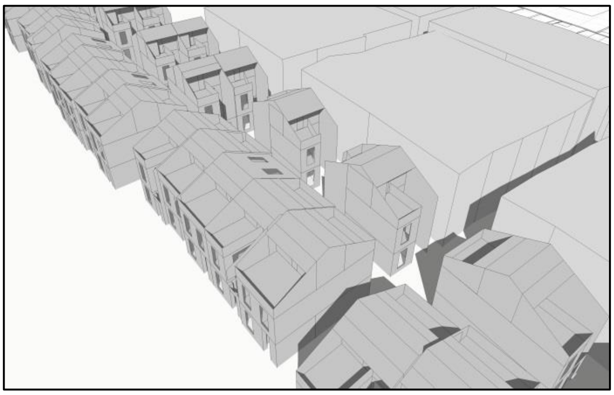


Figure 4-38. Lighting Analysis

4.7.2 Solar Study

<u>21st of June (Equinox of Winter)</u>





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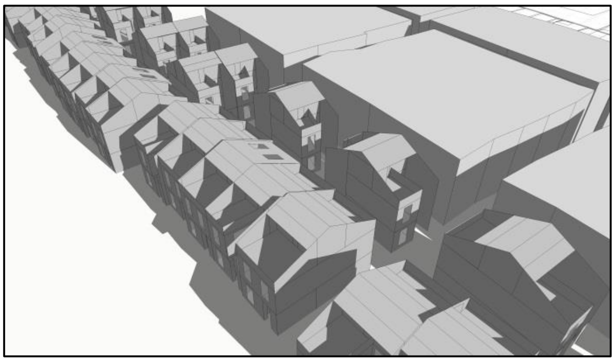
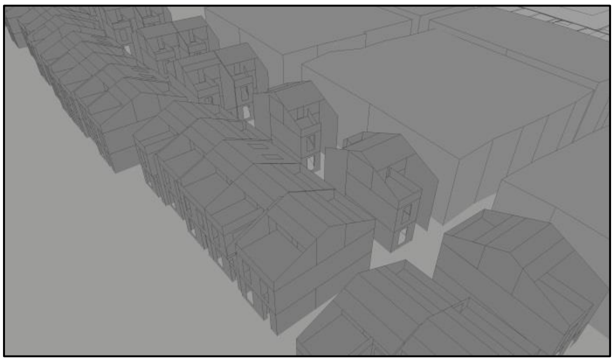


15:00



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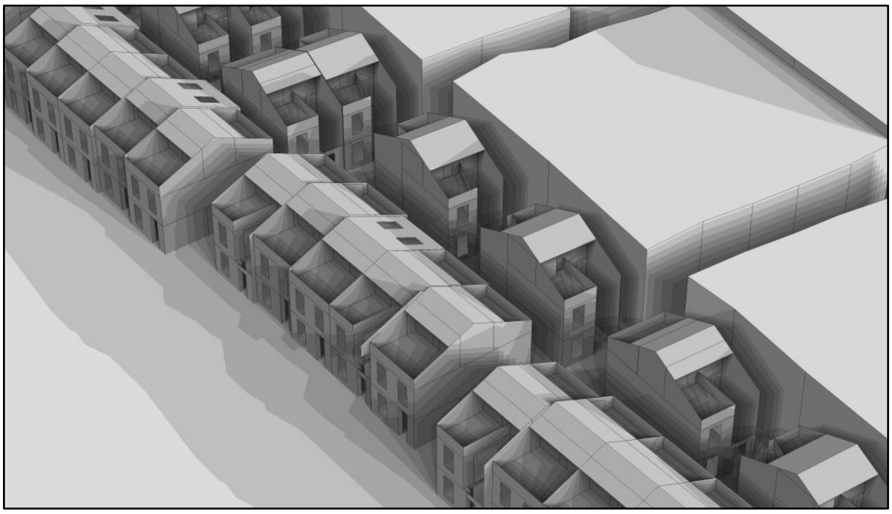
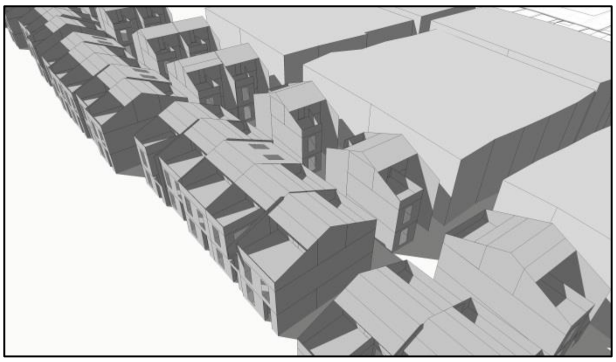


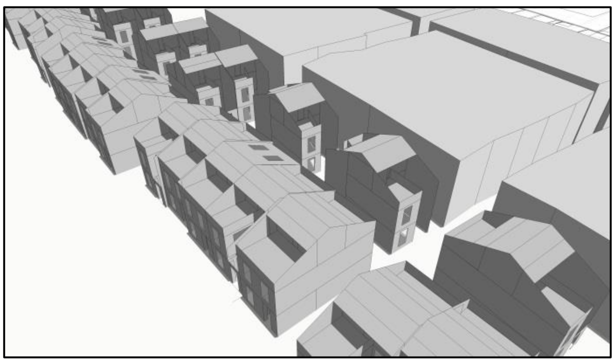
09:00 – 18:00

Figure 4-39. Lighting Analysis in different hours of the day 21th of June

21st of December (Equinox of Summer)



09:00



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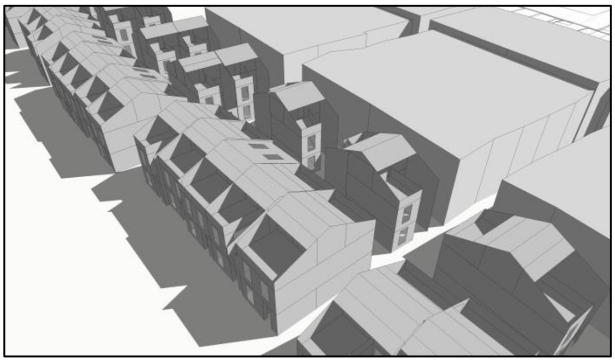
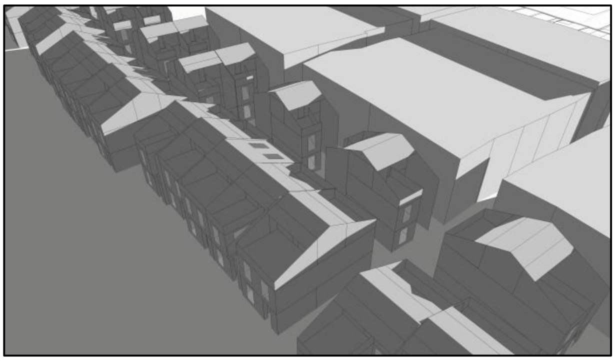
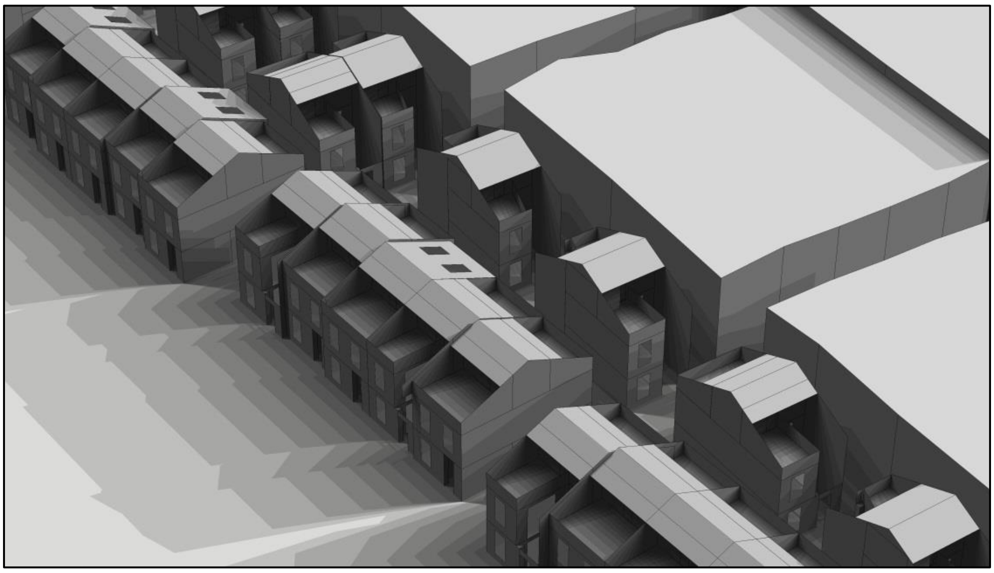




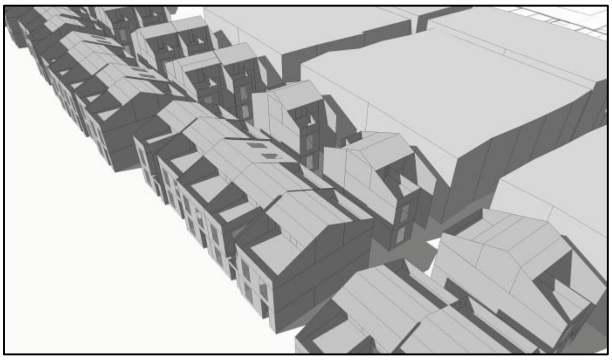
15:00 18:00



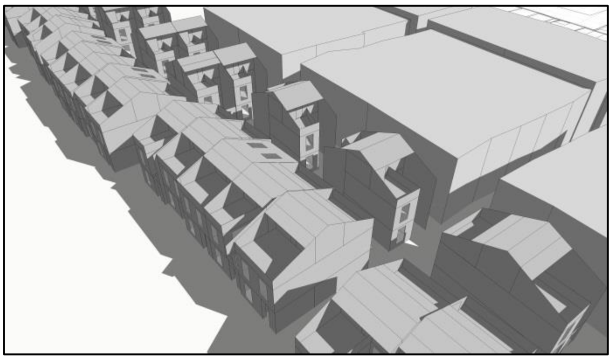
09:00 – 18:00

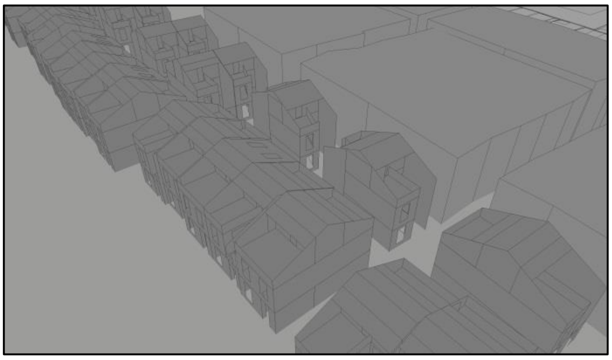
Figure 4-40. Lighting Analysis in different hours of the day 21th of December

21st of March (Equinox of Spring)

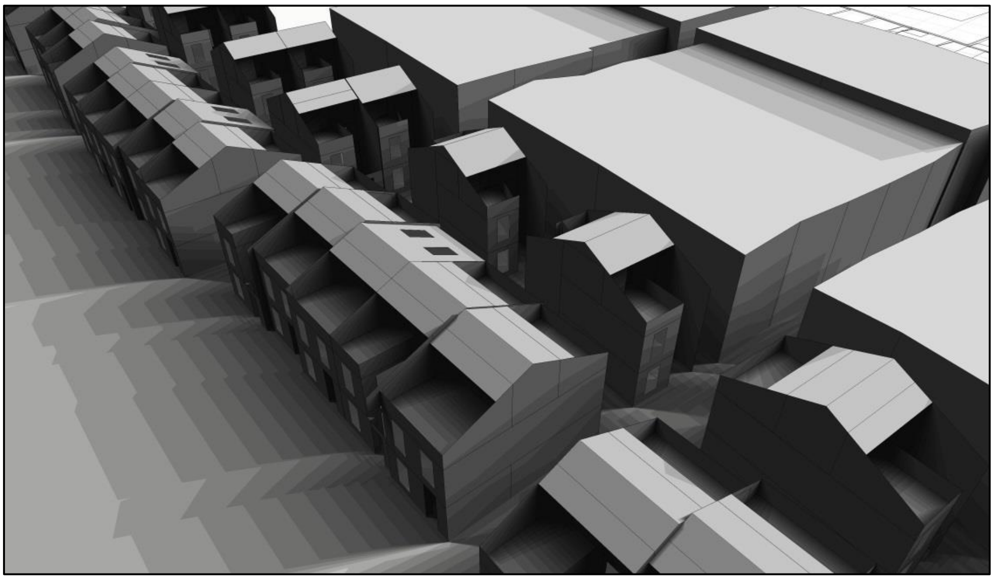


09:00 12:00





15:00 18:00



09:00 – 18:00

Figure 4-41. Lighting Analysis in different hours of the day 21th of March

4.7.3 Conclusions

From the solar study we discovered that on the north side of the roof we don’t have significant shadow during the year, so it means that is reasonable to plan some solar strategies in order to use irradiation for thermal and energy purpose but also to control sunlight with shading elements not to have heavy heat loads during the summer that, in case, would need more energy for cool the inner space to reach the thermal comfort point.

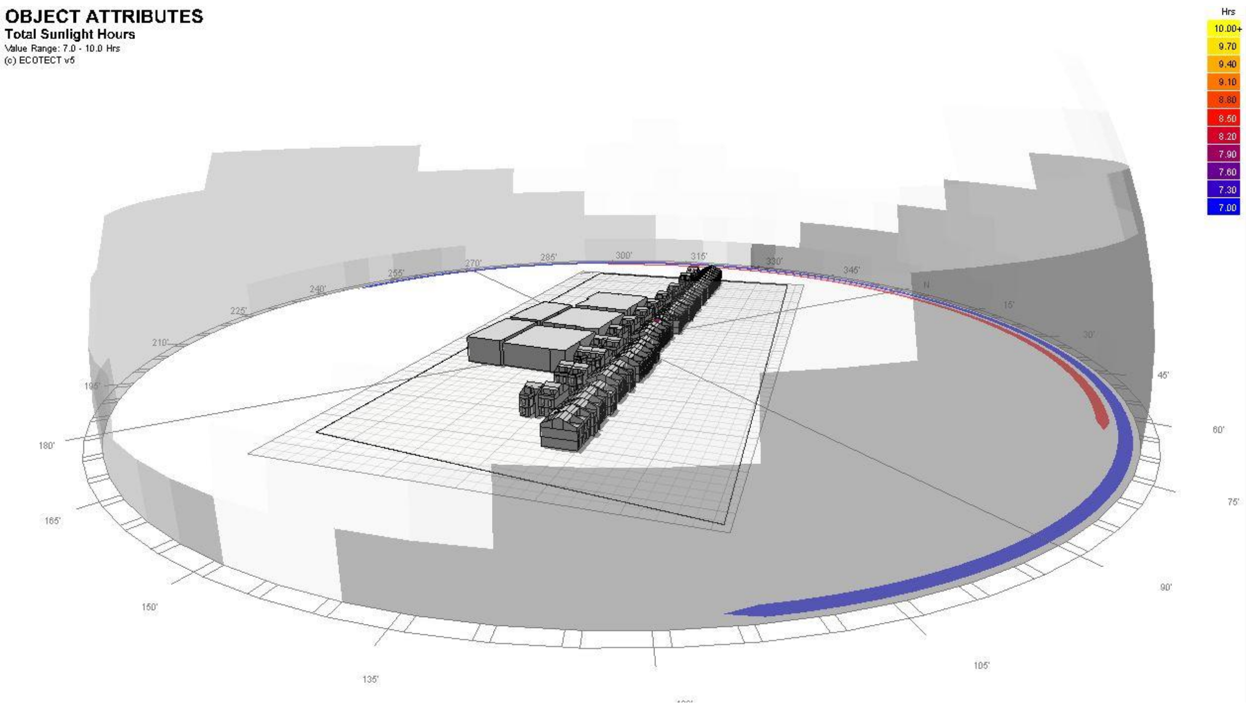


Figure 4-42. Total sunlight hours on the roof top (3d pic.)

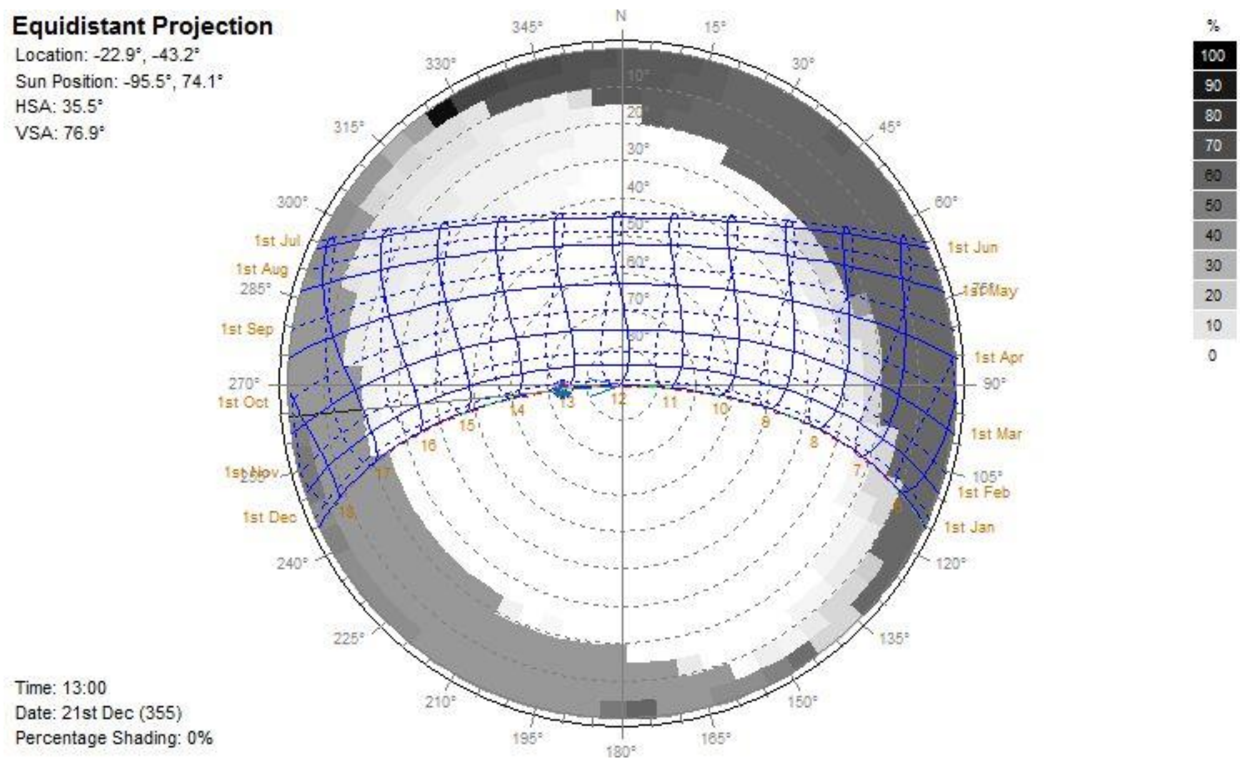


Figure 4-43. Total sunlight hours on the roof top (Equidistant Projection)

4.8. Shading.

Due to highly exposed northern facades with glazed surfaces, shading devices is necessary to bring down the cooling loads and intense direct sunlight during the summer. By generating optimized shading devices in Ecotect and then run a solar simulation, it is possible to see where it is necessary to have shading during certain periods over the year.

The benefits with an overhanging fixed shading system like this are that in the summer, the shading protects the windows from the high sun. In the winter, when the sun stands lower, it allows the rays to enter the building and provide with natural light and solar gain.

Also we provide the line of trees in front of the building which will help us to protect the building from the afternoon high sunlight.

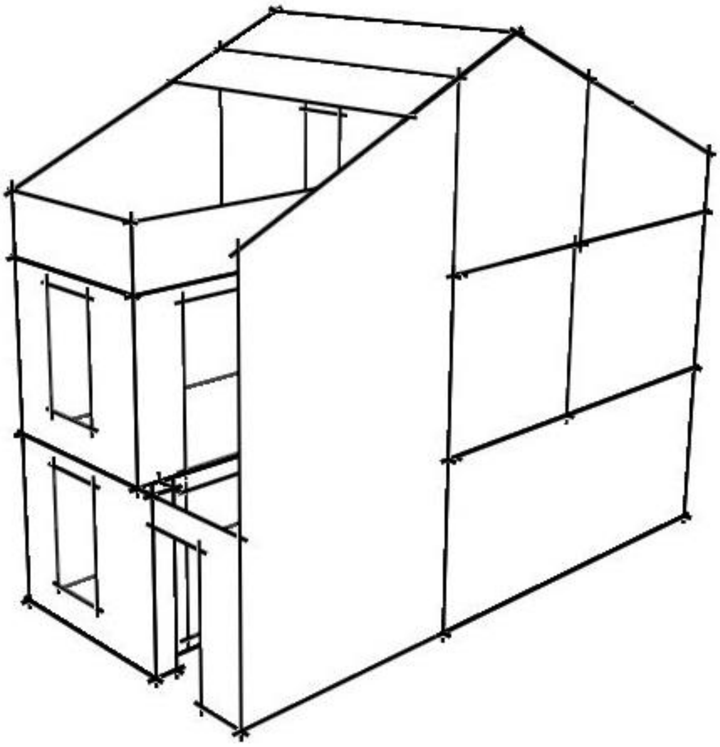


Figure 4-44. Ecotect model of building for shading analysis

Conclusion:

With this shading system we will lower the cooling demand due to reduced amount of solar radiation entering the envelope of the building. The high intensity solar light does not enter the building directly if the shading system is operated correctly. Sense the blades of the shading system always should face the sun; there is a possibility to use solar panels and obtain further sustainability.

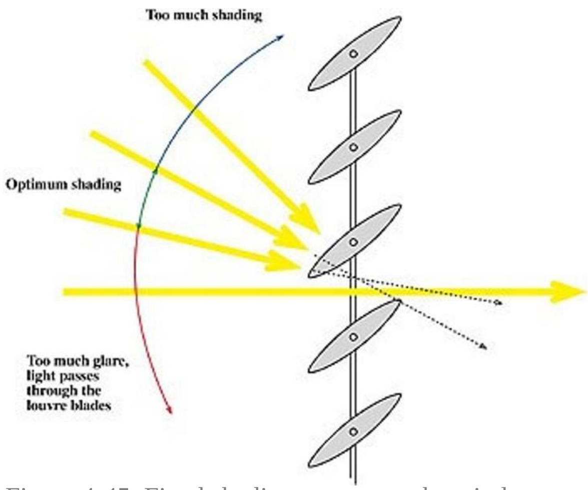


Figure 4-45. Fixed shading system on the windows

Shadow Design Wizard from Ecotect helps us to create the optimal and best conditions for a specific window.

This was done and the image to the right shows the result. We can see how not all of the shading is really used; this means that a smaller version of the shading can be created without exposing the windows to the most intense radiation. The image shows our building with an optimized shading system during the whole year from 10:00 to 15:00.

The drawback s with an overhanging fixed shading system like this is that in the summer, the shading protects the windows from the high sun. In the winter, when the sun stands lower, it allows the rays to enter the building. The problem with this type of shading is that in summer during morning and afternoon, when the sun is lower, a large amount of the solar rays shoots straight in the building.

Another type of shading system is the fixed kind; this option viewed on the right has horizontal fixed blades to control the solar ray penetration of the building envelope.

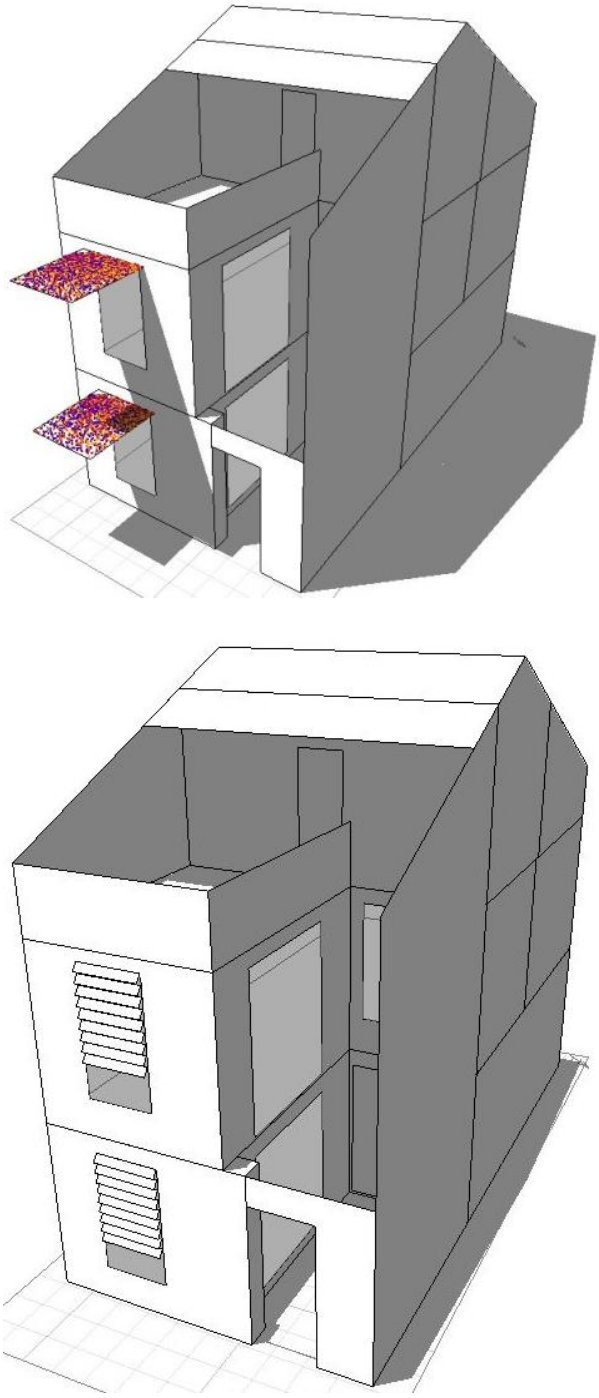


Figure 4-46. Two cases of shading systems

4.9. Daylight comfort study.

This analysis is made to see the light comfort, measured thanks to the daylight factor, inside our building, but also the impact of some windows on this light comfort.

Daylight Factor is a ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time under overcast skies, and define as follow:

DF = (Ei / Eo) x 100%

Where:

Ei = illuminance due to daylight at a point on the indoors working plane

Eo = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

In order to calculate Ei, one must establish the amount of light received from the outside to the inside of a building. There are three separate components of the natural light that reaches any point inside a building through a glazed window, rooflight, or aperture, as folloes:

Sky Component (SC): Directly from the sky, through an opening such as a window.

Externally Reflected

Component (ERC): Light reflected from an exterior surface and then reaching the point considered, Reflected off the ground, trees or other buildings.

Internally Reflected Component (IRC): The inter reflection of 1 and 2 off surfaces within the room.

The sum of the three components gives the illuminance level(lux) at the point considered: Lux = SC + ERC + IRC

Daylight factors are used in architecture and building design in order to assess the internal natural lighting levels as perceived on the working plane or surface in question, in order to determine if they will be sufficient for the occupants of the space to carry out their normal duties.

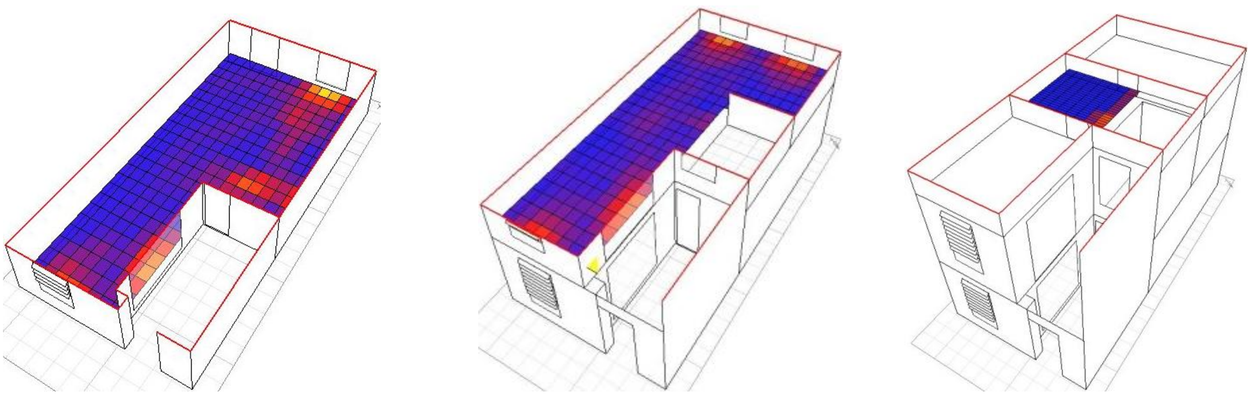


Figure 4-47. 3d model of Daylight Factor

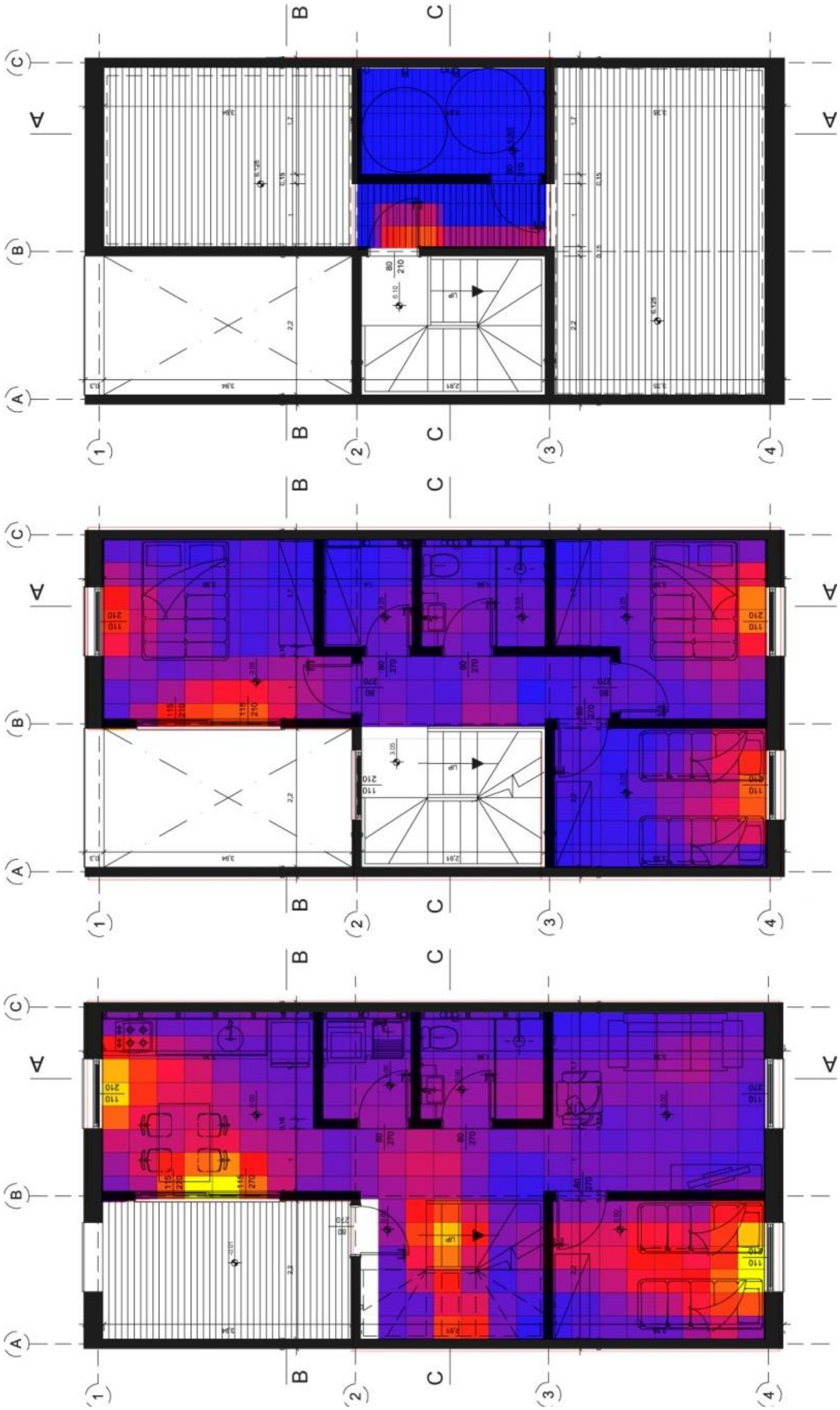


Figure 4-48. 3d model of Daylight Factor

4.9.1. Solar Irradiance Calculator

This solar irradiance calculator shows you how much power you get from the sun at our location on an average day for every month of the year.

Solar irradiance is a measure of the sun power. Irradiance levels vary considerably at different times of the year, depending on the seasons, the weather and the time of day.

Irradiance calculator provides monthly figures showing the average kWh per square metre per day of energy that the sun provides.

Station Identification	
City:	Santos Dumont�Rio
Country/Province:	BRA
Latitude:	22.90° S
Longitude:	43.17° W
Elevation:	3 m
Weather Data:	SWERA
PV System Specifications	
DC Rating:	4.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.08 kW
Array Type:	Fixed Tilt
Array Tilt:	20.0°
Array Azimuth:	49.0°
Energy Specifications	
Energy Cost:	0.3140 real/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value (real)
1	6.19	517	162.34
2	6.43	489	153.55
3	5.44	457	143.50
4	5.14	425	133.45
5	4.27	362	113.67
6	4.08	345	108.33
7	4.17	359	112.73
8	4.74	407	127.80
9	4.82	397	124.66
10	5.39	461	144.75
11	5.90	483	151.66
12	5.89	497	156.06
Year	5.20	5199	1632.49

Table 4-3. Solar irradiance calculator results

4.10. Thermal analysis

The monthly loads/discomfort graph is calculated for an air-conditioned zone, the graph displays the heating and cooling loads for the selected zone, measured in Watts (W). The red bars represent when heating is required and are plotted in the positive axis for the graph. The blue bars represent when cooling is required, and are plotted in the negative axis of the graph.

Total annual heating loads for this module is around 1 MW/h and the total annual cooling loads there which around 22 MW/h is.

The total load of the building during the year is 23 KWh/m2.

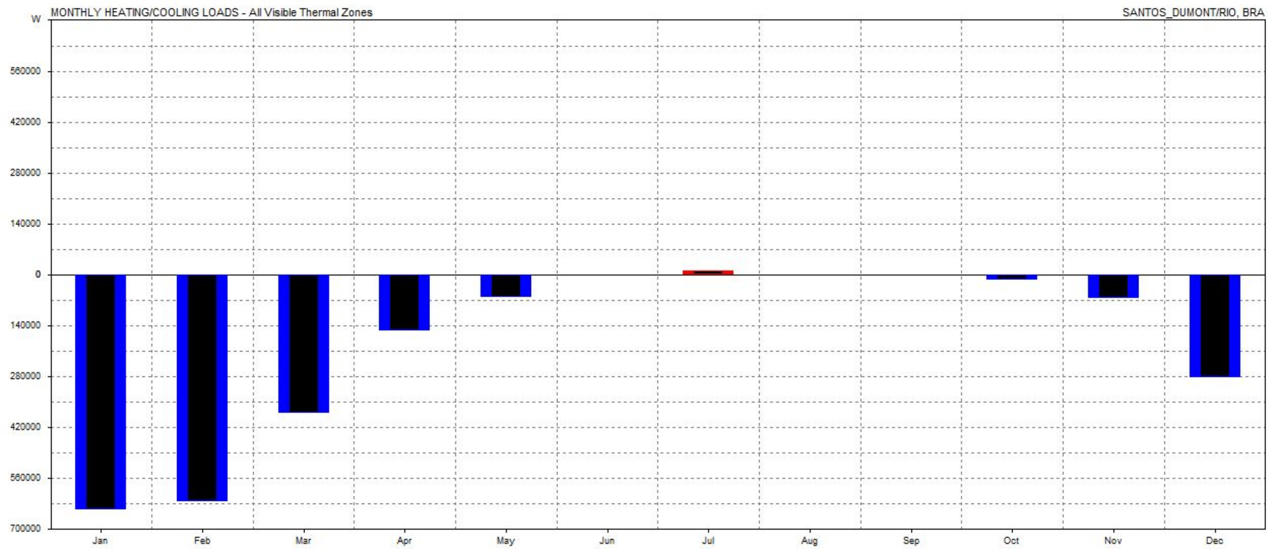


Figure 4-48. Thermal Calculation (Monthly loads/Discomfort)

MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 681 W at 00:00 on 2nd July			
Max Cooling: 3750 W at 16:00 on 15th March			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	0	645612	645612
Feb	0	622448	622448
Mar	0	380799	380799
Apr	0	154888	154888
May	0	60771	60771
Jun	0	0	0
Jul	12547	0	12547
Aug	0	0	0
Sep	1361	0	1361
Oct	0	15333	15333
Nov	0	63099	63099
Dec	0	282927	282927
TOTAL	**13908**	**2225876**	**2239785**
PER MI	**97**	**15525**	**15622**
Floor Area:	**143.378 m2**		

Table 4-4. Thermal Calculation (Table results)

CHAPTER 5: STRUCTURAL DESIGN

5.1 Overview of the structure

While choosing the structural system and the using of the materials, we were taking into consideration following aspects:

- Cost. Developing the idea of social housing, this factor becomes crucial. Using the pre-fabricated ceramic slabs and masonry helps to reduce the total cost of the construction, doesn't require heavy machinery, transportation and high-qualified labor;
- Availability. Being commonly used and highly-spread in the area, masonry becomes the most desirable type of structure;
- High Speed of construction;
- Sustainability. Exploration and production of bricks requires a minimum of energy and practically does not harm the environment. The modern concept of factories allows producing ceramic blocks with almost no harmful emissions, using clean primary energy sources. Also it has high thermal and sound insulation properties that creates healthy microclimate at home.
- Traditions. Providing the type of dwelling that people are used to increases the comfort in wellness in the neighborhood.

More about the material and structure choice you can read in the Chapter III - Architectural Design (3.5)

5.3 Loading.

Dead, live, roof live loads were calculated according to EUROCODE1. [38]

5.3.1 Dead Load

Dead load is a total weight of all the structural components (masonry walls, pre-manufactured slabs, roof).

Figure 5-1 – Floor and wall types

Roof Type - R01

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	ceramic roof tile (portuguese style)	0,01	-	39,8	390,3
2	air gap (between the wooden bars)	0,04	-	-	-
3	thermal insulation (cellulose insulation batt panel)	0,045	30	1,35	13,239
4	air gap (between the wooden bars)	0,12	-	-	-
5	plywood board	0,015	700	10,5	102,97
6	roof system (13,57+4,8+7,5)	-	-	25,87	253,7
				77,52	760,21

Table 5-1 – Loading of the Roof Type R01

Floor Type - F01

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	wooden deck	0,035	510	17,85	175,05
2	screed	0,03	1800	54	529,56
3	waterproof membrane	0	-	-	-
4	concrete slab	0,04	2300	92	902,21
5	pre-cast slab (system beam/ceramic blocks)	-	-	182	1784,8
				345,85	3391,6

Table 5-2 – Loading of the Floor Type F01

Floor Type - F02

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	screed	0,03	1800	54	529,56
2	concrete slab	0,04	2300	92	902,21
3	pre-cast slab (system beam/ceramic blocks)	-	-	182	1784,8
				328	3216,6

Table 5-3 – Loading of the Floor Type F02

Floor Type - F03

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	polished cement layer	0,01	1500	15	147,1
2	screed	0,03	1800	54	529,56
3	concrete slab	0,04	2300	92	902,21
4	pre-cast slab (system beam/ceramic blocks)	-	-	182	1784,8
				343	3363,7

Table 5-4 – Loading of the Floor Type F03

Floor Type - F04

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	wooden deck	0,02	510	10,2	100,03
2	air gap (between wooden bars)	0,08	-	-	-
				10,2	100,03

Table 5-5 – Loading of the Floor Type F04

Wall Type - W01

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,09	765	68,85	675,1879
3	air gap	0,05	-	-	-
4	ceramic hollow brick	0,14	700	98	961,0517
5	internal plaster	0,01	1600	16	156,9064
				198,85	1950,052

Table 5-6 – Loading of the Wall Type W01

Wall Type - W02

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,14	700	98	961,0517
3	internal plaster	0,01	1600	16	156,9064
				130	1274,865

Table 5-7 – Loading of the Wall Type W02

Wall Type - W03

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,09	765	68,85	675,1879
3	ceramic hollow brick	0,14	700	98	961,0517
4	internal plaster	0,01	1600	16	156,9064
				198,85	1950,052

Table 5-8 – Loading of the Wall Type W03

Wall Type - W04

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,09	765	68,85	675,1879
3	ceramic hollow brick	0,14	700	98	961,0517
4	rough plaster	0,01	1600	16	156,9064
5	ceramic tile + synthetic cement glue	0,005	1800	9	88,25985
				207,85	2038,312

Table 5-9 – Loading of the Wall Type W04

Wall Type - W05

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	ceramic tiles	0,04	1900	76	745,3054
2	ceramic hollow brick	0,115	650	74,75	733,0471
3	internal plaster	0,01	1600	16	156,9064
				166,75	1635,259

Table 5-10 – Loading of the Wall Type W05

Wall Type - W06

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	internal plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,14	700	98	961,0517
3	internal plaster	0,01	1600	16	156,9064
				130	1274,865

Table 5-11 – Loading of the Wall Type W06

Wall Type - W07

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,115	650	74,75	733,0471
3	external plaster	0,01	1600	16	156,9064
				106,75	1046,86

Table 5-12 – Loading of the Wall Type W07

Wall Type - W08

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	external plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,09	765	68,85	675,1879
3	air gap	0,05	-	-	-
4	ceramic hollow brick	0,14	700	98	961,0517
5	external plaster	0,01	1600	16	156,9064
				198,85	1950,052

Table 5-13 – Loading of the Wall Type W08

Wall Type - W09

	Layer	Thickness	Specific weight	Weight/ area	Weight/ area
		(m)	(kg/m³)	(kg/m²)	(N/m²)
1	internal plaster	0,01	1600	16	156,9064
2	ceramic hollow brick	0,115	650	74,75	733,0471
3	ceramic hollow brick	0,115	650	74,75	733,0471
4	internal plaster	0,01	1600	16	156,9064
				181,5	1779,907

Table 5-14 – Loading of the Wall Type W09

5.3.2 Live Load

According to EN1991-1-1: section 6 [38], there are imposed loads to be considered for a wide variety

of cases. For the we used a variable load of 2 kN/m^2 for the floors and stairs and 0,4 kN/m^2 for the roofs.

Table 6.9 - Categorization of roofs

Categories of loaded area	Specific Use
H	Roofs not accessible except for normal maintenance and repair.
I	Roofs accessible with occupancy according to categories A to ⟨AC1⟩ G ⟨AC1⟩
K	Roofs accessible for special services, such as helicopter landing areas

Table 5-15 – Categorization of the roof. EN1991-1-1: Section 6.

Table 6.10 - Imposed loads on roofs of category H

Roof	q_k [kN/m^2]	Q_k [kN]
Category H	q_k	Q_k

NOTE 1 For category H q_k may be selected within the range 0,00 kN/m^2 to 1,0 kN/m^2 and Q_k may be selected within the range 0,9 kN to 1,5 kN.

Where a range is given the values may be set by the National Annex. The recommended values are:

$$q_k = 0{,}4 \text{ kN/m}^2,\ Q_k = 1{,}0\text{kN}$$

NOTE 2 q_k may be varied by the National Annex dependent upon the roof slope.

NOTE 3 q_k may be assumed to act on an area A which may be set by the National Annex. The recommended value for A is 10 m^2, within the range of zero to the whole area of the roof.

NOTE 4 See also 3.3.2 (1)

Table 5-16 – Imposed loads on roofs H. EN1991-1-1: Section 6.

Table 6.1 - Categories of use

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.

Table 5-17 – Categories of use. EN1991-1-1: Section 6.

Table 6.2 - Imposed loads on floors, balconies and stairs in buildings

Categories of loaded areas	q_k [kN/m^2]	Q_k [kN]
Category A		
- Floors	1,5 to2,0	2,0 to 3,0
- Stairs	2,0 to4,0	2,0 to 4,0
- Balconies	2,5 to 4,0	2,0 to 3,0

Table 5-18 – Imposed loads on floors, balconies and stairs in buildings. EN1991-1-1: Section 6.

5.3.3 Wind Load

EN 1991-1-4 gives guidance on the determination of natural wind actions for the structural design of building and civil engineering works for each of the loaded areas under consideration.

1. **Determination of the Basic Wind Velocity, V_b:**

$V_b = C_{dir} \cdot C_{season} \cdot V_{b,0}$

Where:

V_b is the basic wind velocity, defined as a function of wind direction and time of year at 10 m above ground of terrain category II

$V_{b,0}$ is the fundamental value of the basic wind velocity

C_{dir} is the directional factor

C_{season} is the season factor

The values for C_{dir} and C_{season} are equal to 1. [38]

EN 1991-1-4 is 1: The value of the directional factor, C_{dir}, for various wind directions may be found in the National Annex. The recommended value is 1,0.

The value of the season factor, C_{season}, may be given in the National Annex. The recommended value is 1,0.

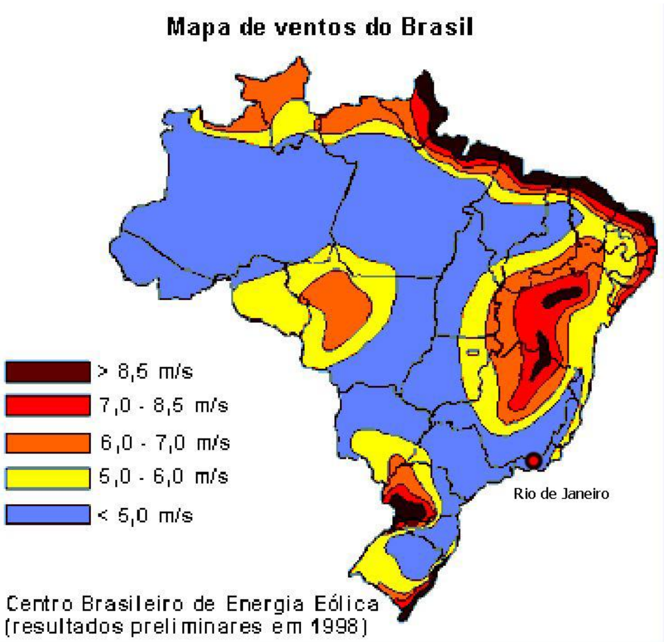


Figure 5-2 – Wind Map of Brazil [39]

Therefore the basic wind velocity is given by:

$$V_b = C_{dir} \cdot C_{season} \cdot V_{b,0}$$

$V_b = 1 \cdot 1 \cdot 4.5$ m/s

$V_b = 4.5$ m/s

2. Basic wind velocity pressure

$q_b = \frac{1}{2} \cdot p_{air} \cdot v_b^2$

Where p_{air} = 1.25 kg/m^3

$q_b = \frac{1}{2} \cdot 1.25 \cdot 4.5^2 = 12.66$ N/m^2

3. Peak pressure

$q_p(z) = [1+7I_v(z)] \cdot \frac{1}{2} \cdot p \cdot V_m(z)^2$

Calculation of the Mean Wind Velocity, V_m (z):

V_m (z) = C_r (z) ·C_o (z) ·V_b

Where:

C_r (z) is the roughness factor,

C_o (z) is the orography factor, taken as 1.0 unless otherwise specified.

C_r (z) = $k_T \cdot \ln(\frac{z}{z_0})$ for $z_{min} < z < z_{max}$

Where: z_0 is roughness length (1m);

$k_T = 0.19 \cdot (\frac{z_0}{z_{0,II}})^{0.07} = 0.19 \cdot (\frac{1}{0.05})^{0.07} = 0.19 \cdot 1.233 = 0.234$

V_m (z) = C_r (z) ·C_o (z) ·V_b = $k_T \cdot \ln(\frac{z}{z_0}) \cdot 1 \cdot 4{,}5 = 0.234 \cdot 2.357 \cdot 4.5 = 2.482$ m/s

Where $z_{0,II}$ = 0.05 (terrain category II). Our terrain category is IV: Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m.

z_{min} is the minimum height (10m);

z_{max} is to be taken as 200m

Calculation of I_v(z).

I_v(z) – turbulence intensity

$I_v = \frac{k_I}{c_o(z) \cdot \ln(\frac{z}{z_0})}$ for $z_{min} < z < z_{max}$

$I_v = \frac{1}{1 \cdot 2.357} = 0.424$

Where: k_I is the turbulence factor, recommended value is 1,0

Z = 10,56m

$q_p(z) = [1+7I_v(z)] \cdot \frac{1}{2} \cdot p \cdot V_m(z)^2 = (1+7 \cdot 0.424) \cdot 0.5 \cdot 1.25 \cdot 2.482^2 = 15.28$ N/m^2

Height, z(m)	C_r (z)	I_v(z)	V_m(z), (m/s)	q_p(z), (N/m^2)
10.56	0.552	0.424	2.482	15.28

Table 5-19 – Peak velocity pressure

Determination of Pressure Coefficient, c_{pe}

The external pressure coefficients c_{pe} for buildings and parts of buildings depend on the size of the loaded area A, which is the area of the structure that produces the wind action in the section to be calculated. The external pressure coefficients are given for loaded areas A of 1 m^2 and 10 m^2 in the tables for the appropriate building configurations as c_{pe1}, for local coefficients, and

c_{pe10}, for overall coefficients, respectively.

Since the pressure coefficients for vertical walls and flat roof vary through the wall and roof surface, the calculation is made considering geometry of the structure, the aspect ratio (h/d) and wind direction.

$c_{pe} = c_{pe,1}$, for A $\leq 1m^2$;

$c_{pe} = c_{pe,1} - (c_{pe,10} - c_{pe,1}) \, log_{10}$ A , for 1<A<10m^2;

$c_{pe} = c_{pe,10}$, for A > $10m^2$.

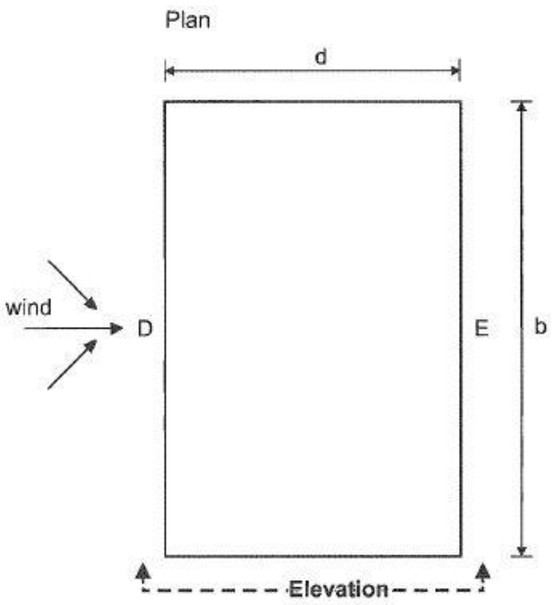


Figure 5-3 – Pressure coefficient for vertical walls

The area is greater A>10 m^2 in all the cases hence the wind pressure on the surfaces is calculated from the peak velocity pressure q_p(z), and external pressure coefficient to be used will be $c_{pe,10}$. Multiplying this coefficient by the characteristic peak velocity pressure (q_p) we obtain the external wind pressure w_e.

$w_e = q_p(z_e) \cdot c_{pe}$

Where:

$q_p(z_e)$ is the peak velocity pressure;

z_e is the reference height for the external pressure;

c_{pe} is the pressure coefficient for the external pressure.

Finally to obtain the wind force acting on the area is used the equation:

$F_w = c_s \, c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref}$

Where:

$c_s \, c_d$, structural factor, defined as 1.0 according to section 6.

c_f, force coefficient for the element, defined as 1.0 according to section 7.

$q_p(z_e)$, characteristic peak velocity pressure at height z_e, calculated before.

A_{ref}, reference area of the structural element.

By this we obtain all the forces that will be acting on the building, and are distributed on the elements for their analysis.

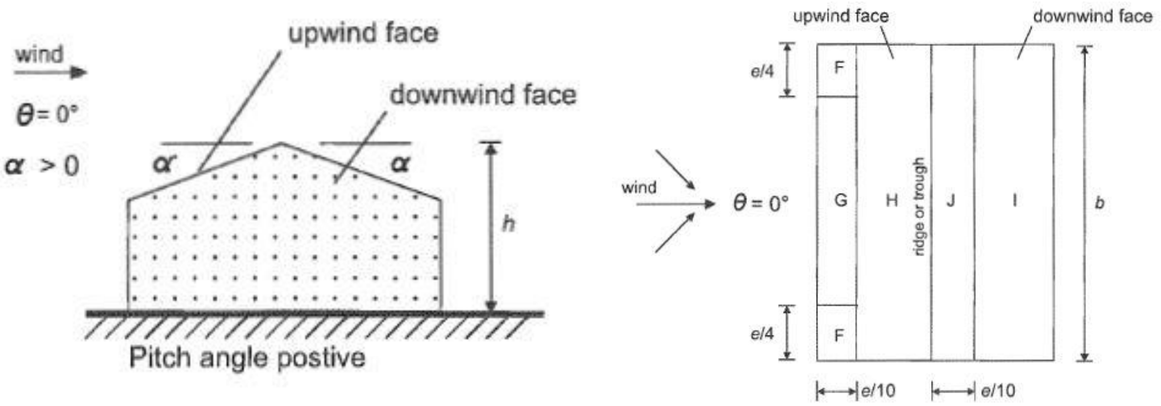


Figure 5-4 – Pressure coefficient for duopitch roof

Zone	$c_{pe,10}$	$q_p(z)$, (N/m^2)	Area (m^2)	w_e, (N/m^2)	F (N)
D	0.8	15.28	42,18	12.22	515,44
E	-0.5	15.28	42,18	-7.64	-322,26
H	-0.3	15.28	10	-4.58	-45,8
I	-0.4	15.28	32,76	-6.11	-200,16

Table 5-20 – Peak velocity pressure

5.3.4. Seismic Load

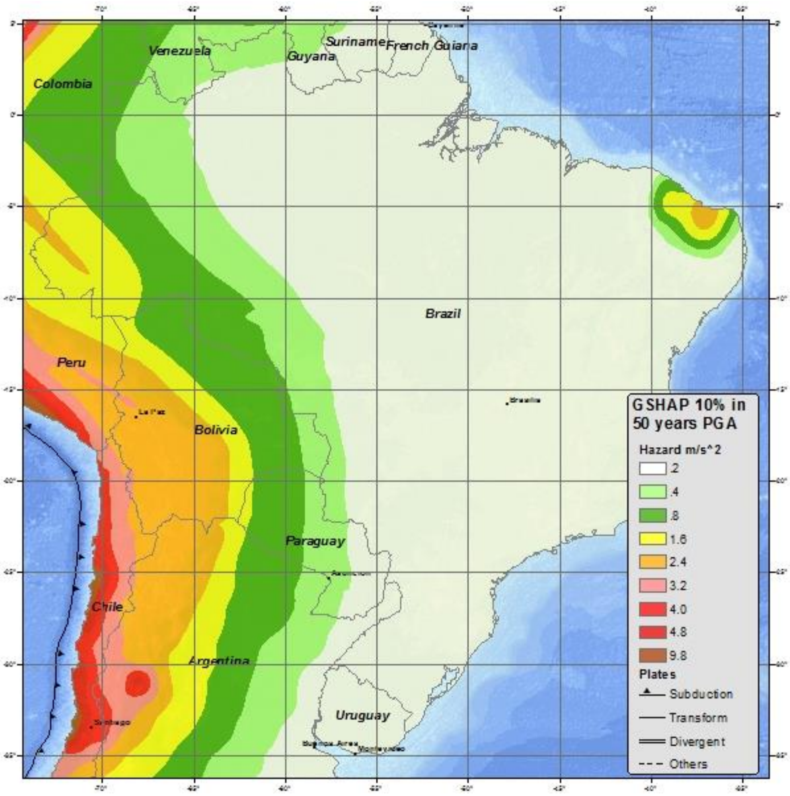


Figure 5-5 – Seismic Hazard Map of Brazil [40]

As we can see from the Hazard Map of Brazil, Rio de Janeiro is situated in the area with almost no possibility of the earthquake. The seismic design calculations could be neglected.

5.4.1. Calculation of roof system.

Loads for 1 m:

Load	Normative load, kg/m²
Dead load:	**63,95**
Ceramic roof tile (portuguese style)	39,8
Supporting laths 5,5x0,032x0,125 м	4,8
Counter laths 6,3x0,075x0,075м	7,5
Thermal insulation (cellulose insulation batt panel)	1,35
Plywood board	10,5
Live load:	**76,48**
Wind load:	**-0,623**

Table 5-21 – Loading of the roof

Design load = 1,35 G_k + 1,5 · 0,7 Q_k + 1,5 · W_k = (1,35 · 63.95) + (1,5 · 0.7 · 76.48) + (1,5 · (-0.623)) = 165.7 kg/m².

Calculation of the ordinary rafter.

<u>Design scheme.</u>

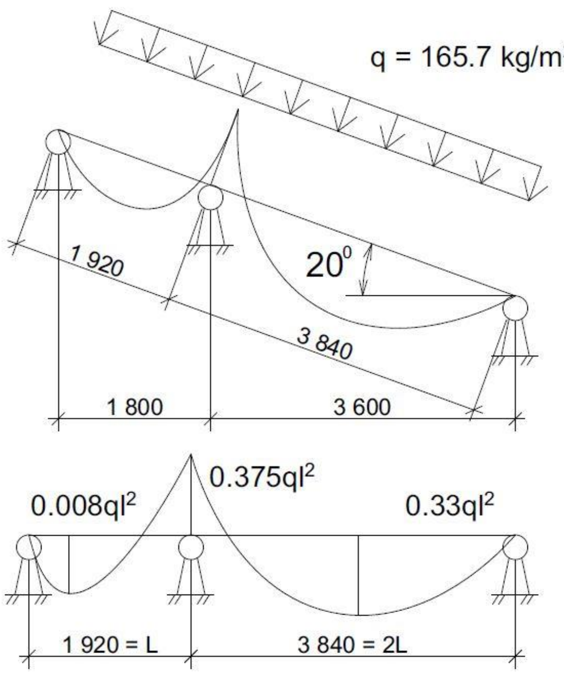


Figure 5-6 – Design scheme

$R_A = \frac{ql_1}{2} - \frac{q(l_1^3+l_2^3)}{8l_1(l_1+l_2)} = \frac{ql}{2} - \frac{q(l^3+8l^3)}{8l(l+2l)} = \frac{ql}{8}$;

$R_B = \frac{q(l+2l)}{2} + \frac{q(l_1^3+l_2^3)}{8l_1(l_1+l_2)} + \frac{q(l_1^3+l_2^3)}{8l_2(l_1+l_2)} = \frac{33ql}{16}$;

$R_C = \frac{ql_2}{2} - \frac{q(l_1^3+l_2^3)}{8l_2(l_1+l_2)} = \frac{13ql}{16}$.

$M_B = - \frac{q(l_1^3+l_2^3)}{8(l_1+l_2)} = - \frac{q(l^3+8l^3)}{8(l+2l)} = - \frac{3ql^2}{8}$;

$M_{left} = \frac{ql}{8}x - \frac{qx^2}{2}$;

$\frac{dM}{dx} = \frac{ql}{8} - qx = 0$

$x = \frac{l}{8}$

$M_{max,left} = M\left(\frac{l}{8}\right) = \frac{ql^2}{64} - \frac{ql^2}{128} = \frac{ql^2}{128}$.

$M_{right} = \frac{13ql}{16}x - \frac{qx^2}{2}$;

$\frac{dM}{dx} = \frac{13ql}{16} - qx = 0$

$x = \frac{13l}{16}$

$M_{max,right} = M\left(\frac{13l}{16}\right) = \frac{13 \cdot 13ql^2}{16 \cdot 16} - \frac{13 \cdot 13ql^2}{16 \cdot 16 \cdot 2} = \frac{169ql^2}{512}$.

As we see from the calculations above: the highest value of the moment is $- \frac{3ql^2}{8} = 0.375\, ql^2$.

Conditions:

The angle of the roof pitch α = 20°;

The length of the rafter is: $l_{raft.}$= 5400 mm

Distance between rafters A= 1,2 m;

Estimated beams span:

$l = \frac{1,80}{\cos 20^0} = \frac{1,80}{0,94}$ =*1,92 m;*

Material - pine (R_{bend} = 140 kg/m²).

Calculations:

1. We find a distributed load per meter of each rafter

q_r*=A·q;*

q_r=165.7 *·1,2=198,84 kg/m;*

M = 0.375 · 198.84 · 1.92² = 274.88 kg·m

Required section modulus for the beam:

$W = \frac{M}{R_u} = \frac{274.88}{140} = 1.96\ m^3$

2. We choose the width of the rafters – 10cm.

We calculate the cross section with a width of rafter section equal to 10cm.

We assume the width to be b=10 cm.

$h = \sqrt{\frac{6 \cdot 1.96}{0.1}}$ = 10.84cm.

We assume the height to be b=10 cm.

h=12.5 cm.

I = $\frac{bh^3}{12} = \frac{10 \cdot 12.5^3}{12}$ = 1623 cm^4

Checking whether the amount of deflection satisfies the standard one. The inequality must satisfy:

$\frac{f}{l} = \frac{5}{384} \cdot \frac{q_n \cdot l^3}{10^6 \cdot I} = \frac{5}{384} \cdot \frac{165.7 \cdot 384^3}{10^6 \cdot 1623}$ = 0,075 cm < $\frac{l}{250}$ = 1.536 cm.

Thus, cross-section of the rafters, set in increments of 1,2 m will be: width – 10,0 cm, height - 12.5 cm.

5.4.2 Calculation of the masonry

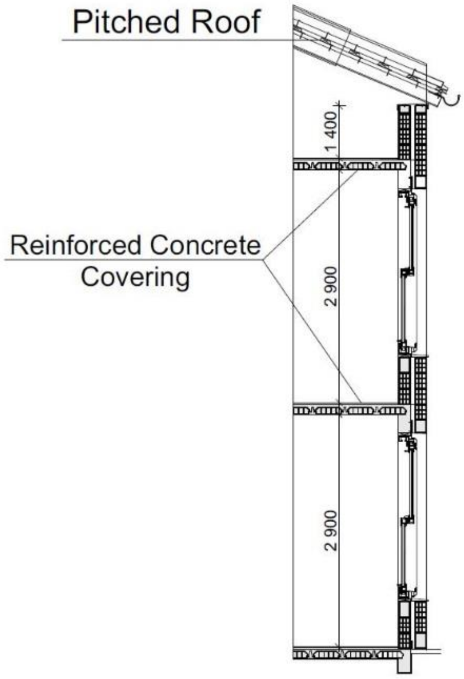


Figure 5-7 – Design scheme of the wall

The diagram below illustrates part of a two-storey building with a mansard roof with load bearing masonry.

The floors and roof loads are carried by the inner leaf of the wall shown, the floors have spans of 3,6 m. The calculation of the roof load is present below:

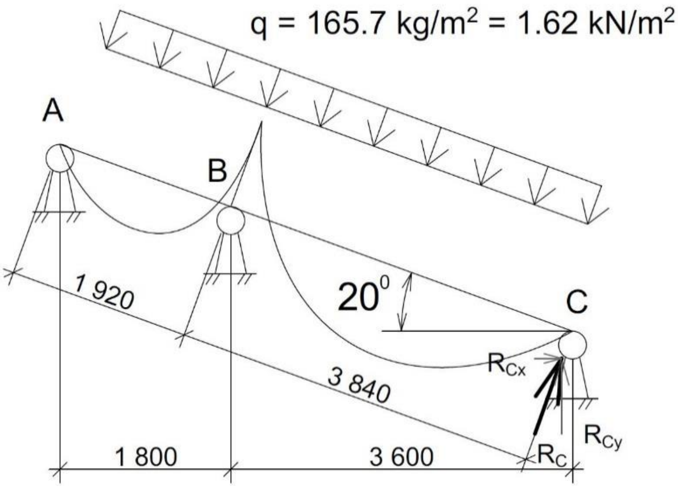


Figure 5-8 – Design scheme of the roof loading

$$R_C = \frac{13ql}{16}; R_{Cy} = \frac{13ql}{16} \cdot \cos\alpha = \frac{13 \cdot 1.92 \cdot 1.62}{16} \cdot \cos 20^0 = 2.37 \text{ kN/m.}$$

The same scheme for the imposed load equal to 0,75 kN/m^2:

$$R_{Cy} = \frac{13ql}{16} \cdot \cos\alpha = \frac{13 \cdot 1.92 \cdot 0.75}{16} \cdot \cos 20^0 = 1.1 \text{ kN/m.}$$

Carry out calculations for the load case of vertical loads only for the wall between ground and first floor. What strength of block masonry unit will be needed?

Assume a concrete block masonry unit of work size 190 mm high by 140 mm thick is to be used in conjunction with M4 mortar.

Assume category II attestation of conformity masonry unit and class 2 execution control

Characteristic loadings

Roof Dead load = 1.37 kN/m

Imposed load = 1.35 kN/m

Floors Dead load = (3,22 + 3,36) kN/m^2

Imposed load = 2,0 kN/m^2

wt of inner leaf of masonry - assume 1,95 kN/m^2

Assume

90 mm thick outer leaf

140 mm thick inner leaf

50 mm cavity

	Dead	Imposed
Roof	2.37	1.1
2 floors	3,6*0.5*(3.22+3.36)=11,84	3,6*0.5*2*2=7,2
3 stories of walling (2*2.9m+1.4m)	7.2*1.95=14.04	0
Total	28 kN/m	9 kN/m

Table 5-22 – Loading of the wall

Design load = 1,35 Gk + 1,5 Qk = (1,35 x 28) + (1,5 x 9) = 51,3 kN/m

Eccentricity of Load:

Building Research Digest No. 246 gives guidance on the assessment of eccentricity.

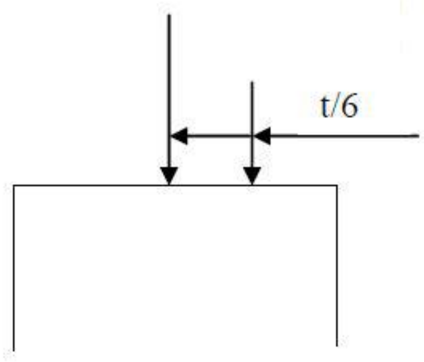
For an end wall with a concrete floor supported over the whole wall leaf thickness the center of action of the force should be taken as 1/6 of the wall thickness from the centerline. However, where the floor is of very short span or very stiff it may be reasonable to regard the load as axial without applied eccentricity.

Therefore load from first floor acts at t/6 while the loads from the upper floors act axially.

Load from first intermediate floor = (1,35 x 6.05) + (1,5 x 3,6) = 13,57 kN/m run

Load of the bottom wall = 1,35 x 5,655= 7,634 kN/m

Load from upper floors + roof = (51,3 – 13,57 – 7,634) = 30,5 kN/m



Load from first floor

= 13,57 kN/m

Figure 5-9 – Design scheme of the loading

Effective thickness of wall, $t_{ef} = \sqrt[3]{t_1^3 + t_2^3}$

$t_{ef} = \sqrt[3]{90^3 + 140^3}$ = 151,44

Effective height of wall, hef h_{ef}= 0,75 x 2900 = 2175 mm

And $\frac{t_{ef}}{h_{ef}} = \frac{2175}{151{,}44}$ = 14,36

Hence eccentricity of design vertical load, $e_i = \frac{M_{id}}{N_{id}} + e_{he} \pm e_{init} \geq$ 0,05t

Therefore e_i = 7,2 + 0 + 4,83 = 12,03 mm (i.e. 0,086t)

where $\frac{M_{id}}{N_{id}} = \frac{13{,}57 \cdot 140}{44{,}07 \cdot 6}$ = 7,2 mm

e_{he} = 0 (horizontal loads effect)

$e_{init} = \frac{h_{ef}}{450} = \frac{2900 \cdot 0{,}75}{450}$ = 4,83 mm

e_i is 0,081t at top and bottom of the wall which are the minimum eccentricity design values to be used

Therefore φ_i= 1 – 2 ($\frac{e_i}{t}$) = 1 – 2 ($\frac{0{,}086t}{t}$) = 0,828

And eccentricity of design vertical load, $e_m = \frac{M_{md}}{N_{md}} + e_{hm} \pm e_{init} \geq$ 0,05t

Therefore , $e_{mk} = e_m \pm e_k$ = 0 + 0 + 4,83 = 4,83 mm (i.e 0,032t)

Where $\frac{M_{md}}{N_{md}}$ = 0 (point of contraflexure of double curvature strut)

e_{hm} = 0 (horizontal loads effect)

$e_{init} = \frac{h_{ef}}{450} = \frac{2900 \cdot 0{,}75}{450}$ = 4,83 mm

e_k = 0 (creep effect)

e_{mk} is 0,05 t at mid-height of the wall which is the minimum eccentricity design value to be used

Hence for E = 1000 f_k Part 1.1 Annex G equations or Figure G1 gives:

φ_m = 0,77 governs design

Assuming category II masonry units and class 2 execution control, γ_m= 3,0

Design resistance per unit length $N_{Rd} = \Phi \cdot t \cdot f_d$

Where $f_d = \frac{f_k}{\gamma_m}$

Therefore $f_k = \frac{N_{Rd} \cdot \gamma_m}{\varphi_{min} \cdot t}$

$f_k = \frac{51,3 \cdot 3,0}{0,77 \cdot 140} = 1,44$ N/mm^2

Group 1 Solid Masonry Unit:

$f_k = K \cdot f_b^{\alpha} \cdot f_m^{\beta}$

Therefore $1,44 = 0,75 \cdot f_b^{0,7} \cdot 4^{0,3}$

$f_b^{0,7} = 1,27$

$f_b = \sqrt[0,7]{1,27} = 1,4$ N/mm^2

Normalised compressive strength, f_b = compressive strength ×δ × conditioning factor.

Using a 190mm high by 140mm wide masonry unit, δ, the shape factor is 1,24 for the air dry condition compressive testing regime.

Therefore masonry unit compressive strength required = 1,4 / (1,24 × 1,0)

= 1,13 N/mm2

Use a Group 1 concrete block masonry unit with a compressive strength of 3 N/mm2 minimum.

5.4.3. Calculation of foundation.

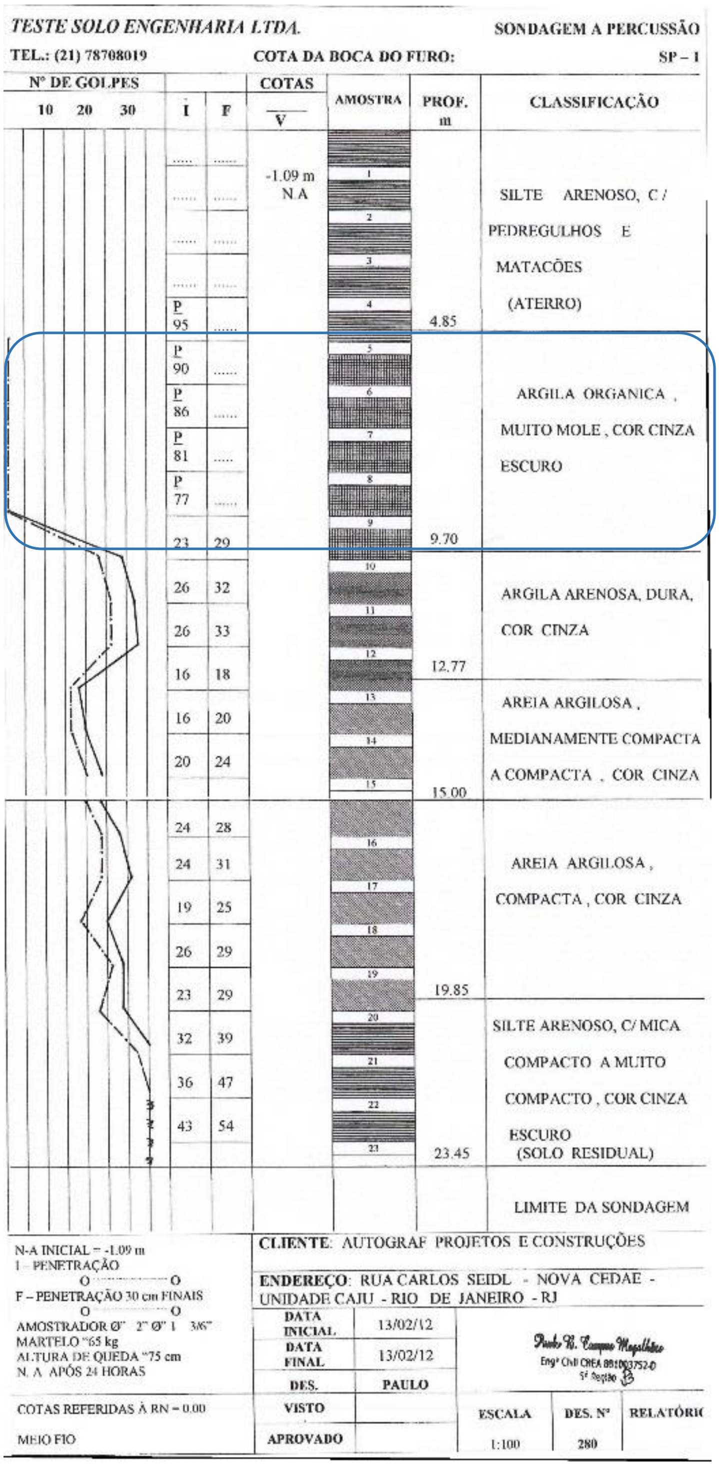


Figure 5-10 – Description of the soil layers. Rio de Janeiro

The load-bearing wall of a building is to be supported on a wide reinforced strip foundation.

A site investigation has revealed soft organic dark gray clay soil from ground level to some considerable depth. The soil has a safe bearing capacity 98 kN/m2.

The building could be supported on ground beams and piles taken down to a firm base, but in this case the solution chosen is to design a wide reinforced strip foundation capable of spanning across a soft area of nominal width.

To minimize differential settlements and allow for the soft areas, the allowable bearing pressure will be limited to na = 80 kN/m2 throughout. Soft spots encountered during construction will be removed and replaced with lean mix concrete; additionally, the footing will be designed to span 2.5 m across anticipated depressions. This value has been derived from the guidance for local depressions given later on raft foundations. The ground floor slab is designed to be suspended, although it will be cast using the ground as permanent formwork.

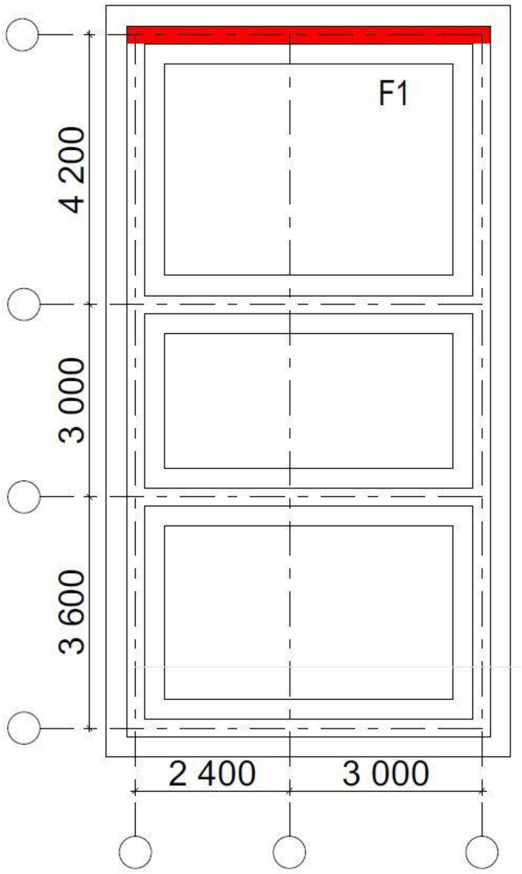


Figure 5-11– Placement of the footing F1

	Dead	Imposed
Roof	-	-
3 floors	4.2*0.5*(3.22+3.36*2)=20.87	4.2*0.5*2*3=12.6
3 stories of walling (2*2.9m+1.4m)	7.2*1.95=14.04	-
Total	34.91 kN/m run	12.6 kN/m run

Table 5-23 – Loading of the footing F1

P = G + Q = 34.91+12.6 = 47.51 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-12.

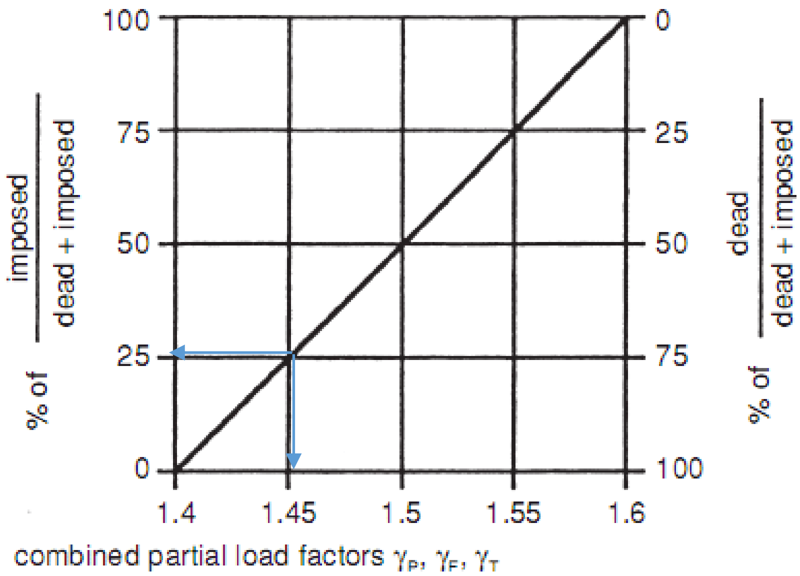


Figure 5-12 – Combined partial safety factor for dead + imposed loads.

Q as a percentage of of P is 100Q/P = (100*12.6)/ 47.51 = 26.52%

From Fig. 5-12, the combined partial safety factor for superstructure loads is γ_P= 1.45.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

Sizing of foundation width

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{47.51}{80} = 0.59 \text{ m}$$

Adopt a 0.9 m wide × 300 mm deep reinforced strip foundation, using grade 35 concrete (see Fig. 5-13).

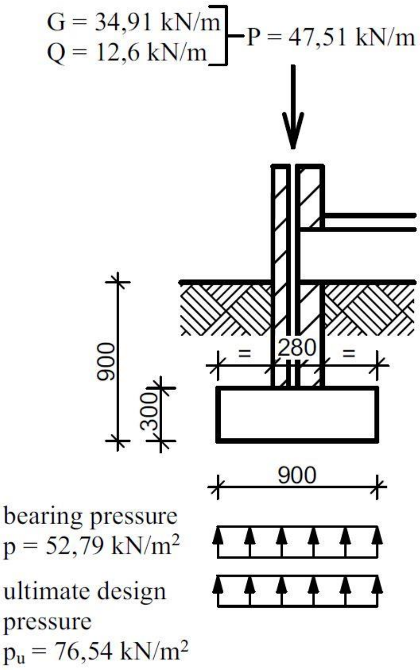


Figure 5-13 – Design scheme for the footing F1

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, p = $\frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{47.51}{0.9}$ = 52.79 kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\ P}{B} = \frac{1.45 \cdot 47.51}{0.9}$ = 76.54 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 300 – 50 (cover) – 12 - $\frac{10}{2}$ = 233 mm

Cantilever moment at face of wall

$$M_u = \frac{P_u\,(\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{76.54\ (\frac{0,9}{2} - \frac{0,233}{2})^2}{2} = 4.26 \text{ Nm/m run}$$

$\frac{M_u}{bd^2} = \frac{4.26 \cdot 10^6}{1000 \cdot 233^2}$ = 0.08

$A_{s\ (req)}$ = 0.02%bd [41]

This is less than the minimum reinforcement in BS 8110: Part 1: 3.12.5:

$A_{s\ (min)}$ = 0.13%bh = $\frac{0.13}{100} \cdot 1000 \cdot 300$ = 390 mm^2/m = 3.9 cm^2/m

Provide 8 bars of reinforcement Ø8mm

A_s = 4,02 cm^2/m = 402 mm^2/m

A_s = 0.134%bh

Allowable shear stress: v_c = 0.39 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2}) = 76.54 \cdot (\frac{0.9}{2} - \frac{0.233}{2})$ = 25,53 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{25,53 \cdot 10^3}{1000 \cdot 233}$ = 0.11 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f B$ = (1.45 · 47.51) + (1.4 · 15,75 · 0.9) = 88.73 kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{88.73 \cdot 2.5^2}{8}$ = 69.32 kN·m

Width for reinforcement design is b = B = 900 mm.

Effective depth, d = 300-50 (cover) - $\frac{12}{2}$ = 244 mm

$\frac{M_u}{bd^2} = \frac{69.32 \cdot 10^6}{900 \cdot 244^2}$ = 1.29

$A_{s\,(req)}$ = 0.344%bd = $\frac{0.344}{100}$ · 900 · 244 = 755,4 mm^2

Provide 10 bars of reinforcement Ø10mm

A_s = 7,85 cm^2/m = 785 mm^2/m

A_s = 0.358%bh [41]

Allowable shear stress: v_c = 0.5 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{88,73 \cdot 2.5}{2}$ = 110,91 kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{110,91 \cdot 10^3}{900 \cdot 244}$ = 0.51 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Depression at corner of building

The previous calculations have assumed that the depression is located under a continuous strip footing. The depression could also occur at the corner of a building where two footings would meet at right angles. A similar calculation should then be carried out, to provide top reinforcement for both footings to cantilever at these corners.

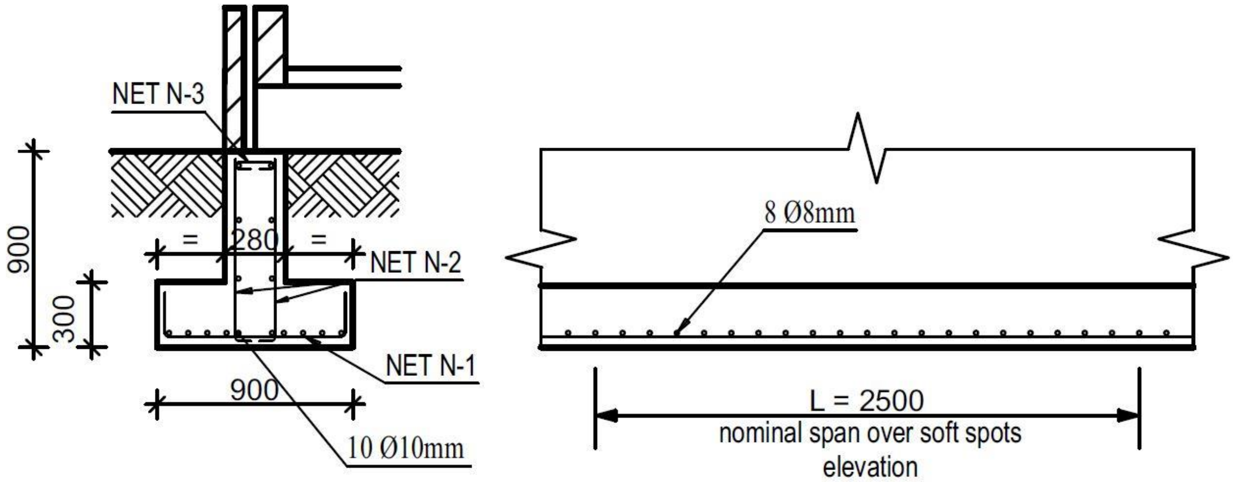


Figure 5-14– Footing F1

Foundation F-2.

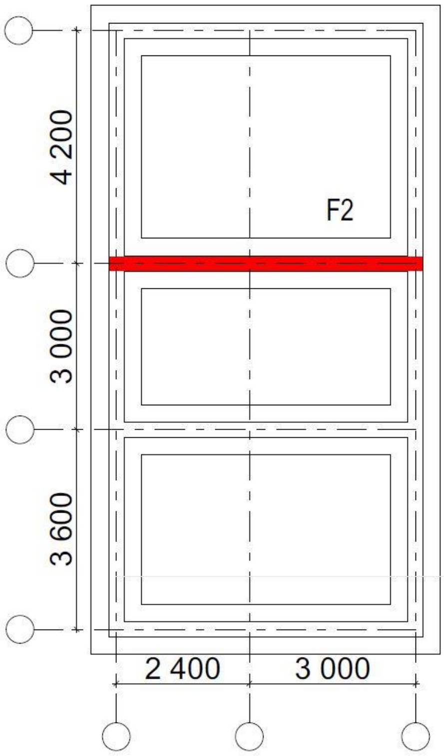


Figure 5-15 – Placement of the footing F2.

The floors and roof loads are carried by the inner leaf of the wall shown, the floors have span of 4,2m. The calculation of the roof load is present below:

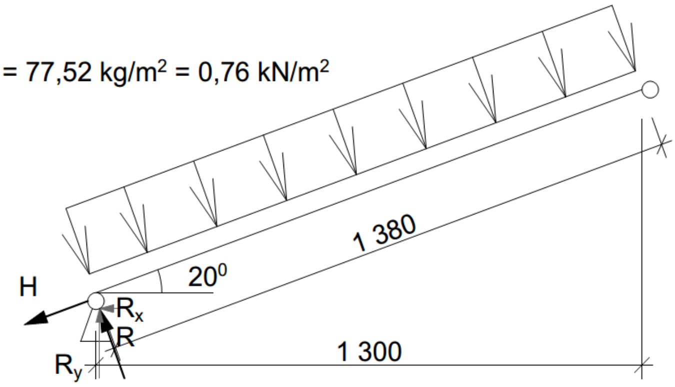


Figure 5-16 – Design scheme for the roof loading.

$$Q \cdot l \cdot \frac{l}{2} - R \cdot l = 0;\ R = \frac{ql}{2};\ R_y = \frac{ql}{2} \cdot \cos\alpha = \frac{0.76 \cdot 1{,}38}{2} \cdot \cos 20^0 = 0{,}49 \text{ kN/m.}$$

The same scheme for the imposed load equal to 0,75 kN/m^2:

$$R_y = \frac{ql}{2} \cdot \cos\alpha = \frac{0.75 \cdot 1{,}38}{2} \cdot \cos 20^0 = 0{,}48 \text{ kN/m.}$$

	Dead	Imposed
Roof	0,49	0,48
3 floors	4.2*0.5*(3.22+3.36*2)=20.87	4.2*0.5*2*3=12.6
3 stories of walling (2*2.9+2.6m)	(2*2,9+2.6)*1.27=10.67	0
2 staircases	(23.54/2.4)*2 = 19.62	4.5*3*0.5*2 = 13,5
Total	51.65 kN/m run	26.58 kN/m run

Table 5-24 – Loading of the footing F2

P = G + Q = 51,65 + 26.58 = 78.23 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-17.

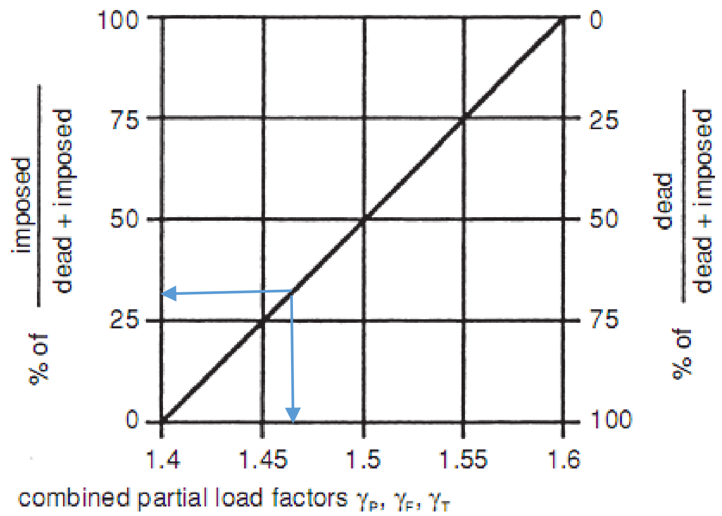


Figure 5-17 – Combined partial safety factor for dead + imposed loads.

Q as a percentage of of P is 100Q/P = (100*26.58)/78.23 = 33.98%

From Fig. 5.4.3.8, the combined partial safety factor for superstructure loads is γ_P= 1.47.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

<u>Sizing of foundation width</u>

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{78.23}{80} = 0.98\ \text{m}$$

Adopt a 1.2 m wide × 350 mm deep reinforced strip foundation, using grade 35 concrete (see Fig. 5-17).

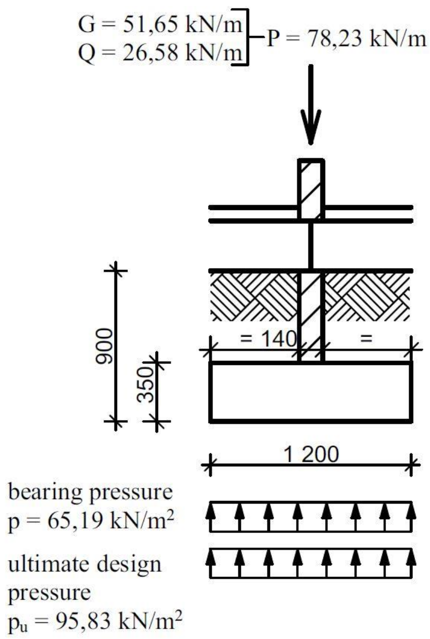


Figure 5-18 – Design scheme for the footing F2

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, p = $\frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{78.23}{1.2}$ =65.19kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\, P}{B} = \frac{1.47 \cdot 78.23}{1.2}$ = 95.83 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 350 – 50 (cover) – 12 - $\frac{10}{2}$ = 283 mm

Cantilever moment at face of wall

$M_u = \frac{P_u\, (\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{95.83\, (\frac{1.2}{2} - \frac{0,283}{2})^2}{2}$ = 10.07 kNm/m run

$\frac{M_u}{bd^2} = \frac{10.07 \cdot 10^6}{1000 \cdot 283^2}$ = 0.13

$A_{s\,(req)}$ = 0.03%bd [41]

This is less than the minimum reinforcement in [41]:

$A_{s\,(min)}$ = 0.13%bh = $\frac{0.13}{100}$ · 1000 · 350 = 455 mm^2/m = 4.55 cm^2/m

Provide 6 bars of reinforcement Ø10mm

A_s = 4,71 cm^2/m = 471 mm^2/m

A_s = 0.135%bh

Allowable shear stress: v_c = 0.37 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2})$ =95.83 · $(\frac{1.2}{2} - \frac{0.283}{2})$ = 43.94 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{43.94 \cdot 10^3}{1000 \cdot 283}$ = 0.16 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f F$ = (1.47 · 78.23) + (1.4 · 15,75 · 1.2) = 141.46 kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{141.46 \cdot 2.5^2}{8}$ = 110.5 kN·m

Width for reinforcement design is b = B = 1200 mm.

Effective depth, d = 350-50 (cover) - $\frac{12}{2}$ = 294 mm

$\frac{M_u}{bd^2} = \frac{110.5 \cdot 10^6}{1200 \cdot 294^2}$ = 1.07

$A_{s\,(req)}$ = 0.285%bd = $\frac{0.285}{100}$ · 1200 · 294 =1005 mm^2

Provide 9 bars of reinforcement Ø12mm

A_s = 10.18 cm^2/m = 1018 mm^2/m

A_s = 0.289%bh [41]

Allowable shear stress: v_c = 0.54 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{141.46 \cdot 2.5}{2}$ =176.83 kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{176.83 \cdot 10^3}{1200 \cdot 294}$ = 0.5 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Depression at corner of building

The previous calculations have assumed that the depression is located under a continuous strip footing. The depression could also occur at the corner of a building where two footings would meet at right angles. A similar calculation should then be carried out, to provide top reinforcement for both footings to cantilever at these corners.

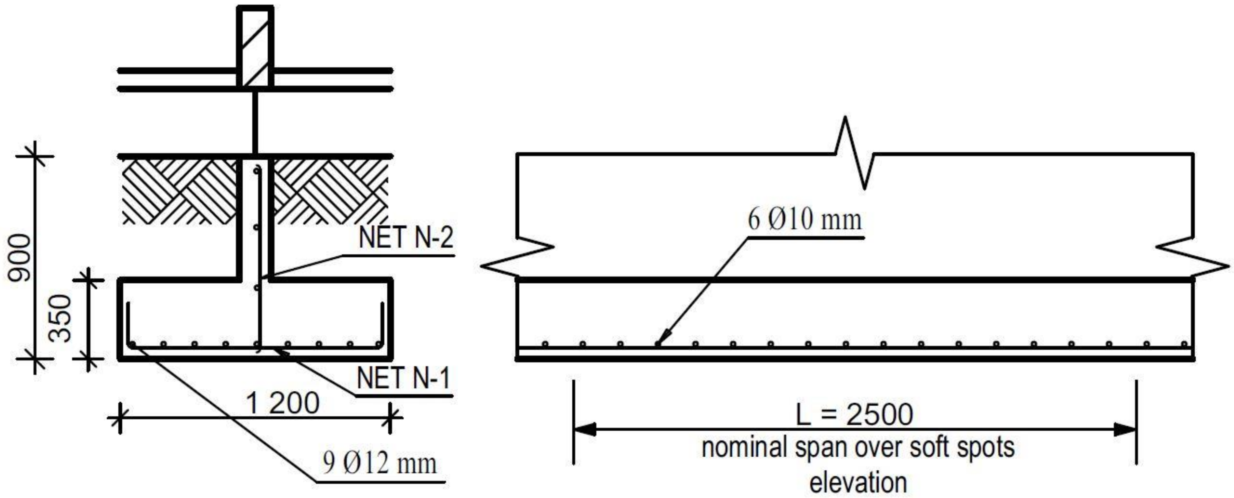


Figure 5-19 – Footing F2

Foundation F-3.

The floors and roof loads are carried by the inner leaf of the wall shown, the floors have span of 3.6 m.

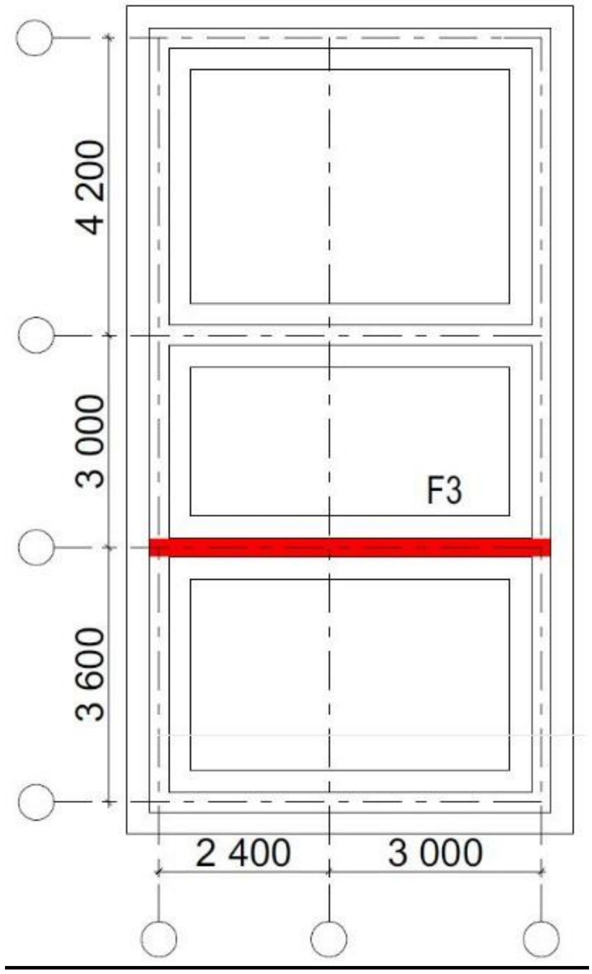


Figure 5-20 – Placement of the footing F3

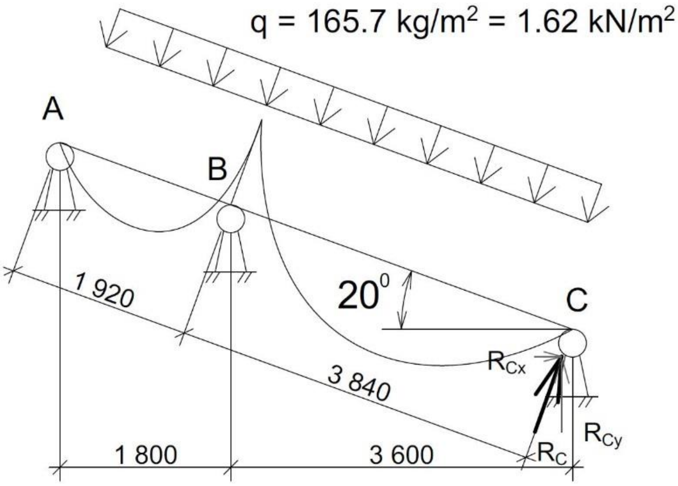


Figure 5-21 – Design scheme for the roof loading

$$R_B = \frac{33ql}{16}; R_{By} = \frac{33ql}{16} \cdot \cos\alpha = \frac{33 \cdot 1.92 \cdot 1.62}{16} \cdot \cos 20^0 = 6.03 \text{ kN/m.}$$

The same scheme for the imposed load equal to 0,75 kN/m^2:

$$R_{By} = \frac{13ql}{16} \cdot \cos\alpha = \frac{33 \cdot 1.92 \cdot 0.75}{16} \cdot \cos 20^0 = 2.79 \text{ kN/m.}$$

	Dead	Imposed
Roof	6.03	2.79
3 floors	3,6*0.5*(3.22+3.36*2)=17,89	3,6*0.5*2*3=10,8
3 stories of walling (2*2.9+2.3m)	(2*2,9+2.3)*1.27=10.29	0
2 staircases	(23.54/2.4)*2 = 19.62	4.5*3*0.5*2 = 13,5
Total	49.17 kN/m run	25.65 kN/m run

Table 5-25– Loading of the footing F3

P = G + Q = 49.17 + 25.65 = 74.82 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-21.

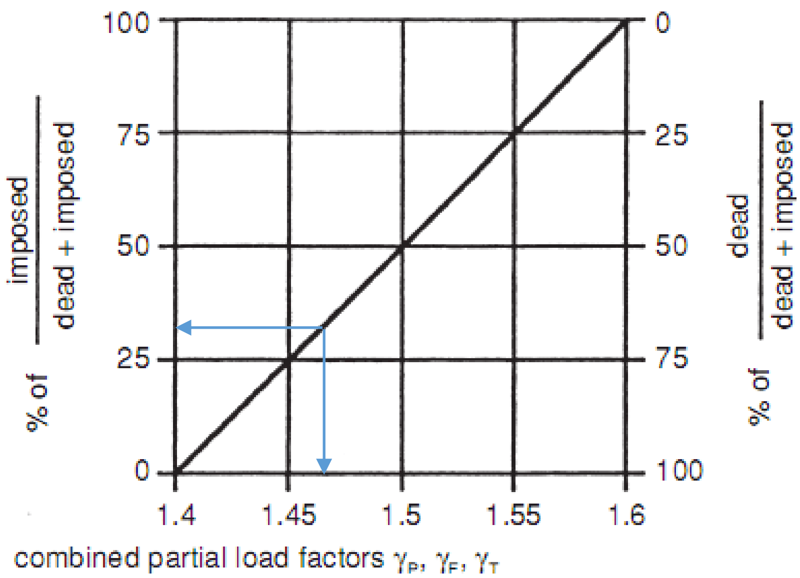


Figure 5-22 – Combined partial safety factor for dead + imposed loads.

Q as a percentage of of P is 100Q/P = (100*25.65)/74.82 = 34.28%

From Fig. 5-21, the combined partial safety factor for superstructure loads is γ_P= 1.47.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

<u>Sizing of foundation width</u>

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{74.82}{80} = 0.94 \text{ m}$$

Adopt a 1,2 m wide × 350 mm deep reinforced strip foundation, using grade 35 concrete (see Fig. 5-23).

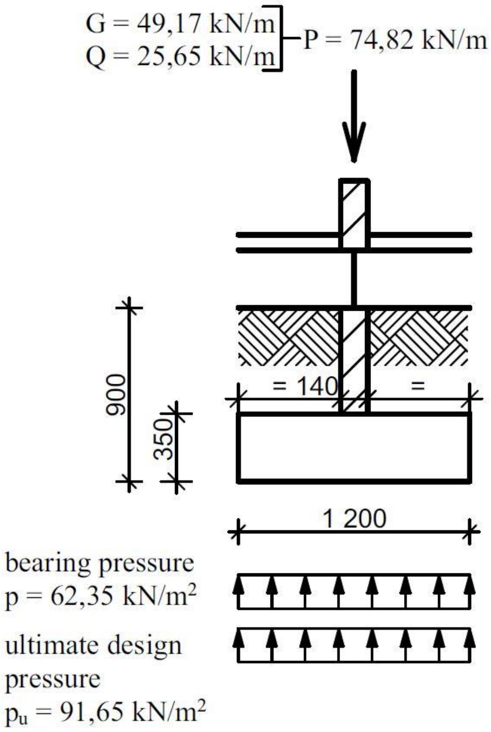


Figure 5-23– Design scheme for the footing F3

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, p = $\frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{74.82}{1,2}$ = 62.35 kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\ P}{B} = \frac{1.47 \cdot 74.82}{1,2}$ = 91.65 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 350 – 50 (cover) – 12 - $\frac{10}{2}$ = 283 mm

Cantilever moment at face of wall

$M_u = \frac{P_u\,(\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{91.65\ (\frac{1,2}{2} - \frac{0,283}{2})^2}{2}$ =9.63 kNm/m run

$\frac{M_u}{bd^2} = \frac{9.63 \cdot 10^6}{1000 \cdot 283^2}$ = 0.12

$A_{s\ (req)}$ = 0.03%bd [41]

This is less than the minimum reinforcement in [41]:

$A_{s\ (min)}$ = 0.13%bh = $\frac{0.13}{100} \cdot 1000 \cdot 350$ = 455 mm^2/m = 4,55 cm^2/m

Provide 10 bars of reinforcement Ø8mm

A_s = 5,03 cm^2/m = 503 mm^2/m

A_s = 0.14%bh

Allowable shear stress: v_c = 0.37 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2})$ = 91.65 $\cdot$ ($\frac{1,2}{2}$ - $\frac{0.283}{2}$) = 42.02 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{42.02 \cdot 10^3}{1000 \cdot 283}$ = 0.15 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f F = (1.47 \cdot 74.82) + (1.4 \cdot 15{,}75 \cdot 1.2) = 136.45$ kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{136.45 \cdot 2.5^2}{8} = 106.6$ kN·m

Width for reinforcement design is b = B = 1200 mm.

Effective depth, d = 350-50 (cover) - $\frac{12}{2}$ = 294 mm

$\frac{M_u}{bd^2} = \frac{106.6 \cdot 10^6}{1200 \cdot 294^2} = 1.028$

$A_{s\ (req)}$ = 0.274%bd = $\frac{0.274}{100} \cdot 1200 \cdot 294 = 967\ mm^2$

Provide 9 bars of reinforcement Ø12mm

A_s = 10.18 cm^2/m = 1018 mm^2/m

A_s = 0.289%bh [41]

Allowable shear stress: v_c = 0.54 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{136.45 \cdot 2.5}{2} = 170.56$ kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{170.56 \cdot 10^3}{1200 \cdot 294} = 0.48$ N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Depression at corner of building

The previous calculations have assumed that the depression is located under a continuous strip footing. The depression could also occur at the corner of a building where two footings would meet at right angles. A similar calculation should then be carried out, to provide top reinforcement for both footings to cantilever at these corners.

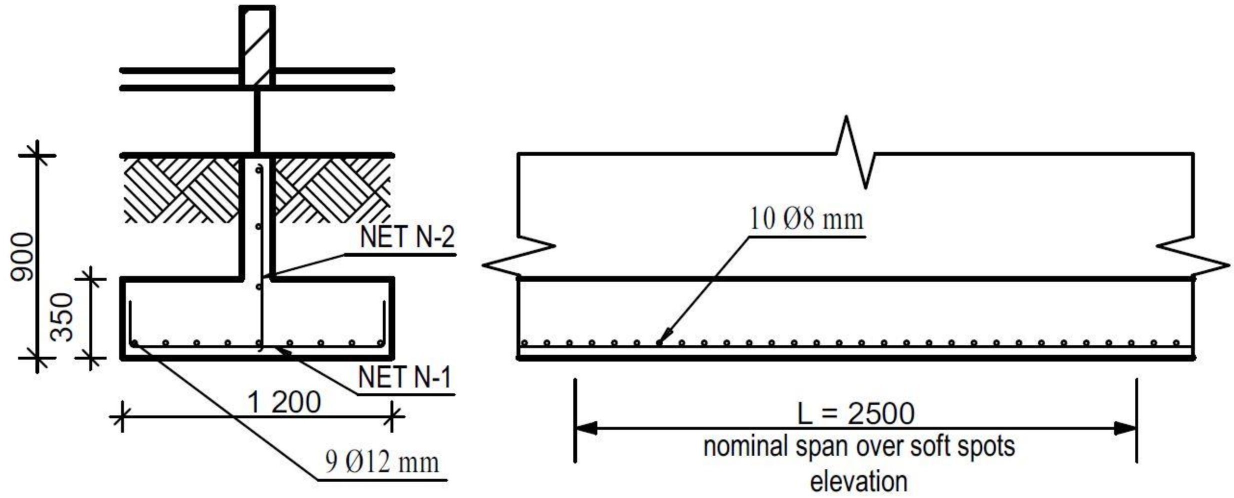


Figure 5-24 – Footing F3

Foundation 4.

The floors and roof loads are carried by the inner leaf of the wall shown, the floors have span of 3.6 m.

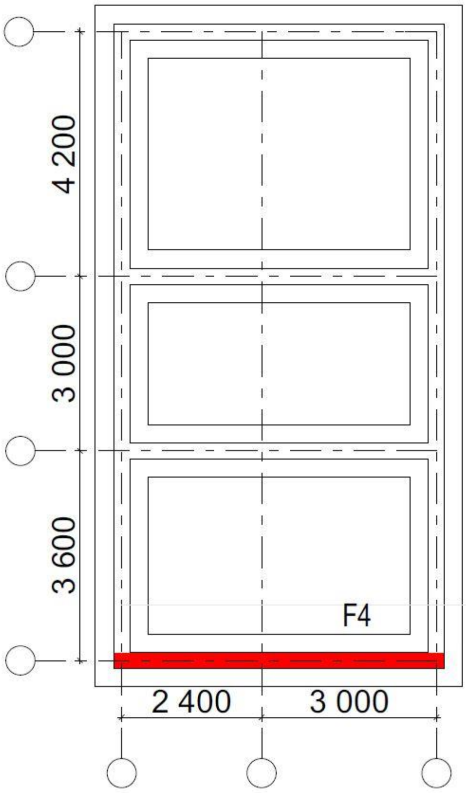


Figure 5-25 – Placement of the footing F4

	Dead	Imposed
Roof	2.37	1.1
3 floors	3.6*0.5*(3.22+3.36*2)=17.89	3.6*0.5*2*3=10.8
3 stories of walling (2*2.9m+1.4m)	7.2*1.95=14.04	-
Total	33.3 kN/m run	12.15 kN/m run

Table 5-26 – Loading of the footing F4

P = G + Q = 33.3+12.15 = 45.45 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-25.

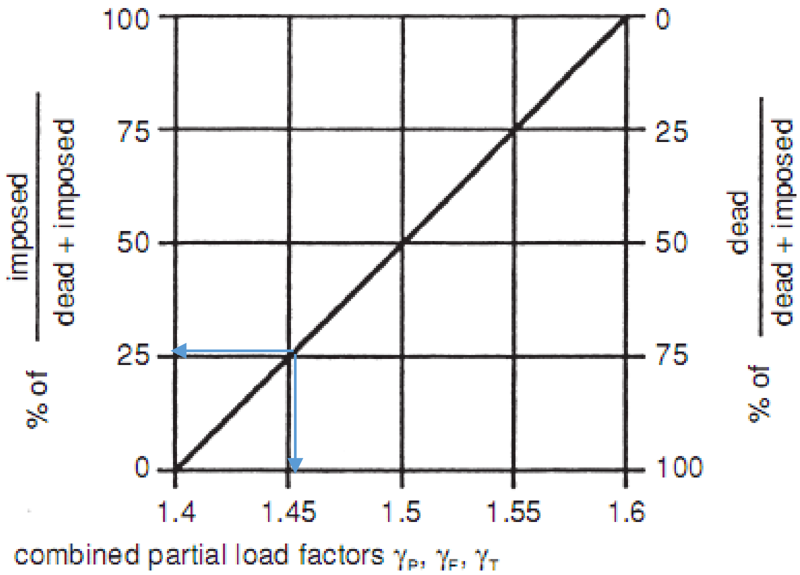


Figure 5-26 – Combined partial safety factor for dead + imposed loads.

Q as a percentage of of P is 100Q/P = (100*12.15)/ 44.45 = 27.33%

From Fig. 5-25, the combined partial safety factor for superstructure loads is γ_P= 1.45.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

Sizing of foundation width

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{44.45}{80} = 0.56\ \text{m}$$

Adopt a 0.9 m wide × 300 mm deep reinforced strip foundation, using grade 35 concrete (see Fig. 5-27).

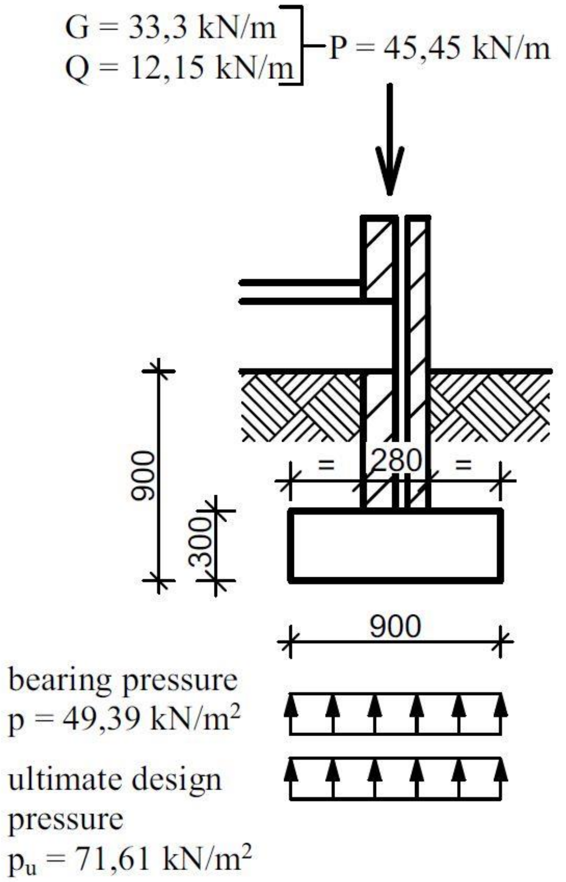


Figure 5-27– Design scheme for the footing F4

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, $p = \frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{44.45}{0.9}$ =49.39 kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\ P}{B} = \frac{1.45 \cdot 44.45}{0.9}$ = 71.61 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 300 – 50 (cover) – 12 - $\frac{10}{2}$ = 233 mm

Cantilever moment at face of wall

$$M_u = \frac{P_u\ (\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{71.61\ (\frac{0,9}{2} - \frac{0,233}{2})^2}{2} = 3.98\ \text{Nm/m run}$$

$$\frac{M_u}{bd^2} = \frac{3.98 \cdot 10^6}{1000 \cdot 233^2} = 0.07$$

$A_{s\ (req)}$ = 0.02%bd [41]

This is less than the minimum reinforcement in [41]:

$A_{s\,(min)}$ = 0.13%bh = $\frac{0.13}{100}\cdot 1000\cdot 300 = 390\ mm^2$/m = 3.9 cm^2/m

Provide 8 bars of reinforcement Ø8mm

A_s = 4,02 cm^2/m = 402 mm^2/m

A_s = 0.134%bh

Allowable shear stress: v_c = 0.39 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2}) = 71.61 \cdot (\frac{0.9}{2} - \frac{0.233}{2})$ = 23.88 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{23.88\cdot 10^3}{1000\cdot 233}$ = 0.1 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f B$ = (1.45 · 45.45) + (1.4 · 15,75 · 0.9) = 85.75 kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{85.75\cdot 2.5^2}{8}$ = 67 kN·m

Width for reinforcement design is b = B = 900 mm.

Effective depth, d = 300-50 (cover) - $\frac{12}{2}$ = 244 mm

$\frac{M_u}{bd^2} = \frac{67\cdot 10^6}{900\cdot 244^2} = 1.25$

$A_{s\,(req)}$ = 0.333%bd = $\frac{0.333}{100}\cdot 900\cdot 244 = 731.27\ mm^2$

Provide 10 bars of reinforcement Ø10mm

A_s = 7,85 cm^2/m = 785 mm^2/m

A_s = 0.358%bh [41]

Allowable shear stress: v_c = 0.5 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{85.75\cdot 2.5}{2}$ = 107.19 kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{107.19\cdot 10^3}{900\cdot 244}$ = 0.49 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

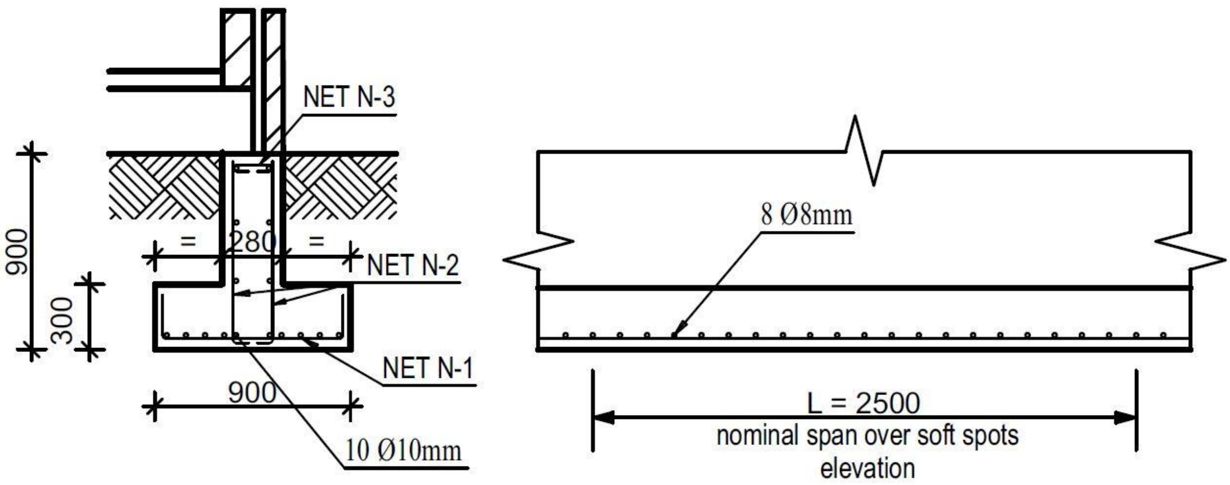


Figure 5-28 – Footing F4

As we can see after the calculation, the foundation N4 is equal to the foundation N1.

Foundation 5.

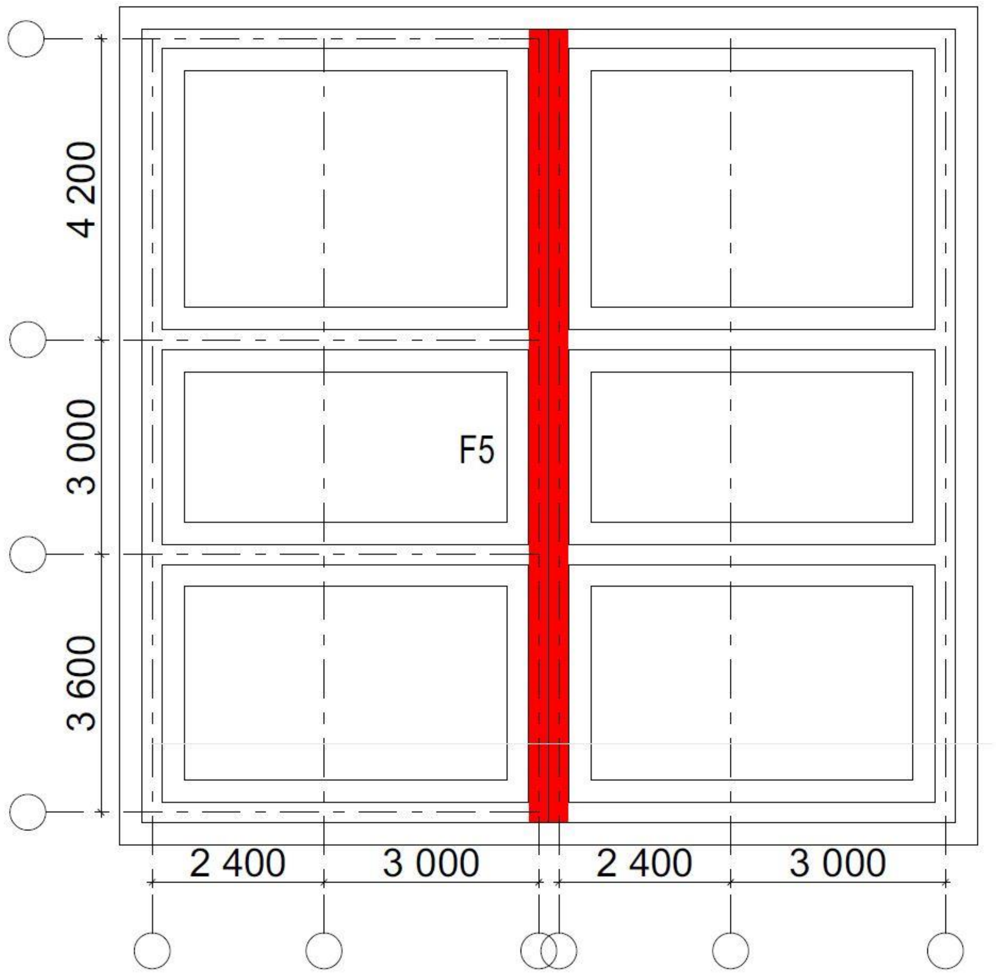


Figure 5-29– Placement of the footing F5

	Dead	Imposed
3 stories of walling (2*2.9m+2.25m)	8.05*1.78=14.33	-

Table 5-27 – Loading of the footing F5

P = G + Q = 14.33+0 = 14.33 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-29.

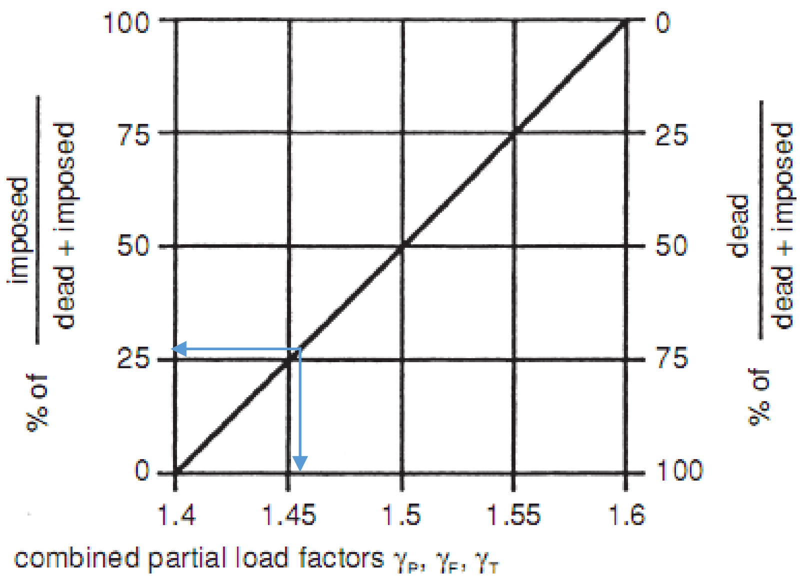


Figure 5-30– Combined partial safety factor for dead + imposed loads.

Q as a percentage of of P is 100Q/P = (100*12.15)/ 44.45 = 27.33%

From Fig. 5-29, the combined partial safety factor for superstructure loads is γ_P= 1.4.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

Sizing of foundation width

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{14.33}{80} = 0.18\text{ m}$$

Adopt a 0.6 m wide × 300 mm deep reinforced strip foundation, using grade 35 concrete (see Fig. 5-31).

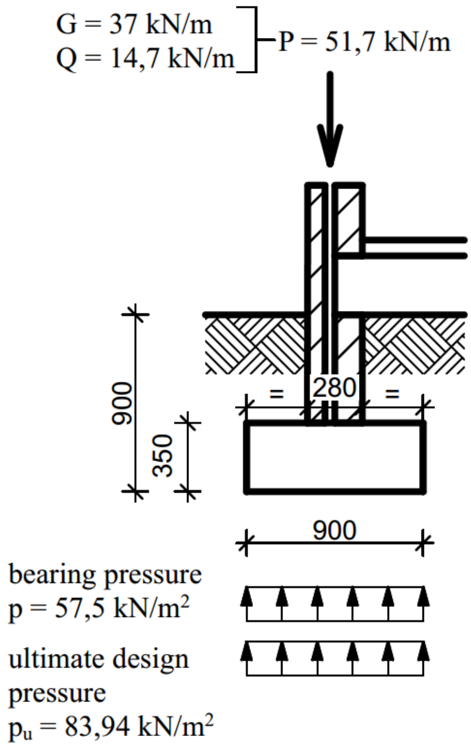


Figure 5-31 – Design scheme for the footing F5

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, p = $\frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{14.33}{0.6}$ =23.88 kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\ P}{B} = \frac{1.4 \cdot 14.33}{0.6}$ = 33.44 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 300 – 50 (cover) – 12 - $\frac{10}{2}$ = 233 mm

Cantilever moment at face of wall

$M_u = \frac{P_u\ (\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{33.44\ (\frac{0,6}{2} - \frac{0,233}{2})^2}{2}$ =0.56 Nm/m run

$\frac{M_u}{bd^2} = \frac{0.56 \cdot 10^6}{1000 \cdot 233^2}$ = 0.01

$A_{s\ (req)}$ = 0.01%bd [41]

This is less than the minimum reinforcement in [41]:

$A_{s\ (min)}$ = 0.13%bh = $\frac{0.13}{100}$ · 1000 · 300 = 390 mm^2/m = 3.9 cm^2/m

Provide 8 bars of reinforcement Ø8mm

A_s = 4,02 cm^2/m = 402 mm^2/m

A_s = 0.134%bh

Allowable shear stress: v_c = 0.39 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2})$ = 33.44 · $(\frac{0.6}{2} - \frac{0.233}{2})$ = 6.14 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{6.14 \cdot 10^3}{1000 \cdot 233}$ = 0.03 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f B$ = (1.4 · 14.35) + (1.4 · 15,75 · 0.6) = 33.32 kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{33.32 \cdot 2.5^2}{8}$ = 26.03 kN·m

Width for reinforcement design is b = B = 600 mm.

Effective depth, d = 300-50 (cover) - $\frac{12}{2}$ = 244 mm

$\frac{M_u}{bd^2} = \frac{26.03 \cdot 10^6}{600 \cdot 244^2}$ = 0.73

$A_{s\,(req)}$ = 0.195%bd = $\frac{0.195}{100}$ · 600 · 244 = 285.5 mm^2

Provide 6 bars of reinforcement Ø8mm

A_s = 3.02 cm^2/m = 302 mm^2/m

A_s = 0.206%bh [41]

Allowable shear stress: v_c = 0.44 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{33.32 \cdot 2.5}{2}$ = 41.65 kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{41.65 \cdot 10^3}{600 \cdot 244}$ = 0.28 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

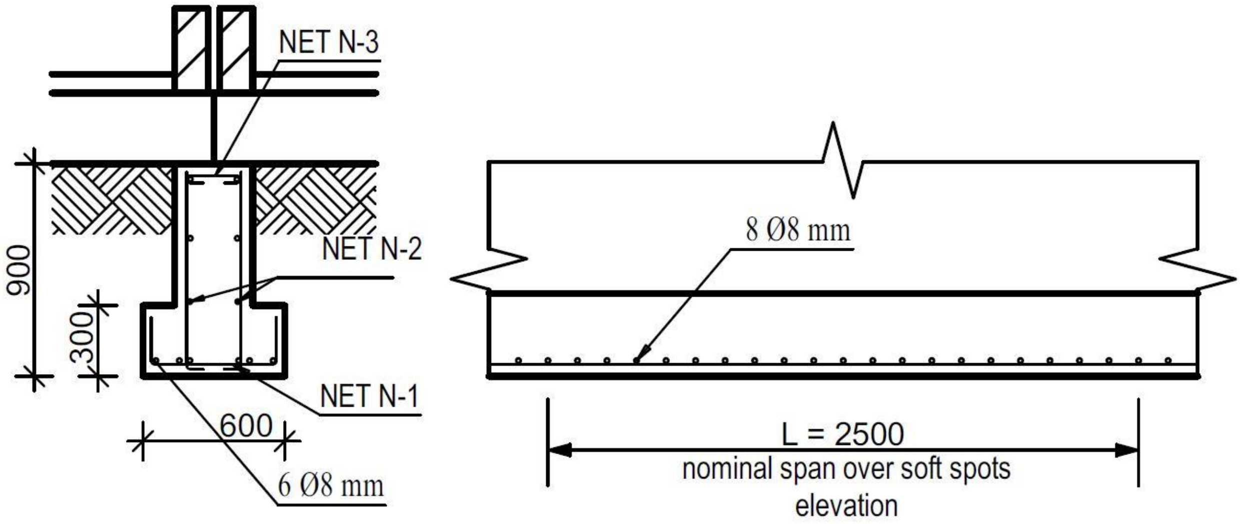


Figure 5-32– Footing F5

Foundation 6.

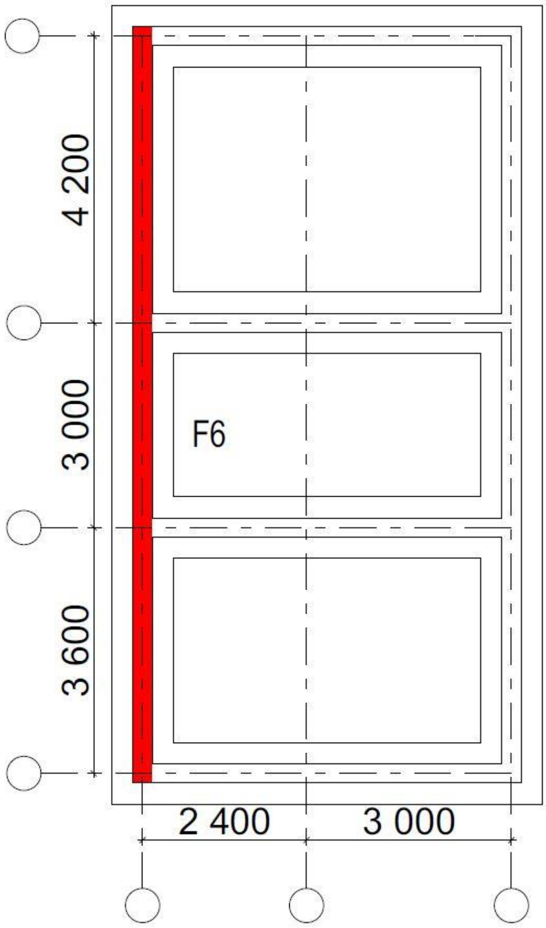


Figure 5-33 – Placement of the footing F6

	Dead	Imposed
3 stories of walling (2*2.9m+2.25m)	8.05*1.95=15.7	-

Table 5-28 – Loading of the footing F6

P = G + Q = 15.7+0 = 15.7 kN/m run

If the foundations and superstructure are being designed to limit state principles, loads should be kept as separate unfactored characteristic dead and imposed values (as above), both for foundation bearing pressure design and for serviceability checks. The loads should then be factored up for the design of individual members at the ultimate limit state as usual.

For foundations under dead and imposed loads only, factoring up loads for reinforcement design is best done by selecting an average partial load factor, γ_P, to cover both dead and imposed superstructure loads from Fig. 5-42.

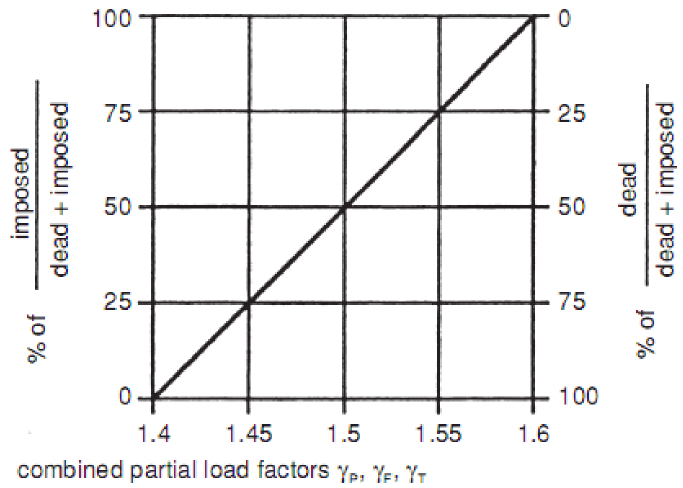


Figure 5-34 – Combined partial safety factor for dead + imposed loads.

Weight of base and backfill, f = average density × depth = 17.5 × 0.9 = 15.75 kN/m2

This is all dead load, thus the combined partial load factor for foundation loads, γ_F= 1.4.

Sizing of foundation width

New ground levels are similar to existing ones, thus the (weight of the) new foundation imposes no additional surcharge, and may be ignored.

The minimum foundation width is given by

$$B = \frac{structure\ load}{net\ allowable\ bearing\ pressure} = \frac{P}{n_a} = \frac{15.7}{80} = 0.2\ \text{m}$$

Adopt a 0.6 m wide × 300 mm deep reinforced strip foundation, using grade 35 concrete (see Fig.5-35).

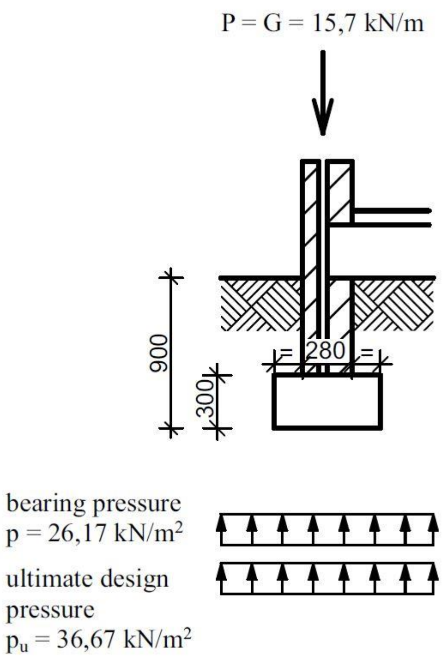


Figure 5-35 – Design scheme for the footing F6

Reactive upwards design pressure for lateral reinforcement design

Actual structure pressure, p = $\frac{structure\ load}{width\ of\ base} = \frac{P}{B} = \frac{15.7}{0.6}$ =26.17 kN/m^2

Ultimate reactive design pressure = $\frac{P_u}{B} = \frac{\gamma_P\ P}{B} = \frac{1.4 \cdot 15.7}{0.6}$ = 36.67 kN/m^2

Lateral bending and shear b = 1000 mm.

Effective depth, d = 300 – 50 (cover) – 12 - $\frac{10}{2}$ = 233 mm

Cantilever moment at face of wall

$$M_u = \frac{P_u\ (\frac{B}{2} - \frac{t_w}{2})^2}{2} = \frac{36.67\ (\frac{0,6}{2} - \frac{0,233}{2})^2}{2}$$ =0.62 Nm/m run

$\frac{M_u}{bd^2} = \frac{0.62 \cdot 10^6}{1000 \cdot 233^2}$ = 0.01

$A_{s\ (req)}$ = 0.01%bd [41]

This is less than the minimum reinforcement in [41]:

$A_{s\ (min)}$ = 0.13%bh = $\frac{0.13}{100}$ · 1000 · 300 = 390 mm^2/m = 3.9 cm^2/m

Provide 8 bars of reinforcement Ø8mm

A_s = 4,02 cm^2/m = 402 mm^2/m

A_s = 0.134%bh

Allowable shear stress: v_c = 0.39 N/mm^2 [41]

Shear force at face of wall

$V_u = P_u \cdot (\frac{B}{2} - \frac{t_w}{2})$ = 36.67 · $(\frac{0.6}{2} - \frac{0.233}{2})$ = 6.73 kN/m run

Shear stress, $v_u = \frac{v_u}{b_v d} = \frac{6.73 \cdot 10^3}{1000 \cdot 233}$ = 0.03 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

Loading for spanning over depressions

Where a local depression occurs, the foundation is acting like a suspended slab. The ultimate load causing bending and shear in the foundation is the total load i.e. structure load + foundation load, which is given by

$T_u = P_u + F_u = \gamma_P P + \gamma_F F = \gamma_P P + \gamma_F f B$ = (1.4 · 15.7) + (1.4 · 15,75 · 0.6) = 35.21 kN/m

Longitudinal bending and shear due to depressions

Ultimate moment due to foundation spanning – assumed simply supported – over a 2.5 m local depression is

$M_u = \frac{T_u \cdot L^2}{8} = \frac{35.21 \cdot 2.5^2}{8}$ = 27.51 kN·m

Width for reinforcement design is b = B = 600 mm.

Effective depth, d = 300-50 (cover) - $\frac{12}{2}$ = 244 mm

$\frac{M_u}{bd^2} = \frac{27.51 \cdot 10^6}{600 \cdot 244^2}$ = 0.77

$A_{s\,(req)}$ = 0.205%bd = $\frac{0.205}{100}$ · 600 · 244 = 300 mm^2

Provide 6 bars of reinforcement Ø8mm

A_s = 3.02 cm^2/m = 302 mm^2/m

A_s = 0.206%bh [41]

Allowable shear stress: v_c = 0.44 N/mm^2 [41]

Shear force at face of wall

$V_u = \frac{T_u \cdot L}{2} = \frac{35.21 \cdot 2.5}{2}$ = 44.01 kN/m run

Shear stress, $v_u = \frac{V_u}{b_v d} = \frac{44.01 \cdot 10^3}{600 \cdot 244}$ = 0.3 N/mm^2

Thus $v_u < v_c$, therefore no shear reinforcement is required.

As we can see after the calculation, the foundation N5 is equal to the foundation N6.

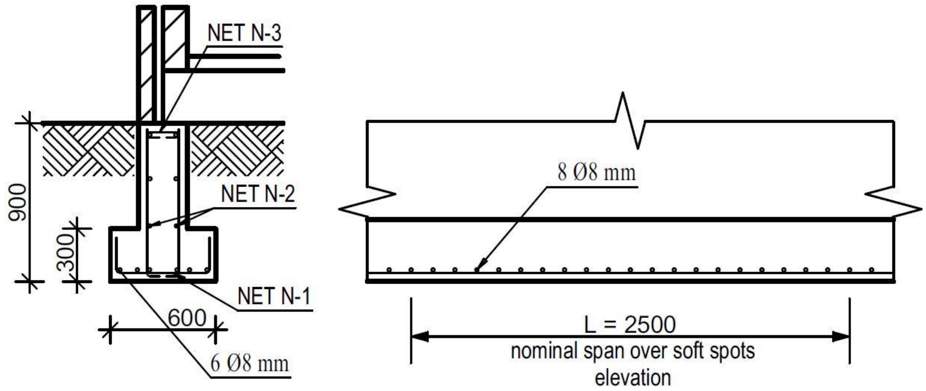


Figure 5-36 – Footing F6

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